ASME BPVC.III.2-2023

SECTION III

Rules for Construction of Nuclear Facility Components

2023 ASME Boiler and Pressure Vessel Code

An International Code

Division 2

Code for Concrete Containments

ACI Standard 359-23

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AN INTERNATIONAL CODE

2023 ASME Boiler & Pressure Vessel Code

2023 Edition July 1, 2023

(ACI Standard 359-23)

III

RULES FOR CONSTRUCTION OF NUCLEAR FACILITY COMPONENTS

Division 2

Code for Concrete Containments

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

ACI-ASME Joint Technical Committee

The American Society of Mechanical Engineers

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 In 2009, the Boiler and Pressure Vessel Committee was superseded by the following committees: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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Revisions and Errata

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

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

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.

THE AMERICAN CONCRETE INSTITUTE

The American Concrete Institute was organized in 1905 to provide industry standards in the field of concrete usage. The organization, which was formed as a result of meetings begun during the Engineering Congress at the Louisiana Purchase Exposition in St. Louis in 1904, was initially entitled the National Association of Cement Users. In 1913, the name of the Society was changed to the American Concrete Institute to better fit the actual scope of its activities and aims, which are to further engineering education, scientific investigation, and scientific research by organizing the efforts of its members for a nonprofit, public service in gathering, correlating, and disseminating information for the improvement of the design, construction, manufacture, use, and maintenance of concrete products and structures.

The day-to-day operation of ACI is administered by an Executive Director, under general supervision of its 18-member Board of Direction, which assigns a part of its administrative duties to standing committees, the ACI Standards Board, and various technical committees.

ACI — TECHNICAL ACTIVITIES COMMITTEE

The Technical Activities Committee, which is appointed by the Board of Direction, is responsible for Institute technical publications, review of standards, the technical program at conventions, and continuing studies of technical committees, from which arise recommendations for the activities, and the formation or discharge of these groups. TAC members are selected by the ACI Board to represent ACI's varied interests.

ACI — STANDARDS BOARD

The Standards Board, also appointed by the Board of Direction, is responsible for matters of policy, procedure, and appeal pertaining to ACI Standards. All proposed new standards or revisions to existing standards, including minority reports from sponsoring technical committees, are forwarded to the Standards Board through the Technical Activities Committee. On release by the Standards Board, these are published, and after ratification by letter ballot of the ACI membership at large are then available for public use. The primary functions of the Standards Board are to verify that proper standardization procedures have been followed and to rule on matters of policy as related to standards.

ACI — TECHNICAL AND EDUCATIONAL COMMITTEES

Much of the important work of the American Concrete Institute is performed by technical committees that prepare committee reports and standards. Technical committees, composed of volunteer personnel, develop ACI recommendations in their respective fields. Their work, subject to review and approval by the Board of Direction through the Technical Activities Committee and the Standards Board, forms the basis for Institute Standards.

Educational committees, also composed of volunteer personnel, develop seminars, workshops, curriculum guides, and student manuals to further ACI's involvement in education. Their work, subject to review and approval by the ACI Educational Activities Committee, forms the basis for Institute manuals and training programs.

INTRODUCTION TO SECTION III, DIVISION 2

This document has been prepared by the Joint ACI-ASME Technical Committee on Concrete Pressure Components for Nuclear Service under the sponsorship of the American Concrete Institute and the American Society of Mechanical Engineers. The two Societies have agreed that it will be published as Section III, Division 2, of the ASME Boiler and Pressure Vessel Code. Any changes to it shall be subject to the standardization procedures of the two sponsoring Societies.

The basic materials for this document were provided by two committee reports, one by ACI and the other by ASME. The ACI Committee 349, Criteria for Nuclear Containment Vessels, and the ASME Boiler and Pressure Vessel Code Committee, Section III, Division 2, Subgroup on Concrete Components, submitted their completed committee reports in September 1971 to ACI and ASME, respectively.

These two documents were melded into a single document dated January 17, 1972, and entitled Proposed Standard — Code for Concrete Reactor Vessels and Containments. A second draft was published August 1, 1972, that included new and revised technical material plus administrative agreements reached by the two Societies. Finally, after approval was received from the two Societies, a third and final draft was published in April 1973 for public "trial use and comment" for a period of about one year. During that year numerous public comments and suggestions were received from different segments of industry and regulatory agencies. In addition, two public hearings were held on the Code: the first on October 10, 1973, in Ottawa, Canada, the second on November 28, 1973, in Atlanta, Georgia. The consideration of all comments received as of November 28, 1973, resulted in a series of six Committee Addenda which were incorporated in the Code. The results of these three years of effort by the Committee have culminated in the present document.

The Joint Committee, whose membership includes individuals from both ACI and ASME and many others actively involved in the field, was formed in September 1971. The three primary goals established for the Committee are

(a) to establish rules in the form of a code for the design, construction, inspection, and testing of reinforced and prestressed concrete containments, including metallic liner, for nuclear power reactors

(b) to interpret these rules when questions arise regarding their intent

(c) to periodically update code provisions, making full use of the expedited procedure for revision of standards as necessary

It is expected that comments and discussions will continue to be received by the Joint Committee for review. Comments shall state clearly which area and wording of the Code is being discussed. Suggested revisions shall be worded as parallel text, giving both the present wording and showing how the proposed changed paragraphs should read, and shall be accompanied by a commentary (including references where appropriate) to support the proposed recommendations. Discussions, commentaries, and committee actions will be printed in the publications of the two Societies. Discussions may be sent to either the ACI or ASME headquarters marked to the attention of the Joint ACI-ASME Committee.

ORGANIZATION OF SECTION III

(23)

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

2 SUBSECTIONS

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

3 ARTICLES

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

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

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

4 SUBARTICLES

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

5 SUBSUBARTICLES

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

6 PARAGRAPHS

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

7 SUBPARAGRAPHS

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

8 SUBSUBPARAGRAPHS

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

9 REFERENCES

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

(a) References to Other Portions of Section III. When a reference is made to another Article, subarticle, or paragraph, all numbers subsidiary to that reference shall be included. For example, reference to Article NB-3000 includes all material in Article NB-3000; reference to NB-3100 includes all material in subarticle NB-3100; reference to NB-3110 includes all paragraphs, NB-3111 through NB-3113.

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

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

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

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

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

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

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

(2) Dimensional standards covering products such as valves, flanges, and fittings are sponsored and published by The American Society of Mechanical Engineers and approved by the American National Standards Institute.* When a product is to conform to such a standard, for example ASME B16.5, the standard is approved by the American National Standards Institute. The applicable year of issue is that suffixed to its numerical designation in Table NCA-7100-1, for example ASME B16.5-2003. Standards published by The American Society of Mechanical Engineers are available from ASME (https://www.asme.org/).

(3) Dimensional and other types of standards covering products such as valves, flanges, and fittings are also published by the Manufacturers Standardization Society of the Valve and Fittings Industry and are known as Standard Practices. When a product is required by these rules to conform to a Standard Practice, for example MSS SP-100, the Standard Practice referred to is published by the Manufacturers Standardization Society of the Valve and Fittings Industry, Inc. (MSS), 127 Park Street, NE, Vienna, VA 22180. The applicable year of issue of such a Standard Practice is that suffixed to its numerical designation in Table NCA-7100-1, for example MSS SP-58-2009.

(4) Specifications for welding and brazing materials are published by the American Welding Society (AWS), 8669 NW 36 Street, No. 130, Miami, FL 33166. Specifications of this type are incorporated in Section II and are identified by the AWS designation with the prefix "SF," for example SFA-5.1.

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

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

(1) Section III Appendices are contained in a separate book titled "Appendices." These appendices have the potential for multiple subsection applicability. Mandatory Appendices are designated by a Roman numeral followed, when appropriate, by Arabic numerals to indicate various articles, subarticles, and paragraphs of the appendix, such as II-1500 or XIII-1210. Nonmandatory Appendices are designated by a capital letter followed, when appropriate, by Arabic numerals to indicate various articles, subarticles, and paragraphs of the appendix, such as D-1200 or Y-1440.

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

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

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

SUMMARY OF CHANGES

Changes listed below are identified on the pages by a margin note, **(23)**, placed next to the affected area.

Page	*Location*	*Change*
ix	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"
xiii	Personnel	Updated
xxxv	Correspondence With the Committee	Added (replaces "Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees")
xxxix	Organization of Section III	In para. 1, Division 4 added
xliv	Cross-Referencing in the ASME BPVC	Updated
1	CC-1140	Revised
2	CC-2110	(1) In CC-2111, subparas. (b) and (d) revised
		(2) CC-2112 reformatted
3	CC-2131.3.2	Subparagraph (i) revised
4	CC-2140	Cross-reference updated
6	CC-2224.3	Revised
6	CC-2224.6	Deleted
16	CC-2331.2	Subparagraph (d) revised
19	Table CC-2438.4.2-1	For "Water-soluble chlorides," reference to ASTM D512 deleted from "Test Method" column
23	CC-2466.2	Below subpara. (c), Note added
25	CC-2522.1.2	Revised
48	CC-3210	Cross-reference updated
66	CC-3532.1.7	Revised
85	Table CC-4333-1	Revised
94	CC-4533.5	Second sentence revised
94	CC-4533.5.1	(1) In subpara. (a), last sentence revised
		(2) In subpara. (d), second line revised
108	CC-4545.1	Revised
110	Table CC-4552-1	Revised
109	CC-4552.2.3	Revised
127	CC-5542	Subparagraph (c) revised
162	Table D2-VIII-1410-1	Revised

(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).

SUBSECTION CC CONCRETE CONTAINMENTS (PRESTRESSED OR REINFORCED)

ARTICLE CC-1000 INTRODUCTION

CC-1100 SCOPE AND GENERAL REQUIREMENTS

CC-1110 SCOPE

Subsection CC establishes rules for material, design, fabrication, construction, examination, testing, marking, stamping, and preparation of reports for prestressed and reinforced concrete containments. The containments covered by this Subsection shall include the following:

(a) structural concrete pressure resisting shells and shell components

(b) shell metallic liners

(c) penetration liners extending the containment liner through the surrounding shell concrete

CC-1120 GENERAL REQUIREMENTS

The rules of Division 1 shall apply as required in this Subsection for parts and appurtenances not backed by structural concrete for load carrying purposes. Those parts or appurtenances stamped in accordance with Division 2 shall meet the requirements of Subsection NCA, Articles CC-1000, CC-6000, CC-7000, and CC-8000 in lieu of the corresponding requirements of Division 1. Those parts or appurtenances stamped in accordance with Division 1 shall meet all the requirements of Division 1 and NCA-2134(e).

CC-1130 RULES FOR CONCRETE CONTAINMENTS

Containments having a Design Pressure greater than 5 psi (35 kPa) that are classified as Subsection CC containments shall be constructed in accordance with the rules of this Subsection.

CC-1140 BOUNDARIES OF JURISDICTION (23)

(a) The jurisdiction of this Subsection for the containment shall conform to the requirements of NCA-3211.19(c)(3) supplemented by the provisions below.

(b) When a structural concrete support is constructed as an integral part of the containment, it shall be included within the jurisdiction of the Division 2 criteria.

ARTICLE CC-2000
MATERIAL

CC-2100 GENERAL REQUIREMENTS FOR MATERIAL

(23) **CC-2110 SCOPE**

CC-2111 Terms

(a) The term *material* as used in this Subsection is defined in Article NCA-9000 and discussed in NCA-1220.

(b) The term *Material Organization (Metallic)* is defined in Article NCA-9000. NCA-3300 defines Metallic Material Organization responsibilities, and Quality System Program requirements are defined in NCA-4200.

(c) The terms *Nonmetallic Material Manufacturer* and *Nonmetallic Material Constituent Supplier* are defined in Article NCA-9000 with Quality System Program requirements being defined in NCA-3900.

(d) The terms *pressure-retaining* and *load-bearing materials* apply to materials such as concrete, reinforcing material, prestressing material, liner material, materials for attachments to liners, and embedment anchor material.

(e) 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*: the thickness shall be as defined in SA-613.

CC-2112 Special Rules

(a) Metallic material for parts and appurtenances that are not backed by concrete for load carrying purposes shall meet the requirements of Division 1.

(b) Material for attachments to parts meeting the requirements of Division 1 shall meet the requirements of this Article.

CC-2120 PRESSURE-RETAINING AND LOAD-BEARING MATERIAL

CC-2121 Permitted Material Specifications

(a) Concrete constituents and concrete shall conform to the requirements of CC-2200. Metallic material for pressure-retaining and load-bearing purposes shall conform to the requirements of one of the specifications included in this Article or in Table D2-I-1.2, Table D2-I-2.2, and Table D2-I-2.3, and to all the special requirements of this Article that apply to the product form in which the material is used.

(b) Metallic or nonmetallic material and constituents other than those described in (a) above shall not be used until the requirements of Mandatory Appendix D2-III have been met.

(c) The requirements of this Article apply only to items associated with the pressure-retaining or load-bearing function of a component. This Article also provides requirements for corrosion prevention materials in CC-2438. Construction equipment or apparatus such as forms, tie wires, chairs, supports, form ties, grease and grout fittings, retaining caps, seals, packing, and gaskets are not covered by this Article.

(d) Welding and brazing materials used in the manufacture of items shall comply with an SFA specification, except as otherwise permitted in Section IX, and shall also comply with the applicable requirements of this Article.

CC-2122 Special Requirements

CC-2122.1 Metallic Materials. The special requirements stipulated in this Article shall apply in lieu of the requirements of the material specifications wherever these special requirements conflict with the material specification requirements. Where the special requirements include an examination, test, or treatment that is also required by the material specification, the examination, test, or treatment need be performed only once. All required examinations, tests, and treatments shall be performed as specified for each metallic product in this Article and may be performed by either the Metallic Material Organization, Fabricator, or Constructor, as provided in CC-4121.

CC-2122.2 Nonmetallic Materials and Constituents. All required examinations, tests, and treatments shall be performed as specified in this Article and may be performed by either the organization providing concrete constituents, the Nonmetallic Material Manufacturer, or the applicable Fabricator or Constructor, as provided in CC-4121.

CC-2122.3 Authorized Inspector. Reports of all required examinations, tests, and treatments shall be made available to the Authorized Inspector of the applicable Fabricator or Constructor and provisions made for inspections as required by the Authorized Inspector.

CC-2123 Size Ranges of Metallic Material

Metallic material outside the limits of size or thickness given in any specification allowed by this Division 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 and 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.

CC-2130 CERTIFICATION OF MATERIAL

CC-2131 Introduction

A Certified Material Test Report (CMTR) or a Certificate of Compliance shall be provided for all metallic materials, nonmetallic materials, and concrete constituents in accordance with the following subparagraphs.

CC-2131.1 Certified Material Test Reports. Certified Material Test Reports (CMTR) shall be provided for concrete constituents, plastic concrete, reinforcing system material, prestressing system material, liner material, other load-bearing and pressure-retaining material, and welding and brazing material, and shall include the following:

(a) certified reports of the actual results of all required chemical analyses, physical tests, mechanical tests, examinations (including radiographic film), repairs, and heat treatments (including times and temperatures) performed on the material

(b) a statement listing any chemical analyses, tests, examinations, and heat treatment required by the material specification, which were not performed

(c) a statement giving the manner in which the material is identified, including specific marking

(d) the Manufacturer of plastic concrete shall provide a Certified Material Test Report consisting of a batch ticket with each individual batch of concrete. The information on the batch ticket shall include the weight or volume of constituents as provided in CC-4222.2

CC-2131.2 Certificate of Compliance. A Material Organization's Certificate of Compliance with the material specification, grade, class, and heat treatment condition, as applicable, may be provided in lieu of a Certified Material Test Report for metallic material $^3/_4$ in. (20 mm) nominal pipe size and less (pipe, tube, flanges, and fittings), and bolting 1 in. (25 mm) nominal diameter and less. The Certificate of Compliance shall contain a description of the marking of the material.

CC-2131.3 Concrete Constituents.

CC-2131.3.1 Laboratory Accreditation. The tests required by CC-2200 shall be performed by an accredited laboratory that complies with ASTM C1077. Required laboratory inspections may be provided by the Cement and Concrete Reference Laboratory of the National Institute of Standards and Technology, with accreditation programs provided by the National Voluntary Laboratory Accreditation Program, American Association for Laboratory Accreditation, and Construction Materials Engineering Council.

CC-2131.3.2 Certified Material Test Reports. The Certified Material Test Reports (CMTR) for concrete constituents shall meet the following requirements: (23)

(a) The CMTR for aggregate shall certify that the aggregates are from the same source (natural deposit) as the aggregate qualified in accordance with CC-2222.

(b) The CMTR for portland cement shall include the standard chemical and physical test results in accordance with ASTM C150/C150M. Sampling and testing frequencies shall meet the requirements of ASTM C183.

(c) The CMTR for blended hydraulic cement shall include the standard chemical and physical test results in accordance with ASTM C595/C595M and any optional requirements in the Construction Specification. Sampling and testing frequencies shall meet the requirements of ASTM C183.

(d) The CMTR for hydraulic cements qualified based on performance characteristics shall include the standard and optional (where appropriate) physical test results in accordance with ASTM C1157 and a report of the chemical composition. Sampling and testing frequencies shall meet the requirements of ASTM C183.

(e) The CMTR for air-entraining admixtures shall include infrared spectrophotometry traces, percent solids, percent chlorides, and pH of each manufacturing lot. A statement shall be included to certify that these tests

or other included tests have established equivalence with admixtures tested in accordance with ASTM C260.

(f) The CMTR for fly ash and natural pozzolan shall include the standard chemical and physical test results in accordance with ASTM C618 and any requirements in the Construction Specification. Sampling and testing frequencies shall meet the requirements of ASTM C311.

(g) The CMTR for ground-granulated, blast-furnace slag shall include the standard chemical and physical test results in accordance with ASTM C989 and any requirements of the Construction Specification. Sampling and testing frequencies shall meet the requirements of ASTM C989.

(h) The CMTR for silica fume shall include the standard chemical and physical test results in accordance with ASTM C1240. Sampling and testing frequencies shall meet the requirements of ASTM C1240.

(i) The CMTR for chemical admixtures shall include infrared spectrophotometry traces, percent solids, and percent chlorides of each manufacturing lot. A statement shall be included to certify that these tests or other included tests have established equivalence with admixtures tested in accordance with ASTM C494/C494M.

(j) A CMTR for water and ice is not required.

CC-2131.4 Personnel Qualification. Laboratory testing personnel performing tests required by Article CC-2000 shall be qualified using appropriate industry or laboratory standards such as ACI Laboratory Technician Certification Programs, Technician Levels 1 and 2. The qualification and certification rules of Mandatory Appendix D2-V are not mandatory for personnel performing tests required in CC-2200.

CC-2132 Certification by Fabricator or Constructor

The Fabricator or Constructor shall provide a Certified Material Test Report for all operations performed by him or his subcontractors. The Fabricator or Constructor shall certify that the contents of his report are correct and accurate and that all operations performed by him or his subcontractors are in compliance with the requirements of the material specification and this Subsection. Alternatively, the Fabricator or Constructor shall provide a Certified Material Test Report for those operations he performed and a Certified Material Test Report from each of his subcontractors for operations they performed. Material identification, including any marking code, shall be described in the Certified Material Test Report.

(23) CC-2140 DETERIORATION OF MATERIAL AND COATINGS DURING SERVICE

Consideration of deterioration of material caused by service is 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), with specific attention being given to the effects of service conditions upon the properties of the material.

CC-2150 HEAT TREATMENT TO ENHANCE MECHANICAL PROPERTIES OF METALLIC MATERIAL

CC-2151 Carbon and Low Alloy Steels

Carbon and low alloy steels may be heat treated by quenching and tempering to enhance notch toughness. Postweld heat treatment of the material at a temperature of not less than 1,100°F (595°C) may be considered to be the tempering phase of the heat treatment when postweld heat treatment is a requirement of CC-4500.

CC-2152 Procedures for Heat Treatment of Material

When heat treating temperature or time is required by the material specification and the rules of the Subsection, the heat treating shall be performed in temperature-surveyed and -calibrated furnaces or shall be performed with thermocouples in contact with the material or attached to blocks in contact with the material. 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.

CC-2153 Steels for Prestressing

Wire, strand, or bars for prestressing systems may be heat treated, as in stress relieving, under load to enhance stress relaxation properties. Quenching and tempering treatments to produce specific mechanical properties are not permitted.

CC-2160 DIMENSIONAL STANDARDS

Dimensions of standard items for pipe, tube, fittings, valves, flanges, and gaskets shall comply with the standards and specifications listed in Table NCA-7100-1, unless otherwise specified in the Construction Specification or designated in the Design Drawings.

CC-2200 CONCRETE AND CONCRETE CONSTITUENTS

CC-2210 INTRODUCTION

This subarticle establishes qualification requirements for concrete constituents and plastic concrete. Testing to establish conformance to the requirements shall be performed prior to use. The required tests in CC-2200 may be performed by the organizations providing concrete constituents, the Nonmetallic Material Manufacturer, or applicable Fabricator or Constructor. The quality control tests described in CC-5200 shall be performed by the Nonmetallic Material Manufacturer, or applicable Fabricator or Constructor.

CC-2211 General Requirements

(a) Consideration shall be given to minimizing the temperature rise in concrete due to heat of hydration, and to proper strength development with respect to formwork removal, construction stresses, and application of prestress.

(b) The concrete and its constituents shall be sufficiently investigated prior to use to ensure acceptable creep and other properties under the environmental conditions and the long-term requirements described in the Construction Specification.

(c) The water–cement ratio is the ratio of the weight of water to the weight of cement. Where other cementitious materials are used, the weight of these materials shall be added to the weight of cement to determine the water–cementitious material ratio.

CC-2212 Substitutions

When an alternate constituent must be substituted for a previously qualified constituent as an alternative to a complete requalification in accordance with CC-2200, the following requirements apply:

(a) The alternate concrete constituent shall meet the requirements of qualification tests required by CC-2220.

(b) Prior to use, the Designer shall confirm the similarity and compatibility of the alternate constituent with the other previously qualified constituents.

(c) Prior to use, the Designer shall establish the need for and extent of testing required by CC-2230.

CC-2220 CONCRETE CONSTITUENTS

CC-2221 Cementitious Materials

CC-2221.1 Portland Cement. Portland cement shall conform to the requirements of ASTM C150/C150M, Type I, Type II, Type IV, or Type V.

CC-2221.2 Blended Hydraulic Cement. Blended hydraulic cement shall conform to the requirements of ASTM C595/C595M. Type IS/IT (≥70) blended cement shall not be used.

CC-2221.3 Performance-Graded Cement. Hydraulic cements shall conform to the requirements of ASTM C1157/C1157M to be accepted based on physical performance characteristics.

CC-2221.4 Fly Ash Class F. Fly ash Class F shall conform to the requirements of ASTM C618.

CC-2221.5 Slag Cement. Slag cement shall conform to ASTM C989/C989M.

CC-2221.6 Silica Fume. Silica fume shall conform to the requirements of ASTM C1240.

CC-2222 Aggregates

CC-2222.1 General. Aggregates shall conform to the requirements of ASTM C33/C33M with the following additional requirements:

(a) Gradation may be adjusted in the Construction Specification provided the requirements of CC-2231.1 are met. Coarse aggregate gradations must require at least two separate gradation sizes if aggregate larger than 1 in. is specified.

(b) Coarse and fine aggregate for normal weight concrete, placed by the preplaced aggregate method, shall meet the gradation requirements specified in ACI 304R.

(c) Coarse aggregate shall be rounded or cubical and shall contain less than 15% (by weight) flat and elongated particles as determined by ASTM D4791.

NOTE: A *flat particle* is defined as one having a ratio of width to thickness greater than three; an *elongated particle* is defined as one having a ratio of length to width greater than three.

(d) A petrographic examination in accordance with ASTM C295 shall be performed. Alkali-silica reactive materials shall not exceed limits in Table CC-2222.1-1. Aggregates identified as having the potential for alkali-carbonate reactivity shall not be used.

(e) The water-soluble chloride content of the aggregate shall be established by the methods described in ASTM D1411.

(f) For reinforced concrete containment designed in accordance with CC-3521.1.1, the maximum loss of weight of the coarse aggregate, when tested in accordance with ASTM C131, shall not exceed 40%.

(g) The maximum size of coarse aggregate shall not be larger than one-fifth of the narrowest dimension of the finished wall or slab, nor larger than three-fourths of the minimum clear spacing between individual reinforcing bars or wires, bundles of bars, or prestressing ducts, or embedments.

Table CC-2222.1-1
Required Limits of Alkali-Silica Reactive Materials in Concrete Aggregates

Reactive Material	Maximum Percentage [Note (1)]
Optically strained, microfractured, or microcrystalline quartz	5.0
Chert or chalcedony	3.0
Tridymite or cristobalite	1.0
Opal	0.5
Natural volcanic glass	3.0

NOTE: (1) Percentage as determined by ASTM C295.

CC-2222.2 Heavy Weight Aggregates. Heavy aggregates required for concrete denser than 160 lb/ft^3 (2 600 kg/m^3) shall conform to one of the following:

(a) ASTM C637

(b) requirements as provided in the Construction Specification for steel punchings, sheared reinforcing steel, iron shot, or materials containing boron used as concrete aggregate.

CC-2223 Mixing Water

CC-2223.1 Requirements. Mixing water or ice comprised of potable water is permitted to be used without testing. Nonpotable water or ice shall be tested for conformance to all requirements of Tables 1 and 2 given in ASTM C1602/C1602M, except that total solids shall not exceed 2,000 ppm. Table 1 of ASTM C1602/C1602M specifies that compressive strength of concrete specimens made with test water shall achieve at least 90% of the strength of companion specimens made with distilled or potable water and that concrete time of set using test water shall not deviate from that using distilled or potable water by more than −1 hr or +1.5 hr. Table 2 of ASTM C1602/C1602M specifies that chloride shall not exceed 500 ppm for prestressed concrete and 1,000 ppm for other reinforced concrete, sulfate shall not exceed 3,000 ppm, and alkalies shall not exceed 600 ppm.

CC-2224 Admixtures

CC-2224.1 General Requirements for Admixtures. When admixtures are to be used, the Construction Specification shall specify the type, quantity, and any additional limitations. Admixtures containing more than 1%, by weight, of chloride ions shall not be used for prestressed containments.

CC-2224.2 Air-Entraining Admixtures. Air-entraining admixtures shall conform to the requirements of ASTM C260.

(23) **CC-2224.3 Chemical Admixtures.** Chemical admixtures shall conform to the requirements of ASTM C494/C494M.

CC-2224.4 Special Grouting Admixtures, Including Grout Fluidifier. When special grouting admixtures, including grout fluidifier, are used, the Construction Specification shall specify the type and any additional limitations, such as a maximum permitted amount of available alkalies and/or chloride ions. In the preparation of cement grout, other types of admixtures, including those containing gels or gelling agents for the purpose of controlling loss of water from the grout, may be used, if permitted in the Construction Specification.

CC-2224.5 Grout Fluidifier. Grout fluidifier for use with preplaced aggregate concrete shall conform to the requirements of ASTM C937.

CC-2224.6 Chemical Admixtures for Use in Producing Flowing Concrete. (23)

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CC-2230 CONCRETE MIXTURE PROPERTIES

CC-2231 Concrete Properties

CC-2231.1 General Requirements. The properties of concrete which influence the design of the containment shall be established in the Construction Specification. Concrete proportions will normally be established on the basis of strength, workability limits, and heat rise.

CC-2231.2 Chloride Content. The water-soluble chloride content of the concrete shall not exceed 0.15% by mass of total cementitious materials for reinforced concrete containments and prestressed concrete containments where the prestressing tendons are placed in ducts and protected by cement grout or a permanent corrosion prevention coating in accordance with CC-2438.4.1. The water-soluble chloride content of the concrete shall not exceed 0.06% by mass of total cementitious materials for concrete that will be placed in direct contact with prestressing steel. Water-soluble chloride shall be determined per ASTM C1218/C1218M. For the purposes of calculating water-soluble chloride limits, the mass of supplementary cementitious materials shall not exceed the mass of cement.

CC-2231.3 Resisting Alkali-Silica Attack.

(a) Total alkalies (equivalent sodium oxides) in cementitious materials shall not exceed 0.6%.

(b) All concrete mixtures shall contain one or more of the cementitious materials given in Table CC-2231.3-1 at the minimum levels indicated. Blended hydraulic cement containing cementitious materials meeting the minimum percentages given in Table CC-2231.3-1 may also be used.

Table CC-2231.3-1
Required Minimum Levels of Cementitious Materials

Cementitious Material	Minimum Percentage by Mass of Total Cementitious Materials
Fly ash Class F (conforming to ASTM C618)	20
Slag cement (conforming to ASTM C989/C989M)	25
Silica fume (conforming to ASTM C1240)	5

GENERAL NOTE: Where combinations of the above materials are employed, the combined minimum percentage shall be the largest individual value assigned to any of the materials used in the combination.

Table CC-2231-1
Concrete Properties

Property	Test Method
Slump	ASTM C143/C143M
Compressive strength	ASTM C39/C39M
Flexural strength	ASTM C78/C78M
Splitting tensile strength	ASTM C496/C496M
Static modulus of elasticity	ASTM C469
Poisson's ratio	ASTM C469
Coefficient of thermal conductivity	CRD-C44
Coefficient of thermal expansion	CRD-C39 or AASHTO T 336
Creep of concrete in compression	ASTM C512
Shrinkage (length change of cement-mortar and concrete)	ASTM C157/C157M
Density (specific gravity)	ASTM C642
Maximum temperature rise in concrete	CRD-C36
Water-soluble chloride	ASTM C1218/C1218M
Sulfate resistance	ASTM C1012/C1012M
SCC specific [Notes (1), (2)]	
Slump flow	ASTM C1611/C1611M
Static segregation	ASTM C1610/C1610 M (column test)
	ASTM C1712/C1712 M (rapid penetration test)
Passing ability	ASTM C1621/C1621M

NOTES:
(1) SCC = self-consolidating concrete.
(2) Samples should be fabricated in accordance with ASTM C1758/1758M.

CC-2231.3.1 Testing for Reactivity. Materials and proportions selected for concrete mixtures shall be tested for reactivity per ASTM C1567 or ASTM C1293. ASTM C1567 expansion at 16 days shall not exceed 0.10%. ASTM C1293 expansion at 24 months shall not exceed 0.04%. Minimum levels of cementitious materials given in Table CC-2231.3-1 may need to be increased in order to achieve the expansion limits specified. ASTM C1567 and ASTM 1293 shall be used to determine the minimum pozzolan or slag replacement level needed to mitigate the risk for alkali-silica reactivity.

CC-2231.4 Specified Properties.

(a) The applicable concrete properties given in Table CC-2231-1 shall be defined in the Construction Specification. For nonprestressed containments, creep testing of concrete in compression is not required unless such testing is specified in the Construction Specification. Testing shall be performed prior to construction with the exception of creep tests conforming to ASTM C512. Creep tests shall be completed prior to the start of prestressing. Alternately, if interim creep test data confirms that the design basis creep value will not be exceeded, creep testing may be completed prior to the start of commercial operation or the start of the first inservice inspection of the post-tensioned tendons, whichever is earlier. If evaluation of creep test data indicates that the design basis creep value may be exceeded, design adequacy of the containment structure to accommodate the larger creep value shall be demonstrated. Testing required as a result of changes in concrete proportions or constituents shall be performed as soon as the change is initiated.

(b) The Construction Specification shall specify the age, strength, and temperature at which the applicable properties listed in Table CC-2231-1 shall be obtained and any environmental or design conditions that apply. If properties other than those listed in Table CC-2231-1 are required, they shall be defined in the Construction Specification.

CC-2231.5 Physical Properties.

(a) Where the Construction Specification includes maximum allowable creep limits (rate and total), tests shall be performed at least for the limiting combination of stress–strength ratios, ages of loading, temperature levels, and cycles stated in the Construction Specification. The creep test procedure shall be based on ASTM C512, with modifications for specimen curing and sealing, and for testing temperatures as described in the Construction Specification.

(b) Where the Construction Specification defines an allowable range of secant moduli of elasticity, Poisson's ratios, and loading rates, concrete specimens shall be tested at those loading rates and the experimental values determined. The testing procedures and acceptance standards shall be based on ASTM C469, with suitable modifications.

CC-2231.6 Thermal Properties. When required by the Construction Specification, the effect of thermal cycles on concrete properties shall be determined by the test standards described therein.

CC-2231.7 Durability.

CC-2231.7.1 Exposure Categories and Classes. The Designer shall assign exposure categories and classes based on the severity of the anticipated exposure of structural concrete members for each exposure category according to Table CC-2231.7.1-1.

CC-2231.7.2 Concrete Requirements. The maximum water-cementitious materials ratio of concrete shall not exceed 0.45. Concrete shall be air-entrained and meet the requirements of Table CC-2231.7.5-1. Requirements of Table CC-2231.7.2-1 for the exposure category

Table CC-2231.7.1-1
Exposure Categories and Classes

Category	Class [Note (1)]	Condition
F Freezing and thawing	F0	Concrete not exposed to freezing and thawing cycles
	F1	Concrete exposed to freezing and thawing cycles with limited exposure to water
	F2	Concrete exposed to freezing and thawing cycles with frequent exposure to water
	F3	Concrete exposed to freezing and thawing cycles with frequent exposure to water and exposure to deicing chemicals
S Sulfate	S0	$SO_4^{2-} < 0.10$ [Note (2)]
		$SO_4^{2-} \le 150$ [Note (3)]
	S1	$0.10 \le SO_4^{2-} < 0.20$ [Note (2)]
		$150 \le SO_4^{2-} < 1{,}500$ or seawater [Note (3)]
	S2	$0.20 \le SO_4^{2-} \le 2.00$ [Note (2)]
		$1{,}500 \le SO_4^{2-} \le 10{,}000$ [Note (3)]
	S3	$SO_4^{2-} > 2.00$ [Note (2)]
		$SO_4^{2-} > 10{,}000$ [Note (3)]
W In contact with water	W0	Concrete dry in service. Concrete in contact with water where low permeability is not required.
	W1	Concrete in contact with water where low permeability is required.
C Corrosion protection of reinforcement	C0	Concrete dry or protected from moisture
	C1	Concrete exposed to moisture but not to an external sources of chlorides
	C2	Concrete exposed to moisture and an external source of chlorides from deicing chemicals, salt, brackish water, seawater, or spray from these sources

NOTES:
(1) Severity of exposure within each category is defined by classes with increasing numerical values representing increasingly severe exposure conditions. A classification of "0" is assigned if the exposure severity has negligible effect (is benign) or the exposure category does not apply to the member.
(2) Water-soluble sulfate (SO_4^{2-}) in soil, percent sulfate by mass of sample as determined by ASTM C1580.
(3) Concentration of dissolved sulfate (SO_4^{2-}) in water, in ppm, as determined by ASTM D516 or ASTM D4130.

and class assigned to the concrete by the Designer shall be met. Concrete in contact with soil or exposed to aggregate fill in contact with soil shall as a minimum be proportioned to meet the requirements of Exposure Class S1 given in Table CC-2231.7.2-1.

CC-2231.7.3 Limits on Quantity of Pozzolans. The quantity of pozzolans, including fly ash and silica fume, and slag in concrete subject to Exposure Class F3 shall not exceed the limits of Table CC-2231.7.3-1.

CC-2231.7.4 Alternative Cementitious Materials for Sulfate Exposure. Alternative combinations of cementitious materials to those listed in Table CC-2231.7.2-1 shall be permitted when tested for sulfate resistance and meeting the criteria in Table CC-2231.7.4-1.

CC-2231.7.5 Air Content. Concrete air content for mixtures containing various sizes of coarse aggregate shall be as shown in Table CC-2231.7.5-1, except that for concrete with a specified compressive strength, f'_c, of 5,000 psi (35 MPa) or greater, the air content may be reduced 1.0%.

CC-2232 Selection of Concrete Proportions

CC-2232.1 Introduction. Proportions of materials for concrete shall be established to provide

(a) workability and consistency to permit concrete to be worked readily into forms and around reinforcement under conditions of placement to be employed, without segregation or excessive bleeding

(b) resistance to special exposures as required by CC-2231.7

(c) conformance with the strength test requirements of CC-5232.3

CC-2232.2 Different Materials. Where different materials are to be used for different portions of proposed work, each combination shall be evaluated.

CC-2232.3 Basis of Selection. Concrete proportions shall be established on the basis of field experience and/or trial mixtures with materials to be employed and as required by CC-2231.7.

The necessary workability of the fresh concrete shall be considered, based on means of placement, reinforcing density, and finishing characteristics, when developing mixture proportions. Self-consolidating concrete (SCC)

Table CC-2231.7.2-1
Requirements for Concrete by Exposure Class

Exposure Class	Max. w/cm	Min. f'_c, psi	Additional Minimum Requirements
W0	N/A	3,000	None
W1	0.45	4,000	None

Exposure Class	Max. w/cm	Min. f'_c, psi	Air Content	Limits on Cementitious Materials
F0	N/A	3,000	N/A	N/A
F1	0.45	4,000	Table CC-2231.7.5-1	N/A
F2	0.45	4,500	Table CC-2231.7.5-1	N/A
F3	0.40	5,000	Table CC-2231.7.5-1	Table CC-2231.7.3-1

Exposure Class	Max. w/cm	Min. f'_c, psi	Cementitious Materials — Types [Note (1)]			Calcium Chloride Admixture
			ASTM C150/C150M	ASTM C595/C595M	ASTM C1157/C1157M	
S0	N/A	3,000	No type restriction	No type restriction	No type restriction	No restriction
S1	0.45	4,000	II [Notes (2), (3)]	Types with MS designation	MS	No restriction
S2	0.45	4,500	V [Note (3)]	Types with HS designation	HS	Not permitted
S3, Option 1	0.45	4,500	V + pozzolan or slag cement [Note (4)]	Types with HS designation plus pozzolan or slag cement [Note (4)]	HS plus pozzolan or slag cement	Not permitted
S3, Option 2	0.40	5,000	V	Types with HS designation	HS	Not permitted

Exposure Class	Max. w/cm	Min. f'_c, psi	Maximum Water-Soluble Chloride Ion (Cl^-) Content in Concrete, Percentage by Mass of Cementitious Materials [Notes (5), (6)]		Related Provisions
			Reinforced Concrete	Prestressed Concrete	
C0	N/A	3,000	1.00	0.06	None
C1	N/A	3,000	0.30	0.06	None
C2	0.40	5,000	0.15	0.06	CC-3534.1

GENERAL NOTE: MS = moderate sulfate resistance; HS = high sulfate resistance.

NOTES:
(1) Alternative combinations of cementitious materials to those listed shall be permitted when tested for sulfate resistance and meeting the criteria in Table CC-2231.7.4-1.
(2) For seawater exposure, other types of portland cements with tricalcium aluminate (C_3A) contents up to 10% are permitted if the w/cm does not exceed 0.40.
(3) Type I cement is permitted in Exposure Class S1 or S2 if the C_3A contents are less than 8% for Exposure Class S1 or less than 5% for Exposure Class S2.
(4) The amount of the specific sources of the pozzolan or slag to be used shall not be less than the amount that has been determined by service record to improve sulfate resistance when used in concrete containing Type V cement. Alternatively, the amount of the specific source of the pozzolan or slag to be used shall not be less than the amount tested in accordance with ASTM C1012/C1012M and meeting the criteria in Table CC-2231.7.4-1.
(5) Water-soluble chloride ion content that is contributed from the ingredients including water, aggregates, cementitious materials, and admixtures shall be determined on the concrete mixture by ASTM C1218/C1218M at an age between 28 days and 42 days.
(6) The mass of supplementary cementitious materials used in determining the chloride content shall not exceed the mass of the portland cement.

Table CC-2231.7.3-1
Limits on Cementitious Materials for Concrete Assigned to Exposure Class F3

Cementitious Materials	Maximum Percentage of Total Cementitious Materials by Mass [Note (1)]
Fly ash or other pozzolans conforming to ASTM C618	25
Slag conforming to ASTM C989	50
Silica fume conforming to ASTM C1240	10
Total of fly ash or other pozzolans, slag, and silica fume	50 [Note (2)]
Total of fly ash or other pozzolans and silica fume	35 [Note (2)]

NOTES:
(1) The total cementitious material also includes ASTM C150/C150M, ASTM C595/C595M, and ASTM C1157/C1157M cement. The maximum percentages above shall include
(a) Fly ash or other pozzolans in Type IP, blended cement, ASTM C595/C595M, or ASTM C1157/C1157M performance-graded cement
(b) Slag used in the manufacture of an IS-blended cement, ASTM C595/C595M, or ASTM C1157/C1157M performance-graded cement
(c) Silica fume, ASTM C1240, present in a blended cement or ASTM C1157/C1157M performance-graded cement
(2) Fly ash or other pozzolans and silica fume shall constitute no more than 25% and 10%, respectively, of the total mass of the cementitious materials.

Table CC-2231.7.4-1
Requirements for Establishing Suitability of Cementitious Materials Combinations Exposed to Water-Soluble Sulfate

Exposure Class	Maximum Expansion When Tested Using ASTM C1012		
	At 6 months	At 12 months	At 18 months
S1	0.10%	N/A	N/A
S2	0.05%	0.10% [Note (1)]	N/A
S3	N/A	N/A	0.10%

NOTE: (1) The 12-month expansion limit applies only when the measured expansion exceeds the 6-month maximum expansion limit.

Table CC-2231.7.5-1
Total Air Content for Concrete Exposed to Cycles of Freezing and Thawing

Nominal Maximum Size of Coarse Aggregate, in. (mm)	Target Air Content, % [Notes (1), (2)]	
	Exposure Class F1	Exposure Classes F2 and F3
$^3/_8$ (10)	6	7.5
$^1/_2$ (13)	5.5	7
$^3/_4$ (19)	5	6
1 (25)	4.5	6
$1^1/_2$ (40)	4.5	5.5
2 (50)	4	5
3 (75)	3.5	4.5

NOTES:
(1) Air content shall not vary more than 1.5% from the listed value.
(2) These air contents apply to total mix, as per the corresponding nominal maximum size of coarse aggregate. Concrete containing aggregates larger than $1^1/_2$ in. (40 mm) shall be wet-sieved over a $1^1/_2$ in. (40 mm) sieve and the air content determined on the fraction passing through the sieve. Air content of the total mix is computed from the value determined on the $-1^1/_2$ in. (−40 mm) fraction in accordance with ASTM C173 or ASTM C231.

may also be considered where conditions make manual consolidation difficult. Alternative mixture proportions shall be used only in limited areas of specific difficulty, and the location, mixture proportioning, and alterations of the mixture shall be subject to the approval of the Designer. If an SCC mixture is selected, it must undergo the same qualification tests as the primary mixture design. SCC mixtures shall also be subject to additional considerations, including but not limited to their resistance to segregation (static and dynamic) and their ability to pass the specified reinforcement. The reproportioned (SCC) mixture and the original (non-SCC) mixture may be used in the same concrete placement, provided that the concrete placed in the difficult-to-consolidate area is still workable or in a fluid condition when the non-SCC concrete is placed.

CC-2233 Proportioning on the Basis of Field Experience and/or Trial Mixtures

CC-2233.1 Standard Deviation. Standard deviation shall be calculated using the methods of ACI 214R.

CC-2233.1.1 Test Record Requirements. Where a concrete production facility has test records not more than 12 months old, a standard deviation shall be established. Test records from which a standard deviation is calculated shall

(a) represent materials, quality control procedures, and conditions similar to those expected, and changes in materials and proportions within the test records shall not have been more restricted than those for proposed work

Table CC-2233.1.2-1
Modification Factor for Standard Deviation When Less Than 30 Tests Are Available

Number of Tests [Note (1)]	Modification Factor for Standard Deviation [Note (2)]
Less than 15	Use Table CC-2233.2.2-1
15	1.16
20	1.08
25	1.03
30 or more	1.00

NOTES:
(1) Interpolate for intermediate numbers of tests.
(2) Modified standard deviation to be used to determine required average strength f'_{cr} from CC-2233.2.1.

(b) represent concrete produced to meet a specified strength or strengths f'_c within 1,000 psi (7 MPa) of that specified for proposed work

(c) consist of at least 30 consecutive tests or two groups of consecutive tests totaling at least 30 tests as defined in CC-5232.3.2(a), except as provided in CC-2233.1.2

CC-2233.1.2 Alternative Test Record Requirements. Where a concrete production facility does not have test records meeting the requirements of CC-2233.1.1(c), but does have a record not more than 12 months old based on 15 to 29 consecutive tests, a modified standard deviation may be established as the product of the calculated standard deviation and modification factor of Table CC-2233.1.2-1. To be acceptable, the test record must meet requirements CC-2233.1.1(a) and CC-2233.1.1(b), and represent only a single record of consecutive tests that span a period of not less than 45 calendar days.

CC-2233.2 Required Average Strength.

CC-2233.2.1 Standard Deviation Method. Required average compressive strength f'_{cr} used as the basis for selection of concrete proportions shall be determined using appropriate equations given in Table CC-2233.2.1-1 and the standard deviation(s) calculated in accordance with CC-2233.1 or CC-2233.1.2.

CC-2233.2.2 Alternative Method. When a concrete production facility does not have field strength test records for calculation of standard deviation meeting requirements of CC-2233.1.1 or CC-2233.1.2, required average strength f'_{cr} shall be determined from Table CC-2233.2.2-1 and documentation of average strength shall be in accordance with the requirements of CC-2233.3.

CC-2233.3 Documentation of Average Strength. Documentation that proposed concrete proportions will produce an average compressive strength equal to or greater than required average compressive strength (see CC-2233.2) may consist of a field strength test record, several strength test records, or trial mixtures.

CC-2233.3.1 Using Test Records. When test records are used to demonstrate that proposed concrete proportions will produce the required average strength f'_{cr} (see CC-2233.2), such records shall represent materials and conditions similar to those expected. Changes in materials, conditions, and proportions within the test records shall not have been more restricted than those for proposed work. For the purpose of documenting average strength potential, test records consisting of less than 30 but not less than 10 consecutive tests may be used provided test records encompass a period of time not less than 45 days. Required concrete proportions may be established by interpolation between the strengths and proportions of two or more test records, each of which meets other requirements of this section.

Table CC-2233.2.1-1
Required Average Compressive Strength When Data Are Available to Establish a Sample Standard Deviation

Specified Compressive Strength, psi (MPa)	Required Average Compressive Strength, psi (MPa)
$f'_c \leq 5{,}000$ (35)	Use the larger value computed from eqs. (1) and (2) below $f'_{cr} = f'_c + 1.34s$ (1) $f'_{cr} = f'_c + 2.33s - 500\,(3.5)$ (2)
$f'_c > 5{,}000$ (35)	Use the larger value computed from eqs. (1) and (3) below $f'_{cr} = f'_{cr} + 1.34s$ (1) $f'_{cr} = 0.90f'_c + 2.33s$ (3)

GENERAL NOTE: The variable s is the standard deviation in psi (MPa).

Table CC-2233.2.2-1
Required Average Compressive Strength When Data Are Not Available to Establish a Standard Deviation

Specified Compressive Strength f'_c, psi (MPa)	Required Average Compressive Strength f'_{cr}, psi (MPa)
Less than 3,000 (21)	f'_c + 1,000 (7)
3,000 (21) to 5,000 (35)	f'_c + 1,200 (8.3)
Over 5,000 (35)	1.10f'_c + 700 (5)

CC-2233.3.2 Using Trial Mixtures. When an acceptable record of field test results is not available, concrete proportions may be established based on trial mixtures made in accordance with ACI 211.1 meeting the following restrictions:

(a) Combination of materials shall be those for proposed work.

(b) Trial mixtures having proportions and consistencies required for proposed work shall be made using at least three different water–cementitious material ratios or cementitious material contents that will produce a range of strengths encompassing the required average strength f'_{cr}.

(c) Trial mixtures shall be designed to produce a slump within ±0.75 in. (±19 mm) of maximum permitted, and for air-entrained concrete, within ±0.5% of maximum allowable air content.

(d) For each water–cementitious material ratio or cementitious material content, at least three test cylinders for each test age shall be made and cured in accordance with ASTM C192/C192M. Cylinders shall be tested at the test age designated in the Construction Specification for determination of f'_{cr}.

(e) From the results of cylinder tests, a curve shall be plotted showing the relationship between water–cementitious material ratio or cementitious material content and compressive strength at designated test age.

(f) Maximum water–cementitious material ratio or minimum cementitious material content for concrete to be used in proposed work shall be that shown by the curve to produce the average strength required by CC-2233.2, unless a lower water–cementitious material ratio or higher strength is required by CC-2231.7.

CC-2240 CEMENTITIOUS GROUT

The term *grout* as used in this Article applies to the following:

(a) grout for general purpose grouting, such as under base plates or around large penetrations

(b) grout for prestressed tendons

(c) grout for preplaced aggregate concrete.

CC-2241 Constituents for Cementitious Grout

CC-2241.1 Cementitious Materials. Cementitious materials shall conform to the requirements of CC-2221.

CC-2241.2 Aggregates. Aggregates shall conform to the requirements of CC-2222.

CC-2241.3 Water. Mixing water shall conform to the requirements of CC-2223.

CC-2241.4 Admixtures. Admixtures shall conform to the requirements of CC-2224.

CC-2241.5 Other Material. Other material, such as aluminum powder of the proper fineness and quality, may be added to the grout mix, provided adequate tests are made to demonstrate the suitability of the mix for the purpose intended.

CC-2242 Cementitious Grout for General Grouting Purposes

CC-2242.1 General Requirements.

(a) Requirements described herein do not apply to grout that is used with grouted prestressing systems.

(b) The proportions of constituents for general purpose grout shall be based upon trial mixes using the same type and brand of cementitious materials, fine aggregate, and admixtures as will be used for construction. Insofar as is practical, the same type of mixer shall be used in preparing trial mixes as will be used for construction.

CC-2242.2 Compressive Strength. The compressive strength of the grout shall be established by 2 in. (50 mm) cubes, molded, cured, and tested in accordance with ASTM C109/C109M, except that, if fluid expansive grout is used, the tests shall be performed in accordance with ASTM C1107/C1107M.

CC-2242.3 Water. The water content shall be the minimum quantity necessary for the proper placement by the grouting method employed, dry pack or fluid grout.

CC-2242.4 Prepackaged Cementitious Grout.

CC-2242.4.1 Permitted Uses. Prepackaged cementitious grout (product) may be used in lieu of site-mixed cementitious grout for general grouting purposes.

CC-2242.4.2 Modification of Product. The product shall be used as received from the supplier, except for the addition of water or aggregate where required by the manufacturer's instructions.

CC-2242.4.3 Approval of Designer. The Designer shall specify the use and required properties of the product in the Construction Specification. The Designer shall consider the effect of the product on the design strength and its effect on other materials based on experience and test data. The product shall be approved by the Designer prior to use.

CC-2242.4.4 Construction Procedures. All storing, batching, mixing, conveying, depositing (including pressure assisted placement), consolidating, curing, testing, and surface preparation shall be in accordance with the requirements of the Construction Specification.

CC-2242.4.5 Aggregate. Aggregate added to the product in accordance with the manufacturer's instructions shall conform to CC-2222 and be tested in accordance with CC-5223.

CC-2242.4.6 Water. Water added to the product in accordance with the manufacturer's instructions shall conform to CC-2223 and be tested in accordance with CC-5224.

CC-2242.4.7 Quality Assurance Program Requirements. The product shall be manufactured under a Quality Assurance Program approved by the Constructor that includes the following as a minimum:

(a) control of the manufacturing processes that are performed in the manufacture of the product

(b) document control

(c) handling, storage, and shipping requirements

(d) identification and marking of product containers

(e) establishment of examination, test, inspection, and report procedures, including proper documentation and controls related to the product measuring and testing equipment

CC-2242.4.8 Certified Material Test Reports. Certified Material Test Reports shall be provided for each lot or shipment to verify that the product meets the physical properties specified in the Construction Specification.

CC-2242.4.9 In-Process Testing. The product shall be tested in accordance with the requirements for general purpose grout in the Construction Specification and CC-5234.2.

CC-2242.5 Epoxy Grouts and Bonding Agents.

CC-2242.5.1 Permitted Uses. Epoxy grouts (product) may be used for general purpose grout and grouting/sealing small or fine cracks in hardened concrete. Epoxy bonding agents (product) may be used to improve the bond between hardened concrete and plastic concrete or grout that is placed thereon.

CC-2242.5.2 Modification of Product. The product shall be used as received from the supplier except for the addition of aggregate where required by the manufacturer's instructions.

CC-2242.5.3 Approval of Designer. The Designer shall specify the use and required properties of the product in the Construction Specification. The Designer shall consider the effect of the product on the design strength and its effect on other materials based on experience and test data. The effect of high and low temperature, radiation, moisture, and other conditions to which the product might be subjected during its service life shall also be considered. The product shall be approved by the Designer prior to use.

CC-2242.5.4 Construction Procedures. All storing, batching, mixing, conveying, curing, depositing (including pressure assisted placement), consolidating, testing, and surface preparation shall be in accordance with the requirements of the Construction Specification.

CC-2242.5.5 Aggregate. Aggregate added to the product in accordance with the manufacturer's instructions shall conform to CC-2222 and be tested in accordance with CC-5223.

CC-2242.5.6 Quality Assurance Program Requirements. The product shall be manufactured under a Quality Assurance Program approved by the Constructor that includes the following as a minimum:

(a) control of the manufacturing processes that are performed in the manufacture of the products

(b) document control

(c) handling, storage, and shipping requirements

(d) identification and marking of product containers

(e) establishment of examination, test, inspection, and report procedures, including proper documentation and controls related to the products measuring and testing equipment

CC-2242.5.7 Certified Material Test Reports. Certified Material Test Reports shall be provided for each lot or shipment to verify that the product meets the physical properties specified in the Construction Specification.

CC-2242.5.8 In-Process Testing. Epoxy grout shall be tested as specified in the Construction Specification.

CC-2243 Grout for Grouted Tendon Systems

CC-2243.1 General Requirements. Grout for grouted tendon systems shall consist of a mixture of cementitious material(s), water, aggregates, and admixture(s), when desired. The maximum water-cementitious materials ratio of grout shall be 0.45.

(a) Grout shall be either batched and mixed using approved constituent materials and proportions or shall be prepackaged grout.

(b) Prepackaged grout shall conform to the requirements in CC-2242.4 and CC-2243.2.

CC-2243.2 Grout Materials.

CC-2243.2.1 Cementitious Material. Cementitious material shall conform to CC-2221.

CC-2243.2.2 Admixtures. Admixtures shall conform to CC-2224.

CC-2243.2.3 Aggregates. When used, aggregates shall have a maximum size of 0.04 in. (1 mm) to facilitate movement of the grout through the duct and provide total encapsulation of the prestressing elements. Aggregates shall meet all requirements of CC-2222.

CC-2243.2.4 Water. Water shall conform to CC-2223 and be tested in accordance with CC-5224.

CC-2243.3 Quality and Performance Criteria for Grout.

CC-2243.3.1 Testing Certifications. The Contractor shall provide certified test reports for all testing listed in CC-2243.3.2.

CC-2243.3.2 Grout Testing and Performance Criteria. Grout mixtures shall be tested for compliance with the following testing quality limits. Testing shall be performed by a laboratory that is regularly inspected by a nationally recognized evaluation authority.

(a) Setting Time. Setting shall be conducted per ASTM C953. Setting time shall be determined according to the provisions of ASTM C953 and the measured value shall be within the limits set forth in the Construction Specification.

(b) Compressive Strength. Compressive strength shall be determined per ASTM C109, ASTM C942, or ASTM C1107/C1107M, as applicable. Minimum compressive strength at 7 days shall be 3,000 psi (21 MPa) and at 28 days shall be 5,000 psi (35 MPa).

(c) Permeability. Permeability testing shall be conducted per ASTM C1202 with voltage modified to 30 V rather than the standard 60 V. After 6 hr at 30 V, a value less than 2,500 coulomb shall be achieved when tested at 28 days.

(d) Volume Change. Volume change shall be determined in accordance with ASTM C1090. Height change at 24 hr shall be 0.0% to less than +0.1%. Maximum change in height at 28 days shall be no greater than +0.2%.

(e) Fluidity. Fluidity of nonthixotropic grouts shall be tested per ASTM C939. Efflux time shall be between 11 sec and 30 sec immediately after mixing. Efflux time, after grout sample has been allowed to stand undisturbed for 30 min, shall be less than 30 sec.

Fluidity of thixotropic grouts shall be tested per ASTM C939 modified as follows: The flow cone shall be filled to the top rim of the cone (not the standard level), and efflux time shall be measured as the time required to fill a one-liter container. Efflux time shall be 5 sec to 30 sec immediately after mixing. Efflux time, after grout sample has been allowed to stand undisturbed for 30 min, shall be less than 30 sec.

(f) Wick-Induced Bleeding. A wick-induced bleed test shall be conducted using ASTM C940 modified as follows:

(1) Condition dry ingredients, mixing water, a 40 in. (1 000 mm) section of prestressing strand, and test apparatus overnight at 65°F to 75°F (18°C to 24°C).

(2) Mix the conditioned dry ingredients with the conditioned water, and fill the 40-in. (1 000-mm) high tube with the resulting grout to a height of approximately 35 in. (900 mm). Mark the level of the top of the grout.

(3) Insert a 40-in. (1 000-mm) length of conditioned, cleaned ASTM A416/A416M seven-wire strand completely into the 40-in. (1 000-mm) tube. Center and fasten the strand so it remains essentially parallel to the vertical axis of the tube. This can be achieved through the use of a spacer at the top of the tube. Mark the level of the top of the grout.

NOTE: Wrap the strand with 2-in. (50-mm) wide duct or electrical tape at each end prior to cutting to avoid splaying of the wires when it is cut. Degrease (with acetone or hexane solvent) and wire brush to remove any surface rust on the strand before temperature conditioning.

(4) Store the mixed grout at 65°F to 75°F (18°C to 24°C).

(5) Observe the bleed water every 15 min for the first hour and then hourly afterward for 3 hr, and record and measure the amount at the end of 3 hr using the procedure outlined in ASTM C940. Express the bleed water as percentage of the initial volume of grout. Note if the bleed water remains above or below the top of the grout. Note if any bleed water is absorbed.

(6) Calculate the bleed water, if any, and the resulting expansion per the procedures outlined in ASTM C940 with the quantity of bleed water expressed as percent of the initial grout volume. Note if the bleed water remains above or below the top of the original grout height. No wick-induced bleeding is allowed.

(g) Schupack Pressure Bleed Test. Bleed stability of grout under static pressure shall be tested per ASTM C1741. Bleed test limits shall conform to Table CC-2243.3.2-1.

(h) Chloride Limits. Water-soluble chloride as Cl^- in grout, determined per ASTM C1218/C1218M, shall not exceed 0.015% by weight of cementitious materials in the mixture.

Table CC-2243.3.2-1
Schupack Pressure Bleed Test Limits

Vertical Rise, *X*, ft (m)	Gelman Pressure, psi (kPa)	Maximum Bleed, % (% of Sample Volume)
0 ≤ *X* ≤ 2 (0.61)	20 (140)	4
2 (0.61) < *X* ≤ 6 (1.8)	30 (220)	2
6 (1.8) < *X* ≤ 20 (6.1)	50 (360)	0
X > 20 (6.1)	100 (720)	0

(i) Wet Density Test. A range of wet density at minimum and maximum water dosage shall be established for the optimized grout using a mud balance test apparatus or by determining grout mass per 400 mL per ASTM C185.

(j) Inclined Tube Test. The inclined tube test shall be performed in accordance with EN 445. Grout bleeding shall not exceed 0.3% of the initial grout volume.

(k) Temperature. Temperature measurement of grout mixture shall be conducted per ASTM C1064.

(l) pH Value. The grout shall be maintained at a pH value above 11.6.

CC-2250 MARKING AND IDENTIFICATION OF CONCRETE CONSTITUENTS

CC-2251 Cementitious Materials

Before leaving the place of manufacture, conveyances of bulk cementitious materials shall be sealed and tagged showing lot number, controlling specification, date of manufacture or processing, and type or class. If bag cementitious materials are used, each shipment shall be tagged with the same identification as for bulk material. All tags and markings shall be maintained with the material at site storage.

CC-2252 Aggregates

Aggregates shall be identified to show size, source, and controlling specification. The identification shall remain with the aggregate during transit and concrete plant storage.

CC-2253 Admixtures

All containers of admixtures shall be clearly marked, showing storage requirements and controlling specification. Bulk storage tanks for admixtures at batch plants shall be identified with the name of the admixture stored, the controlling specification, and the storage requirements.

CC-2300 MATERIAL FOR REINFORCING SYSTEMS

CC-2310 INTRODUCTION

(a) The material to be used for reinforcing bars for containments shall conform to ASTM A615 or A706 and the special requirements described in CC-2330. The bar designations listed in this Division with the soft metric conversions in parentheses are consistent with these ASTM standards.

(b) The material to be used for bar-to-bar splice sleeves in reinforcing bars shall conform to ASTM A108, A513, A519, or A576.

(c) The material to be used for reinforcing bar splice sleeves attached to liner plates or structural steel shapes shall be carbon steel conforming to one of the grades of ASTM A108, A513, A519, or A576 listed in Table D2-I-2.2.

(d) The material to be used for the heads of mechanically headed deformed bars shall conform to ASTM A108, A513, A519, or A576.

(e) Mechanically headed deformed bar assemblies shall conform to Figure CC-2310-1.

CC-2311 Mechanical Anchorage Devices

Mechanical anchorage devices shall

(a) be round or square with a smooth outer surface free of debris or irregularities.

(b) have a minimum net bearing area of 4 times the area of the bar. The net bearing area is calculated by taking the gross cross-sectional area of the head minus the nominal cross-sectional area of the bar.

(c) have a bearing face that consists of a single, nominally flat surface that lies in a plane perpendicular to the longitudinal axis of the bar.

(d) not have obstructions or interruptions of the bar deformation and nonplanar features on the bearing face that extend more than two nominal bar diameters from the bearing face and have a diameter greater than 1.5 times the nominal bar diameter, per Figure CC-2310-1.

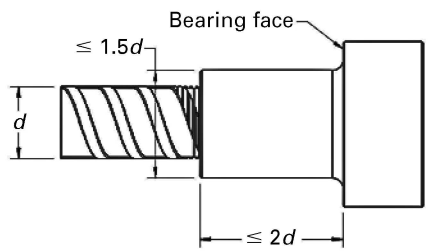
(e) be designed in accordance with CC-3532.4.

(f) be tested in accordance with CC-4333.

CC-2320 MATERIAL IDENTIFICATION

Reinforcing systems material shall be tagged or marked to ensure traceability to the Certified Material Test Report during production and while in transit and storage.

Figure CC-2310-1
Maximum Dimensions of Obstruction or Interruptions of Bar Deformations and Nonplanar Features of the Bearing Face



CC-2330 SPECIAL MATERIAL TESTING

CC-2331 Tensile Tests

CC-2331.1 Number of Tests Required. One full-diameter tensile bar of each bar size shall be tensile tested for each 50 tons (45 Mg), or fraction thereof, of reinforcing bars produced from each heat of steel. The tensile test procedures shall be in accordance with SA-370.

(23) **CC-2331.2 Acceptance Standards.** The acceptance standards shall be in conformance with the tensile requirements of ASTM A615 or ASTM A706, as applicable. If a test specimen fails to meet the tensile requirements, two additional specimens from the same heat and of the same bar size shall be tested. If either of the two additional specimens fails to meet the tensile requirements, the material represented by the tests shall not be accepted.

ASTM A615 shall be further subject to the following conditions:

(a) The actual yield strength based on mill tests shall not exceed f_y by more than 18,000 psi (125 MPa).

(b) The ratio of the actual tensile strength to the actual yield strength shall not be less than 1.25.

(c) For Grade 60 bars, the minimum elongation in 8 in. (200 mm) shall be at least 14% for bar sizes No. 3 (10) through No. 6 (19), at least 12% for bar sizes No. 7 (22) through No. 11 (36), and at least 10% for bar sizes No. 14 (43) and No. 18 (57).

(d) For Grade 80 bars, the minimum elongation in 8 in. (200 mm) shall be at least 12% for bar sizes No. 3 (10) through No. 11 (36) and at least 10% for bar sizes No. 14 (43) and No. 18 (57).

CC-2332 Chemical Analysis

A ladle analysis of each heat of reinforcing bar shall be made and reported in accordance with ASTM A615 or ASTM A706, as applicable.

CC-2332.1 Reinforcing Bar Intended for Welding.

(a) ASTM A706 and ASTM A615 may be welded by any of the welding processes listed in D2-VIII-1400.

(b) The ladle analysis of ASTM A615 reinforcing bar heats intended for welding shall be as follows:

(1) carbon, 0.30% maximum
(2) manganese, 1.50% maximum
(3) sulfur, 0.045% maximum
(4) phosphorus, 0.035% maximum
(5) silicon, 0.50% maximum

An analysis for the following residual elements shall also be performed and reported: copper, nickel, chromium, molybdenum, vanadium. The carbon equivalent of such bars shall be computed per D2-VIII-1430 for application in Table D2-VIII-1430-1.

(c) The results of the product verification analysis for ASTM A706 reinforcing bar shall not exceed that specified in ASTM A706. Product verification analysis for ASTM A615 reinforcing bar shall not exceed the following:

(1) carbon, 0.33%
(2) manganese, 1.55%
(3) sulfur, 0.053%
(4) phosphorus, 0.043%
(5) silicon, 0.55%

CC-2400 MATERIAL FOR PRESTRESSING SYSTEMS

CC-2410 INTRODUCTION

This subarticle establishes the requirements for the material to be used for bonded and unbonded containment prestressing systems.

CC-2420 PRESTRESSING STEEL

CC-2421 Permitted Material

Prestressing elements are limited to those listed in Table D2-I-1.2. The materials shall conform to their respective material specifications and to the additional requirements described in the following subparagraphs.

CC-2422 Test Specimen Sizes

All mechanical tests on prestressing elements shall be performed on full-diameter test pieces.

CC-2423 Tensile Tests

Material produced to an ASTM specification shall be sampled and tested as required by that specification. The tensile strength, yield strength, elongation, and other pertinent data shall be reported on the Certified Material Test Report.

CC-2424 Stress Relaxation Properties

The stress relaxation properties of the prestressing elements tested in accordance with ASTM E328 shall be provided by the Material Organization. Reports relating thereto shall be based upon tests performed on material previously manufactured to the same ASTM or other applicable specification, and produced in the same plant utilizing the same procedures that will be employed to produce the prestressing elements for the production tendons.

CC-2424.1 Data to Be Furnished. The following data shall be furnished:

(a) deviations from ASTM E328 recommended testing
(b) specimen identification
(c) initial and final stress
(d) loss of stress at intervals during test
(e) temperature control limits

(f) predicted stress relaxation design life and basis for extrapolation

CC-2424.2 Number of Tests. A minimum of three relaxation tests of 1,000 hr duration shall be performed and reported to document adequately that the relaxation losses are in compliance with the Construction Specification.

CC-2430 COMPONENT STANDARDS

CC-2431 General

Ensure all connectors, connections, and components of post-tensioning system hardware are completely sealed against leakage of cement paste. All hardware, components, and connections shall be airtight and watertight and pass the pressure test requirements herein.

CC-2432 Anchorage Components

CC-2432.1 Bearing Plates. Materials for bearing plates shall conform to their respective material specifications. The dimensions, finish, alignment, and tolerances of the bearing plates shall be within the limits set forth in the Construction Specification.

Bearing plates and associated concrete test block shall be tested in accordance with CC-2441.

For items requiring heat treatment to develop mechanical properties, the alloy and heat treatment shall be selected to preclude embrittlement.

CC-2432.2 Wedge Plates and Wedges. Wedge plates and wedges shall meet the requirements of CC-2442.

CC-2432.3 Trumpets. Trumpets associated with bearing plates shall be made of ferrous metal. The thickness of the trumpet at the duct end shall not be less than the thickness of the duct. Connections from the trumpet to the duct and the trumpet to the bearing plate shall have the same leak tightness requirements as duct-to-duct couplers.

CC-2432.4 Alignment. Maximum allowable angular misalignment of bars with respect to the bearing plate shall be as follows:

(a) for spherical bearing plate/nut applications: ±2 deg for all live-end anchor nuts, and ±3 deg for all fixed-end anchor nuts

(b) for nonspherical bearing plate applications: ±1 deg at live-end and fixed-end anchor nuts

CC-2433 Bar Couplers

High strength bar couplers shall meet the requirements of ASTM A722 and shall develop 110% of the minimum ultimate tensile strength, f_{pu}, of the bar when tested in unbounded state. Test and provide written certification that the couplers meet these requirements. Couplers and components shall be enclosed in an enclosure of sufficient length to permit the necessary movements. Tendon enclosure shall be designed so the complete grouting of all coupler components is achievable.

CC-2434 Permanent Grout Caps

Use permanent grout caps made from ASTM A240/A240M, Type 316 stainless steel. Seal the cap to the bearing plate precision fitted flat gaskets. Place a grout vent on top of the cap. Grout caps shall be pressure tested prior to grout injection and certified to a minimum pressure of 150 psi (1 MPa) by the Post-Tensioning System (PTS) supplier. Use ASTM F593, Type 316 stainless steel bolts to attach cap to the anchorage. When stainless steel and/or galvanized ferrous metal (ASTM A153/A153M) grout caps are supplied, provide CMTRs documenting the chemical analysis of the steel.

CC-2435 Ducts

Ducts and their couplers shall be tight enough to prevent the entrance of cement paste and strong enough to retain their shape and resist damage during handling and concrete placement. Duct material shall not have any adverse chemical reaction with the concrete, prestressing element, or grout.

CC-2435.1 Types of Ducts. Ducts shall be made from ferrous metal.

CC-2435.2 Duct Wall Thickness. The minimum wall thickness shall be 26 gauge (0.45 mm) for ducts 2.625 in. (67 mm) or less in diameter, and 24 gauge (0.6 mm) for ducts greater than 2.625 in. (67 mm) in diameter.

CC-2435.3 Duct Size. The nominal internal cross sectional area of duct for ungrouted multi-element tendons shall be at least 2.0 times the net area of the prestressing steel. For cement-grouted multi-element tendons, provide the duct with a nominal internal cross sectional area of at least 1.75 times the net area of the prestressing steel, and adequacy of this duct size shall be proven by grout field mock-up testing in accordance with CC-2454.1. For prestressing bars, provide the duct with a minimum inside diameter of at least $\frac{1}{2}$ in. (13 mm) larger than the outside diameter of the bar, measured across the deformations. For prestressing bars with couplers, size the duct to be $\frac{1}{2}$ in. (13 mm) larger than the outside diameter of the bar and/or coupler.

CC-2436 Mechanical Tests

CC-2436.1 Scope and Extent of Testing. The tendon Manufacturer shall develop a production test program designed to ensure that all materials used in the production of anchorhead assemblies and wedge blocks will meet the strength and ductility requirements called for by the parts design and substantiated by the performance test.

As a minimum, the following tests shall be conducted:

(a) Tensile test specimen shall be taken in such locations and orientations to provide strength and ductility information reflecting the critical stress–strain direction in the piece.

For parts heat treated after machining, the tensile test specimen shall be heat treated together with the furnace load they represent.

The number of tests shall be set forth in the Construction Specification. The test shall be conducted in accordance with CC-2436.2

(b) Hardness tests shall be conducted on heat-treated materials. A minimum 10% random sample of the parts shall be tested for heat of steel, but not less than one sample from each furnace load. The tests shall be conducted in accordance with CC-2436.2.

(c) Liquid-dye penetrant or magnetic particle inspection shall be conducted on 100% of anchorhead assemblies and wedge blocks subject to heat treatment. The tests shall be conducted in accordance with CC-2436.2.

CC-2436.2 Test Procedures.

(a) Tensile test procedures shall conform to SA-370, and report tensile strength, yield strength, elongation, and reduction of area at failure.

(b) Either Rockwell or Brinell Hardness Testing shall be conducted. Each hardness test shall consist of taking three measurements on each part. The test procedures for Rockwell Hardness Testing and for Brinell Hardness Testing shall conform to SA-370.

(c) For wedges, either Knoop or Vickers Indentation Hardness Testing shall be conducted. The test procedures for Knoop Hardness Testing and for Vickers Hardness Testing shall conform to ASTM E384.

(d) Liquid-dye penetrant testing shall conform to SE-165. Magnetic particle testing shall conform to SE-109.

CC-2436.3 Acceptance Standards. The results of all measurements shall be within the limits set forth in the Construction Specification.

Heat-treated parts, where the liquid-dye penetrant or magnetic particle inspection reveals the presence of cracks, shall be rejected.

CC-2436.4 Rework and Retests. If the physical requirements are not met by any single part, then all parts of the heat or the lot shall be tested. For heat-treated parts, those parts failing to meet the physical requirements, may be rejected or reheat treated once. Parts that are reheat treated shall be retested in accordance with CC-2436.

CC-2437 Hardness of Wedge Plates, Wedges, and Anchor Nuts

CC-2437.1 General. Materials for wedge plates, wedges, and anchor nuts shall conform to their respective material specifications and the hardness test requirements of CC-2437.2. The dimensions, finish, alignment, and tolerances of the wedge plates, wedges, and anchor nuts shall be within the limits set forth in the Construction Specification.

CC-2437.2 Hardness Tests.

CC-2437.2.1 Scope and Extent of Testing. Surface hardness tests shall be conducted on not less than 5% of the wedge plates, wedges and anchor nuts from each heat treatment lot. In addition, core hardness, and for wedges, case depth tests, shall be conducted on three samples of each heat treatment lot. The samples shall be taken at random after heat treatment. Each heat treatment lot shall consist of material from only one heat of steel.

CC-2437.2.2 Test Procedures. The test procedures shall be the same as stated in CC-2436.2.

CC-2437.2.3 Acceptance Standards. All measurements shall be within the limits set down in the construction procedures. Lots not meeting the requirements shall be rejected.

CC-2438 Corrosion Prevention Material

CC-2438.1 Introduction. This subparagraph describes the requirements for material to be used for the temporary and permanent corrosion prevention of prestressing systems.

CC-2438.2 Temporary Coatings.

CC-2438.2.1 Bonded Systems. Temporary corrosion prevention for bonded tendons shall be provided by environmental control. If any temporary corrosion preventive coating is used, it shall allow the portland cement grout to bond uniformly to all parts of the tendon steel. The temporary coating shall be specified in the Construction Specification.

CC-2438.2.2 Unbonded Systems. A temporary corrosion prevention coating shall be applied to all unbonded tendons during or after fabrication. The coating material shall be compatible with the permanent corrosion preventing coating described in CC-2438.4. The temporary coating shall be specified in the Construction Specification. It shall be made to be easily removable in the field with the use of nonchlorinated petroleum solvents for the installation of field attached anchorages.

CC-2438.3 Corrosion Protection for Unbonded Tendons.

(a) Unbonded prestressing steel shall be encased with sheathing. The prestressing steel shall be completely coated, and the sheathing around the prestressing steel filled with suitable material to inhibit corrosion.

(b) Sheathing shall be watertight and continuous over entire length to be unbonded.

(c) For applications in corrosive environments, the sheathing shall be connected to all stressing intermediate and fixed anchorages in a watertight fashion.

Table CC-2438.4.2-1
Analysis Limits of Permanent Coating Material for CRV Prestressing (23)

Test	Acceptance Criteria	Test Method
Consistency (cone penetration) at 77°F (25°C)	260 max.	ASTM D937
Flash point, °F (°C)	400°F min. (205°C min.)	ASTM D92
Congealing point, °F (°C)	135°F min. (57°C min.)	ASTM D938
Oil separation	3% by weight at 100°F (38°C) max.	ASTM D6184 [Note (1)]
Salt spray (fog) 0.5 mil (0.01 mm) coating	200 hr min.	ASTM B117 [Note (2)]
Neutralization number (TBN — total base number)	35 mg KOH/g of sample, min.	ASTM D974 (modified) [Note (3)]
Gamma radiation resistance 1 × 10^6 rad	TBN 25 min. must meet all other specification limits in this Table	...
Water-soluble chlorides, Cl^-	10 ppm max.	ASTM D4327 [Note (4)]
Water-soluble nitrates, NO_3^-	10 ppm max.	ASTM D3867 or ASTM D4327 [Note (4)]
Water-soluble sulfides, S^-	10 ppm max.	APHA 4500-S^{2-} [Note (4)]
Specific gravity at 60°F (15°C)	0.88–1.10	ASTM D1298

NOTES:
(1) Nickel cone must be packed until product exudes through screen and then excess wiped off before test is begun.
(2) Test specimens shall consist of steel meeting the requirements of ASTM D609 Type 1B size 3 in. × 6 in. (75 mm × 150 mm), coating film thickness 0.5 mils ± 0.05 mils (0.01 mm ± 0.001 mm). Failure criteria: ASTM D610 Rust Grade 8, on two out of three faces in an area that is 6.4 mm in from all edges or edge of coating.
(3) Heat 10 g sample in a 500 mL Erlenmeyer flask. Add 10 mL isopropyl alcohol and 5 mL toluene. Heat until sample is solubilized. Add 90 mL distilled water and 20 mL 1N sulfuric acid. Place in steam bath for $\frac{1}{2}$ hr. Stir well. Add phenolphthalein indicator and titrate with 1N sodium hydroxide. Calculate total base number mg KOH/g of sample [(20) (acid normality) — (mL base) × (base normality)] × 56/g of sample.
(4) The inside (bottom and sides) of a 1L beaker, approximate O.D. 105 mm, height 145 mm, is thoroughly coated with 100 g ± 10 g of the tendon sheathing filler coating material. The coated beaker is filled with approximately 900 cc of distilled water and heated in an oven at a controlled temperature of 100°F ± 2°F (38°C ± 1°C) for 4 hr. The water extraction is tested by the noted test procedures for the appropriate water-soluble ions. Results are reported as ppm in the extract water.

(d) Unbonded single-strand tendons shall be protected against corrosion in accordance with ACI 423.7 and PTI M10.2.

CC-2438.4 Permanent Coating Material. The permanent corrosion prevention coating applied to the tendons shall be a microcrystalline wax (petrolatum) base material containing additives to enhance the corrosion inhibiting, wetting, and moisture displacing properties, as well as the ability to form a polar bond with the tendon steel.

CC-2438.4.1 Properties of Permanent Coatings. The coating Manufacturer shall provide certified test data verifying that the following properties are met for the service life and temperature for evaluation and acceptance by the Designer:

(a) freedom from cracking and brittleness
(b) continuous self-healing film over the coated surfaces
(c) chemical and physical stability
(d) nonreactivity with the surrounding and adjacent materials such as concrete, tendons, and ducts
(e) moisture displacing characteristics

CC-2438.4.2 Analysis of Permanent Coatings. The coating Manufacturer shall provide certified Qualification Test Data for the Oil Separation, Salt Spray (Fog), Gamma Radiation Resistance tests, and Cone Penetration tests.

The coating Manufacturer shall supply with each shipment a certified test report with an analysis of the Flash Point; Congealing Point; Neutralization Number (TBN); Specific Gravity; Consistency (Cone Penetration); and Water-Soluble Chlorides, Nitrates, and Sulfides.

The acceptance criteria and test methods shall conform to Table CC-2438.4.2-1.

CC-2440 COMPONENT QUALIFICATION TESTS AND PERFORMANCE REQUIREMENTS

CC-2441 Bearing Plates and Concrete Test Block

CC-2441.1 Testing. Adequacy of bearing plates and concrete test block shall be established by three successful tests. If one of the three specimens fails to pass the test, a supplementary test of three additional test specimens is allowed. The results of three additional test specimens shall meet all acceptance criteria. Concrete test block, size, test procedure, and acceptance criteria are specified in CC-2441.1.1 through CC-2441.1.3.

CC-2441.1.1 Concrete Test Block. The concrete test block shall be a square or rectangle depending on the shape of the bearing plate and shall contain representative embedded tendon components including transitions and ducts. The concrete test block shall further meet the following requirements:

(a) Concrete test block width and depth in each direction shall be the smaller of

(1) two times the minimum edge distance from the centerline of bearing place to face of concrete

(2) the minimum center-to-center spacing of the bearing plate plus 3 in.

(b) The length of a concrete test block containing a single anchorage and local zone, loaded in a testing machine, shall be at least two times the larger cross-sectional concrete test block dimension.

(c) The length of a concrete test block with an anchorage and local zone on either end, loaded by stressing a test tendon, shall be at least four times the larger cross-sectional concrete test block dimension.

(d) The reinforcement in the local zones shall represent the local zone reinforcement required in actual structures.

(e) The concrete strength at time of testing shall not exceed the minimum strength specified for the system at time of tensioning nor 85% of the 28-day cylinder strength.

CC-2441.1.2 Test Procedure. The test force shall be applied to the wedge plate or anchor nut either in a testing apparatus or through an oversized tendon. The force shall be applied in stages to 40% then to 90% of minimum ultimate tensile strength, f_{pu}. At 40% the force shall be held for 10 min to allow inspection for cracks. At 90% the force shall be held for 1 hr, and at 100% of the force for 1 hr. Thereafter, the force shall be increased to at least 120% of f_{pu}, then to failure or to the limit of the testing equipment.

CC-2441.1.3 Acceptance Criteria.

(a) For forces up to 40% of f_{pu}, the width of the concrete cracks shall not exceed 0.002 in. (0.05 mm).

(b) After holding the force at 90% of f_{pu} for 1 hr, the width of concrete cracks shall not exceed 0.010 in. (0.25 mm).

(c) After holding the force at 100% of f_{pu} for 1 hr, the width of concrete cracks shall not exceed 0.016 in. (0.40 mm).

(d) The concrete test block shall not fail prior to reaching 120% of f_{pu}, and the bearing plate shall not yield or visually distort.

CC-2442 Wedge Plates, Wedges, and Strand-Wedge Connections

CC-2442.1 General. Wedge plates, wedges, and strand-wedge connections shall meet the test requirements of CC-2442.2, CC-2442.3, and CC-2442.4, respectively.

CC-2442.2 Wedge Plate Test Requirements. Adequacy of wedge plates shall be established by static tests. The following requirements shall be met:

(a) After loading to 95% of tendon minimum ultimate tensile strength, f_{pu}, and subsequent force release, the permanent deflection of the wedge plate's top surface shall not be more than $^1/_{600}$ of clear span (equal to bearing plate hole diameter). The load test shall be performed with the wedge plate support simulating conditions in the anchorage assembly. The force shall be applied by pulling on a sample tendon using the standard system wedges.

(b) Wedge plates shall be tested to failure in static load tests or to the loading capacity of the testing equipment. The tests shall simulate actual tendon forces applied to the wedges. The failure force shall be at least 120% of f_{pu}.

CC-2442.3 Wedge Performance Requirements. Manufacturing quality control must be adequate to assure uniform quality of the essential manufacturer specified wedge properties including

(a) dimension and tolerances

(b) minimum specified surface hardness

(c) minimum depth of surface hardness (case depth)

(d) maximum core hardness

CC-2442.3.1 Lot Testing. For each lot of 3,000 wedges (not wedge segments) or for each heat-treatment batch, whichever is smaller, manufacturers shall perform the following tests and certify compliance with the minimum requirements of Article CC-2000 and the design documents.

(a) Five percent of wedge segments shall be visually inspected for dimensions and surface defects.

(b) Two percent of wedge segments shall be checked for surface hardness.

(c) One percent of wedges shall be checked for dimensional compliance.

(d) Three cut and polished wedge segments shall be tested using microindentation hardness tests made with Knoop or Vickers indenters as per ASTM E384 to determine case-hardening depth, case hardness, and core hardness. Case-hardening depth, case hardness, and core hardness shall be measured using the same measurement method as that given in ASTM B934. The serration profile shall be checked for dimensional compliance.

CC-2442.3.2 Acceptance Criteria. All test samples must meet the manufacturer's specified wedge properties. If any sample fails any of the above specified quality control tests, then all wedge segments or wedges shall be inspected, and those not in compliance shall be rejected for use.

CC-2442.4 Strand-Wedge Connection Performance Requirements. Strand-wedge connections shall be tested in single strand-wedge tests. Separate tests are required for each strand and wedge type combination, considering these variables: wedge properties, strand size, grade, and manufacturer.

(a) For testing purposes, strand and wedges shall be installed in wedge plates made from identical material and shall have identical wedge hole dimensions and surface finish as the tendon system wedge plates.

(b) The following test requirements shall be met for single strand-wedge connections: (1) and (3) are applicable for strand-wedge connections used for bonded and unbonded tendons; (2) applies to strand-wedge connections used in unbonded systems.

(1) Under static forces, single strand-wedge connections shall hold 95% of the actual tensile strength of the type of strand they will anchor and reach 2% elongation prior to rupture.

(2) Under dynamic forces, single strand-wedge connections shall withstand, without causing wire failure, at least 500,000 force cycles between 60% and 66% of actual strand tensile strength and thereafter 50 force cycles between 40% and 80% of actual strand tensile strength.

(3) During the tests, none of the wedges shall break into separate pieces. Surface cracks are permitted.

CC-2443 Bar-Anchor Nut and Bar-Coupler Connections

CC-2443.1 Performance Requirements. Bar-anchor nut and bar-coupler connections shall be tested for each size, type, and grade.

(a) Bar connections shall support 110% of bar f_{pu} or 95% of actual ultimate tensile strength, whichever is larger.

(b) Anchor nuts shall permit a 5 deg misalignment between bar and bearing plate and still support 110% of f_{pu}.

CC-2444 Tendon Assemblies

Tendon assemblies shall be tested in accordance with CC-2460, and shall meet the requirements in CC-2444.1, CC-2444.2, and CC-2444.3

CC-2444.1 Anchorages. During static tensile test, a full capacity straight tendon, complete with anchorages, shall develop an ultimate tensile strength equal to at least 100% of the minimum specified ultimate tensile strength of the prestressing steel without exceeding the anticipated set of the anchorage elements. The total elongation under ultimate load of the tendon shall not be less than the 2% measured in a minimum gage length of 100 in. (2 500 mm).

CC-2444.2 Low Temperature Requirements. The tendon assembly shall be designed to meet the requirements of Article CC-3000 when exposed to the lowest service temperature as specified in the Construction Specification.

CC-2444.3 Electrical Isolation. Complete electrical isolation of the entire tendon shall be provided. Electrical isolation of the tendon or encapsulation shall be able to be monitored or inspected at any time.

CC-2450 SYSTEM APPROVAL TESTING

CC-2451 General

All components and system testing shall be witnessed and verified by an independent inspection and testing agency. This testing shall be completed prior to submission of post-tension drawings and other related documents to the Designer for approval. The operations of the inspection and testing agency shall be evaluated for conformance to required procedures by a nationally recognized evaluation authority.

CC-2452 Grouting Components Assembly Pressure Test

Assemble anchorage and grout cap with all required grouting attachments. Seal the opening in the anchorage where the duct connects. Condition the assembly in concrete at 150 psi (1 MPa) for 3 hr before conducting the pressure test. The assembly shall sustain internal pressure of 150 psi (1 MPa) for 5 min with no more than 15 psi (103 kPa) reduction in pressure.

CC-2453 Duct Testing

Duct and duct connections installed and cast into concrete prior to prestressing steel installation shall be capable of withstanding 10 ft (3 m) of concrete fluid pressure. Duct and duct connections for use with straight preinstalled prestressing steel, installed prior to concreting, shall be capable of withstanding 5 ft (1.5 m) of concrete pressure. Duct and duct connections shall not permanently dent more than $^1/_8$ in. (3.2 mm) under 150 lb (0.7 kN) of concentrated force applied between corrugations, using No. 4 (13) reinforcing bar. Apply force for 2 min and measure the dent 2 min after force removal. The duct shall have adequate longitudinal bending stiffness so that a smooth interior is maintained for grout placement.

CC-2454 System Pressure Field Tests

The following pressure field tests shall be performed for all assemblies of the bonded or unbonded post-tension system in the concrete containment. The post-tensioning assembly test shall include all components required to make a tendon from grout cap to grout cap for bonded tendons or grease cap to grease cap for unbonded tendons. The assembly of the post-tension system in concrete shall sustain internal pressure of 75 psi to 105 psi (517 kPa to 724 kPa) for 3 min with no more than 15 psi (103 kPa) reduction in pressure.

Figure CC-2462-1
Manufacturer's Record of Tendon Performance Qualification Tests

Specification No. ______	Date ______
Prestressing System Type ______ (wire, strand, or bar)	Single or Multiple Element ______
	If Multiple, No. of Elements ______
Prestressing Element Material ______	Nominal Size ______
Bearing Plate Material ______	Thickness ______ Diameter ______
Wedge Material ______	Hardness ______ (Attach diagram showing shape and size)
Buttonhead Shape and Size (Attach diagram)	
Swaged Fitting Material ______	Hardness ______ (Attach diagram showing shape and size)
Screwed Fitting Material ______	Hardness ______ (Attach diagram showing shape and size)

CC-2454.1 Grout Field Mock-Up Testing. Field mock-up testing shall be conducted to confirm the effectiveness of the grouting operation. Testing shall employ the approved grout mixture, mixing and installation procedures, duct materials, and duct configurations that represent the most critical tendon arrangements (greatest height change and length) anticipated for the project. Grouted duct work shall be destructively examined for a complete encapsulation of tendons and complete filling of duct cavities per a procedure approved by the Designer.

CC-2460 PERFORMANCE TESTS

CC-2461 General Requirements

A series of performance tests shall be conducted to qualify the tendon system for use in the concrete containment. The required tests are designed to demonstrate that the combination of materials for the tendon system is adequate and to assess the overall strength and integrity of the tendon system.

The requirements for static tensile test are specified in CC-2463.1, and the requirements for dynamic tensile tests are specified in CC-2463.2 and CC-2463.3. These tests of the tendon system are in addition to the tests of the separate tendon system components required by CC-2440.

CC-2462 Material to Be Used for Performance Tests

The materials to be used for the performance test tendons shall be those that the tendon Manufacturer proposes using for production tendons. All of the actual materials used and the necessary dimensions shall be documented on a form the same as or similar to that shown in Figure CC-2462-1.

CC-2463 Type and Number of Performance Tests

CC-2463.1 Static Tensile Test. The Construction Specification shall specify the number of static tensile tests (not less than two) to be conducted to destruction so that the following information may be obtained:

(a) yield strength (or proof stress)

(b) ultimate tensile strength

(c) elongation [over 100 in. (2 500 mm) minimum gage length]

(d) number of failed wires or strands

The results shall comply with the requirements of CC-2462.

CC-2463.2 High Cycle Dynamic Tensile Test. One high cycle dynamic tensile test shall be conducted so that the tendon shall withstand, without failure, 500,000 cycles of stress variation from 60% to 66% of the minimum specified ultimate tensile strength of the tendon. One cycle is defined as an increase from the lower load to the higher load and return.

CC-2463.3 Low Cycle Dynamic Tensile Test. One low cycle dynamic tensile test shall be conducted so that the tendon shall withstand, without failure, 50 cycles of stress variation from 40% to 80% of the minimum specified ultimate tensile strength of the tendon. One cycle is defined as an increase from the lower load to the higher load and return.

NOTE: It is considered satisfactory to use the same test specimen for performing the tests prescribed in both CC-2463.2 and CC-2463.3.

CC-2464 Size of Performance Test Specimens

CC-2464.1 Length. The test specimens for static tensile tests shall have a gage length not less than 100 in. (2 500 mm).

Figure CC-2465-1
Record of Mechanical Test Results Obtained From Tendon Performance Qualification Tests

1: STATIC TENSILE TEST

Specimen No.	Effective Area in.^{2} (mm^2)	Yield Load, lb (kN)	Tensile Load, lb (kN)	Yield Strength, psi (MPa)	Tensile Strength, psi (MPa)	Elongation in 100, %	Number of Failed Wires/Strands

2: HIGH CYCLE DYNAMIC TENSILE TEST

Specimen No.	Effective Area in.^{2} (m^2)	Low Load, lb (kN)	High Load, lb (kN)	Low Stress, psi (MPa)	High Stress, psi (MPa)	Cycle Period

3: LOW CYCLE DYNAMIC TENSILE TEST

Specimen No.	Effective Area in.^{2} (m^2)	Low Load, lb (kN)	High Load, lb (kN)	Low Stress, psi (MPa)	High Stress, psi (MPa)	Cycle Period

CC-2464.2 Number of Prestressing Elements.

CC-2464.2.1 Single Element Tendons. A single element specimen shall be used for both static and dynamic tensile tests.

CC-2464.2.2 Multiple Element Tendons.

(a) Static Tensile Tests. All static tensile tests shall be performed on specimens having the full-anchorage capacity of the proposed tendons.

(b) Dynamic Tensile Tests. All dynamic tensile tests shall be performed on specimens having at least 10% of the full-size prestressing steel area of the proposed production tendons.

CC-2465 Test Results

The measurements and results obtained from the tests shall be documented on a form the same as or similar to that shown in Figure CC-2465-1.

CC-2466 Essential Variables

CC-2466.1 General Requirements. The performance tests must be completely reconducted when any of the applicable changes listed below are made to the tendon system material. Changes other than those listed below may be made in the tendon system material without the necessity for repeating the performance tests.

CC-2466.2 Essential Variables in Prestressing (23)
Element Material. Essential variables in prestressing element material shall be as stipulated in (a) through (e) below:

(a) a change in the prestressing element material from one ASTM or ASME specification to another

(b) a change in the tensile grade of the prestressing element material within the same ASTM or ASME specification

(c) a change in the heat treatment condition of the prestressing element material

NOTE: A change in heat treatment process including temperature, holding time, or cooling rate does not constitute a change in the heat treatment condition as long as the change does not violate the ASTM material specification or the Construction Specification.

(d) a change in the prestressing element diameter

(e) in multiple element systems, an increase of more than 10% in the number of elements in the tendon

CC-2466.3 Essential Variables in Anchorage Items. Essential variables in anchorage items shall be as stipulated in (a) through (f):

(a) for buttonhead anchorage systems, a change in the shape or dimensions of the buttonhead

(b) for wedge anchorage systems, a change in the shape, size, material, or dimensions of the wedge

(c) for threaded nut anchorage systems, a change in the nut, thread size, or material

(d) for swaged systems, a change in the shape, size, or material of the swaged fitting

(e) a change in the anchor block material from one type to another

(f) a change in the bearing plate material from one P-Number to another P-Number from Section IX or any other material

CC-2470 MARKING AND IDENTIFICATION OF PRESTRESSING MATERIAL

Prestressing system material shall be marked or tagged in such a manner as to ensure traceability to the Certified Material Test Report during production and while in transit and storage.

CC-2500 MATERIAL FOR LINERS

CC-2510 PERMITTED MATERIAL SPECIFICATIONS

CC-2511 General

Materials to be used for containment liners are listed in Table D2-I-2.2.

CC-2512 Permitted Stainless Steel Specifications

When the desired type of approved stainless steel is lacking in the specification covering the applicable form, the material may be furnished to the general requirements of an approved specification with the chemical composition and mechanical properties conforming to those shown in another approved specification for the desired grade.

CC-2513 Permitted Clad Plate Specifications

(a) Clad plate used in construction in which the design calculations are based on the total thickness including cladding shall conform to one of the following specifications:

(1) SA-263, Corrosion-Resisting Chromium–Nickel Clad Plate, Sheet and Strip

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

(b) Clad plate used in construction in which the design calculations are based on the clad–plate thickness, exclusive of the thickness of the cladding material, may consist of any base plate material satisfying the requirements of CC-2511 and any metallic cladding material of weldable quality that in the judgment of the user is suitable for the intended service.

(c) Integrally clad steel plate, in which any part of the cladding is included in the design calculations, shall show a minimum shear strength of 20,000 psi (140 MPa) when tested in the manner described in the plate specification. One shear test shall be made on each such clad plate as rolled, and the results shall be reported on the CMTR.

(d) When any part of the cladding thickness is specified as an allowance for corrosion, such added thickness shall be removed before mill tension tests are made. When no part of the cladding thickness is specified as an allowance for corrosion, the cladding material need not be removed before testing.

CC-2514 Permanent Structural Attachment Material

Materials to be used for attachments to liners are listed in Table D2-I-2.2. In addition to Table D2-I-2.2, any material permitted to be attached to the pressure-retaining shell under NE-2190(a) of Class MC containment vessel may be welded to the Class CC liner. In which case, the rules of NF-2000 shall be used for the material, and the attachment weld shall meet the requirements of Subsection CC for welding and nondestructive examination.

Structural steel rolled shapes, which are permitted by CC-2121 to be furnished with a certificate of compliance, may be repaired by welding using the welders, documentation, and examination requirements specified in SA-6.

CC-2520 FRACTURE TOUGHNESS REQUIREMENTS FOR MATERIALS

CC-2521 Materials to Be Impact Tested

CC-2521.1 Materials for Which Impact Testing Is Required. Carbon steel and low alloy steel for liners shall be tested either by drop weight tests or the Charpy V-notch impact test. Such tests are not required for

(a) materials with a nominal section thickness of $^5/_8$ in. (16 mm) or less where the thickness shall be taken as defined in (1) through (4)

(1) for liners, use the nominal thickness of the shell or head as applicable

(2) for nozzles or parts welded to liners, use the lesser of the liner thickness to which the item is welded, or the maximum radial thickness of the item exclusive of integral shell buttwelding projections

(3) for flat heads or flanges, use the maximum shell thickness associated with the buttwelding hub

Table CC-2521.1-1
Exemptions From Impact Testing Under CC-2521.1(h)

Material [Note (1)]	Material Condition [Note (2)]	T_{NDT}, °F (°C) [Note (3)]
SA-537 Class 1	N	−30 (−34)
SA-516 Grade 70	Q & T	−10 (−23)
SA-516 Grade 70	N	0 (−18)
SA-508 Class	Q & T	+10 (−12)
SA-299 [Note (4)]	N	+20 (−7)
SA-216 Grades WCB, WCC	Q & T	+30 (−1.0)
SA-36 Plate	HR	+40 (4)

NOTES:
(1) These materials are exempt from toughness testing when A or LSMT − T_{NDT} is above the curve in Figure CC-2521.1-1 for the thickness as defined in CC-2524.2.1 or CC-2524.2.2.
(2) Material Condition letters refer to
N = Normalize
Q & T = Quench and Temper
HR = Hot Rolled
(3) These values for T_{NDT} were established from data on heavy section steel [thickness greater than 2½ in. (64 mm)]. Values for sections less than 2½ in. (64 mm) thick are held constant until additional data are obtained.
(4) Materials made to a fine grain melting practice.

(4) for integral fittings used to attach process piping to the liner (see Figure NE-1120-1), use the larger nominal thickness of the pipe connections

(b) studs, attached to the liner, with a nominal size of 1 in. (25 mm) diameter or less

(c) bars with a nominal cross-sectional area which does not exceed 1 in.^{2} (645 mm^2)

(d) austenitic stainless steels

(e) all thicknesses of material for pipe, tube, and fittings with a nominal pipe size of 6 in. (150 mm) and smaller

(f) material for fittings with pipe connections of ⅝ in. (16 mm) nominal wall thickness and less

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

(h) materials listed in Table CC-2521.1-1 for which the listed value of T_{NDT} is lower than the expression LSMT − A, where LSMT is the lowest service metal temperature specified in the Construction Specification and A is a temperature increment determined from Figure CC-2521.1-1. T_{NDT} is the temperature at or above the nil-ductility transition temperature (NDT) (ASTM E208), and T_{NDT} shall be 10°F (6°C) below the temperature at which at least two material specimens show no-break performance. The LSMT shall be the lowest temperature that the metal may experience in service while the plant is in operation and shall be established by appropriate calculations based on atmospheric ambient conditions, the insulation or enclosure provided, and the minimum temperature that will be maintained inside the containment during the plant operation. This exemption does not apply to either the weld metal impact tests required by CC-2612 or the welding procedure qualification impact tests required by CC-4533.5.

(i) material for which the lowest service metal temperature exceeds 150°F (66°C)

(j) material for embedment anchors when the maximum stress does not exceed 6,000 psi (40 MPa) tension or is in compression

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

CC-2522 Impact Test Procedures

CC-2522.1 Types of Tests.

CC-2522.1.1 Drop Weight Tests.

(a) The drop weight test, when required, shall be performed in accordance with ASTM E208.

(b) Type P1, P2, or P3 specimens shall be prepared in accordance with ASTM E208.

CC-2522.1.2 Charpy V-Notch Tests. Charpy V-notch test (C_v), when required, shall be performed in accordance with SA-370. Specimens shall be in accordance with SA-370, Figure 11, Type A. A test shall consist of a set of three full-size ⅜ in. × ⅜ in. (10 mm × 10 mm) specimens and meet the requirements of CC-2524. 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. (23)

CC-2523 Test Specimens

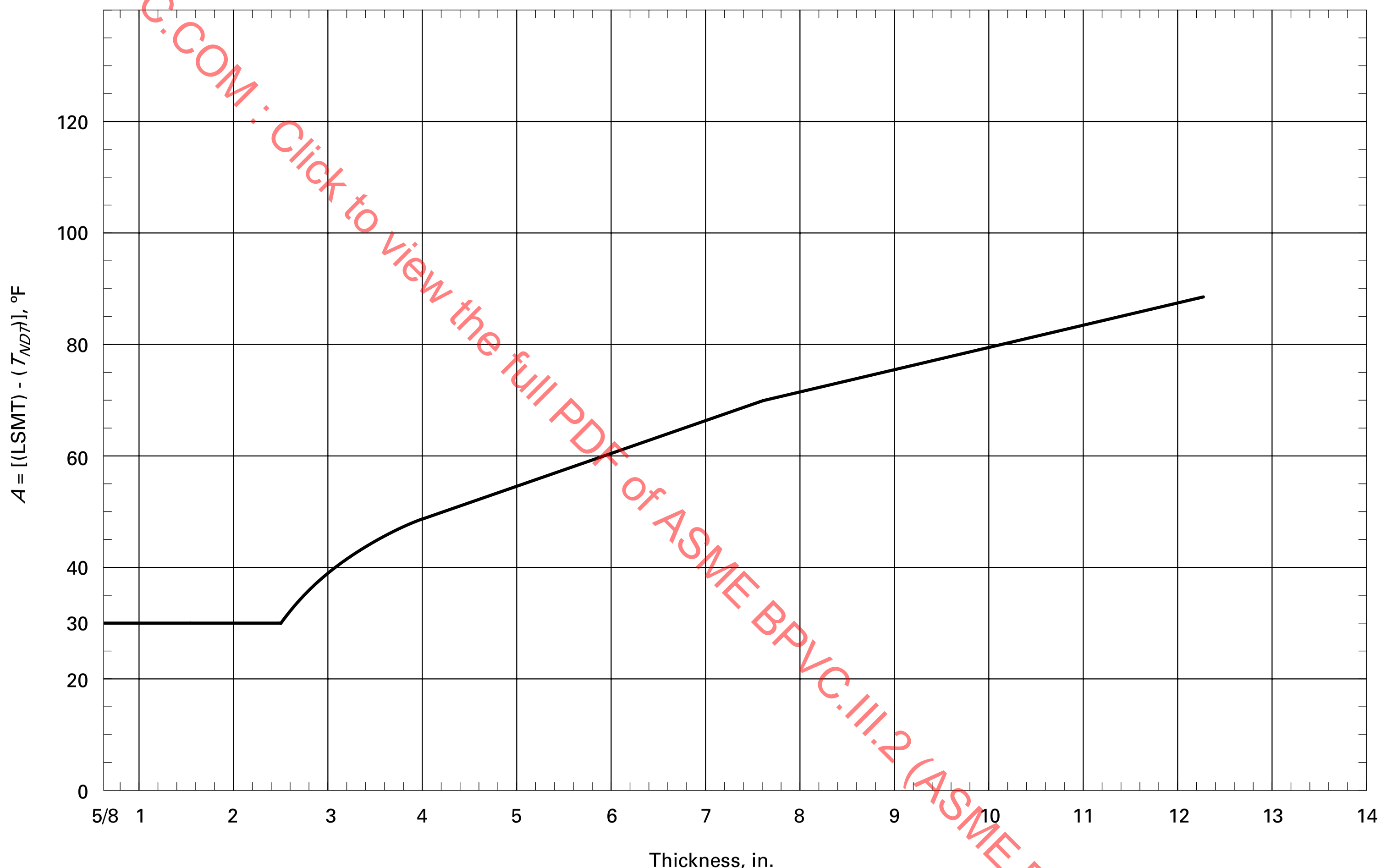
CC-2523.1 Location of Test Specimens. Impact test specimens shall be removed from a depth within the material that is at least as far from the material surface as that specified for tensile test specimens in the material specification. For bolting, the C_v impact test specimens shall be taken with the longitudinal axis of the specimen located at least one-half radius or 1 in. (25 mm) below the surface plus the machining allowance per side, whichever is less. The fracture plane of the specimen shall be at least one diameter or thickness from the heat-treated end.

CC-2523.2 Orientation of Test Specimens.

(a) Impact test specimens for Charpy V-notch tests shall be oriented in accordance with the requirements given for tensile test specimens in SA-370.

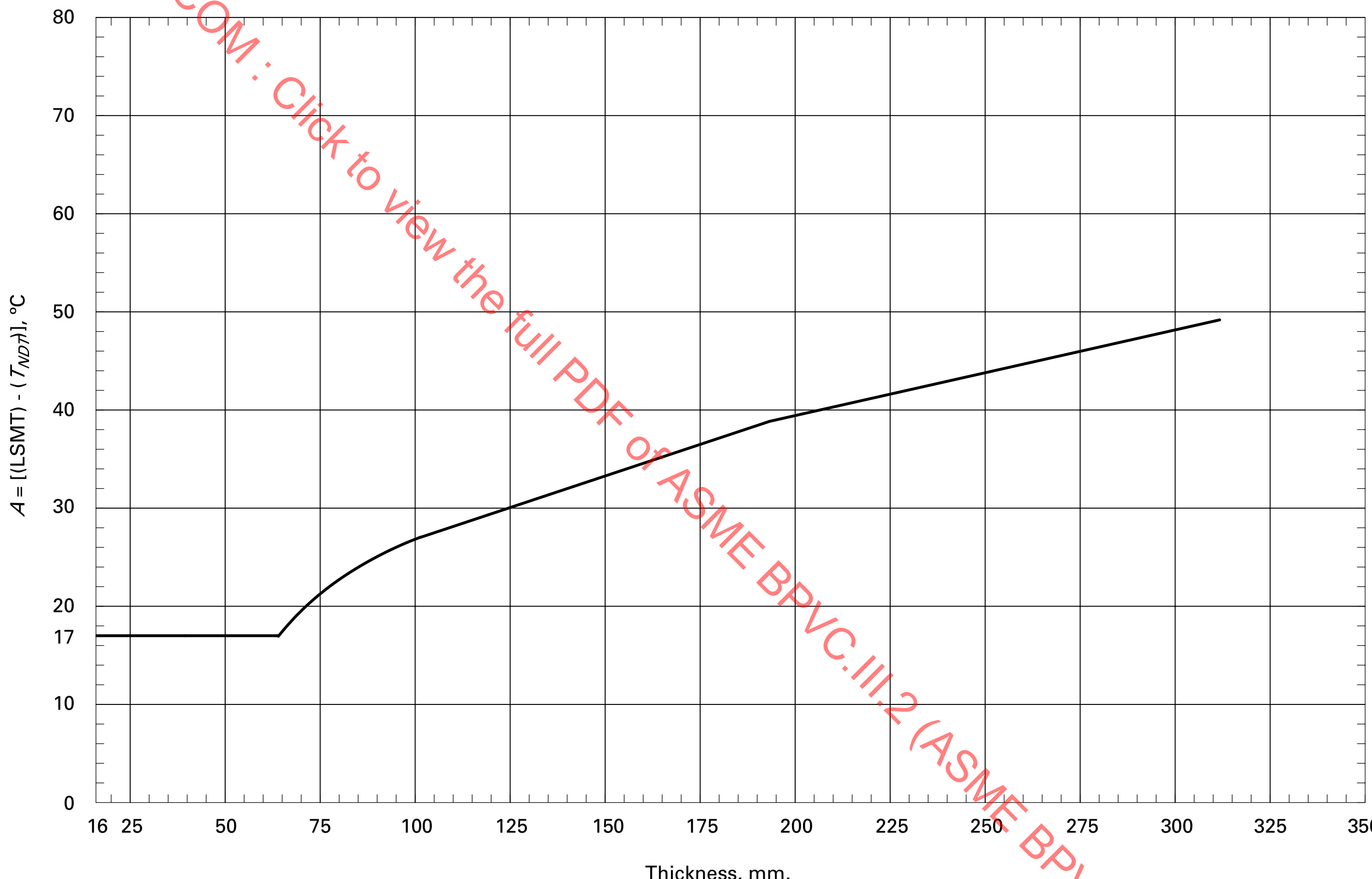
(b) Specimens for drop weight tests may have their axes oriented in any direction.

Figure CC-2521.1-1
Determination of Permissible Lowest Service Metal Temperature



GENERAL NOTE: Permissible lowest service metal temperature = $T_{\text{NDT}} + A$

Figure CC-2521.1-1M
Determination of Permissible Lowest Service Metal Temperature



GENERAL NOTE: Permissible lowest service metal temperature = $T_{NDT} + A$

Table CC-2524.2-1
Required C_v Lateral Expansion Values for Liner Material Other Than Bolting

Nominal Wall Thickness, in. (mm)	Lateral Expansion, mils (mm)	
	Average of 3	Lowest 1 of 3
$^5/_8$ (16) or less [Note (1)]	...	...
Over $^5/_8$ to 1 (16 to 25), incl.	20 (0.50)	15 (0.38)
Over 1 to $1^1/_2$ (25 to 38), incl.	25 (0.64)	20 (0.50)
Over $1^1/_2$ to $2^1/_2$ (38 to 64), incl.	35 (0.90)	30 (0.76)
Over $2^1/_2$ (64) [Note (2)]	45 (1.14)	40 (1.0)

GENERAL NOTES:
(a) Where weld metal tests of CC-2600 are made to these requirements, the impact lateral expansion shall conform to the requirements of either of the base materials being joined.
(b) Where two base materials having different required lateral expansion values are joined, the weld metal lateral expansion requirements of CC-4533 shall conform to the requirements of either of the base materials.

NOTES:
(1) No test required.
(2) For use with CC-2524.2.2.

CC-2523.3 Structural Shapes. The location and orientation of impact test specimens for structural shapes shall be as specified in ASTM A673.

CC-2524 Test Requirements and Acceptance Standards

CC-2524.1 Liner Material Test Method and Temperature.

(a) Liner material shall be impact tested in accordance with one of the following test methods:

(1) Charpy V-notch testing at or below the lowest service metal temperature (requirements for impact testing of the heat-affected zone specified in CC-4533.5 may result in reduced impact test temperatures for the base material)

(2) Drop weight testing to establish a T_{NDT} and demonstrate that $T_{NDT} \leq (\text{LSMT} - A)$

(b) In addition, when the Construction Specification requires that the pneumatic pressure test (see Article CC-6000) be performed at a temperature that is lower than the LSMT, the impact tests for liner material shall be performed in accordance with (a) above, at or below the lowest specified test temperature.

As an alternative, a lowest overpressure test metal temperature shall be specified. The lowest overpressure test metal temperature shall be the lowest temperature that the metal may experience during the overpressure test and shall be established by appropriate calculations based on atmospheric conditions, the insulation or enclosure provided, and the temperature that will be maintained inside the vessel during the test. In this case, Charpy V-notch testing, in addition to the tests required by (a), shall be performed as specified in CC-2522.1.2 at a temperature 30°F (17°C) or more below the lowest overpressure test metal temperature in accordance with CC-2524.4.

CC-2524.2 Specific Test Methods and Acceptance Standards for Liner Material for Tests Based on Lowest Service Metal Temperature.

CC-2524.2.1 Liner Material With $2^1/_2$ in. (64 mm) Maximum Thickness.

(a) Except as limited in CC-4533.5, apply one of the methods of CC-2524.1(a) to test the following:

(1) the base material

(2) the base material, the heat-affected zone, and the weld metal for the weld procedure qualification tests of CC-4533.5

(3) the weld metal for CC-2612.1

(b) The impact test results shall meet one of the acceptance standards applicable to the specified 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 CC-2524.2-1.

(2) Charpy V-Notch Testing for Absorbed Energy Values. The test results of the three specimens collectively and singly shall meet the respective requirements of Table CC-2524.2-2.

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

CC-2524.2.2 Liner Material With Thickness Exceeding $2^1/_2$ in. (64 mm).

(a) The base material and the weld procedure qualification weld metal tests of CC-4533.5 shall be tested by the drop weight method as specified in CC-2522.1.1 and CC-2524.1(a)(2).

(b) Except as limited in CC-4533.5, apply one of the methods of CC-2524.1(a) to test the base material and the heat-affected zone of the weld procedure qualification tests for CC-4533.5 and the weld metal for CC-2612.1.

(c) The acceptance standards shall be given in CC-2524.2.1(b)(1), CC-2524.2.1(b)(2), or CC-2524.2.1(b)(3), as applicable.

CC-2524.3 Bolting Material. The drop weight test is not applicable to bolting materials. For bolting material including nuts, studs, and bolts, a Charpy V-notch test shall be performed. Optionally, the test may be performed at the lowest service metal temperature or at a temperature 30°F (17°C) or more below the lowest service metal temperature.

Table CC-2524.2-2
Required C_v Energy Values for Liner Material Other Than Bolting

Nominal Wall Thickness, in. (mm)	Energy, ft-lb (J), for Base [Note (1)] Materials for Specified Minimum Yield Strength, ksi (MPa)					
	55 ksi (380 MPa) or Below		Over 55 ksi to 75 ksi (Over 380 MPa to 517 MPa), Incl.		Over 75 ksi to 105 ksi (Over 520 MPa to 724 MPa), Incl.	
	Average of 3	Lowest 1 of 3	Average of 3	Lowest 1 of 3	Average of 3	Lowest 1 of 3
$^5/_8$ (16) or less [Note (2)]	...	...	...	...	...	...
Over $^5/_8$ to 1 (16 to 25), incl.	20 (27)	15 (20)	25 (34)	20 (27)	30 (41)	25 (34)
Over 1 to $1^1/_2$ (25 to 38), incl.	25 (34)	20 (27)	30 (41)	25 (34)	35 (48)	30 (41)
Over $1^1/_2$ to $2^1/_2$ (38 to 64), incl.	35 (48)	30 (41)	40 (54)	35 (48)	45 (61)	40 (54)
Over $2^1/_2$ (64) [Note (3)]	45 (61)	40 (54)	50 (68)	45 (61)	55 (74)	50 (68)

GENERAL NOTE: Where weld metal tests of CC-2600 are made to these requirements, the impact energy shall conform to the requirements of either of the base materials being joined.

NOTES:
(1) Where two base materials having different required energy values are joined, the weld metal impact energy requirements of the procedure qualification tests of CC-4533 shall conform to the requirements of either of the base materials.
(2) No test required.
(3) For use with CC-2524.2.2.

(a) When tested at the lowest service metal temperature, lateral expansion and absorbed energy values shall be determined and all three specimens shall meet the requirements of Table CC-2524.3(a)-1.

(b) When tested at 30°F (17°C) or more below the lowest service metal temperature, lateral expansion and absorbed energy values shall be determined and all three specimens shall meet the requirements of Table CC-2524.3(b)-1.

CC-2524.4 Specific Test Methods and Acceptance Standards for Liner Material for Tests Based on Lowest Overpressure Test Metal Temperature.

CC-2524.4.1 Liner Material. Apply the method of CC-2524.1(a)(1) to test the following:

(a) the base material

(b) the base material, the heat-affected zone, and the weld metal for the weld procedure qualification tests of CC-4533.5

(c) the weld metal for CC-2612.1

The impact test results of the three specimens collectively and singly shall meet the respective requirements of Table CC-2524.4-1.

Table CC-2524.3(a)-1
Required C_v Values for Bolting Material Tested in Accordance With CC-2524.3(a)

Nominal Diameter, in. (mm)	Lateral Expansion, mils (mm)	Absorbed Energy, ft-lb (J)
1 (25) or less	No test required	No test required
Over 1 (25) through 4 (100)	25 (0.64)	No requirements
Over 4 (100)	25 (0.64)	45 (61)

Table CC-2524.3(b)-1
Required C_v Values for Bolting Material Tested in Accordance With CC-2524.3(b) and CC-2524.4

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

Table CC-2524.4-1
Required C_v Energy Values for Liner Material for the Overpressure Test

Nominal Wall Thickness, in. (mm)	Energy, ft-lb (J), for Base Materials of Specified Minimum Tensile Strength, ksi (MPa) [Note (1)]			
	60 ksi (420 MPa) or Below		Over 60 ksi (420 MPa)	
	Average of 3	Lowest 1 of 3	Average of 3	Lowest 1 of 3
$^5/_8$ (16) or less [Note (2)]	...	...	...	...
Over $^5/_8$ (16)	15 (20)	10 (14)	20 (27)	15 (20)

GENERAL NOTE: Where weld metal tests of CC-2600 are made to these requirements, the impact energy shall conform to the requirements of either of the base materials being joined.

NOTES:
(1) Where two base materials having different required energy values are joined, the weld metal impact energy requirements of the procedure qualification tests of CC-4533 shall conform to the requirements of either of the base materials.
(2) No test required.

CC-2524.4.2 Bolting Material. For bolting material including nuts, studs, and bolts, a Charpy V-notch test shall be performed. Lateral expansion and absorbed energy values shall be determined and all three specimens shall meet the requirements of Table CC-2524.3(b)-1.

CC-2524.5 Data to Be Reported.

(a) When Charpy V-notch tests are performed to meet the requirements of CC-2520, the test temperature, absorbed energy, lateral expansion, and percent shear shall be reported on the Certified Material Test Report.

(b) When drop weight tests are performed to meet the requirements of CC-2520, the test temperature and the results shall be reported on the Certified Material Test Report.

CC-2525 Number of Impact Tests Required

CC-2525.1 Plate. One test shall be made from each plate as heat treated. Where plates are furnished in the nonheat-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 ingot plate rolled from a slab or directly from an ingot, not to its heat-treated condition.

CC-2525.2 Forgings and Castings. When an individual forging or casting is less than 1,000 lb (450 kg), one test shall be made to represent each heat in each heat treatment charge. When heat treatment is performed in continuous-type furnaces with suitable temperature controls and equipped with recording pyrometers so that complete heat treatment records are available, a heat treatment charge shall be considered as any continuous run not exceeding 8 hr duration or a total weight, so treated, not exceeding 2,000 lb (900 kg). 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. Ring or disk forgings, or castings larger than 10,000 lb (4 500 kg), shall have two tests per part for Charpy V-notch and one test for drop weight. The location of drop weight or Charpy V-notch test specimens shall be selected so that an equal number of specimens is obtained from positions in the forging or casting 180 deg (3.1 rad) apart. When a separate forging or casting is used to represent forgings or castings of any size, one test shall be required.

CC-2525.3 Tubular Products and Fittings. On products that are seamless or welded without filler metal, one test shall be made from each lot. On products that are welded with filler metal, one additional test with the specimens taken from the weld area shall also be made on each lot. A *lot* shall be defined as stated in the applicable material specification, but in no case shall a lot consist of products from more than one heat of material and of more than one diameter, with the nominal thickness of any product included not exceeding that to be impact tested by more than $\frac{1}{4}$ in. (6 mm). Such a lot shall be in a single heat treatment load or in the same continuous run in a continuous-type furnace controlled within a 50°F (28°C) range and equipped with recording pyrometers.

CC-2525.4 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:

Diameter, in (mm)	Weight, lb (kg)
$1\frac{3}{4}$ (44) and less	1,500 (700)
Over $1\frac{3}{4}$ to $2\frac{1}{2}$ (44 to 64)	3,000 (1 400)
Over $2\frac{1}{2}$ to 5 (64 to 125)	6,000 (2 700)
Over 5 (125)	10,000 (4 500)

CC-2525.5 Bars and Rolled Shapes.

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

(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).

CC-2526 Test Coupon Heat Treatment for Ferritic Material

Where ferritic steel material is subject to heat treatment during fabrication or installation of a liner, the material used for the tensile and impact test specimens shall be heat treated in the same manner as the liner, except that test coupons and specimens for P-No. 1 materials with a nominal thickness of 2 in. (50 mm) or less are not required to be so heat treated. Any postweld heat treatment time that is anticipated to be applied to the ferritic material during fabrication or construction after completion of manufacture shall be specified in the Construction Specification. The Material Organization shall include this time in the total time at temperature specified to be applied to the test specimens. The Fabricator shall provide the Material Organization with the temperature and heating and cooling rates 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 may be performed in a single cycle.

CC-2527 Retests

CC-2527.1 Retests for Material Other Than Bolting.

(a) For Charpy V-notch tests required by CC-2524, one retest at the same temperature may be conducted provided

(1) the average value of the test results meets the average of three requirements specified in Table CC-2524.2-1, Table CC-2524.2-2, or Table CC-2524.4-1, as applicable

(2) not more than one specimen per test is below the lowest one of three requirements specified in Table CC-2524.2-1, Table CC-2524.2-2, or Table CC-2524.4-1, as applicable

(3) the specimen not meeting the requirements is not lower than 5 ft-lb (7 J) or 5 mils (0.13 mm) below the lowest one of three requirements specified in Table CC-2524.2-1, Table CC-2524.2-2, or Table CC-2524.4-1, as applicable

(b) A retest consists of two additional specimens taken as near as practicable to the failed specimens. For acceptance of the retests, both specimens shall be equal to or greater than the average of three requirements specified in Table CC-2524.2-1, Table CC-2524.2-2, or Table CC-2524.4-1, as applicable.

CC-2527.2 Retests for Bolting Material.

(a) For Charpy V-notch tests required by CC-2524, one retest at the same temperature may be conducted provided

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

(2) the specimen not meeting the acceptance requirements is not lower than 5 ft-lb (7J) or 5 mils (0.13 mm) below the acceptance requirements

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

CC-2528 Calibration of Instruments and Equipment

Calibration of temperature instruments and Charpy V-notch impact test machines used in impact testing shall be performed at the following frequency:

(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) Charpy V-notch 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).

CC-2530 EXAMINATION AND REPAIR OF LINER MATERIAL

CC-2531 Liner Material

Liner material shall be examined and repaired in accordance with the material specification and as otherwise required by this Article.

CC-2532 Examination After Quenching and Tempering

Ferritic steel products that are used in the quenched and tempered condition shall be examined by the methods specified in this Article for each product form after the quenching and tempering phase of the heat treatment.

CC-2533 Examination and Repair of Plate

CC-2533.1 Required Examination. Plates shall be examined in accordance with the requirements of the material specification.

CC-2533.2 Time of Examination. Acceptance examinations shall be performed at the following times:

(a) Examinations shall be performed as required by the material specification.

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

(c) Ultrasonic examination shall be performed after heat treatment.

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

CC-2533.3 Elimination of Surface Defects. Unacceptable surface defects may be removed by grinding or machining provided

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

(b) The remaining thickness of the plate is not less than that required by Article CC-3000.

(c) elimination of the defect does not reduce the required section thickness by more than $^1/_{16}$ in. (1.5 mm)

(d) if the elimination of the defect reduces the required thickness of the section by more than $^1/_{16}$ in. (1.5 mm), the product shall be repaired by welding in accordance with CC-2533.4 or rejected

CC-2533.4 Repair by Welding. The Material Organization may repair by welding materials from which defects have been removed, provided the requirements of the following subparagraphs are met. Prior approval of the Certificate of Authorization Holder shall be obtained.

CC-2533.4.1 Defect Removal. The defect shall be removed or reduced to an acceptable size by suitable mechanical or thermal cutting or gouging methods, and the cavity prepared for welding. The area shall be examined by magnetic particle or liquid penetrant testing before repair by welding. When thermal cutting and gouging methods are used, preheating in accordance with CC-4521.1.1 shall be used.

CC-2533.4.2 Qualification of Welding Procedures and Welders. The welding procedures and welders or welding operators shall be qualified in accordance with CC-4500 and Section IX.

CC-2533.4.3 Blending of Repaired Areas. After repair, the surface shall be blended uniformly into the surrounding surface.

CC-2533.4.4 Examination of Repair Welds. Each repair weld shall be examined by the magnetic particle method or by the liquid penetrant method. In addition, when the depth of the repair cavity exceeds the lesser of $^3/_8$ in. (10 mm) or 50% of the section thickness, the weld repair shall be radiographed and evaluated to the acceptance standards of CC-5542. The penetrameter and the acceptance standards for radiographic examination of repair welds shall be based on the section thickness of the repair area.

CC-2533.4.5 Heat Treatment After Repairs. The product shall be heat treated after repair in accordance with the heat treatment requirements of CC-4554.

CC-2533.4.6 Material Report Describing Defects and Repairs. Each defect repair exceeding $^3/_8$ in. (10 mm) in depth or 50% of the section thickness shall be described in the CMTR when the repair is made by the Material Organization. The CMTR for each piece shall include a chart that shows the location and size of the prepared cavity, the welding material identification, the welding procedure, the heat treatment, and a report of the results of the examinations, including radiographic film.

CC-2534 Examination and Repair of Forgings and Bars

CC-2534.1 Required Examinations. Forgings and bars shall be examined visually for the presence of chip marks, blemishes, or other surface irregularities.

CC-2534.2 Time of Examination. Acceptance examinations shall be performed at the time of manufacture and in accordance with CC-2533.1.

CC-2534.3 Elimination of Surface Defects. Elimination of surface defects shall be made in accordance with CC-2533.3.

CC-2534.4 Repair by Welding. Repair by welding shall be made in accordance with CC-2533.4.

CC-2535 Examination and Repair of Seamless and Welded (Without Filler Metal) Tubular Products and Fittings

CC-2535.1 Required Examination.

(a) Wrought seamless tubular products and fittings shall comply with the requirements of CC-2535.1.4, CC-2535.1.5, and CC-2535.1.6 in addition to the basic material specification.

(b) Welded (without filler metal) tubular products and fittings shall comply with the requirements of CC-2535.1.4, CC-2535.1.5, and CC-2535.1.6; in addition, the welds shall be examined by one of the following methods:

(1) ultrasonic examination in accordance with CC-2535.1.1

(2) eddy current examination in accordance with CC-2535.1.3

(3) radiographic examination in accordance with CC-2535.1.2

CC-2535.1.1 Ultrasonic Examination. The volumetric examinations required by this paragraph need only be conducted from one surface.

CC-2535.1.1.1 Examination Procedure for Welds in Pipe and Tubing.

(a) Circumferential Direction $6^3/_4$ in. (171 mm) O.D. and Smaller. The welds in pipe and tubing shall be examined in two circumferential directions. The procedure for ultrasonic examination of pipe and tubing in the circumferential directions shall be in accordance with SE-213 and the requirements of this paragraph. The procedure shall provide a sensitivity that will consistently detect defects that produce indications equal to or greater than the indications produced by standard defects included in the reference specimens specified in CC-2535.1.1.3.

(b) Pipe and Tubing Larger Than $6^3/_4$ in. (171 mm) O.D. The welds in pipe and tubing shall be examined in two circumferential directions. The procedure for ultrasonic examination of pipe and tubing larger than $6^3/_4$ in. (171 mm) O.D. shall be in accordance with the requirements of SA-388 for angle beam scanning in the circumferential direction or with the requirements of SE-213. The reference standard shall be in accordance with CC-2535.1.1.3.

(c) Acceptance Standards. Products with defects that produce indications in excess of the indications produced by the standard defects in the reference specimen are unacceptable, unless the defects are eliminated or repaired in accordance with CC-2535.1.5 or CC-2535.1.6.

CC-2535.1.1.2 Examination Procedure for Welds in Fittings.

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

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

CC-2535.1.1.3 Reference Specimens.

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

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

CC-2535.1.1.4 Checking and Calibration of Equipment. The proper functioning of the examination equipment shall be checked and the equipment shall be calibrated by the use of the reference specimens, as a minimum:

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

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

(c) at the end of the production run.

(d) at any time that malfunctioning is suspected.

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

CC-2535.1.2 Radiographic Examination.

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

(b) Examination Procedure. The radiographic examination shall be performed in accordance with Section V, Article 2, as modified by CC-5111.

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

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

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

(-a) $^1/_4$ in. (6 mm) for t up to $^3/_4$ in. (19 mm), inclusive

(-b) $^1/_3t$ for t from $^3/_4$ in. (19 mm) to $1^1/_4$ in. (32 mm), inclusive

(-c) $^3/_4$ in. (19 mm) for t over $1^1/_4$ in. (32 mm)

where t is the thickness of the thinner portion of the weld

(3) any group of aligned indications having an aggregate length greater than t in a length of $12t$, unless the minimum distance between successive indications exceeds $6L$, in which case the aggregate length is unlimited, L being the length of the largest indication

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

CC-2535.1.3 Eddy Current Examination. This examination method is restricted to materials with uniform magnetic properties and of sizes for which meaningful results can be obtained.

CC-2535.1.3.1 Examination Procedure. The procedure for eddy current examination shall provide a sensitivity that will consistently detect defects by comparison with the standard defects included in the reference specimen specified in CC-2535.1.1.3. Products with defects that produce indications in excess of the reference standards are unacceptable unless the defects are eliminated or repaired in accordance with CC-2535.1.5 or CC-2535.1.6, as applicable.

CC-2535.1.3.2 Reference Specimens. The reference specimen shall be of the same nominal diameter and thickness and of the same nominal composition and heat-treated condition as the product that is being examined. The standard shall contain tangential or circumferential notches on the outside surface plus a $^1/_{16}$ in. (1.5 mm) diameter hole drilled through the wall. These shall be used to establish the rejection level for the product to be tested. The reference notches shall have a depth not greater than the larger of 0.004 in. (0.10 mm) or 5% of the wall thickness. The width of the notch shall not exceed $^1/_{16}$ in. (1.5 mm). The length shall be approximately 1 in. (25 mm) or less. The size of reference specimens shall be as specified in CC-2535.1.1.3.

CC-2535.1.3.3 Checking and Calibration of Equipment. The checking and calibration of examination equipment shall be the same as in CC-2535.1.1.4.

CC-2535.1.4 Time of Examination.

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

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

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

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

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

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

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

CC-2535.1.5 Elimination of Surface Defects. Surface defects shall be removed by grinding or machining, provided the requirements of (a) through (c) below are met.

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

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

(c) If the elimination of the defect reduces the thickness of the section below the minimum required to satisfy the rules of Article CC-3000, the product shall be repaired in accordance with CC-2535.1.6.

CC-2535.1.6 Repair by Welding. Repair of defects shall be in accordance with CC-2533.4.

CC-2536 Examination and Repair of Tubular Products and Fittings Welded With Filler Metal

CC-2536.1 Required Examination.

(a) Welded (with filler metal) tubular products, such as pipe made in accordance with SA-358, SA-671, and SA-691 and fittings made in accordance with the WPW grades of SA-234, SA-403, and SA-420, which are made by welding with filler metal, shall be treated as material; however, inspection by an Inspector and stamping with a Certification Mark with NPT Designator shall be in accordance with Section III requirements. In addition to the Certification Mark with NPT Designator, a numeral 2 shall be stamped below and outside the official Certification Mark.

(b) In addition to the requirements of the material specification and of this Article, all welds shall be examined 100% by radiography in accordance with the basic material specification. When radiographic examination is not specified in the basic material specification, the welds shall be examined in accordance with CC-2536.2.

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

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

CC-2536.2 Radiographic Examination. The radiographic examination shall be performed in accordance with the requirements of CC-2535.1.2.

CC-2536.3 Time of Examination. The time of examination shall be in accordance with the requirements of CC-2535.1.4.

CC-2536.4 Elimination of Surface Defects. Unacceptable surface defects shall be removed in accordance with the requirements of CC-2535.1.5.

CC-2536.5 Repair by Welding. When permitted by the basic material specification, base material defects shall be repair welded in accordance with the requirements of CC-2535.1.6. Repair welding of weld seam defects shall be in accordance with CC-4545.

CC-2537 Examination and Repair of Statically and Centrifugally Cast Products

CC-2537.1 Required Examinations. Cast material shall be examined by either radiographic or ultrasonic methods, or a combination of the two methods. Castings or sections of castings that have coarse grains or configurations that do not yield meaningful results by ultrasonic examination shall be examined by radiographic methods.

CC-2537.2 Ultrasonic Examination of Ferritic Steel Castings. The requirements for ultrasonic examination of statically and centrifugally cast products are given in the following subparagraphs.

CC-2537.2.1 Straight Beam Method. When ferritic castings are to be examined ultrasonically, all sections, regardless of thickness, shall be examined in accordance with SA-609; however, supplementary angle beam examination in accordance with CC-2537.2.2 or radiographic examination in accordance with CC-2537.3 shall be performed in areas where a back reflection cannot be maintained during the straight beam examination or where the angle between the two surfaces of the casting is more than 15 deg.

CC-2537.2.2 Angle Beam Method. Examinations shall be conducted in accordance with Section V, Article 5, T-571.4, except that the acceptance standards of CC-2537.2.3 apply.

CC-2537.2.3 Acceptance Standards.

(a) The Quality Levels of SA-609 shall apply for the casting thicknesses indicated in (1) through (3).

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

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

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

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

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

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

GENERAL NOTES:

(a) The area for the Ultrasonic Quality Levels in SA-609 refers to the surface area on the casting over which a continuous indication exceeding the corrected transfer distance amplitude curve is maintained.

(b) Area is to be measured from dimensions of the movement of the search unit, using the center of the search unit as the reference point.

(c) In certain castings, because of very long metal path distances or curvature of the examination surfaces, the surface area over which a given discontinuity is detected may be considerably larger or smaller than the actual area of the discontinuity in the casting; in such cases, other criteria that incorporate a consideration of beam angles or beam spread must be used for realistic evaluation of the discontinuity.

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

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

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

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

CC-2537.3 Radiographic Examination.

CC-2537.3.1 Extent, Methods, and Acceptance Standards. Radiographic examination, when required, shall be performed on castings. The extent of radiographic coverage shall be of the maximum feasible volume. The radiographic methods shall be in accordance with ASTM E94 and shall meet the acceptance requirements of Severity Level 2 of ASTM E446, ASTM E186, or ASTM E280, as applicable, for the thickness being radiographed (except that Category D, E, F, or G defects are not acceptable). The requirements of ASTM E280 shall apply for castings over 12 in. (300 mm) in thickness.

NOTE: The reference radiographs accompanying previous editions of ASTM E186, E280, and E446 may be used with later editions of the specification provided the text of the specified edition is used.

CC-2537.3.2 Procedure. The supplemental requirements of (a) through (d) below apply to the radiographic methods specified by ASTM E94.

(a) Type 4 film is not permitted.

(b) For those areas where relatively uniform thicknesses occur, the minimum film density shall be 1.5 for single viewing and 2.0 for composite viewing of multiple film exposures; each film of a composite set shall have a minimum density of 1.0, and the maximum film density permitted shall be 4.0.

(c) For those sections where the thickness varies sufficiently to cause difficulty in meeting the density requirements with one penetrameter, two penetrameters shall be used representing the thinnest and thickest sections in the area to be interpreted. Densities at or between the densities on the penetrameters shall be considered acceptable, except that the minimum density of the penetrameter image shall be 1.3 for single film viewing and 2.0 for composite film viewing of multiple film exposures; each film of a composite set shall have a minimum density of 1.0.

(d) The radiographic quality level shall be 2 – 4T for section thicknesses up to and including $^3/_4$ in. (19 mm) and 2 – 2T for section thicknesses greater than $^3/_4$ in. (19 mm) Radiographic quality is defined in ASTM E94, Section 6.2.

CC-2537.4 Magnetic Particle Examination.

CC-2537.4.1 Examination Procedure. The procedure for magnetic particle examination shall be in accordance with the methods of Section V, Article 7.

CC-2537.4.2 Evaluation of Indications.

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

(b) Any indication in excess of the CC-2537.4.3 acceptance standards that is believed to be nonrelevant shall be regarded as a defect and shall be reexamined to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications that would mask indications of defects are unacceptable.

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

CC-2537.4.3 Acceptance Standards.

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

(b) The relevant indications of (1) through (4) are unacceptable.

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

(2) rounded indications with dimensions greater than $^{1}/_{8}$ in. (3 mm) for thickness less than $^{5}/_{8}$ in. (16 mm), and greater than $^{3}/_{16}$ in. (5 mm) for thicknesses $^{5}/_{8}$ in. (16 mm) and greater

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

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

CC-2537.5 Liquid Penetrant Examination.

CC-2537.5.1 Examination Procedure. The procedure for liquid penetrant examination shall be in accordance with the methods of Section V, Article 6.

CC-2537.5.2 Evaluation of Indications.

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

(b) Any indication in excess of the CC-2537.5.3 acceptance standards that is believed to be nonrelevant shall be regarded as a defect and shall be reexamined to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation that would mask indications of defects are unacceptable.

(c) Relevant indications are those that result from unacceptable mechanical discontinuities. Linear indications are those indications in which the length is more than three times the width. Rounded indications are indications that are circular or elliptical with the length less than three times the width.

CC-2537.5.3 Acceptance Standards.

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

(b) The relevant indications of (1) through (4) are unacceptable.

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

(2) rounded indications with dimensions greater than $^{1}/_{8}$ in. (3 mm) for thicknesses less than $^{5}/_{8}$ in. (16 mm), and greater than $^{3}/_{16}$ in. (5 mm) for thicknesses $^{5}/_{8}$ in. (16 mm) and greater

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

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

CC-2537.6 Time of Examination. Acceptance examinations, including those for weld repairs, shall be performed at the time of manufacture as stipulated in the following subparagraphs.

CC-2537.6.1 Ultrasonic Examination. Ultrasonic examination, if required, shall be performed at the stage of manufacture as required for radiography.

CC-2537.6.2 Radiographic Examination. Radiography, when required, may be performed prior to heat treatment, and shall be performed at the stage of manufacture defined in this subparagraph. Castings, prior to finish machining, shall be radiographed at the limiting thicknesses stipulated in (a) and (b).

(a) For thicknesses less than 6 in. (150 mm), castings shall be radiographed within 20% of the finished thickness. The penetrameter shall be based on the final thickness.

(b) For thicknesses 6 in. (150 mm) and greater, castings shall be radiographed within 10% of the finished thickness. The penetrameter shall be based on the final thickness.

CC-2537.6.3 Magnetic Particle or Liquid Penetrant Examination. Magnetic particle or liquid penetrant examination shall be performed after the final heat treatment required by the material specification. Repair weld areas shall be examined after postweld heat treatment when a postweld heat treatment is performed, except that repair welds to P-No. 1 material 2 in. (50 mm) nominal thickness and less may be examined prior to postweld heat treatment. For cast products with machined surfaces, all finished machined surfaces, except threaded surfaces, shall also be examined by magnetic particle or liquid penetrant methods.

CC-2537.7 Elimination of Surface Defects. Elimination of surface defects shall be in accordance with CC-2533.4.

CC-2537.8 Repair by Welding. The Material Organization may repair castings by welding after removing the material containing unacceptable defects. The depth of the repair is not limited. A cored hole or access hole may be closed by the Material Organization by welding in accordance with the requirements of this paragraph, provided the hole is closed by filler metal only. If the hole is closed by welding in a metal insert, the welding shall be performed by a Certificate Holder in accordance with the requirements of Article CC-4000.

CC-2537.8.1 Defect Removal. Prior to repair by welding, material containing unacceptable defects shall be removed by suitable mechanical or thermal cutting or gouging methods to sound metal or until any defect remaining is within the acceptance standards, and the cavity shall be prepared for welding.

CC-2537.8.2 Qualification of Welding Procedures and Welders. The welding procedure and welders or welding operators shall be qualified in accordance with Article CC-4000 and Section IX.

CC-2537.8.3 Blending of Repaired Areas. After welding, the surface shall be blended uniformly into the surrounding surface.

CC-2537.8.4 Examination of Repair Welds. Each repair weld shall be examined by the magnetic particle method (see CC-2537.4) or by the liquid penetrant method (see CC-2537.5). In addition, when radiography of the casting is required, repair welds in cavities, the depth of which exceeds the lesser of $^3/_8$ in. (10 mm) or 10% of the section thickness, shall be radiographed in accordance with CC-2537.3. The radiographic method and acceptance standards of CC-2537.3 shall apply, except that weld slag, including elongated slag, shall be considered as an inclusion under Category B of the applicable reference radiographs. The total area of all inclusions, including slag inclusions, shall not exceed the limits of the applicable severity level of Category B of the reference radiographs.

CC-2537.8.5 Heat Treatment After Weld Repair. After repair, the casting shall be heat treated in accordance with CC-4552, except that the heating and cooling limitations of CC-4552.3 do not apply.

CC-2537.8.6 Material Report Describing Defects and Repairs. Each repair weld exceeding in depth either $^3/_8$ in. (10 mm) or 10% of the section thickness shall be described in the Certified Material Test Report. The Certified Material Test Report shall include a chart for each repaired casting, which shows the location and size of the repaired cavity, the welding material identification, the welding procedure, the heat treatment, and the examination results, including radiographic film.

CC-2540 MATERIAL IDENTIFICATION

The identification of liner material shall meet the requirements of NCA-4256 except that materials for leak-chase systems, embedments, and attachments may be bundled and tagged when permitted by the SA material specifications. Materials for small items shall be controlled during manufacture so that they are identifiable as acceptable materials at all times. Welding materials shall be controlled during the repair of material and the manufacture of liners so that they are identifiable as acceptable until the materials are actually consumed in the process (see CC-4122).

CC-2600 WELDING MATERIAL

CC-2610 WELDING MATERIAL REQUIREMENTS

All welding materials used in the construction and repair of components or materials, except welding materials used for hard surfacing, shall conform to the requirements of the welding material specification or to the requirements for other welding materials as permitted by Section IX. In addition, welding materials shall conform to the requirements of this subarticle.

CC-2611 Required Tests

(a) The required tests shall be conducted for

(1) each *lot* of covered, flux cored, or fabricated electrodes

(2) each *heat* of bare electrodes, rod, or wire for use with the OFW, GMAW, GTAW, PAW, and EGW (electrogas welding) processes (QG-109 of Section IX)

(3) each *heat* of backing filler metal (consumable inserts)

(4) each combination of *heat* of bare electrodes and *lot* of submerged arc flux

(5) each combination of *lot* of fabricated electrodes and *lot* of submerged arc flux

(6) each combination of *heat* of bare electrodes and *lot* of electroslag flux

(b) The definitions of SFA-5.01 and the Lot Classes specified in (1) through (4) below shall apply.

(1) each Lot Class C3 of covered electrodes

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

(3) each Lot Class S2 of fully metallic solid welding consumables (bare electrode, rod, wire, or consumable insert)

(4) 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

In all cases, when 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, 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 CC-4533 and this subarticle are made and the results conform to the requirements of this Article.

CC-2612 Weld Metal Tests

CC-2612.1 Mechanical Properties Tests. Tensile and impact tests shall be made for welding material that is used to join P-No. 1 base material with the following exceptions:

(a) austenitic stainless steel welding material used to join P-No. 1 base material

(b) consumable inserts (backing filler material)

(c) welding material to be used for the welding of base material exempted from impact testing by CC-2521.1(a) through CC-2521.1(g) shall likewise be exempted from the impact testing required by this paragraph

CC-2612.1.1 General Test Requirements. The welding test coupon shall be made in accordance with the requirements of (a) through (f) for each process with which the weld material will be used in production welding.

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

(b) The weld metal to be tested for all processes except electroslag welding shall be deposited in such a manner as to substantially eliminate the influence of the base material on the results of the tests. Weld metal to be used with the electroslag process shall be deposited in such a manner as to conform to one of the applicable Welding Procedure Specifications (WPS) for production welding, Section IX. 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 with the range of preheat and interpass temperatures that will be used in production welding. Coupons shall be tested in the as-welded condition, or, where indicated by the WPS, they shall be postweld heat treated to the specified temperatures. The postweld heat treatment holding time shall be at least 80% of the maximum time to be applied to the weld metal in production application. The total time for postweld heat treatment of the test coupon may be applied in one heating cycle. The cooling rate from the postweld heat treatment temperature shall be of the same order as that applicable to the weld metal in the component. In addition, weld coupons for weld metal to be used with the electroslag process that are tested in the as-welded condition, or following a postweld heat treatment within the holding temperature ranges of Table CC-4552-1 or Table CC-4552-3, 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 CC-4552-1 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. Drop weight impact test specimens, where used, shall be oriented so that the longitudinal axis is transverse to the weld with the notch in the weld face, or in a plane parallel to the weld face. For impact specimen preparation and testing, the applicable parts of CC-2522.1.1 and CC-2522.1.2 shall apply. The longitudinal axis of the specimens shall be at a minimum depth of $\frac{1}{4}t$ from a surface, where t is the nominal thickness of the test weld.

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

specified minimum tensile strength 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 parts of CC-2524.2.1, CC-2524.2.2, or CC-2524.4.1, as applicable.

CC-2612.1.2 Standard Test Requirements. In lieu of the use of the general test requirements specified in CC-2612.1.1, tensile and impact tests may be made in accordance with this paragraph where they are required for mild and low alloy steel covered electrodes. The material combinations to require weld material testing as listed in CC-2612.1 shall apply for the standard test requirements option. The limitations and testing under the 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 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 Charpy V-notch specimens or the drop weight test specimens required by CC-2524 or CC-2525, 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 temperature shall be in accordance with Table CC-4552-1 for the applicable P-Number equivalent. The time at postweld heat treatment temperature shall be 8 hr, which qualifies postweld heat treatments of 10 hr or less. Where the postweld heat treatment (PWHT) of the production weld exceeds 10 hr, or the PWHT temperature is other than that required above, the general test of CC-2612.1.1 shall be used.

(d) The tensile and Charpy V-notch specimens shall be located and prepared in accordance with the requirements of SFA-5.1 or SFA-5.5, as applicable. Drop weight impact test specimens, where required, shall be located and oriented as specified in CC-2612.1.1(d).

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

(f) The requirements of CC-2612.1.1(f) shall be applicable to the impact testing of the standard test.

CC-2613 Chemical Analysis Test

Chemical analysis of filler metal or weld deposits shall be made in accordance with CC-2611 and as required by the following subparagraphs.

CC-2613.1 Test Method. The chemical analysis test shall be performed in accordance with this subparagraph and Table CC-2613.1-1, and the results shall conform to CC-2613.2.

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

(b) See (1) and (2) below.

(1) A-No. 8 welding material to be used with other than the GTAW and PAW processes and other welding materials 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) and (d) below. The removal of chemical analysis samples shall be from an undiluted weld deposit made in accordance with (c) below.

(2) 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 the filler metal analysis, 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 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 guidance given in Annex A of SFA-5.9, Specification for Stainless Steel Welding Electrodes and Rods, shall be used to establish a welding and sampling method for the pad, groove, or

Table CC-2613.1-1
Sampling of Welding Materials for Chemical Analysis

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

Table CC-2613.2-1
Welding Material Chemical Analysis

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

other test weld to ensure that the weld deposit being sampled will be substantially free of base metal dilution.

The test sample for ESW shall be removed from the weld metal of the mechanical properties test coupon. Where a chemical analysis is required for a welding material which does not have a mechanical properties test requirement, a chemical analysis test coupon shall be prepared as required by CC-2612.1.1(c), except that heat treatment of the coupon is not required and the weld coupon thickness requirements of CC-2612.1.1(c) do not apply.

(d) The alternative method provided in (b)(2) above for the preparation of samples for chemical analysis of welding material to be used for corrosion resistant overlay cladding shall require a test weld made in accordance with the essential variables of the Welding Procedure Specification that will be followed when the welding material is consumed. The test weld shall be made in conformance with the requirements of Section IX, QW-214.1. The removal of chemical analysis sample shall conform with QW-462 for the minimum thickness for which the Welding Procedure Specifications are qualified.

CC-2613.2 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 the following:

(a) Welding material of ferrous alloy A-No. 8 (Section IX, Table QW-442) shall be analyzed for the elements listed in Table CC-2613.2-1 and for any other elements specified either in the welding material specification referenced by the Welding Procedure Specification or in the Welding Procedure Specification.

(b) The chemical composition of the weld metal or filler metal shall conform to the welding material specification for elements having specified percentage composition 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 the Certified Material Test Report. Elements listed in Table CC-2613.2-1, but not specified in the welding material specification or Welding Procedure Specification shall be reported for information only.

CC-2613.3 Delta Ferrite Determination. A determination of delta ferrite shall be performed on A-No. 8 weld material (Section IX, Table QW-442), backing filler metal (consumable inserts), bare electrode, rod, or wire filler metal, or weld metal, except that delta ferrite determinations are not required for SFA-5.4, Type 16-8-2, or A-No. 8 weld filler metal to be used for weld metal cladding.

CC-2613.3.1 Method. Delta ferrite determinations of welding material, including consumable insert material, shall be made using a magnetic measuring instrument and weld deposits made in accordance with (b) below. Alternatively, the delta ferrite determinations for welding materials may be performed by the use of chemical analysis of CC-2613 in conjunction with Figure CC-2613.3.1-1.

(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 CC-2613.1(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.

CC-2613.3.2 Acceptance Standards. The minimum acceptable delta ferrite shall be 5FN (Ferrite Number). The results of the delta ferrite determination shall be included in the Certified Material Test Report of CC-2130 or CC-4120.

CC-2614 Storage and Handling of Welding Material

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

CC-2620 STUD WELDING MATERIAL

CC-2621 General Requirements

CC-2621.1 Material Specifications. Stud material shall conform to ASTM A108, Grades 1010, 1015, 1016, 1018, or 1020, and to the additional requirements described in this paragraph.

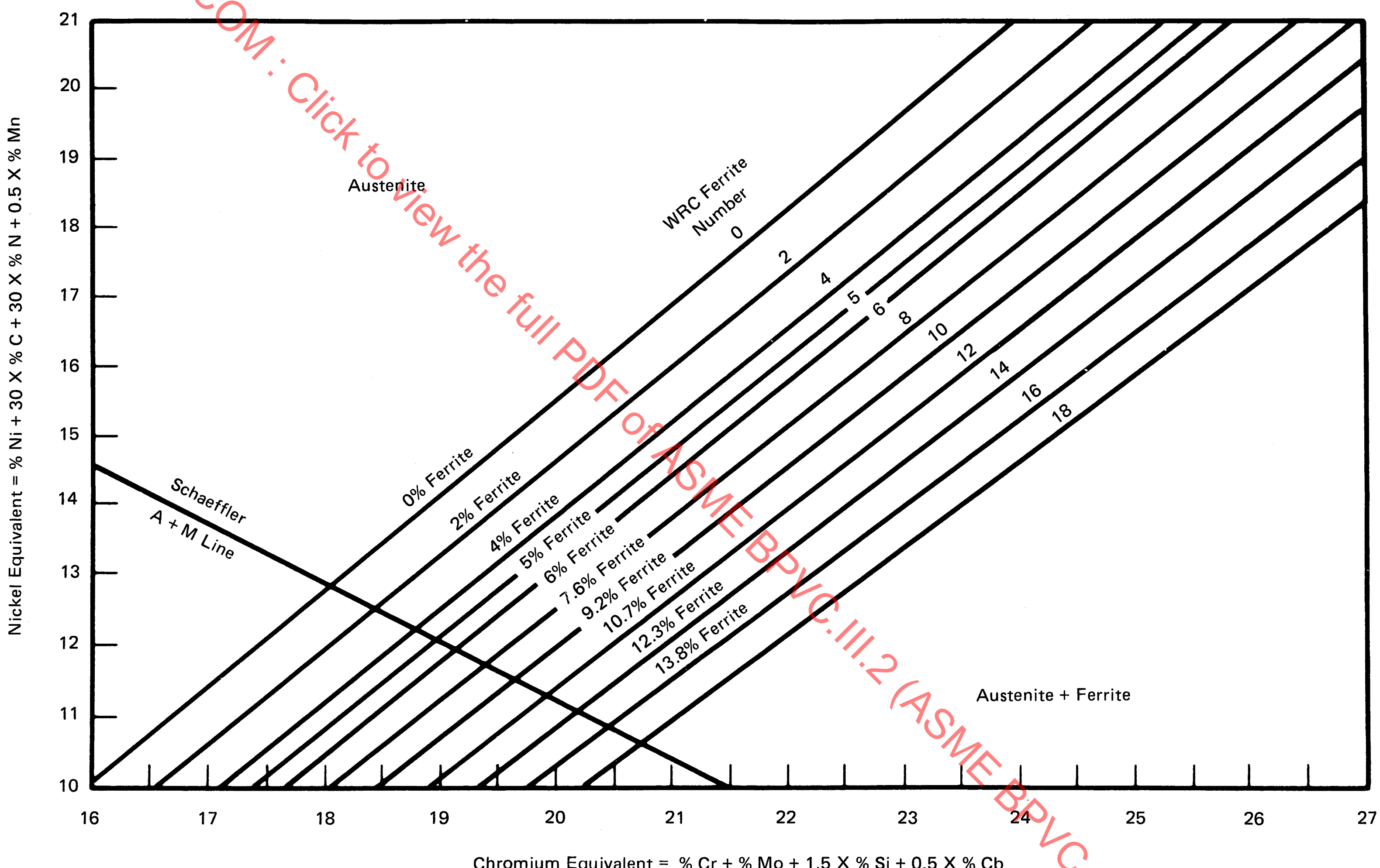
CC-2621.2 Definitions.

(a) Stud base as used herein shall be considered as the stud tip at the welding end, including flux and container, and $^1/_8$ in. (3 mm) of the body of the stud adjacent to the tip.

(b) Angle of bend in testing studs as used herein shall be measured between the original axis of the base material and a line passing through the centers of the two ends of the bent stud.

CC-2621.3 Stud Design. Studs shall be of a design suitable for arc welding to steel members with automatically timed stud welding equipment. The type, size or

Figure CC-2613.3.1-1
Delta Ferrite Content

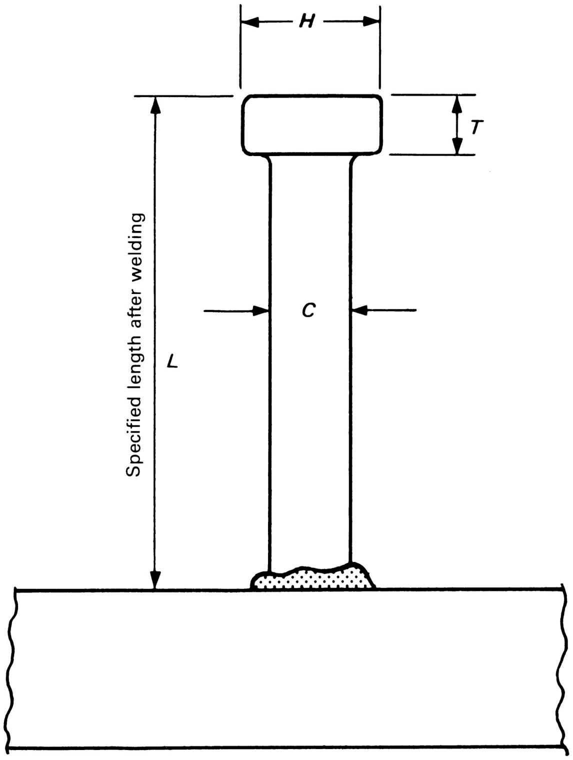


GENERAL NOTES: The actual nitrogen content is preferred. If this is not available, the following applicable nitrogen value shall be used:

(1) GMAW welds — 0.08% (except self-shielding flux-cored electrode GMAW welds — 0.12%)

(2) welds of other processes — 0.6%

Figure CC-2620-1
Dimensions and Tolerances of Standard Studs



Standard Dimensions, in. (mm)

C	Length, L, Tolerances	H	T
$\frac{1}{2}\,^{+0.000}_{-0.010}\left(12.7\,^{+0.00}_{-0.25}\right)$	+ $\frac{1}{16}$ (1.6) − $\frac{1}{8}$ (3.2)	1 ± $\frac{1}{64}$ (25 ± 0.4)	$\frac{9}{32}$ (7) min.
$\frac{5}{8}\,^{+0.000}_{-0.010}\left(15.9\,^{+0.00}_{-0.25}\right)$	+ $\frac{1}{16}$ (1.6) − $\frac{1}{8}$ (3.2)	$1\frac{1}{4}$ ± $\frac{1}{64}$ (32 ± 0.4)	$\frac{9}{32}$ (7) min.
$\frac{3}{4}\,^{+0.000}_{-0.015}\left(19.0\,^{+0.00}_{-0.38}\right)$	+ $\frac{1}{16}$ (1.6) − $\frac{1}{8}$ (3.2)	$1\frac{1}{4}$ ± $\frac{1}{64}$ (32 ± 0.4)	$\frac{3}{8}$ (10) min.
$\frac{7}{8}\,^{+0.000}_{-0.015}\left(22.2\,^{+0.00}_{-0.38}\right)$	+ $\frac{1}{16}$ (1.6) − $\frac{1}{8}$ (3.2)	$1\frac{3}{8}$ ± $\frac{1}{64}$ (35 ± 0.4)	$\frac{3}{8}$ (10) min.

diameter, and length of stud shall be as specified by the Construction Specification. Dimensions and tolerances of standard type studs are given in Figure CC-2620-1.

CC-2621.4 Surface Condition. Finished studs shall be of uniform quality and condition, free of injurious laps, fins, seams, cracks, twists, bends, or other injurious defects. Heads of studs are subject to cracks or bursts, i.e., abrupt interruptions of the periphery of the head of the stud by radial separation of the metal. Such interruptions do not adversely affect the structural strength, corrosion resistance, or other functional requirements of studs. However, studs with cracks or bursts deeper than one-half the distance from the periphery of the head to the shank shall be cause for rejection.

CC-2622 Stud Base Requirements

CC-2622.1 Arc Shield. An arc shield (ferrule) of heat resistant ceramic or other suitable material shall be furnished with each stud.

CC-2622.2 Flux. A suitable deoxidizing and arc stabilizing flux for welding shall be furnished with each stud of $\frac{5}{16}$ in. (8 mm) diameter or larger. Studs less than $\frac{5}{16}$ in. (8 mm) diameter may be furnished with or without flux.

CC-2622.3 Base. The stud base shall not be painted, galvanized, or plated.

CC-2622.4 Qualification Requirements.

CC-2622.4.1 Introduction. The stud base qualification tests described in this subparagraph shall constitute qualification of stud bases with the same geometry, material, flux, and arc shield, of the same diameter and down to but not including $\frac{1}{8}$ in. (3 mm) and smaller nominal diameters.

CC-2622.4.2 Duration of Qualification. A size of stud base with arc shield, once qualified, is considered qualified until the Manufacturer makes any change in the stud base geometry, material, flux, or arc shield.

CC-2622.4.3 Preparation of Specimens.

(a) Test specimens shall be prepared by welding representative studs to suitable plates of P-No. 1 material. Tests for threaded studs shall be on blanks (studs without threads).

(b) Studs shall be welded with power source, welding gun, and automatically controlled equipment. Welding voltage, current, and time shall be measured and recorded for each specimen.

CC-2622.4.4 Number of Test Specimens.

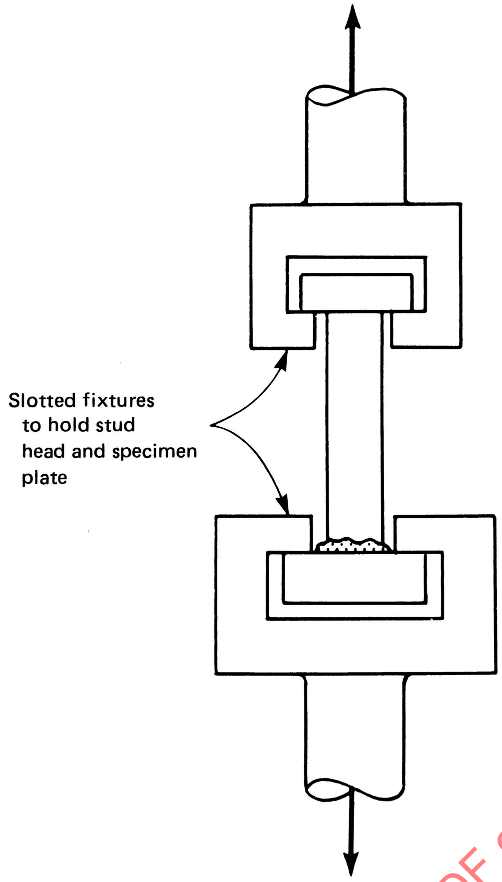
(a) Thirty test specimens shall be welded consecutively with constant optimum time but with current 10% above optimum. Optimum current and time shall be the midpoint range normally recommended for production welding.

(b) Thirty test specimens shall be welded consecutively with constant optimum time but with current 10% below optimum.

CC-2622.4.5 Tensile Tests.

(a) Number of Tests. Ten of the specimens welded in accordance with CC-2622.4.4(a) and 10 in accordance with CC-2622.4.4(b) shall be subjected to a tensile test in a fixture similar to that shown in Figure CC-2620-2, except that studs without heads may be gripped on the unwelded end in the jaws of the tensile testing machine.

Figure CC-2620-2
Typical Tensile Test Fixture



(b) *Acceptance Standards*. A stud base shall be considered qualified if all test specimens have a tensile strength equal to or greater than 60.0 ksi (410 MPa).

CC-2622.4.6 Bend Tests.

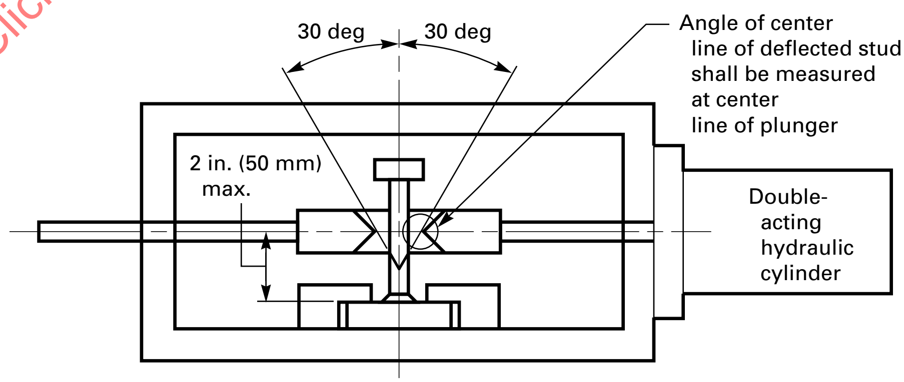
(a) *Number of Tests*. Twenty of the specimens welded in accordance with CC-2622.4.4(a) and 20 in accordance with CC-2622.4.4(b) shall be bend tested by being bent alternately 30 deg in opposite directions until failure occurs. Studs shall be bent in a bend testing device as shown in Figure CC-2620-3, except that studs less than $^1/_2$ in. (13 mm) diameter may be bent using a device as shown in Figure CC-2620-4.

(b) *Acceptance Standards*. A stud base shall be considered qualified if, on all test specimens, fracture occurs in the shank of the stud or plate material and not in the weld or heat-affected zone.

CC-2622.4.7 Retests. If failure occurs at less than the specified minimum tensile strength of the stud during tensile tests, or in the weld or heat-affected zone during bend testing, a new test group as specified in CC-2622.4.4(a) or CC-2622.4.4(b) shall be made and tested. If such failure is repeated, the lot of studs represented shall not be acceptable.

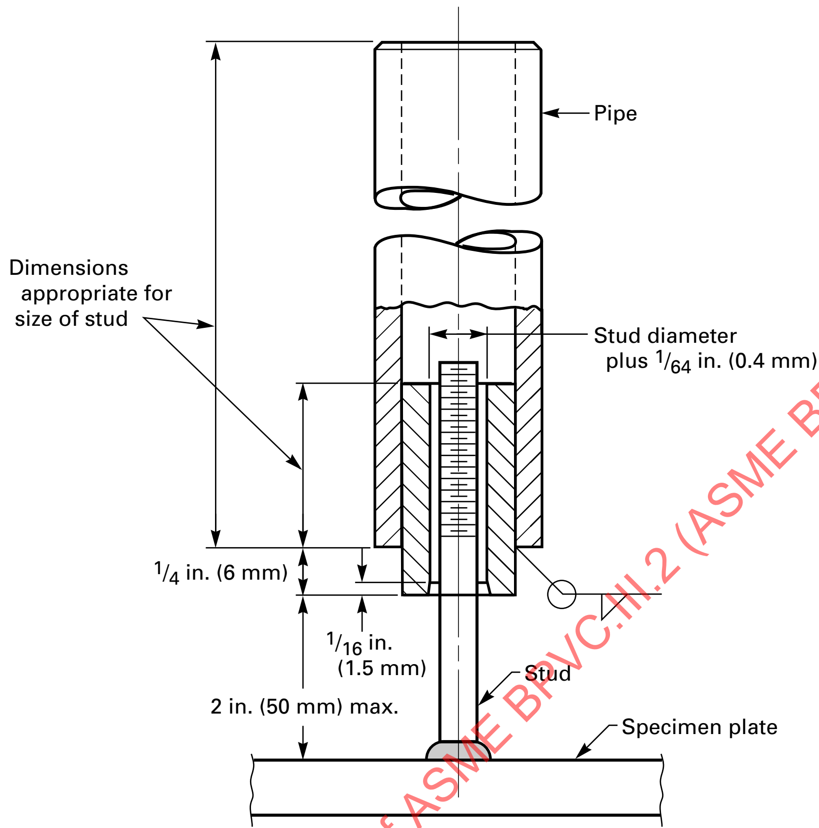
CC-2622.4.8 Acceptance Standards. For a Manufacturer's stud base and arc shield combination to be qualified, each stud of each group of 30 studs shall, by test or retest, meet the requirements of CC-2622.4.5 and CC-2622.4.6. Qualification of a given diameter of stud base shall be considered qualification for stud bases of the same nominal diameter, stud base geometry, material flux, and arc shield.

Figure CC-2620-3
Bend Testing Device



GENERAL NOTE: Fixture holds specimen and stud is bent 30 deg in opposite directions alternately. Load can be applied with hydraulic cylinder (shown) or fixture adopted for use with tensile test machines.

Figure CC-2620-4
Typical Device for Bend Testing of Small Studs



CC-2623 Stud Requirements

CC-2623.1 Chemical Analysis. A chemical analysis shall be made of each heat of stud material. The analysis shall conform to that required for the material specification.

CC-2623.2 Tensile Requirements.

CC-2623.2.1 Tensile Tests. Tensile tests shall be made on each heat of bar stock after drawing or on full-diameter finished studs. Tensile testing shall be performed in accordance with the applicable paragraphs of SA-370. When the tensile requirements for shear connector studs are determined from finished studs, the tensile tests may be made on studs welded to test plates of P-No. 1 material, using a test fixture similar to that shown in Figure CC-2620-2. When the tensile requirements for studs other than shear connectors are determined from finished studs, the ends of the studs may be gripped in the jaws of a tensile testing machine. Plates of adequate size may be fillet welded to the unwelded end for studs without heads. If fracture occurs outside the middle half of the gage length, the test shall be repeated.

CC-2623.2.2 Acceptance Standards. Studs are classified into three types according to strength levels. The tensile test specimens shall conform to the requirements of each type as shown in Table CC-2623.2-1.

CC-2624 Documentation Requirements

The following information shall be incorporated into the Certified Material Test Report (CMTR) in accordance with CC-2130:

(a) drawings showing shape and dimensions, with tolerances, of studs, arc shields, and flux (when used)

(b) results of stud base qualification requirements, including a description of the quantity and type of flux, and a description of the arc shield

(c) chemical analysis of the bar stock

(d) tensile test results from stud tensile tests

Table CC-2623.2-1
Strength Requirements for Studs

	Type A [Note (1)]	Type B [Note (2)]	Type C [Note (3)]
Yield strength, psi (MPa) (minimum)	49,000 (340)	51,000 (350)	70,000 (485)
Tensile strength, psi (MPa) (minimum)	61,000 (420)	65,000 (450)	80,000 (552)
Elongation in 2 in. (50 mm), % (minimum)	17	20	...
Reduction of area, % (minimum)	50	50	...

NOTE:
(1) Type A studs shall be general purpose studs of any type (including threaded) and size used for purposes other than shear transfer.
(2) Type B studs shall be studs that are headed, bent, or of other configuration in $^1/_2$-in. (12-mm), $^5/_8$-in. (16-mm), $^3/_4$-in. (20-mm), $^7/_8$-in. (22-mm), or 1-in. (25-mm) diameter used for purposes including shear transfer, such as liner anchors.
(3) Type C studs shall be cold-worked deformed steel bars manufactured in accordance with specification ASTM A1064 Grade 70 having a nominal diameter equivalent to the diameter of a plain wire having the same weight per foot as the deformed wire. ASTM A1064 specifies a maximum diameter of 0.628 in. (16 mm). Type C studs shall be welded only to the thickened liner plate and shall not be used for shear transfer.

(e) drawing showing shape and dimensions with tolerances of studs, arc shields, and flux, when used

CC-2630 IDENTIFICATION OF WELDING MATERIAL

(a) The identification of welding material (including stud welding material) shall meet the requirements of NCA-4256.4.

(b) Welding material shall be controlled during the repair of material and the manufacture and installation of components so that they are identifiable as accepted material until the material is actually consumed in the process (see CC-4122).

CC-2700 MATERIAL FOR EMBEDMENT ANCHORS

CC-2710 INTRODUCTION

This subarticle establishes the requirements for load-bearing steel materials that are embedded in the concrete containment to perform a containment function or provide anchorage to items attached to thickened liner plates. Anchors that are stud welded to thickened liner plates shall also meet the requirements of CC-2620. These requirements do not apply to the liner, liner anchors, or anchor components of prestressing systems.

CC-2711 Permitted Material Specifications

The material to be used for the construction of embedment anchors are listed in Table D2-I-2.3. Material listed in Table D2-I-2.2 may also be used.

CC-2712 Requirements for Nuts and Washers

(a) Material for nuts shall conform to ASTM A563 or to the requirements for nuts in the specification for the bolting material which is to be used.

(b) Nuts shall be threaded to Class 2B or finer tolerances according to ANSI B1.1. Materials for nuts and washers shall be selected as follows:

(1) Carbon steel nuts and carbon steel washers may be used with carbon steel bolts or studs.

(2) Carbon or alloy steel nuts and carbon or alloy steel washers of approximately the same hardness as the nuts may be used with alloy steel bolts or studs.

(c) Nuts shall be semifinished, extra heavy, chamfered, and trimmed.

CC-2720 FRACTURE TOUGHNESS REQUIREMENTS FOR EMBEDMENT ANCHOR MATERIALS

Fracture toughness requirements for embedment anchor materials shall be in accordance with CC-2520.

CC-2730 EXAMINATION AND REPAIR OF EMBEDMENT ANCHOR MATERIAL

CC-2731 Examination and Repair of Embedment Anchor Material Other Than Bolting

(a) Material for embedment anchors shall be examined in accordance with the material specification. Unacceptable defects may be repaired as permitted by the material specification.

(b) Structural steel rolled shapes, which are permitted by the section to be furnished with a certificate of compliance, may be repaired by welding using welders, documentation, and examination requirements specified in SA-6.

CC-2732 Examination of Bolting Material and Rods

Bolts, partially or fully threaded rods, studs, and nuts shall be examined in accordance with the requirements of the material specification and CC-2733.

CC-2733 Visual Examination

The final surfaces of threads, shanks, and heads of bolts, studs, and nuts shall be visually examined for workmanship, finish, and appearance in accordance with the requirements of ASTM F788 for bolting material and ASTM F812 for nuts. The visual examination personnel shall be trained and qualified in accordance with the Material Organization's Quality System Program or the Certificate Holder's Quality Assurance Program. These examinations are not required to be performed either in accordance with procedures qualified to CC-5112 or by personnel qualified in accordance with CC-5120.

CC-2734 Repair by Welding

Weld repairs of bolting material and rods are not permitted.

CC-2740 MARKING OF EMBEDMENT ANCHOR MATERIAL

CC-2741 Identification

The identification of material requiring Certified Material Test Reports shall meet the requirements of NCA-4256. Material furnished 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 Material Organization that furnishes the embedment anchors as material has verified that the material meets the requirements of this Section.

Materials for small items shall be controlled during the manufacture of the embedment anchor 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 embedment anchors so that it is identifiable as acceptable material until the material is actually consumed in the process.

CC-2800 MATERIAL ORGANIZATION'S QUALITY SYSTEM PROGRAMS

CC-2810 DOCUMENTATION AND MAINTENANCE OF QUALITY SYSTEM PROGRAMS

CC-2811 General

Material Organizations, Nonmetallic Material Manufacturers, and Constituent Suppliers shall document and maintain Quality System Programs (NCA-3800, NCA-3900).

CC-2812 Manufacturers of Nonmetallic Material and Constituent Suppliers

Nonmetallic Material Manufacturers and Constituent Suppliers shall have a Quality System Program that meets the requirements of NCA-3900.

CC-2813 Metallic Material Organizations

Material Organizations shall have a Quality System Program that meets the requirements of NCA-3800.

ARTICLE CC-3000
DESIGN

CC-3100 GENERAL DESIGN

CC-3110 CONCRETE CONTAINMENT

(a) These design criteria apply to concrete containments with steel reinforcement, prestressed tendons or a combination thereof, and metallic liners.

(b) The requirements for radiation shielding, allowable leak rate, design life span of the structure, and quantitative values of the design loads shall be presented in the Design Specification.

(c) The metallic liner shall be designed within limits of stress, strain, and deformation specified in this Article.

(d) The criteria for the containment as demonstrated by the design calculations shall consider factored as well as service load conditions. For factored load conditions, the following requirements shall be met.

(1) Primary forces shall not bring the local section to a general yield state with respect to any component of section membrane strain or section flexural curvature. General yield state is the point beyond which additional section deformation occurs without increase in section forces.

(2) Under combined primary and secondary forces on a section, the development of a general yield state with respect to those membrane strains and/or flexural curvatures which correspond to secondary stress components is acceptable, subject to rebar and concrete strain limits in CC-3420. The concept of a general yield state is not applicable to strains associated with radial shear stress.

(e) The design of parts designated to meet the requirements for Class MC and that are not backed up by concrete for load carrying purposes shall meet the requirements of NE-3000 and Subsection NCA.

CC-3120 METALLIC LINER

CC-3121 General

The liner shall not be used as a strength element in combination with the concrete and rebar. Interaction of the liner with the containment shall be considered in determining maximum strains.

CC-3122 Liner

The general requirements to be used in the design of metallic liners are as follows:

(a) The liner shall be designed to withstand the effects of imposed loads and to accommodate deformation of the concrete containment without jeopardizing leak-tight integrity.

(b) The liner shall be welded using weld details that do not jeopardize leak-tight integrity of the containment.

(c) The liner shall be anchored to the concrete containment. This does not preclude local flexural deformation between anchor points.

CC-3123 Liner Anchors

(a) The liner anchorage system shall be designed to accommodate all design loads and deformations without loss of structural or leak-tight integrity.

(b) The anchorage system shall be so designed that a progressive failure of the anchorage system is precluded in the event of a defective or missing anchor.

CC-3124 Penetration Assemblies

Penetration assemblies, including nozzles, reinforcing plates, and penetration anchors, shall be designed to accommodate all design loads and deformations without loss of structural or leak-tight integrity. Effects such as temperature, concrete creep, and shrinkage shall be considered.

CC-3125 Brackets and Attachments

Temporary or permanent brackets and attachments shall be designed to resist the design loads without loss of the liner integrity due to excessive deformation or load from bracket or attachment loads.

CC-3130 DEFINITION OF TERMS

CC-3131 Service Load Category

Service loads are any loads encountered during construction and in the normal operation of a nuclear power plant. Included in such loads are any anticipated transient or test loads during normal and emergency startup and shutdown of the nuclear steam supply, safety, and auxiliary systems. Also included in this category are those severe environmental loads which may be anticipated during the life of the facility.

CC-3132 Factored Load Category

Factored loads include loads encountered infrequently, such as severe environmental, extreme environmental, and abnormal loads.

CC-3133 Serviceability

Serviceability defines behavior for service or factored load conditions that are not defined by strength or stress limitations. It includes those items where distortion, concrete crack size, or strain are limited. Examples are weathering of concrete, mechanism distortion at hatches and penetrations, liner leakage, and containment interaction with adjacent structures.

CC-3134 Reinforced Concrete

Reinforced concrete is concrete containing reinforcement and designed on the assumption that the two materials act together in resisting forces.

CC-3135 Prestressed Concrete

Prestressed concrete is reinforced concrete in which there have been introduced internal stresses of such magnitude and distribution that the stresses resulting from loads are counteracted to a desired degree.

CC-3136 Stresses and Forces

CC-3136.1 Membrane Stress. Membrane stress is the component of normal stress, hoop or meridional, which is uniformly distributed and equal to the average of stress across the thickness of the section under consideration.

CC-3136.2 Bending Stress. Bending stress is the variable component of normal stress. The variation may or may not be linear across the thickness.

CC-3136.3 Shear Stress. Shear stress may be radial, tangential, peripheral (punching), or torsional.

(a) Radial shear stress is a flexural shear stress which acts perpendicular to the plane of the wall or other element of the containment structure.

(b) Tangential shear stress is a membrane shear stress which acts in the plane of the wall or other element of the containment structure.

(c) Peripheral shear stress is a shear stress around a punching type shear surface, produced by local externally applied forces acting perpendicular to the plane of the wall or other element.

(d) Torsional shear stress is a stress in the plane of the wall or other element of the containment structure produced by components of local externally applied moments about an axis perpendicular to the wall or other element.

CC-3136.4 Primary Force. Primary force is a local, internal force (kip/ft) (N/m) or moment (kip-ft/ft) (N·m/m) which is required to equilibrate applied loads. In some regions of the shell, and for some loadings, there is a redundancy of internal force systems. In such cases the primary, load equilibrating force system shall be justified in the Design Report.

CC-3136.5 Secondary Force. Secondary force is a local, internal force (kip/ft) (N/m) or moment (kip-ft/ft) (N·m/m) that is not required for equilibrating the applied loads. Thus, a secondary force may be either:

(a) a local, internal, force, or moment that results from applied loads, but is not required to equilibrate such loads; or

(b) a local, internal force, or moment that results from nonload, volume change effects, such as shrinkage strain and thermal strain.

CC-3136.6 Classification of Forces. Forces shall be classified in accordance with Table CC-3136.6-1.

CC-3140 TOLERANCES

The Construction Specification shall delineate the tolerance requirements for fabrication and construction. The Designer shall ensure that the tolerances specified in the Construction Specification are compatible with the design assumptions.

CC-3200 LOAD CRITERIA

CC-3210 GENERAL (23)

The containment shall be designed to resist the loads and load combinations given in this Article and as specified in the Design Specification (see NCA-3211.19). The design shall not be limited to the loads specified herein if any other loads are applicable to the particular site conditions.

CC-3220 LOAD CATEGORIES

CC-3221 Service Loads

CC-3221.1 Normal Loads. Normal loads are loads which are encountered during normal plant operation and shutdown.

D = dead loads, including hydrostatic and permanent equipment loads
F = loads resulting from the application of prestress
G = loads resulting from relief valve or other high energy device actuation
L = live loads, including any movable equipment loads and other loads which vary with intensity and occurrence, such as soil pressures
P_v = external pressure loads resulting from pressure variation either inside or outside the containment

Table CC-3136.6-1
Classification of Forces in Concrete Containments for Steel Reinforcing and Concrete Allowable Stresses

Location	Origin of Loads	Type of Force	Classification
Regions away from discontinuities	External [Note (1)]	Membrane	Primary
		Bending	Primary
		Shear [Note (2)]	Primary
	Volume change effects such as creep shrinkage and thermal strains	Membrane	Secondary
		Bending	Secondary
		Shear	Primary
Regions at and near gross changes in shell geometry	External [Note (1)]	Membrane	Primary
		Bending	Primary [Note (3)]
		Shear	Primary
	Volume change effects such as creep shrinkage and thermal strains	Membrane	Secondary
		Bending	Secondary
		Shear	Primary
Regions near large openings	External [Note (1)]	Membrane	Primary
		Bending	Primary
		Shear	Primary
	Volume change effects such as creep shrinkage and thermal strains	Membrane	Secondary
		Bending	Secondary
		Shear	Primary

GENERAL NOTE: Allowable stresses for concrete may be considered secondary in the region defined in CC-3422.1(c)(3).

NOTES:
(1) Includes prestressing.
(2) Includes both radial and tangential shear force.
(3) For allowable stresses, bending at discontinuities due to external loads is considered primary.

R_o = pipe reactions during normal operating or shutdown conditions, based on the most critical transient or steady state condition
T_o = thermal effects and loads during normal operating or shutdown conditions, based on the most critical transient or steady state condition

CC-3221.2 Construction Loads. Construction loads are loads which are applied to the containment from start to completion of construction. The definitions for D, L, F, and T_o given in CC-3221.1 are applicable but shall be based on construction conditions.

CC-3221.3 Test Loads. Test loads are loads which are applied during structural integrity or leak rate testing. The definitions for D, L, and F given in CC-3221.1 are applicable but shall be based on test conditions. In addition, the following shall also be considered:

P_t = pressure during the structural integrity and leak rate tests
T_t = thermal effects and loads during the test

CC-3222 Factored Loads

CC-3222.1 Severe Environmental Loads. Severe environmental loads are loads that could infrequently be encountered during the plant life.

E_o = loads generated by the operating basis earthquake. Only the actual dead load and existing live load weights need be considered in evaluating seismic response forces.
W = loads generated by the design wind specified for the plant site

CC-3222.2 Extreme Environmental Loads. Extreme environmental loads are loads which are credible but are highly improbable.

E_{ss} = loads generated by the safe shutdown earthquake. Weights considered shall be the same as for E_o.
W_t = tornado loading including the effects of missile impact. Included in W_t are the following:
W_{tm} = the tornado generated missile impact effects. The type of impact, such as plastic or elastic, together with the ability of the structure to deform beyond yield shall be considered in

establishing the structural capacity necessary to resist the impact.

W_{tp} = the differential pressure loads due to rapid atmospheric pressure change

W_{tq} = the loads due to tornado wind pressure

CC-3222.3 Abnormal Loads. Abnormal loads are loads generated by the design basis accident (DBA).

H_a = load on the containment resulting from internal flooding, if such an occurrence is defined in the Design Specification as a design basis event

P_a = Design Pressure load within the containment generated by the DBA, based upon the calculated peak pressure with an appropriate margin

R_a = pipe reaction from thermal conditions generated by the DBA including R_o

R_r = the local effects on the containment due to the DBA. The local effects shall include the following:

- R_{rj} = load on the containment generated by jet impingement from a ruptured high energy pipe during the postulated event of the DBA. The time-dependent nature of the load and the ability of the containment to deform beyond yield shall be considered in establishing the structural capacity necessary to resist the effects of R_{rj}.
- R_{rm} = the load on the containment resulting from the impact of a ruptured high energy pipe during the DBA. The type of impact, for example, plastic or elastic, together with the ability of the containment to deform beyond yield shall be considered in establishing the structural capacity necessary to resist the impact.
- R_{rr} = load on the containment generated by the reaction of a ruptured high energy pipe during the postulated event of the DBA. The time-dependent nature of the load and the ability of the containment to deform beyond yield shall be considered in establishing the structural capacity necessary to resist the effects of R_{rr}.

T_a = thermal effects and loads generated by the DBA including T_o

CC-3230 LOAD COMBINATIONS

(a) Table CC-3230-1 lists the load combinations and applicable load factors for which the containment shall be designed.

(b) The live load shall be considered to vary from zero to full value for all load combinations.

(c) The maximum effects of P_a, T_a, R_a, R_r, and G shall be combined unless a time–history analysis is performed to justify lower combined values.

CC-3240 LOAD DEFINITIONS

CC-3241 Static and Seismic Loads

Static loads are defined as those loads that are considered to remain constant with respect to time or that have a long period of application or rise time relative to the response period of the containment. This category also includes seismic loads for which the dynamic effects have been included in their determination. The following are examples of loads in this category:

(a) dead load D, live load L, and prestress F

(b) accident pressure P_a

(c) pipe reactions during normal and postulated accident conditions R_o and R_a

(d) design wind W, tornado wind pressure W_{tq}, and differential pressure W_{tp}

(e) operating and safe shutdown earthquake, E_o and E_{ss}, except when combined with impulse loading and impact effects

CC-3242 Impulse Loads

Impulse loads are time dependent and include the following:

(a) the dynamic effects of accident pressure P_a where rate of loading affects the response of the structure

(b) the effects of pipe rupture reactions R_{rr} and jet impingement loading R_{rj}

(c) the dynamic effects of valve actuation G such as steam relief valve or other high energy device actuation effects where rate of loading affects the response of the structure

CC-3243 Impact Effects

Impact effects are those that can be specified in terms of kinetic energy at impact. These include the impact energies resulting from tornado missiles W_{tm}, pipe rupture generated missiles R_{rm}, and any other specific site-dependent missiles, including the case where a gap exists between the pipe and its structural restraint.

CC-3300 CONTAINMENT DESIGN ANALYSIS PROCEDURES

CC-3310 GENERAL

(a) Methods of analysis that are based on accepted principles of engineering mechanics and that are appropriate to the geometry of the containment shall be used. In the design of local sections, consideration shall be given to the redistribution of moments and forces in a statically indeterminate structure because of cracking of the

Table CC-3230-1
Load Combinations and Load Factors

Category	D	L [Note (1)]	F	P_t	G	P_a	T_t	T_o	T_a	E_o [Note (2)]	E_{ss}	W	W_t	R_o	R_a	R_r	P_v	H_a
Service																		
Test	1.0	1.0	1.0	1.0	...	...	1.0	...	...	...	...	...	...	...	...	...	...	...
Construction	1.0	1.0	1.0	...	...	...	...	1.0	...	...	...	1.0	...	...	...	...	...	...
Normal	1.0	1.0	1.0	...	1.0	...	...	1.0	...	...	...	...	...	1.0	...	...	1.0	...
Factored																		
Severe environmental	1.0	1.3	1.0	...	1.0	...	...	1.0	...	1.5	...	...	...	1.0	...	...	1.0	...
	1.0	1.3	1.0	...	1.0	...	...	1.0	...	...	...	1.5	...	1.0	...	...	1.0	...
Extreme environmental	1.0	1.0	1.0	...	1.0	...	...	1.0	...	...	1.0	...	...	1.0	...	...	1.0	...
	1.0	1.0	1.0	...	1.0	...	...	1.0	...	...	...	...	1.0	1.0	...	...	1.0	...
Abnormal	1.0	1.0	1.0	...	1.0	1.5	...	...	1.0	...	...	...	...	...	1.0	...	...	...
	1.0	1.0	1.0	...	1.0	1.0	...	...	1.0	...	...	...	...	...	1.25	...	...	...
	1.0	1.0	1.0	...	1.25	1.25	...	...	1.0	...	...	...	...	...	1.0	...	...	...
Abnormal/severe environmental	1.0	1.0	1.0	...	1.0	1.25	...	...	1.0	1.25	...	...	...	...	1.0	...	...	...
	1.0	1.0	1.0	...	1.0	1.25	...	...	1.0	...	...	1.25	...	...	1.0	...	...	...
	1.0	1.0	1.0	...	1.0	...	...	1.0	...	1.0	...	...	...	...	...	...	...	1.0
	1.0	1.0	1.0	...	1.0	...	...	1.0	...	...	...	1.0	...	...	...	...	...	1.0
Abnormal/extreme environmental	1.0	1.0	1.0	...	1.0	1.0	...	...	1.0	...	1.0	...	...	...	1.0	1.0	...	...

NOTES:
(1) Includes all temporary construction loading during and after construction of containment.
(2) If the operating basis earthquake (E_o) ground motion is set equal to one-third or less of the safe shutdown earthquake (E_{ss}) ground motion design response spectra, an explicit analysis or design for load combinations including E_o is not required.

concrete, and to the stiffening effect of buttresses or other integral portions of the containment.

(b) The short-term as well as the long-term foundation soil properties shall be considered. In order to ensure consideration of the critical condition, a range of values of soil constants shall be considered.

(c) For prestressed containments, the analytical methods selected for construction and normal category load combinations shall account for the creep characteristics and the thick section geometry that is characteristic at ring girders and buttresses.

CC-3320 SHELLS

(a) Containments are normally thin shell structures. Elastic behavior shall be the accepted basis for predicting internal forces, displacements, and stability of thin shells. Effects of reduction in shear stiffness and tensile membrane stiffness due to cracking of the concrete shall be considered in methods for predicting maximum strains and deformations of the containment. Equilibrium check of internal forces and external loads shall be made to ensure consistency of results.

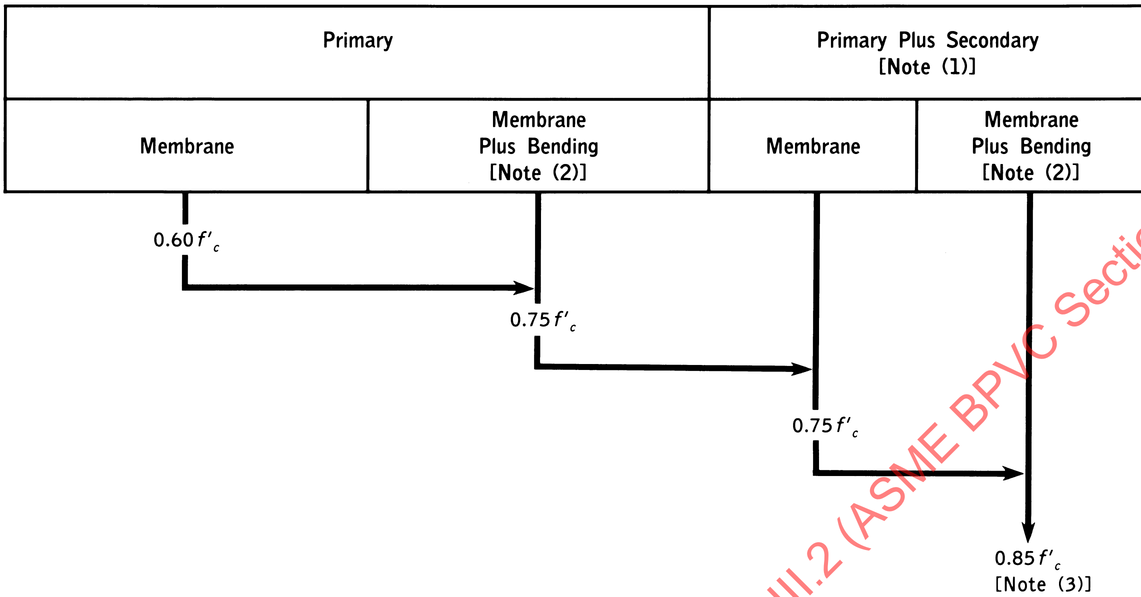
(b) Although shell analysis may be based on membrane theory, additional consideration is required for bending and shear forces at penetrations, intersection with base mat, discontinuities, and the stresses and strains caused by temperature variations.

(c) The stability of the containment shall be verified, giving consideration to the possible reduction in the buckling capacity caused by large deflections, creep effects, and specified construction tolerances.

(d) Model tests may be used instead of the design analysis if they are conservative and represent the prototype containment.

(e) Model tests may be used to check the validity of assumptions involved in mathematical analysis.

Figure CC-3421-1
Allowable Compression Stresses for Factored Loads



NOTES:
(1) The primary portion of this calculated stress shall not exceed the allowable stress applicable when primary stress acts alone.
(2) The membrane portion of this calculated stress shall not exceed the allowable stress applicable when membrane stress acts alone.
(3) The maximum allowable primary-plus-secondary membrane and bending compressive stress of $0.85f'_c$ corresponds to a limiting strain of 0.002 in./in. (0.002 mm/mm).

CC-3330 BASE MAT, FRAMES, BOX-TYPE STRUCTURES, AND ASSEMBLIES OF SLABS

Analyses based on elastic behavior, or other methods generally accepted in conventional practice, shall be used. Effects of discontinuities and loading from the foundation soils shall be considered.

CC-3340 PENETRATIONS AND OPENINGS

(a) Careful attention shall be given to the analysis of the containment in the vicinity of openings. The effect of an opening on the overall containment shall be considered and the containment shall be thickened around the opening, if necessary, to satisfy allowable stresses and facilitate concrete placement.

(b) The thermal stresses caused by process piping passing through the wall shall be considered.

CC-3400 CONCRETE CONTAINMENT STRUCTURE DESIGN ALLOWABLES

CC-3410 GENERAL

In order to keep the containment basically elastic under service load conditions and below the range of general yield under factored primary loads, the allowable stresses and strains specified in this subarticle shall be used. The allowable stresses given in CC-3421, CC-3422, CC-3423, CC-3431, CC-3432, and CC-3433 shall not be exceeded when the containment is subjected to the loads given in Table CC-3230-1.

CC-3420 ALLOWABLE STRESS FOR FACTORED LOADS

CC-3421 Concrete

CC-3421.1 Compression. The allowable stresses for factored compression loads are summarized in Figure CC-3421-1. These allowables shall be reduced, if necessary, to maintain structural stability.

CC-3421.2 Tension. Concrete tensile strength shall not be relied upon to resist flexural and membrane tension.

CC-3421.3 Shear. If the calculated shear is greater than the allowables given in the following paragraphs, then reinforcement or prestressing forces shall be provided in accordance with CC-3520.

CC-3421.4 Radial Shear. Radial shear is a transverse shear and is similar to shear in beam analysis. It occurs in the vicinity of discontinuities in shell flexural or membrane behavior. An example of radial shear is the shear caused by self-constraint of a cylinder and base mat during pressurization of the containment. Another example is the shear in the base mat caused by primary vertical forces in structures supported by the mat. A third example is the shear resulting from discontinuity effects that can occur at the perimeter of penetrations or near other concentrated loads. In this example, peripheral shear must also be considered.

CC-3421.4.1 Reinforced Concrete.

(a) The nominal shear stress v_c shall not exceed the lesser of:

(U.S. Customary Units)

$$v_c = 3.5\sqrt{f'_c} \tag{1}$$

(SI Units)

$$v_c = 0.3\sqrt{f'_c}$$

(U.S. Customary Units)

$$v_c = \left[\left(1.9p\sqrt{f'_c}/0.015\right) + 2500\rho(V_u d/M_u)\right] \tag{2}$$

(SI Units)

$$v_c = 0.16\sqrt{f'_c}\left(\frac{\rho}{0.015}\right) + 17\rho\left(\frac{V_u d}{M_u}\right)$$

for $\rho < 0.015$, and

(U.S. Customary Units)

$$v_c = 1.9\sqrt{f'_c} + 2500\rho(V_u d/M_u) \tag{3}$$

(SI Units)

$$v_c = 0.16\sqrt{f'_c} + 17\rho\left(\frac{V_u d}{M_u}\right)$$

for $\rho \geq 0.015$, where $(V_u d/M_u)$ shall not exceed 1.0.

(b) For sections subjected to membrane compression either eq. (4) or eq. (5) may be used, but v_c shall not be larger than the value given by eq. (6):

(U.S. Customary Units)

$$v_c = 1.9\sqrt{f'_c} + 2500\rho(V_u d/M') \tag{4}$$

(SI Units)

$$v_c = 0.16\sqrt{f'_c} + 17\rho\left(\frac{V_u d}{M'}\right)$$

where $M' = M_u - N_u\,[(4t - d)/8]$ then M' can be less than $V_u d$. If M' is negative, use eq. (6).

(U.S. Customary Units)

$$v_c = 2\left(1 + 0.0005N_u/A_g\right)\sqrt{f'_c} \tag{5}$$

(SI Units)

$$v_c = 0.17\left[1 + 0.07\left(\frac{N_u}{A_g}\right)\right]\sqrt{f'_c}$$

(U.S. Customary Units)

$$v_c = 3.5\sqrt{f'_c}\sqrt{1 + 0.002N_u/A_g} \tag{6}$$

(SI Units)

$$v_c = 0.29\sqrt{f'_c}\sqrt{1 + 0.29\left(\frac{N_u}{A_g}\right)}$$

The units for N_u/A_g are psi (MPa), and N_u is positive for compression.

(c) For sections subjected to membrane tension, eq. (7) shall be used with N_u negative for tension:

(U.S. Customary Units)

$$v_c = 2.0\sqrt{f'_c}\left(1 + 0.002N_u/A_g\right) \tag{7}$$

When $v_u \leq 0.5\sqrt{f'_c}$, v_c may be taken to equal v_u.

(SI Units)

$$v_c = 0.17\sqrt{f'_c}\left[1 + 0.3\left(\frac{N_u}{A_g}\right)\right]$$

When $v_u \leq 0.042\sqrt{f'_c}$, v_c may be taken to equal v_u.

CC-3421.4.2 Prestressed Concrete. The allowable shear stress v_c shall be the lesser of v_{ci} or v_{cw}, as calculated by eqs. (8) and (9):

(U.S. Customary Units)

$$v_{cw} = 3.5\sqrt{f'_c}\sqrt{1 + \frac{f_{pc}}{3.5\sqrt{f'_c}}} \quad (8)$$

(SI Units)

$$v_{cw} = 0.3\sqrt{f'_c}\sqrt{1 + \frac{f_{pc}}{0.3\sqrt{f'_c}}}$$

(U.S. Customary Units)

$$v_{ci} = K\sqrt{f'_c} + \frac{\left(M_{cr} - M_i\right)\frac{V}{M} + V_i}{b'd} \quad (9)$$

(SI Units)

$$v_{ci} = 0.083K\sqrt{f'_c} + \frac{(M_{cr} - M_i)\frac{V}{M} + V_i}{b'd}$$

For $\rho \geq 0.003$, $K = 1.75 - (0.036/n\rho) + 4.0n\rho$, but not less than 0.6.

For $\rho < 0.003$, K shall be taken as zero.

(U.S. Customary Units)

$$M_{cr} = \left(I/y_t\right)\left(6\sqrt{f'_c} + f_{pc}\right)$$

(SI Units)

$$M_{cr} = \left(I/y_t\right)\left(0.5\sqrt{f'_c} + f_{pc}\right)$$

and

(U.S. Customary Units)

$$n = 505/\sqrt{f'_c}$$

(SI Units)

$$n = \frac{41.9}{\sqrt{f'_c}}$$

(a) Loads shall be applied in their chronological order.

(b) The loads at a particular time shall be divided into the following two categories:

(1) the applied load or loads

(2) those loads existing prior to application of the applied load or loads under consideration

(c) If the actual chronological loading order cannot be determined between two or more loads, then the load with the least V/M ratio at the section under consideration shall be applied first.

(d) If $(M_{cr} - M_i)$ is not positive in sign, then it shall be considered as zero.

(e) All existing and applied shear loads shall be taken at the section under consideration.

(f) All moments and other loads affecting the determination of M_{cr} shall be taken at a distance $d/2$ from the section being investigated for shear measured in the direction of decreasing moment.

(g) If the section under consideration is subjected to membrane tension, then eq. CC-3421.4.1(c)(7) shall be used in conjunction with eqs. (8) and (9) with the lowest value of v_c used in the design.

(h) The following definitions shall be used:

f_{pc} = the membrane stress, due to all loads, in the concrete at the centroid of the section where V is applied (positive if compression)

I = moment of inertia at the distance $d/2$ from the section being investigated for shear, measured in the direction of decreasing moment

M = the applied moment associated with the applied shear load

M_{cr} = the moment necessary to cause cracking (always positive)

M_i = the existing moments associated with the existing shear loads (positive if applied in the same direction as the applied moments)

V = the applied shear load at the section under consideration

V_i = the existing shear loads at the section under consideration (positive if applied in the same direction as V)

y_t = distance from the centroidal axis of gross section, neglecting the reinforcement, to the extreme fiber in tension

ρ = A_s/bd, ratio of bonded tension reinforcement

CC-3421.5 Tangential Shear. Tangential shear is a membrane shear in the plane of the containment shell resulting from lateral load such as earthquake, wind, or tornado loading.

CC-3421.5.1 Reinforced Concrete. No tangential shear strength shall be considered as provided by the concrete, i.e.,

$$V_c = 0$$

CC-3421.5.2 Prestressed Concrete. Where a minimum prestress as defined in CC-3521.1.2 is present,

(U.S. Customary Units)

$$V_c = 4\sqrt{f'_c}\,bt\sqrt{1 + \left[\frac{f_m + f_h}{4\sqrt{f'_c}}\right] + \left[\frac{f_m f_h}{\left(4\sqrt{f'_c}\right)^2}\right]} \quad (10)$$

(SI Units)

$$V_c = \frac{\sqrt{f'_c}}{3}\,bt\sqrt{1 + \left[\frac{f_m + f_h}{\frac{\sqrt{f'_c}}{3}}\right] + \left[\frac{f_m f_h}{\left(\frac{\sqrt{f'_c}}{3}\right)^2}\right]}$$

where f_m and f_h are membrane stresses respectively in meridional and hoop directions, compression positive, psi. Thermal membrane stresses shall be included in f_m and f_h.

CC-3421.6 Peripheral Shear. Peripheral shear is a transverse shear and is similar to punching shear in slab analysis. It is the shear resulting from a concentrated force or reaction acting transverse to the plane of the wall. An example of peripheral shear is the transverse shear associated with a local concentrated load. Another example of peripheral shear is the transverse shear which can occur at the perimeter of penetrations. In this example, radial shear must also be considered.

(a) The value of v_c shall be calculated as a weighted average of v_{ch} and v_{cm}: v_{ch} is the allowable shear stress on a failure surface perpendicular to a meridional line, and v_{cm} is the allowable shear stress on a meridional failure surface perpendicular to the plane of the shell. For a circular failure surface, v_c is the average of v_{ch} and v_{cm}.

(b) When the membrane stress f_h or f_m is tensile, the peripheral or punching shear stress taken by the concrete on the assumed failure surface at loaded areas that are circular, square, or rectangular with an aspect ratio β_c less than 2, shall not exceed v_c as obtained in (a) above.

(1) For $f_h/\rho'_h f_y \geq (-0.9)$

(U.S. Customary Units)

$$v_{cm} = \sqrt{f'_c}\left(4 + k_p f_h/\rho'_h f_y\right)$$

(SI Units)

$$v_{cm} = 0.083\sqrt{f'_c}\left(4 + k_p f_h/\rho'_h f_y\right)$$

(2) For $f_h/\rho'_h f_y < (-0.9)$

(U.S. Customary Units)

$$v_{cm} = 0.5\sqrt{f'_c}$$

(SI Units)

$$v_{cm} = 0.042\sqrt{f'_c}$$

(3) For $f_m/\rho'_m f_y \geq (-0.9)$

(U.S. Customary Units)

$$v_{ch} = \sqrt{f'_c}\left(4 + k_p f_m/\rho'_m f_y\right)$$

(SI Units)

$$v_{ch} = 0.083\sqrt{f'_c}\left(4 + k_p f_m/\rho'_m f_y\right)$$

(4) For $f_m/\rho'_m f_y < (-0.9)$

(U.S. Customary Units)

$$v_{ch} = 0.5\sqrt{f'_c}$$

(SI Units)

$$v_{ch} = 0.042\sqrt{f'_c}$$

where

d_p = average outside diameter of penetration in containment wall
f_h = concrete membrane stress in hoop direction, compression positive, psi (MPa)
f_m = concrete membrane stress in meridional direction, compression positive, psi (MPa)
k_p = adjustment factor for penetrations
= $1 + 2.9d_p/t$ (not to exceed 3.9)
t = containment wall thickness
β_c = ratio of long side to short side of loaded rectangular area
ρ'_h = hoop direction reinforcing ratio based on wall thickness t
ρ'_m = meridional direction reinforcing ratio based on wall thickness t

When the aspect ratio β_c of the loaded rectangular area is greater than 2, and when v_{cm} or v_{ch} is greater than $0.5\sqrt{f'_c}$ ($0.042\sqrt{f'_c}$), the values of v_{cm} or v_{ch} shall be reduced by the factor ($^1\!/_2 + {}^1\!/_{\beta_c}$).

(c) Where the membrane stress f_h or f_m is compressive but less than 125 psi, (0.86 MPa), v_{cm} or v_{ch} shall be taken equal to $4\sqrt{f'_c}$ ($0.33\sqrt{f'_c}$).

(d) For load conditions where the membrane stress f_h or f_m, as defined above, is at least 125 psi (0.86 MPa) compression, the peripheral or punching shear taken by the concrete on the assumed failure surface shall not exceed v_c as obtained in (a) above:

(U.S. Customary Units)

$$v_{cm} = 3.5\sqrt{f'_c} + 0.3f_h$$

(SI Units)

$$v_{cm} = 0.3\sqrt{f'_c} + 0.3f_h$$

(U.S. Customary Units)

$$v_{ch} = 3.5\sqrt{f'_c} + 0.3f_m$$

(SI Units)

$$v_{ch} = 0.3\sqrt{f'_c} + 0.3f_m$$

where f'_c shall not be taken as greater than 5,000 psi (34.5 MPa) and neither f_h nor f_m shall be taken greater than 500 psi (3.5 MPa).

CC-3421.6.1 Critical Section. The failure surface for peripheral shear shall be perpendicular to the surface of the containment and located so that its periphery is at a distance $d/2$ from the periphery of the concentrated load or reaction area, except for impact loads where the critical section is defined in CC-3931.

CC-3421.7 Torsion. Torsional shear stress is a local, in-plane shear stress produced in the containment wall by a direct external torsional loading applied about an axis normal to the containment wall. In the case of piping penetrations normal to and anchored in the containment wall, the applicable loading is the torsional moment in the penetration. When the penetration is on a skew from the containment wall, the applicable loading is the sum of the components, along an axis normal to the containment, of the internal moments (torsion and bending) in the penetration. Such a loading and anchorage will produce in-plane shear stress in the concrete normal to a radius from the center line of the penetration.

(a) The shear stress carried by the concrete v_{ct} resulting from a torsional loading shall not exceed v_{ct} as calculated from the eq. (11):

(U.S. Customary Units)

$$v_{ct} = 6\sqrt{f'_c}\sqrt{1 + \frac{f_h + f_m}{6\sqrt{f'_c}} + \frac{f_m f_h}{\left(6\sqrt{f'_c}f'_c\right)^2}} \quad (11)$$

(SI Units)

$$v_{ct} = 0.5\sqrt{f'_c}\sqrt{1 + \frac{f_h + f_m}{0.5\sqrt{f'_c}} + \frac{f_m f_h}{\left(0.5\sqrt{f'_c}\right)^2}}$$

but need not be taken less than $4\sqrt{f'_c}\left(0.33\sqrt{f'_c}\right)$.

(b) The torsional shear failure surface shall be a cylindrical surface perpendicular to the surface of the containment and located at a distance r from the center line of the penetration or embedment plate.

Failure surfaces located nearer to the center line than r_{min} need not be evaluated.

(c) The following definitions shall be used:

r = the distance measured along a radial line from the center of a containment piping penetration or embedded plate to the failure surface

r_{min} = the distance measured along a radial line from the center of a containment penetration to the end of penetration anchors attached normal to the penetration wall, or the radial distance from the center line of containment penetration or embedded plate to the center line of the furthest anchor, for anchors mounted normal to the containment surface

CC-3421.8 Brackets and Corbels.

CC-3421.8.1 General. These provisions shall apply to brackets and corbels with a shear span-to-depth ratio a/d not greater than unity, and subject to a horizontal tensile force N_{uc} not larger than V_u. Distance d shall be measured at face of support.

CC-3421.8.2 Depth. Depth at outside edge of bearing area shall not be less than $0.5d$.

CC-3421.8.3 Design. Section at face of support shall be designed to resist simultaneously a shear V_u, a moment $[V_u a + N_{uc}(h - d)]$, and a horizontal tensile force N_{uc}.

(a) In all design calculations in accordance with these provisions, the nominal shear stress v_u shall be computed as

$$v_u = \frac{V_u}{0.85bd}$$

where V_u is the factored shear force at the section.

(1) Design of shear-friction reinforcement A_{vf} to resist shear V_u shall be in accordance with CC-3424.

(2) The nominal shear stress v_u shall not exceed the smallest of $0.2f'_c$, 480 psi (3.3 MPa) + $0.08f'_c$ and 1,600 psi (11 MPa).

(b) Reinforcement A_f to resist moment $[V_u a + N_{uc}(h - d)]$ shall be computed in accordance with CC-3500.

(c) Reinforcement A_n to resist tensile force N_{uc} shall be determined from $N_{uc} \le 0.85 A_n f_y$. Tensile force N_{uc} shall not be taken less than $0.2V_u$ unless special provisions are made to avoid tensile forces. Tensile force N_{uc} shall be regarded as a live load even when tension results from creep, shrinkage, or temperature change.

(d) Area of primary tension reinforcement A_3 shall be made equal to the greater of $(A_f + A_n)$ or $(2A_{vf}/3 + A_n)$.

CC-3421.8.4 Stirrups. Closed stirrups or ties parallel to A_3, with a total area A_h not less than 0.5 $(A_3 - A_n)$, shall be uniformly distributed within two-thirds of the effective depth adjacent to A_3.

CC-3421.8.5 Reinforcement Ratio. Ratio $\rho = A_3/bd$ shall not be less than $0.04(f'_c/f_y)$.

CC-3421.8.6 Anchorage. At front face of bracket or corbel, primary tension reinforcement A_3 shall be anchored by one of the following:

(a) by a structural weld to a transverse bar of at least equal size; weld to be designed to develop specified yield strength f_y of A_3 bars;

(b) by bending primary tension bars A_3 back to form a horizontal loop; or

(c) by some other means of positive anchorage.

CC-3421.8.7 Bearing Area. Bearing area of load on bracket or corbel shall not project beyond straight portion of primary tension bars A_3, nor project beyond interior face of transverse anchor bar (if one is provided).

CC-3421.9 Bearing. Bearing stresses shall not exceed $0.6f'_c$, except as provided below.

(a) When the supporting surface is wider on all sides than the loaded area or otherwise confined, the permissible bearing stress on the loaded area may be multiplied by $\sqrt{A_2 / A_1}$ but not by more than 2.

(b) When the supporting surface is sloped or stepped, A_2 may be taken as the area of the lower base of the largest frustum of a right pyramid or cone contained wholly within the support and having for its upper base the loaded area, and having side slopes of one vertical to two horizontal.

(c) This Subsection does not apply to post-tensioning anchorages.

CC-3422 Reinforcing Steel

CC-3422.1 Design Strength.

(a) The design yield strength of reinforcement shall not exceed 80,000 psi (550 MPa). For shear friction, radial shear, peripheral shear, torsional and beam shear reinforcement, the design yield strength of reinforcement shall not exceed 60,000 psi (420 MPa).

(b) The allowable stress for load resisting purposes shall not exceed $0.9f_y$.

(c) Under the primary forces only, the tensile strain in reinforcement resisting membrane and flexural components of the local section forces (but not the strain in reinforcement resisting local section shear forces) may exceed $0.9\epsilon_y$, provided a sufficient number of reinforcement bars remains below $0.9\epsilon_y$, such that attainment of a general yield state is precluded with respect to any components of curvature. Reinforcement may be permitted to exceed $0.9\epsilon_y$ under the effects of primary forces for the following conditions only.

(1) Primary Bending Moment. If more than one layer of reinforcement is provided to resist primary bending moments, one or more layers of reinforcement may be permitted to exceed $0.9\epsilon_y$, provided the strain at the centroid of all bars more than $h/6$ from the center of the concrete section on the maximum tension side of the section shall not exceed $0.9\epsilon_y$.

(2) Tension Diagonal Reinforcement. The strain in a tension diagonal reinforcement of a four-way reinforcement system to primary forces may exceed $0.9\epsilon_y$. To avoid the possible buckling of compression diagonal reinforcement, either the diagonal reinforcement shall be enclosed by at least one layer of hoop reinforcement or the tension and compression diagonal reinforcement shall be tied at their intersections.

(3) Adjacent to Large Openings. The maximum strain in reinforcement adjacent to large openings may exceed $0.9\epsilon_y$ provided that, when a section of width one-half nominal containment shell thickness h extending from the opening or 25% of the opening diameter, whichever is smaller, is analyzed for the total forces and moments assumed uniformly distributed over the section width, no reinforcement strain shall exceed $0.9\epsilon_y$.

(d) Under combined primary and secondary forces, the tensile strain in reinforcement may exceed $0.9\epsilon_y$.

(e) Calculated tensile strains in any reinforcement due to primary forces and the major principal membrane strain due to primary forces shall not exceed $2\epsilon_y$. For analysis purposes, ϵ_y is defined as the yield stress divided by Young's modulus.

CC-3422.2 Compression.

(a) For load resisting purposes, the stress shall not exceed $0.9f_y$.

(b) The strains may exceed yield when acting in conjunction with the concrete if the concrete requires strains larger than the reinforcing yield to develop its capacity.

CC-3423 Tendon System Stresses

The axial tensile capacity of the tendon shall not be taken as greater than $0.9f_{py}$.

CC-3424 Shear Friction

CC-3424.1 General. The provisions of CC-3424 are to be applied where it is appropriate to consider shear transfer across a given plane, such as an

(a) existing or potential crack
(b) interface between dissimilar materials, or
(c) interface between two concretes cast at different times.

CC-3424.2 Crack Location. A crack shall be assumed to occur along the shear plane considered. Required area of shear-friction reinforcement A_{vf} across the shear plane may be designed using either CC-3424.3 or any other shear transfer design methods that result in prediction of strength in substantial agreement with results of comprehensive tests.

CC-3424.3 Shear-Friction Design Method.

CC-3424.3.1 When shear-friction reinforcement is perpendicular to shear plane, the area of reinforcement required shall be computed by

$$A_{vf} = \frac{V_u}{0.85 \mu f_y}$$

where μ is the coefficient of friction in accordance with CC-3424.3.3 and V_u is the factored shear force at section.

CC-3424.3.2 When shear-friction reinforcement is inclined to shear plane, such that the shear force produces tension in shear-friction reinforcement, the area of reinforcement required shall be computed by

$$A_{vf} = \frac{V_u}{0.85\, f_y \left(\mu \sin \alpha_f + \cos \alpha_f\right)}$$

where α_f is the angle between shear-friction reinforcement and shear plane. This equation is not valid if α_f is greater than 90 deg.

CC-3424.3.3 Coefficient of friction μ in CC-3424.3.1 and CC-3424.3.2 shall be

(a) 1.4 for concrete placed monolithically
(b) 1.0 for concrete placed against hardened concrete with surface intentionally roughened as specified in CC-3424.8
(c) 0.6 for concrete placed against hardened concrete not intentionally roughened
(d) 0.7 for concrete anchored to as-rolled structural steel by headed studs or by reinforcing bars (see CC-3424.9)

CC-3424.4 Maximum Shear. The shear friction provisions of CC-3424 are not applicable if the nominal shear stress v_u exceeds the smallest of $0.2f'_c$, 480 psi (3.3 MPa) + $0.08f'_c$ and 1,600 psi (11 MPa) for normal weight concrete either placed monolithically or placed against hardened concrete with surface intentionally roughened as specified in CC-3424.8 or the smallest of $0.2f'_c$ and 800 psi (5.5 MPa) for all other cases. Where concrete of different strengths are cast against each other, the value of f'_c used to evaluate v_u shall be that of the lower-strength concrete.

CC-3424.5 Strength of Reinforcement. Design yield strength of shear-friction reinforcement shall not exceed 60,000 psi (420 MPa).

CC-3424.6 Tension. Net tension across shear plane shall be resisted by additional reinforcement. Permanent net compression across shear plane may be taken as additive to the force in the shear-friction reinforcement $A_{vf}f_y$ when calculating required A_{vf}.

CC-3424.7 Anchorage. Shear-friction reinforcement shall be appropriately placed along the shear plane and shall be anchored to develop the specified yield strength on both sides by embedment, hooks, or welding to special devices.

CC-3424.8 Concrete-to-Concrete Interface. For the purpose of CC-3424, when concrete is placed against previously hardened concrete, the interface for shear transfer shall be clean and free of laitance. The construction specification shall include requirements for roughening and cleaning the hardened surface. If μ is assumed equal to 1.0, the interface shall be roughened to a full amplitude of approximately $\frac{1}{4}$ in.

CC-3424.9 Concrete-to-Steel Interface. When shear is transferred between as-rolled steel and concrete using headed studs or welded reinforcing bars, steel shall be clean and free of paint.

CC-3430 ALLOWABLE STRESSES FOR SERVICE LOADS

CC-3431 Concrete Stresses

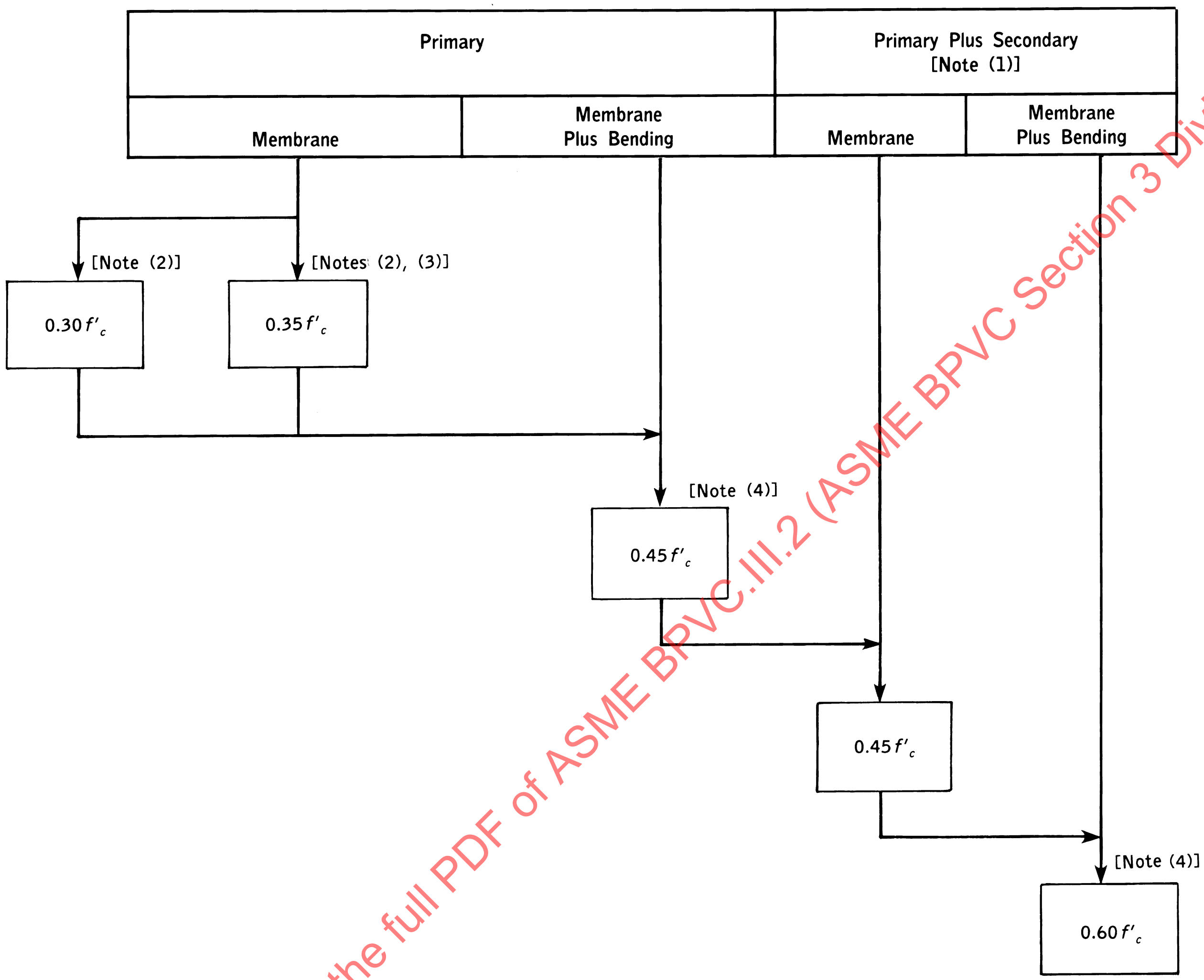
CC-3431.1 Compression. The allowable stresses for service compression loads are summarized in Figure CC-3431-1. Compression under the tendon end anchor bearing plates shall not exceed $0.6f_{ci} (A_2/A_1)^{1/3}$. The compression stress shall be calculated by dividing the initial tendon force at anchoring by the net area of the bearing plate, but shall not be greater than f_{ci}. These allowables shall be reduced, if necessary, to maintain the structural stability.

CC-3431.2 Tension. Concrete tensile strength (membrane and flexure) shall not be relied upon to resist the external loads and moments or the forces and moments resulting from internal self-constraint.

CC-3431.3 Shear, Torsion, and Bearing.

(a) The allowable concrete stresses and the limiting maximum stresses for shear, torsion, and bearing shall be 50% of the values given for factored loads in CC-3421.3 through CC-3421.9, except as follows.

Figure CC-3431-1
Allowable Compression Stresses for Service Loads



NOTES:
(1) The primary portion of this calculated stress shall not exceed the allowable stress applicable when primary stress acts alone.
(2) These allowable stresses may be increased by $0.05f'_c$ for sections with radial tension reinforcement.
(3) At initial prestress.
(4) The membrane portion of this calculated sresss shall not exceed the allowable stress applicable when membrane stress acts alone.

(1) In CC-3421.4.1(c) and CC-3421.6(b), the allowable concrete stress need not be reduced below

$$0.5\sqrt{f'_c}\ (0.042\sqrt{f'_c}\,)$$

(2) The allowable concrete stress shall be 67% of the values given for factored loads in load combinations that include the temporary pressure loads during the test condition or the temporary loads from prestressing that will decrease at completion of prestressing.

(3) The allowable concrete stress shall be 67% of the values given for factored loads when secondary forces, defined in Table CC-3136.6-1, are combined with other forces, provided the section thus required is not less than that required for the combination of other loads in the loading combination.

(b) The computed membrane stress on the gross section resulting from service loads shall be multiplied by 2 and substituted for N_u/A_g, f_m, F_h, or f_{pc}, in invoking the provisions of CC-3421.4.1, CC-3421.4.2, CC-3421.6, and CC-3421.7, except in those instances listed in (a) above, where 67% of the values given for factored loads is specified, in which case a 1.5 multiplier shall be used.

(c) Reinforcement requirements for brackets and corbels shall be computed using a factor of $0.5f_y$ instead of the $0.85f_y$ given in CC-3421.8 and CC-3424.

CC-3432 Reinforcing Steel Stresses and Strains

CC-3432.1 Bar Tension.

(a) The average tensile stress shall not exceed $0.5f_y$.

(b) The calculated average stress for the reinforcing in zones which have predicted concrete tension due to prestressing loads shall not exceed $0.5f_y$. The maximum load considered need not exceed the initial force at tendon anchoring. The values given in (a) above may be increased by 33⅓% when the following loads are combined with other loads in the load combination:

(1) the temporary loads from prestressing that will reduce at completion of prestressing

(2) when secondary forces, defined in Table CC-3136.6-1, are combined with other forces, provided the section thus required is not less than that required for the combination of other loads in the loading combination

(c) The values given in (a) above may be increased by 50% when the temporary pressure loads during the test condition are combined with other loads in the load combination.

CC-3432.2 Bar Compression.

(a) For load resisting purposes, the stress shall not exceed $0.5f_y$.

(b) The stress may exceed that given in (a) above for compatibility with the concrete but this stress may not be used for load resistance.

(c) The values given in (a) above may be increased by 33⅓% when the following loads are combined with other loads in the load combination:

(1) the temporary loads from prestressing which will be reduced at completion of prestressing

(2) the temporary pressure loads during the test condition

(3) when secondary forces, defined in Table CC-3136.6-1, are combined with other forces, provided the section thus required is not less than that required for the combination of other loads in the loading combination

CC-3433 Tendon System Stresses

Tensile stress in prestressing steel shall not exceed the following:

(a) Due to prestressing steel jacking force, the tendon tensile stress shall not exceed $0.94f_{py}$ but not greater than the lesser of $0.80f_{pu}$ and the maximum value recommended by the manufacturer of prestressing steel or anchorage devices.

(b) Immediately after anchoring, the tension stress at the anchor point shall not exceed $0.81f_{py}$ or $0.73f_{pu}$, and the average tension stress at the anchorage point of the tendon group after anchoring shall not exceed $0.70f_{pu}$. The tendon group is defined by its geometry and position in the containment (e.g., vertical, hoop, dome, inverted "U").

(c) For the purpose of design, the effective prestress shall be based on tendon stresses not exceeding those calculated to occur immediately after anchoring minus all applicable losses defined in CC-3542.

CC-3440 CONCRETE TEMPERATURES

(a) The following temperature limitations are for normal operation or any other long-term period. The temperatures shall not exceed 150°F (65°C) except for local areas, such as around a penetration, which are allowed to have increased temperatures not to exceed 200°F (95°C).

(b) The following temperature limitations are for accident or any other short-term period. The temperatures shall not exceed 350°F (175°C) for the interior surface. However, local areas are allowed to reach 650°F (345°C) from steam or water jets in the event of a pipe failure.

(c) Higher temperatures than given in (a) and (b) above may be allowed in the concrete if tests are provided to evaluate the reduction in strength and this reduction is applied to the design allowables. Also, evidence shall be provided which verifies that the increased temperatures do not cause deterioration of the concrete either with or without load.

CC-3500 CONTAINMENT DESIGN DETAILS

CC-3510 DESIGN FOR FLEXURE AND AXIAL LOADS

CC-3511 Assumptions

CC-3511.1 Factored Load Design.

(a) The design of sections for flexure and membrane loads shall be based on the assumptions given in this paragraph and on satisfaction of the applicable conditions of equilibrium and compatibility of strains.

(b) Strain in the reinforcing steel and concrete shall be assumed directly proportional to the distance from the neutral axis.

(c) Stress in reinforcement below 0.9 of the specified yield strength for the grade of steel used shall be taken as E_s times the steel strain. For strains greater than that corresponding to $0.9f_y$, the stress in the reinforcement shall be considered independent of strain and equal to $0.9f_y$.

(d) Tensile strength of the concrete shall be neglected in flexural calculations of reinforced concrete.

(e) The relationship between the concrete compressive stress distribution and the concrete strain used in the analysis of sections may be assumed to be a triangle, parabola, or any other shape that results in prediction of stress and strains in substantial agreement with the results of comprehensive tests. The stresses determined shall be compared to the stress limits of CC-3420 to ensure design adequacy.

CC-3511.2 Service Load Design. The straight line theory of stress and strain shall be used and the following assumptions shall be made.

(a) A section plane before bending remains plane after bending; strains vary as the distance from the neutral axis.

(b) The stress–strain relation for concrete is a straight line under service loads within the allowable stresses; stresses vary as the distance from the neutral axis.

(c) Tensile stress of the concrete shall be neglected in flexural calculations of reinforced concrete.

(d) The modular ratio, $n = E_s/E_c$, may be taken as the nearest whole number but not less than 6. In doubly reinforced members, an effective modular ratio of $2E_s/E_c$ may be used to transform the compression reinforcement for stress computations.

CC-3520 DESIGN OF SHEAR REINFORCEMENT

CC-3521 Factored Load Design

CC-3521.1 Tangential Shear and Membrane Forces.

CC-3521.1.1 Reinforced Concrete.

(a) Required area of orthogonal (hoop and meridional) reinforcement, with or without inclined reinforcement, provided for combined tangential shear and membrane strength shall be computed by

$$A_{sh} + A_{si} = \frac{N_h + \left(N_{h\ell}^2 + V_u^2\right)^{1/2}}{0.9f_y} \qquad (12)$$

$$A_{sm} + A_{si} = \frac{N_m + \left(N_{m\ell}^2 + V_u^2\right)^{1/2}}{0.9f_y} \qquad (13)$$

(b) Any combination of orthogonal and inclined reinforcement as required for strength according to eqs. (a)(12) and (a)(13), and as required to control shear deformations may be used with the following limits on maximum shear force.

(1) Tangential shear strength provided by orthogonal reinforcement V_{so} and computed by

$$V_{so} = V_u - 0.9f_y A_{si} \qquad (14)$$

(U.S. Customary Units)

$$V_{so} = 10\sqrt{f'_c}\,bt$$

shall not be greater than the following:

(SI Units)

$$V_{so} = 0.83\sqrt{f'_c}\,bt$$

(2) Tangential shear force V_u shall not exceed the following, where V_{so} is computed according to eq. (1)(14):

(U.S. Customary Units)

$$20\sqrt{f'_c}\,bt - V_{so}$$

(SI Units)

$$1.66\sqrt{f'_c}\,bt - V_{so}$$

where

A_{sh} = area of bonded reinforcement in the hoop direction (in.^{2}/ft) (mm^2/m)

A_{si} = area of bonded reinforcement in one direction of inclined bars at 45 deg to horizontal [in.^{2}/ft (mm^2/m) along a line perpendicular to the direction of the bars]. Inclined reinforcement shall be provided in both directions.

A_{sm} = area of bonded reinforcement in the meridional direction (in.^{2}/ft) (mm^2/m)

N_h and N_m = membrane force in the hoop and meridional direction respectively due to pressure, prestress, and dead load. The prestress force shall be the effective value. N_h and N_m are positive when tension and negative when compression.

$N_{h\ell}$ and $N_{m\ell}$ = membrane force in the hoop and meridional direction, respectively, from lateral load such as earthquake, wind, or tornado loading. When considering earthquake loading, this force is based on the square root of the sum of the squares of the components of the two horizontal and vertical earthquakes. The force is always considered as positive.

V_c = tangential shear strength provided by concrete

V_{si} = tangential shear strength provided by inclined reinforcement

V_{so} = tangential shear strength provided by orthogonal reinforcement

V_u = the peak membrane tangential shear force resulting from lateral load such as earthquake, wind, or tornado loading. When considering earthquake loading, this force is based on the square root of the sum of the squares of the components of the two horizontal and vertical earthquakes. The shear force shall be considered as positive.

All forces and strengths are expressed in kip/ft.

The strain compatibility of the concrete and reinforcement shall be checked to ensure that the strain allowables in CC-3422 are not exceeded for orthogonal and inclined reinforcement.

CC-3521.1.2 Prestressed Concrete.

(a) A sufficient amount of effective prestress shall be provided so that N_h and N_m are either negative (compression) or zero. Thermal membrane forces shall be included in N_h and N_m for the calculation of effective prestress.

(b) No reinforcement is required for tangential shear forces if

$$V_u \leq 0.85 V_c \tag{15}$$

where V_c is calculated according to CC-3421.5.2.

(c) When the section under consideration does not meet the requirements of either (a) or (b), reinforcement shall be provided for tangential shear forces according to the requirements of CC-3521.1.1.

CC-3521.1.3 Strength of Reinforcement. Design yield strength of tangential shear reinforcement shall not exceed 80,000 psi (550 MPa). In cases where the minimum specified concrete strength is less than 4,000 psi (28 MPa), the design yield strength of tangential shear reinforcement shall not exceed 60,000 psi (420 MPa).

CC-3521.2 Radial Shear.

CC-3521.2.1 Nominal Shear Stress. The nominal shear stress v_u shall be computed by

$$v_u = V_u / 0.85bd \tag{16}$$

where d need not be less than $0.85h$ for prestressed members.

CC-3521.2.2 Applied Shear Stress. When the reaction, in the direction of applied shear, introduces compression into the end region of the containment, sections located less than a distance d from the face of the support may be designed for the same v_u as that computed at a distance d. For prestressed concrete, sections located at a distance less than $t/2$ may be designed for the shear computed at $t/2$.

CC-3521.2.3 Shear Reinforcement.

(a) When shear reinforcement perpendicular to the containment surface is used, the required area of shear reinforcement shall not be less than

$$A_v = (v_u - v_c) bs / f_y \tag{17}$$

The perpendicular shear reinforcement shall not be spaced further apart than $0.50d$.

(b) When inclined stirrups or bent bars are used as shear reinforcement in reinforced concrete members, the following provisions apply.

(1) When inclined stirrups are used, the required area shall not be less than

$$A_v = \frac{(v_u - v_c) bs}{f_y \left(\sin \alpha + \cos \alpha \right)} \tag{18}$$

(2) When shear reinforcement consists of a single bar or a single group of parallel bars, all bent at the same distance from the support, the required area shall be not less than

$$A_v = \frac{(v_u - v_c) bd}{f_y \sin \alpha} \tag{19}$$

in which $(v_u - v_c)$ shall not exceed $3\sqrt{f'_c}$ (in.) [SI Units: $0.25\sqrt{f'_c}$ (mm)].

(3) When shear reinforcement consists of a series of parallel bent bars or groups of parallel bent bars at different distances from the support, the required area shall be not less than that computed by eq. (2)(19).

(c) Only the center three-fourths of the inclined portion of any bar that is bent shall be considered effective for shear reinforcement.

(d) Where more than one type of shear reinforcement is used to reinforce the same portion of the section, the required area shall be computed as the sum for the various types separately. In such computations, v_c shall be included only once.

(e) Inclined stirrups and bent bars shall be so spaced that every 45 deg line extending toward the reaction from the mid-depth of the section, $0.50d$, to the tension bars shall be crossed by at least one line of shear reinforcement.

(f) The value of $(v_u - v_c)$ shall not exceed $8\sqrt{f'_c}$ (in.) [SI Units: $0.67\sqrt{f'_c}$ (mm)].

CC-3521.3 Peripheral Shear. Shear stress shall be investigated at the critical section and at successive sections more distant from the critical section in accordance with the following rules:

(a) The nominal shear stress v_u shall be calculated by

$$v_u = V_u / 0.85\, bd$$

where V_u and b are taken at the critical section specified in CC-3421.6.1.

(b) Shear stress v_c shall be calculated in accordance with CC-3421.6. When v_u is less than v_c, and membrane steel stresses are not greater than $0.6f_y$, no additional reinforcing is required.

(c) When v_u is less than v_c, and either of the membrane steel stresses exceeds $0.6f_y$, the corresponding meridional or hoop reinforcement shall be designed to resist 1.0 times the shear force corresponding to v_u in addition to any membrane forces and in-plane shear forces. These forces shall be considered as additional membrane forces.

(d) When v_u is greater than v_c, the excess shear force corresponding to $(v_u - v_c)$ shall be resisted by shear reinforcement designed in accordance with CC-3521.2.3. $(v_u - v_c)$ shall be determined as follows:

(1) v_u shall not exceed the greater of $6\sqrt{f'_c}$ (in.) [SI Units: $0.5\sqrt{f'_c}$ (mm)] or $1.5v_c$ where v_c is calculated in accordance with CC-3421.6.

(2) The shear stress v_c carried by the concrete at any section shall not exceed the greater of $\sqrt{f'_c}$ (in.) [SI Units: $0.083\sqrt{f'_c}$ (mm)] or $\frac{1}{2}v_c$ when v_c, calculated in accordance with CC-3421.6, is greater than or equal to $\sqrt{f'_c}$ (in.) [SI Units: $0.083\sqrt{f'_c}$ (mm)]. When v_c is less than $\sqrt{f'_c}$ (in.) [SI Units: $0.083\sqrt{f'_c}$ (mm)], the value of v_c, calculated in accordance with CC-3421.6, shall be used.

CC-3521.4 Torsional Shear. Torsional shear stress shall be investigated at the section where $r = r_{\min}$ and at successive surfaces more distant until v_{ut}, as defined below, is equal to or less than v_{ct} as defined in CC-3421.7(a).

(a) The nominal torsional shear stress shall be calculated by:

$$v_{ut} = \frac{T_u}{0.85t\left(2\pi r^2\right)} \tag{20}$$

where T_u = the maximum factored torsional loading applied to the containment wall.

(b) When v_{ut} is less than or equal to v_{ct}, no reinforcing is required.

(c) Where v_{ut} is greater than v_{ct}, the entire shear stress shall be resisted by reinforcing that which is within the plane of the wall and normal to the failure surface. Such reinforcing shall be designed by the following equation:

$$A_{vt} = \frac{V_{ut}(2\pi r)t}{\left(f_y\right)\mu} \tag{21}$$

where

t = concrete thickness

μ = a coefficient of friction that shall be taken equal to 1.0 when the failure surface is concrete to concrete and 0.7 when the failure surface is concrete to steel

(d) A_{vt} [in.^{2} (mm^2)] shall be distributed uniformly around the failure surface and shall be fully developed by embedment or mechanical means on either side of the failure surface. Uniformly distributed shall be taken as requiring at least eight approximately equally spaced bars crossing the failure surface.

(e) v_{ut} shall not exceed $0.2f'_c$ nor 800 psi (5.5 MPa).

CC-3522 Service Load Design

The same requirements stated in CC-3521 shall be used in designing shear reinforcement for service loads with the following modifications:

(a) Equation CC-3521.2.1(16) shall be replaced by $v = V/bd$.

(b) The reinforcement steel stress allowable from CC-3432.1 shall replace f_y in eqs. CC-3521.2.3(a)(17) through CC-3521.2.3(b)(2)(19).

(c) The reinforcing steel stress allowable from CC-3432.1 shall replace $0.9f_y$ in eqs. CC-3521.1.1(a)(12) through CC-3521.1.1(b)(1)(14).

(d) V_u in eqs. CC-3521.1.1(a)(12) through CC-3521.1.1(b)(1)(14) shall be replaced by V.

(e) The maximum tangential shear stress provided by orthogonal reinforcement and limiting maximum tangential shear stresses shall be 50% of the values given for factored loads in CC-3521.1.1(b).

(f) Equation CC-3521.1.2(b)(15) shall be replaced by $v \leq 0.5v_c$.

(g) The requirements of CC-3521.3 shall be used for peripheral shear design for service loads with the following modifications.

(1) The nominal shear stress shall be calculated by $v = V/bd$.

(2) Shear stress v_c shall be calculated in accordance with CC-3431.3.

(3) When v is greater than v_c, the excess shear force corresponding to $(v - v_c)$ shall be resisted by shear reinforcement designed in accordance with (b) above. $(v - v_c)$ shall be determined as follows:

(-a) v shall not exceed the greater of $3\sqrt{f'_c}$ (in.) [SI Units: $0.25\sqrt{f'_c}$ (mm)] or $1.5v_c$ when v_c is calculated in accordance with CC-3431.3.

(-b) The shear stress v_c carried by the concrete at any section shall not exceed the greater of $\sqrt{f'_c}$ (in.) [SI Units: $0.083\sqrt{f'_c}$ (mm)] or $\frac{1}{2}v_c$ when v_c, calculated in accordance with CC-3431.3, is greater than or equal to $\sqrt{f'_c}$ (in.) [SI Units: $0.083\sqrt{f'_c}$ (mm)]. When v_c is less than $\sqrt{f'_c}$ (in.) [SI Units: $0.083\sqrt{f'_c}$ (mm)], the value of v_c, calculated in accordance with CC-3431.3, shall be used.

(h) Torsional shear provisions for Service Load Design shall be as follows:

(1) v_{ct} shall be calculated in accordance with CC-3431.3 and the reinforcement steel stress allowable from CC-3432.1 shall replace f_y in eq. CC-3521.4(c)(21).

(2) In eq. CC-3521.4(a)(20), v_t and T shall be substituted for v_{ut} and T_u, respectively.

(3) In eq. CC-3521.4(c)(21), v_t shall be substituted for v_{ut}.

(4) The limits on v_t shall be calculated in accordance with CC-3431.3.

CC-3530 REINFORCING STEEL REQUIREMENTS

CC-3531 General

The following requirements shall govern design of the reinforcing steel:

(a) The reinforcing steel shall be designed with consideration of placement tolerances specified herein and in the Construction Specification.

(b) The following paragraphs relate to all load combinations in Table CC-3230-1.

CC-3532 Reinforcing Steel Splicing and Development

(a) Splices of reinforcement shall be made only as required or permitted on the Design Drawings or in the Construction Specification.

(b) Lap splices shall not be used for bars larger than No. 11 (36). Lap splices of bundled bars shall be based on the lap splice length required for individual bars of the same size as the bars spliced. Individual bar splices within a bundle shall not overlap. Entire bundles shall not be lap spliced. Bars spliced by noncontact lap splices in flexural members shall not be spaced transversely farther apart than one-fifth the required length of lap nor more than 6 in. (150 mm).

(c) Where a non-prestressed reinforcement bar splice must be located in a region where tension is predicted in a direction perpendicular to the bar to be spliced, only a positive mechanical splice or a welded butt splice shall be used, unless calculations or tests of the selected splice detail are made to demonstrate that there is an adequate transfer of force. These provisions do not apply to nominal temperature reinforcement.

(d) The values of $\sqrt{f'_c}$ shall not exceed 100 psi (8.3 MPa).

(e) Mechanical splices shall be staggered if the strain measured over the full length of the splice (at 0.9 yield) exceeds that of a bar that is not mechanically spliced by more than 50%. If staggered mechanical splices are required, no more than $\frac{1}{2}$ of the bars shall be spliced in one plane normal to the bars, and the mechanical splices shall be staggered at least 30 in. (760 mm).

CC-3532.1 Tension Splices.

CC-3532.1.1 Classification of Tension Lap Splices. The minimum length of lap for tension lap splices shall be as follows:

(a) Class A splices: $1.0l_d$

(b) Class B splices: $1.3l_d$

The tensile development length l_d to develop f_y is as given in CC-3532.1.2.

CC-3532.1.2 Development Length.

(a) Reinforcing steel which must terminate in a location where biaxial tension is predicted, such as at penetrations, shall be anchored by hooks, bends, or by positive mechanical anchorage in such a manner that the force in the terminated bar is adequately transferred to other reinforcement. Bar development lengths at such locations shall be increased by at least 25% over those permitted for uniaxial tension. Mechanical devices for end anchorage shall be qualified by testing to be capable of developing at least 125% of the specified minimum yield strength of the bar. Mechanical anchorage devices listed in CC-4331.3(a) through CC-4331.3(e) are allowed as end anchorage. These devices shall be in accordance with the provisions of CC-2310 and shall be qualified by testing per CC-4330. These special precautions are not required for nominal temperature reinforcement.

(b) Where bars no longer required to carry load are terminated in areas of biaxial tension, the bar development lengths shall be increased at least 25% over that required for areas of uniaxial tension, provided that biaxial tension forces are carried by other reinforcement. This requirement does not apply to nominal temperature reinforcement.

(c) The calculated tension in the reinforcement at each section shall be developed on each side of that section by embedment length or end anchorage or a combination thereof. For bars in tension, hooks may be used in developing the bars. If mechanical devices are used in whole or in part for end anchorage, the system shall be qualified by testing to be capable of developing at least 125% of the specified minimum yield strength of the bar and shall be in accordance with CC-2310 and CC-4330. Mechanical anchorage devices for end anchorage are limited to only the processes listed in CC-4331.3(a) through CC-4331.3(e).

(d) Tension reinforcement may be anchored by bending it across the section and either making it continuous with the reinforcement on the opposite face of the section, or anchoring it there by any mechanical device capable of developing at least 125% of the specified minimum yield strength of reinforcement.

(e) The critical sections for development of reinforcement are at points of maximum stress and at points where adjacent reinforcement terminates or is bent.

(f) Reinforcement shall extend beyond the point at which it is no longer required to resist flexure for a distance equal to the effective depth of the section or 12 bar diameters, whichever is greater. The extension need not exceed 5 ft (1.5 m) if shear reinforcement is provided in the same area.

(g) Continuing reinforcement shall have an embedment length not less than the development length l_d beyond the point where bent or terminated reinforcement is no longer required to resist flexure or tension.

(h) Reinforcement shall not be terminated in a tension zone unless one of the following conditions is satisfied.

(1) The shear at the cutoff point shall not exceed two-thirds that permitted, including the shear strength of furnished radial reinforcement.

(2) Stirrup area in excess of that required for shear and torsion is provided along each terminated bar over a distance from the termination point equal to three-fourths the effective depth of the member. The excess stirrups shall be proportioned such that $(A_v/b_{w}s)\, f_y$ is not less than 60 psi (0.4 MPa). The resulting spacings shall not exceed $d/(8\beta_b)$, where β_b is the ratio of the area of bars cut off to the total area of bars at the section.

(3) For No. 11 (36) and smaller bars, the continuing bars provide double the area required for flexure at the cutoff point and the shear does not exceed three-fourths that permitted.

(i) The development length l_d, in inches, shall be computed as the product of the basic development length of (1) below and the applicable modification factor or factors of (2) below, but l_d shall be not less than 12 in. (300 mm)

(1) The basic development length shall be as follows:

(-a) For No. 6 (19) and smaller bars

(U.S. Customary Units)

$$l_d = \left(\frac{3}{40} \times \frac{f_y}{\sqrt{f'_c}} \times \frac{0.8}{\left(\frac{c_b + K_{tr}}{d_b} \right)} \right) d_b$$

(SI Units)

$$l_d = \left(\frac{f_y}{1.1\sqrt{f'_c}} \times \frac{0.8}{\left(\frac{c_b + K_{tr}}{d_b} \right)} \right) d_b$$

(-b) For No. 7 (22) and larger bars

(U.S. Customary Units)

$$l_d = \left(\frac{3}{40} \times \frac{f_y}{\sqrt{f'_c}} \times \frac{1}{\left(\frac{c_b + K_{tr}}{d_b} \right)} \right) d_b$$

(SI Units)

$$l_d = \left(\frac{f_y}{1.1\sqrt{f'_c}} \times \frac{1}{\left(\frac{c_b + K_{tr}}{d_b} \right)} \right) d_b$$

in which the confinement term $(C_b + K_{tr})/d_b$ shall not be taken greater than 2.5, and

$$K_{tr} = \frac{40A_{tr}}{sn} \quad \text{(U.S. Customary and SI Units)}$$

It is permitted to use $K_{tr} = 0$ as a design simplification even if transverse reinforcement is present.

A_{tr} = total cross-sectional area of all transverse reinforcement that is within the spacing s and that crosses the potential plane of splitting through the reinforcement being developed, in.^{2} (mm^2)

c_b = smaller of the distance from center of a bar to nearest concrete surface or one-half the center-to-center spacing of bars being developed, in. (mm)

K_{tr} = transverse reinforcement index

n = number of bars being spliced or developed along the plane of splitting

s = maximum center-to-center spacing of transverse reinforcement within l_d, in. (mm)

Development length of individual bars within a bundle, in tension or compression, shall be that for the individual bar, increased 20% for a three-bar bundle and 33% for a four-bar bundle.

For determining the appropriate confinement term, a unit of bundled bars shall be treated as a single bar of a diameter derived from the equivalent total area and having a centroid that coincides with that of the bundled bars.

(2) For horizontal reinforcement, the basic development length shall be multiplied by 1.3 if more than 12 in. (300 mm) of concrete is placed below the reinforcement during the concrete placement that embeds the reinforcement in the section. For the purpose of these requirements, reinforcement is considered to be horizontal if the angle the reinforcement makes with the horizontal plane is 30 deg or less.

(3) The basic development length may be reduced by the ratio of (area required) / (area provided), except where anchorage or development for f_y is specifically required.

CC-3532.1.3 Splices in Region of Maximum Tensile Stress. Splices in regions of maximum tensile stress should be avoided. Where such splices must be used, they shall be mechanically spliced in accordance with CC-4333, welded butt splice in accordance with CC-4334, or Class B lap spliced in accordance with CC-3532.1.1.

CC-3532.1.4 Splices Away From Regions of Maximum Tensile Stress. Splices away from regions of maximum tensile stress (maximum computed stress less than $0.5f_y$) shall be mechanically spliced in accordance with CC-4333, welded butt spliced in accordance with CC-4334, or lap spliced in accordance with CC-3532.1 as follows:

(a) if no more than one-half of the bars are lap spliced within a required lap length — Class A

(b) if more than one-half of the bars are lap spliced within a required lap length — Class B

CC-3532.1.5 Splices in Tension Tie Members. Splices shall be made with a welded butt splice in accordance with CC-4334 or a positive mechanical connection in accordance with CC-4333 and be staggered at least $1.3l_d$.

CC-3532.1.6 Bars of Different Sizes. When bars of different size are lap spliced in tension, splice length shall be the tension lap splice length of the larger bar.

(23) **CC-3532.1.7 Grade 80 Reinforcement.** Development length, l_d, of Grade 80 reinforcement calculated using CC-3532.1.2(i) shall be multiplied by a factor of 1.2.

CC-3532.2 Compression Splices.

CC-3532.2.1 General. Splices in compression may be lap or butt spliced. Lap splices shall meet the requirements of CC-3532.2.2 and butt splices (welded or mechanical) shall meet the requirements of CC-4333 or CC-4334.

CC-3532.2.2 Lap Splices. The minimum length of a lap splice in compression shall be the development length in compression l_{dc} in accordance with CC-3532.2.3 but not less, in inches, than $0.0005f_yd_b$ (in mm, than $0.0725f_yd_b$) for f_y of 60,000 psi (420 MPa) or less or $(0.0009f_y - 24)d_b$ [SI Units: $(0.13f_y - 24)d_b$] for f_y greater than 60,000 psi (420 MPa) but not less than 12 in. (300 mm). When bars of different size are lap spliced in compression, splice length shall be the larger of l_{dc} of the larger bar and compression lap splice length of the smaller bar. Lap splices of No. 14 (43) and No. 18 (57) bars to No. 11 (36) and smaller bars shall be permitted.

CC-3532.2.3 Development Length for Bars in Compression.

(a) The calculated compression in the reinforcement at each section shall be developed on each side of that section by embedment length or end anchorage or a combination thereof.

(b) The development length l_{dc} for bars in compression shall be computed as $0.02f_yd_b/\sqrt{f'_c}$ (in.) $\left[\text{SI Units: } 0.25f_yd_b/\sqrt{f'_c}\,(\text{mm})\right]$ but shall be not less than $0.0003f_yd_b$ ($0.044f_yd_b$) or 8 in. (200 mm). l_{dc} may be modified by a reduction factor equal to (A_s required)/(A_s provided).

(c) Hooks and heads for mechanical devices for end anchorage shall not be considered effective in developing bars in compression.

CC-3532.3 Development of Standard Hooks in Tension.

(a) Development length l_{dh}, in inches, for deformed bars in tension terminating in a standard hook (see CC-4321) shall be computed from (b) below and the applicable modification factor or factors of (c) below, but l_{dh} shall not be less than $8d_b$ or 6 in. (150 mm), whichever is greater.

(b) Development length l_{dh} for a hooked bar shall be $0.02f_yd_b/\sqrt{f'_c}$ (in.) $\left[\text{SI Units: } 0.24f_yd_b/\sqrt{f'_c}\,(\text{mm})\right]$.

(c) Development length l_{dh} shall be multiplied by applicable factor or factors as follows:

(1) For No. 11 (36) and smaller bars, side cover (normal to plane of hook) not less than $2\frac{1}{2}$ in. (64 mm), and for 90 deg hook, cover on bar extension beyond hook not less than 2 in. (50 mm): 0.7.

(2) For 90 deg hooks of No. 11 (36) and smaller bars that are either enclosed within ties or stirrups perpendicular to the bar being developed, spaced not greater than $3d_b$ along l_{dh} or enclosed within ties or stirrups parallel to the bar being developed, spaced not greater than $3d_b$ along the length of the tail extension of the hook plus bend: 0.8.

(3) For 180 deg hooks of No. 11 (36) and smaller bars that are enclosed within ties or stirrups perpendicular to the bar being developed, spaced not greater than $3d_b$ along l_{dh}: 0.8.

In (2) and (3) above, d_b is the diameter of the hooked bar, and the first tie or stirrup shall enclose the bent portion of the hook, within $2d_b$ of the outside of the bend.

(4) Where anchorage or development for f_y is not specifically required, reinforcement in excess of that required by analysis: (A_s required)/(A_s provided).

(d) For bars being developed by a standard hook at discontinuous ends of members with both side cover and top (or bottom) cover over hook less than $2\frac{1}{2}$ in. (64 mm), hooked bar shall be enclosed within ties or stirrup ties spaced along the full development

length l_{dh} not greater than $3d_b$, where d_b is diameter of hooked bar. For this case, factor of (c)(2) and (c)(3) above shall not apply.

(e) Notation

d_b = nominal diameter of bar

l_{dh} = development length of standard hook in tension, measured from critical section to outside end of hook [straight embedment length between critical section and start of hook (point of tangency) plus radius of bend and one bar diameter]

CC-3532.4 Development of Mechanically Headed Deformed Bars In Tension.

(a) Development length for mechanically headed deformed bars in tension, l_{dt}, shall be determined from (c).

(b) Use of mechanical anchorage devices to develop deformed bars in tension shall be limited to the following conditions:

(1) Specified yield strength of the reinforcing steel, f_y, shall not exceed 60,000 psi (420 MPa).

(2) Bar size shall not exceed No. 11 (36).

(3) Concrete shall be normal weight.

(4) Net bearing area of head, A_{brg}, shall not be less than $4A_b$, where A_b is defined as the nominal area of the deformed reinforcing bar.

(5) Clear spacing between bars shall not be less than $4d_b$ when measured from bar to bar, not including the head, where d_b is defined as the nominal bar diameter of the deformed reinforcing bar.

(6) Clear cover for bar shall not be less than $2d_b$ when measured from the bar, not the head.

(c) The development length for mechanically anchored headed deformed bars in tension shall be calculated by

(U.S. Customary Units)

$$l_{dt} = \left[\frac{0.016 f_y}{\sqrt{f'c}}\right] d_b$$

(SI Units)

$$l_{dt} = \left[\frac{0.19 f_y}{\sqrt{f'c}}\right] d_b$$

where

l_{dt} = development length in tension of the headed deformed bar, measured from the critical section to the bearing face of the head

NOTE: Critical section for development of the mechanically headed deformed bars is defined in CC-3532.1.2(e).

The value of f'_c used to calculate l_{dt} shall not exceed 6,000 psi (40 MPa). Length l_{dt} shall not be less than the larger of $8d_b$ and 6 in. (150 mm).

(d) Mechanically anchored headed deformed bars in sizes No. 14 (43) and No. 18 (57) may be used, provided that test data is presented indicating that the system is capable of developing at least 125% of the specified minimum yield strength of the reinforcing bar. The Designer shall proportion deformed headed bar concrete anchorage and investigate the need for supplemental reinforcing steel so the required reinforcing bar force is reached before either a concrete pullout cone or side blowout failure occurs. The deformed headed bar shall be in accordance with CC-2310. Development of reinforcement shall be permitted to consist of a combination of mechanical anchorage and additional embedment length of reinforcement between the critical section and the mechanical device.

CC-3533 Reinforcing Steel Anchorage

CC-3533.1 Anchorage of Radial Shear Reinforcement.

(a) Radial shear reinforcement shall be carried as close to the compression and tension surfaces of the section as cover requirements and the proximity of other steel will permit. The ends shall be anchored by one of the following means:

(1) a standard hook plus an effective embedment of $0.5l_d$; the effective embedment of a stirrup leg shall be taken as the distance between the mid-depth of the member $d/2$ and the start of the hook (point of tangency)

(2) embedment on the compression side of mid-depth $d/2$ for a full-development length l_d but not less than 24 bar diameters

(3) bending around the membrane reinforcement through at least 135 deg (2.36 rad); hooking or bending stirrups around the membrane reinforcement shall be considered effective anchorage

(4) a mechanically headed deformed bar per CC-2311 plus an effective embedment of $0.5l_{dt}$ in accordance with CC-3532.4; the effective embedment of a stirrup leg shall be taken as the distance between the mid-depth of the member $d/2$ and the bearing face of the head

(b) Between the anchored ends, each bend in the continuous portion of a transverse simple U- or multiple U-stirrup shall enclose a longitudinal bar.

(c) Bars bent to act as section reinforcement shall, in a region of tension, be continuous with the main reinforcement and in a compression zone shall be anchored on the compression side of mid-depth as specified for development length in CC-3532.2.3 for that part of f_y that is needed to satisfy eq. CC-3521.2.3(b)(2)(19).

(d) Pairs of U-stirrups so placed as to form a closed tie shall be considered properly spliced when the laps are each $1.3l_d$.

CC-3534 Reinforcing Steel Cover and Spacing Requirements

CC-3534.1 Cover.

(a) The following minimum concrete cover shall be provided for reinforcing bars, prestressing tendons, or ducts:

Exposure	Minimum Cover, in. (mm)
Cast against and permanently exposed to earth	3 (75)
Exposed to earth or weather:	
No. 6 (19) through No. 18 (57) bars	2 (50)
No. 5 (16) bars, $^5/_8$-in. (16-mm) wire and smaller	$1^1/_2$ (38)
Not exposed to weather or in contact with the ground: Principal reinforcement, ties, and stirrups	$1^1/_2$ (38)
Other reinforcement	1 (25)

For bar bundles, the minimum cover shall equal the equivalent diameter of the bundle but need not be more than 2 in. (50 mm) or the tabulated minimum, whichever is greater.

(b) The concrete cover shall be established by considering the placing tolerances of the formwork and reinforcement. The minimum concrete cover specified in (a) above shall not be reduced by the placing tolerances of the formwork and reinforcement.

CC-3534.2 Spacing. The clear distance between parallel bars in a layer shall not be less than the nominal diameter of the bars, nor $1^1/_3$ times the maximum size of the coarse aggregate, nor 1 in. (25 mm). The clear distance between parallel layers shall not be less than $1^3/_8$ in. (35 mm). The clear distance limitation between bars shall also apply to the clear distance between a contact (lap) splice and adjacent splices or bars.

CC-3535 Concrete Crack Control

(a) When an expected crack formation is so located that critical elements of the containment, such as anchor zone concrete, buttresses, ring girders, and large opening edges, may be weakened, bonded nonprestressed reinforcement shall be provided to carry the total tensile force in the concrete.

(b) Nonprestressed reinforcement shall be provided in the containment shell to control surface and membrane cracking from the effects of shrinkage, temperature, and membrane tension. The area of such reinforcement in each direction at each face of the concrete shall be a minimum of 0.0020 times the gross cross-sectional area of the section. This requirement may be met in whole or in part by reinforcement otherwise required to resist calculated loads. An integral steel liner, if provided, may be included to satisfy the requirement for inside face reinforcement. Reinforcing bars considered as face reinforcement shall not be more than one-fifth of the total section thickness from the concrete face.

(c) For base mat structures, the ratio of nonprestressed reinforcement area to gross concrete cross-sectional area shall be not less than 0.0018 in each direction, unless the area of reinforcement provided at each face is at least one-third greater than that required by analysis.

Nonprestressed reinforcement for crack control shall not be spaced farther apart than 18 in. (450 mm).

NOTE: Where reinforcement with yield stress exceeding 60,000 psi (420 MPa) is used, specified ratios should be multiplied by (60,000 psi/f_y) or (420 MPa/f_y).

CC-3536 Curved Reinforcement

All forces imposed by curved reinforcement shall be considered in the design of local areas such as around penetrations.

CC-3540 PRESTRESSED CONCRETE

CC-3541 General

(a) Provisions in this subarticle apply to structural members prestressed with high strength steel meeting the requirements for prestressing material in CC-2400.

(b) The following assumptions shall be made for purposes of design:

(1) Strains vary linearly with depth through the entire load range.

(2) At cracked sections, the ability of the concrete to resist tension is neglected.

(3) In calculations of section properties prior to bonding of tendons, areas of the open ducts shall be deducted. The transformed area of reinforcing steel and bonded tendons may be included.

(c) The effects on the adjoining structure of elastic and plastic deformations, deflections, changes in length, and rotations caused by the prestressing shall be provided for.

CC-3542 Prestress Losses

(a) Prestress losses shall be considered in the calculation of effective prestress in the prestressing steel and shall include (1) through (6).

(1) prestressing steel seating loss at transfer
(2) elastic shortening of concrete
(3) creep of concrete
(4) shrinkage of concrete
(5) relaxation of prestressing steel
(6) friction loss due to intended or unintended curvature in the tendons

(b) Calculated friction loss in post-tensioning tendons shall be based on experimentally determined wobble and curvature coefficients and shall be verified during stressing operations. The values of coefficients assumed for design and the acceptable ranges of jacking forces and

steel elongations shall be specified. Friction losses shall be calculated as follows:

$$P_x = P_s e^{-\left(Kl_x + \mu_p \alpha_x\right)} \tag{22}$$

Where $(Kl_x + \mu_p\alpha_x)$ is not greater than 0.3, eq. (23) may be used.

$$P_x = P_s\left(1 + Kl_x + \mu_p \alpha_x\right)^{-1} \tag{23}$$

(c) Where loss of prestress in a member is anticipated due to connection of the member with adjoining construction, such loss of prestress shall be included in design calculations.

CC-3543 Tendon End Anchor Reinforcement

Reinforcement oriented perpendicular to the direction of applied force shall be provided to control cracking in the end anchor zone.

(a) Reinforcement shall be sized to resist a load of at least 10% of the applied permanent prestressing force. This reinforcement shall be located starting not more than 2 in. (50 mm) from the bearing plate and extending not more than twice the minimum bearing plate width when measured in the direction of the load. However, the 2 in. (50 mm) limitation on reinforcement spacing around tendon anchorage bearing plates may be waived provided the following conditions are met:

(1) The anchorage is embedded in a reinforced base mat.

(2) The distance from the center of the bearing plate to the edge of the mat shall be at least 2$^1/_2$ times the dimension of the bearing plate measured along the radius of the mat.

(3) Base mat reinforcement in each direction is designed for 10% of the tendon force, to resist the splitting tensile stress in addition to all concurrent loads.

(b) In lieu of the provisions of (a) above, reinforcement may be based on the result of tests that show the end anchor zone can adequately resist a force equivalent to the design ultimate force of the prestressing tendon.

CC-3544 Curved Tendons

All forces imposed by curved tendons shall be considered in the design of local areas, such as around penetrations.

CC-3545 Radial Tension Reinforcement

For portions of prestressed containments with single curvature, radial reinforcement shall be provided to resist radial tensile forces unless detailed analysis together with concrete tensile strength characteristics confirm that such reinforcement is not necessary. The detailed analysis shall include consideration for curvature, location, size, and placement of tendon ducts, tendon stressing sequence, discontinuities, stress concentration, and Poisson's effects. Radial reinforcement shall be provided to resist radial tensile forces from curved tendons in portions of the containment with double curvature.

The spacing of radial reinforcement shall not be greater than half the shell thickness or 24 in. (600 mm), whichever is smaller. The radial reinforcement shall be developed on either side of the centroid of the curved tendons in accordance with CC-3530.

CC-3550 SEPARATION OF STRUCTURES

Since the containment will deform under the design loadings and temperature effects, such deformations and interaction with integral, adjacent, and internal structures and components shall be considered in the design of the containment; otherwise, the containment shall be sufficiently separated from adjacent and internal structures to ensure no contact during deformation.

CC-3560 FOUNDATION REQUIREMENTS

CC-3561 General

(a) The foundation properties used in the design shall be supported by analysis made from information provided by laboratory or field tests of specimens taken from the subsurface strata supporting the containment.

(b) The bottom of the foundation shall be placed at a sufficient distance below finished grade to preclude the possibility of undermining due to flood or possible future adjacent construction.

(c) The short-term as well as the long-term foundation soil properties shall be considered. In order to ensure use of the maximum loading conditions, a range of values of soil constants shall be used which bracket the expected values.

CC-3564 Water Table

The design analysis shall include the effect of possible significant changes in the groundwater table. The effect of moisture changes upon the soils being loaded shall be included in the settlement analysis.

CC-3565 Deterioration of Material

The design shall provide due protection against possible deterioration of the foundation material.

CC-3566 Containment Displacement

Containment movements shall be considered in determining potential interaction with adjacent or attached piping or equipment. Long-term settlements, such as consolidation of clay or silt layers, shall be given full consideration. An investigation shall be made to preclude the founding of a containment on strata subject to liquefaction under the specified design conditions.

The load combinations shown in Table CC-3230-1 are applicable to containment displacement considerations, except that load factors for all load cases shall be taken equal to 1.0.

CC-3570 CONTAINMENT EXTERNAL ANCHORS

CC-3571 General

The effects of anchors, embedments, or other attachment details not attached to the steel liner or a load carrying steel element, that provide anchorage into the containment concrete from the external surface, shall be considered. The anchors are, however, not under the jurisdiction of the Code. The induced effects on the containment shall be considered in accordance with this Section.

CC-3572 Loads and Displacements

The resulting loads on the containment shall be considered in the appropriate load categories and load combinations as described in CC-3200. Containment displacements and their effects shall be considered in accordance with CC-3550 and CC-3566.

CC-3573 Analysis Methods

The analysis necessary to predict the effects of such anchors shall be consistent with CC-3300.

CC-3574 Design Allowables

The effects of the anchors shall not cause stresses or strains, in combination with the other loads on the containment as determined by CC-3572 and CC-3573, that exceed the allowables of CC-3400.

CC-3575 Additional Design Requirements

The Design Specification shall contain requirements that the external anchors are designed to preclude structural damage to the containment.

CC-3600 LINER DESIGN ANALYSIS PROCEDURES

CC-3610 GENERAL

(a) An analysis shall be prepared in sufficient detail to show that each of the design allowables of CC-3700 is satisfied when the liner, penetrations, brackets, and attachments are subjected to the loadings of CC-3200.

(b) Experimental results may be used to evaluate the capacity of components to withstand static or cyclic loading.

CC-3620 LINER

The liner analysis shall consider deviations in liner geometry due to the fabrication and erection tolerances, which are stated in CC-4522, and any additional tolerances stated in the Construction Specification. Since the liner will be anchored at relatively close intervals compared to its diameter, the analysis may be based on plate or beam theory, provided all assumptions made in the analysis are conservative.

CC-3630 LINER ANCHORS

The anchors may be analyzed assuming the liner remains elastic under all conditions; for example, the liner strains shall be converted to stress using Hooke's law with the modulus of elasticity and Poisson's ratio below yield. If the liner anchor design relies on liner yielding to limit the forces applied to the anchors, then the liner material yield strength may be determined in accordance with CC-3810(c)(3) or by performing the biaxial yield strength tests as indicated in CC-3810(c)(2).

CC-3640 PENETRATION ASSEMBLIES

The penetration assemblies shall be analyzed using the same techniques and procedures used for metal containments in Division 1, where applicable. The analysis shall consider the concrete confinement for penetration sleeves embedded in the concrete containment. Local thickening of the liner at an opening is allowed.

CC-3650 BRACKETS AND ATTACHMENTS

Brackets and attachments connected to the liner shall be designed and analyzed using accepted techniques applicable to beams, columns, and weldments such as those illustrated in AISC N690 or AISC 360, as applicable.

CC-3700 LINER DESIGN

CC-3710 GENERAL

Due to the nature of the loads and other effects, together with the types of components, the allowable capacities of the components will be specified in terms of stress, strain, force or displacement, whichever is applicable. Since many of the allowable capacities are based on ultimate capacities, testing of a prototype may be necessary to verify the ultimate capacity of a particular part.

CC-3720 LINER

The calculated strains and stresses for the liner shall not exceed the values given in Table CC-3720-1. The load combinations shown in Table CC-3230-1 are applicable to the liner, except that load factors for all load cases may be taken equal to 1.0. Strains associated with construction-related liner deformations may be excluded

Table CC-3720-1
Liner Plate Allowables

Category	Stress–Strain Allowable [Notes (1), (2)] Membrane	Combined Membrane and Bending
Construction	$f_{st} = f_{sc} = {}^2\!/_3 f_{py}$	$f_{st} = f_{sc} = {}^2\!/_3 f_{py}$
Service	$\epsilon_{st} = \epsilon_{sc} = 0.002$	$\epsilon_{st} = \epsilon_{sc} = 0.004$
Factored	$\epsilon_{sc} = 0.005$	$\epsilon_{sc} = 0.014$
	$\epsilon_{st} = 0.003$	$\epsilon_{st} = 0.010$

NOTES:
(1) The types of strains limited by this Table are strains induced by other than construction-related liner deformations.
(2) Strain in in./in. or mm/mm.

when calculating liner strains for the Service and factored load combinations.

CC-3730 LINER ANCHORS

(a) The liner shall be anchored to the concrete so that the liner strains do not exceed the strain allowable given in CC-3720. The anchor size and spacing shall be chosen so that the response of the liner is predictable for all the loads and load combinations given in CC-3200. The anchorage system shall be designed so that it can accommodate the design in-plane (shear) loads or deformations exerted by the liner and loads applied normal to the liner surface.

(b) The allowable force and displacement capacity are given in Table CC-3730-1. The load combinations shown in Table CC-3230-1 are applicable to the liner anchors, except that load factors for all load cases may be taken equal to 1.0. Mechanical loads are those that are not self-limiting or self-relieving with load application. Displacement limited loads are those resulting from constraint of the structure or constraint of adjacent material and are self-limiting or self-relieving.

(c) The anchorage forces to be transferred to the concrete shall be established in the Design Specification.

CC-3740 PENETRATION ASSEMBLIES

(a) Each penetration shall be provided with an anchorage system capable of transferring loads and thermal effects to the concrete. The anchorage design shall be in accordance w ith liner anchor requirements.

(b) The design allowables for the penetration nozzles shall be the same as those used for Division 1. A nozzle is a part of the assembly not backed up by concrete.

(c) The design allowables for the liner in the vicinity of the penetration shall be the same as those given in AISC N690.

(d) The portion of the penetration sleeve backed by concrete shall be designed to meet the requirements of CC-3700 and CC-3800.

(e) The anchorage forces to be transferred to the concrete shall be established in the Design Specification.

CC-3750 BRACKETS AND ATTACHMENTS

(a) The design allowables for brackets, attachments, and the liner in their vicinity shall be the same as those given in AISC N690.

(b) The anchorage forces to be transferred to the concrete shall be established in the Design Specification.

CC-3760 FATIGUE

In general, the design of liners is not fatigue controlled since most stress and strain changes will occur only a small number of times and produce only minor stress– strain fluctuations. The occurrence of earthquake and design basis accident full-design strains occurs too infrequently and with too few cycles to generally be controlling. Nevertheless, because of the critical nature of the liner, the Designer shall ensure the suitability of the liner for the specific operating conditions involving cyclic application of loads and thermal conditions that have been established in the Design Specification. The fatigue methods and limits established by Division 1 shall apply.

CC-3800 LINER DESIGN DETAILS

CC-3810 LINER ANCHORS

The anchor design and analysis shall consider the effects of the following:

Table CC-3730-1
Liner Anchor Allowables

Category	Force and Displacement Allowables: Mechanical Loads, Lesser of:	Displacement Limited Loads
Test, normal, severe environmental, extreme environmental	$F_a = 0.67\ F_y$ $F_a = 0.33\ F_u$	$\delta_a = 0.25\ \delta_u$
Abnormal, abnormal/severe environmental, abnormal/extreme environmental	$F_a = 0.9\ F_y$ $F_a = 0.5\ F_u$	$\delta_a = 0.50\ \delta_u$

(a) The unbalanced loads resulting from the variation of liner curvature. Some areas of the liner may have inward curvature between the anchors, whereas other areas will have outward curvature. The variation will result in shear load and displacement at the anchor.

(b) Liner thicker than nominal due to the rolling tolerances given in SA-20. The thicker plate will impose greater forces and displacements on the anchorage system than a nominal thickness liner.

(c) Yield strength higher than the minimum specified due to the rolling processes and biaxial loading. Adequate consideration of yield strength in excess of the minimums may be provided by one of the following options:

(1) converting liner strains to stress and membrane forces assuming the material remains elastic.

(2) conducting biaxial yield strength tests to establish the biaxial yield strength of materials used for the liner. If biaxial yield strength tests are performed, the anchor loads may be determined considering the liner material is in a plastic state when justified by the design.

(3) considering liner plate biaxial compressive yield strength equal to 1.5 times the yield strength value specified in Section II, Part D, Subpart 1, Table Y-1. For this option, reported uniaxial tensile yield strength of liner material shall not exceed 1.25 times the yield strength specified in Section II, Part D, Subpart 1, Table Y-1.

(d) Weld offset, structural discontinuities, and concrete voids behind the liner.

(e) Variation in anchor spacing.

(f) Variation in anchor stiffness due to a variation of the concrete modulus.

(g) Local concrete crushing in the anchor zone.

(h) Stud anchors shall be designed to fail before tearing the liner.

CC-3820 PENETRATION LINERS

For penetration assemblies designed for pipe rupture loads, the design shall consider one of the following:

(a) the moment, axial, torque, and shear loadings that the piping is capable of producing

(b) penetration loads based on a dynamic analysis considering pipe rupture thrust as a function of time

CC-3830 TRANSITIONS FROM CONCRETE TO STEEL

CC-3831 Transition Details

When containments use a combination of concrete and metal (see Figure CC-3831-1), the design rules below shall govern. Transition sections shall be divided into two categories.

(a) *Category One*: full-containment diameter transitions, penetration with nozzles embedded in the concrete containment wall for attachment of piping, hatches, and locks

(b) *Category Two*: local zones backed up by compressible materials

CC-3831.1 Category One: Transition Sections.

(a) Metal sections not backed by concrete shall meet all the design requirements of Division 1 and shall consider the concrete confinement.

(b) Metal sections may be attached to the concrete portion of the containment with anchor rods, anchor bolts, attachment to the primary reinforcement or prestressing system, or any anchorage method capable of transferring the design loads.

CC-3831.2 Category Two: Transition Sections. Metal sections backed up by compressible material to provide local flexibility shall meet all design requirements of Division 1 in the region where compressible material is present. Where the sections attach to concrete backed or embedded members, only the requirements of Article CC-3000 apply.

CC-3840 WELDED CONSTRUCTION

CC-3841 Joint Category

The term *category* as used herein defines the location of a joint in a liner and illustrates some acceptable details. The joints included in each category are designated A, B, C, D, E, F, G, H, and J. Figure CC-3831-1 illustrates typical joint locations.

(a) *Category A*: longitudinal welded joints within the liner or penetration nozzles

(b) *Category B*: circumferential welded joints within the liner or penetration nozzles

(c) *Category C*: detailed descriptions and requirements for this category are covered in Division 1

(d) *Category D*: welded joints connecting penetration nozzles in the liner

(e) *Category E*: welded joints connecting flat liner bottom sections to elements of spherical, cylindrical, or conical liner sections or for intersection of liner sides to sides, or sides to bottoms

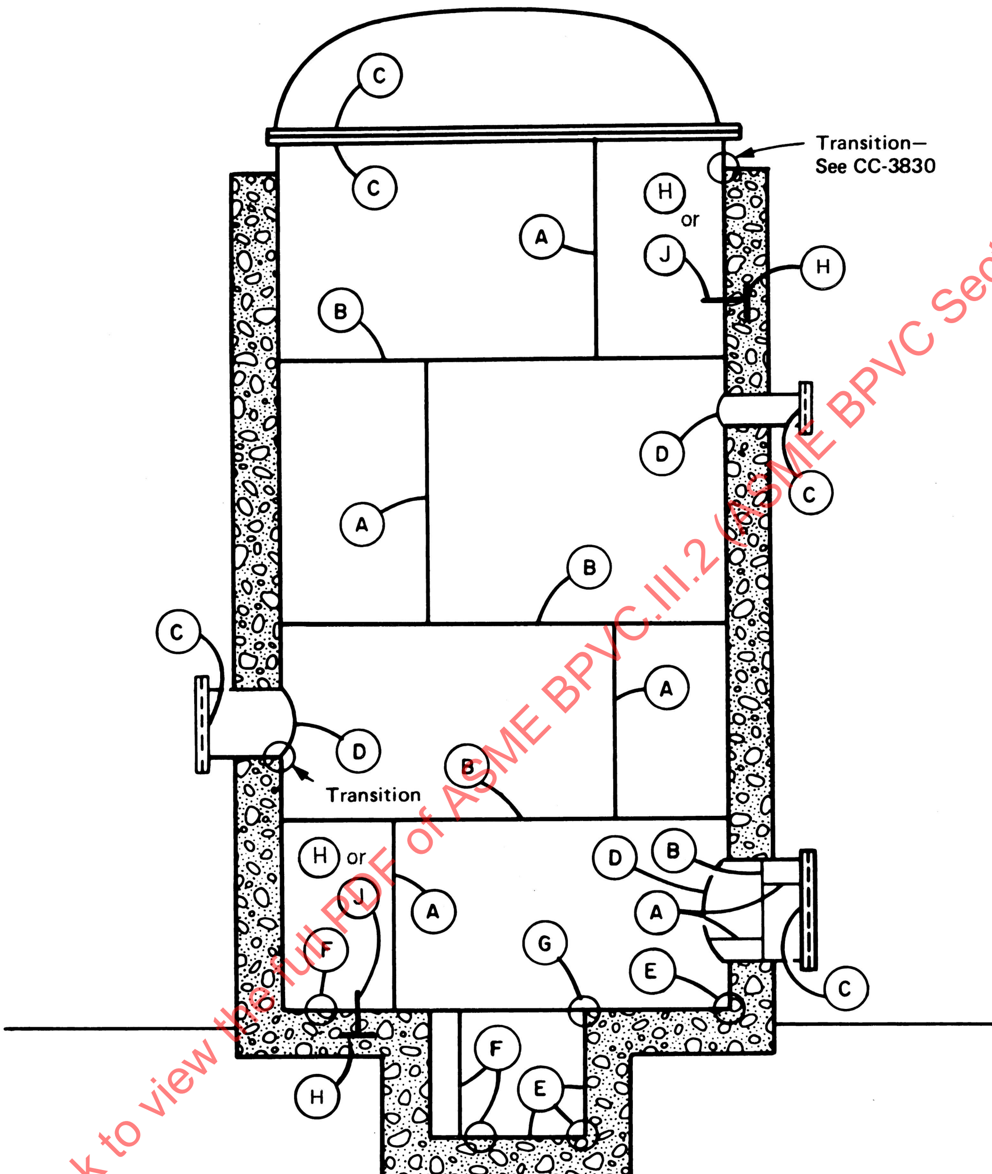
(f) *Category F*: welded joints connecting liner floor plates together and to liner transition sections and joints connecting liner sides and bottom plates together

(g) *Category G*: welded joints connecting the sides of liner side plates to liner floor plates

(h) *Category H*: welded joints connecting attachments (including liner anchors) to the liner or thickened liner plate and welded joints connecting embedment anchors to attachments or other embedment anchors

(i) *Category J*: welded joints connecting liner plates to embedments that are continuous throughout liners

Figure CC-3831-1
Illustration of Welded Joint Locations Typical of All Categories



GENERAL NOTE: For definitions of categories, see CC-3841.

CC-3842 Permissible Types of Welded Joints

Joints of any category shall meet the requirements of CC-3830 for transition zones from concrete to steel when compressible material is present between the liner and the concrete.

CC-3842.1 Category A. All welded joints of Category A shall meet the fabrication requirements of CC-4542 and shall be capable of being examined in accordance with CC-5520.

CC-3842.2 Category B. All welded joints of Category B shall meet the fabrication requirements of CC-4542 and shall be capable of being examined in accordance with CC-5520.

CC-3842.3 Category C. Rules for joints of Category C are included in Division 1.

CC-3842.4 Category D.

(a) Joints of Category D shall meet the requirements of Figure CC-4542.2-1 for nozzles over 3 in. (75 mm) diameter.

(b) Joints of Category D shall meet the requirements of Figure CC-4542.2-2 for nozzles 3 in. (75 mm) diameter and under.

CC-3842.5 Category E. Joints shall be of the type shown in Figure CC-4542.2-3.

CC-3842.6 Category F. Joints shall be of the type shown in Figure CC-4542.2-4.

CC-3842.7 Category G. Joints shall be of the type shown in Figure CC-4542.2-5.

CC-3842.8 Category H. Welded joints shall be of the type shown in Figure CC-4542.2-6.

CC-3842.9 Category J. Welded joints shall be of the type shown in Figure CC-4542.2-7.

CC-3842.10 Minimum Dimensions. The minimum dimensions of Figure CC-4542.2-1 through Figure CC-4542.2-7 shall be met where:

r_1 = $\frac{1}{4}t$ or $\frac{3}{4}$ in. (19 mm), whichever is less
r_2 = $\frac{1}{4}$ in. (6 mm) min.
t = nominal thickness of liner
t_a = nominal thickness of attachments to liner
t_c = $0.7t_n$, $0.7t_1$, $0.7t_a$, or $\frac{1}{4}$ in. (6 mm), whichever is less
t_{min} = the smaller of $\frac{3}{4}$ in. (19 mm) or the thickness of the thinner of the parts joined
t_n = nominal thickness of penetrating part
t_w = $0.7t_{min}$
t_1 or t_2 = not less than the smaller of $\frac{1}{4}$ in. (6 mm) or $0.7t_{min}$

$$t_1 + t_2 \geq 1\tfrac{1}{4}\, t_{min}$$

CC-3843 Unequal Thickness Transitions

A tapered transition section having a length not less than three times the offset between the adjacent section surfaces as shown in Figure CC-3840-1 shall be provided at joints of Categories A and B between sections that differ in thickness by more than one-fourth of the thickness of the thinner section. The transition section may be formed by any process that will provide a uniform taper.

CC-3900 DESIGN CRITERIA FOR IMPULSE LOADINGS AND MISSILE IMPACT

CC-3910 GENERAL

Containment and liner shall be designed to resist the effects of impulse loadings from pipe rupture and the impact of missiles resulting from pipe rupture, tornadoes, or any other missile specified in the Design Specification in accordance with CC-3200. Load classifications are given in CC-3240.

CC-3920 DESIGN ALLOWABLES

CC-3921 General

CC-3921.1 Normal and Severe Environmental Load Categories. Structural members designed to resist loads in the normal and severe environmental load categories are not allowed to exceed yield.

CC-3921.2 Abnormal, Extreme Environmental, Abnormal and Extreme Environmental Load Categories. Structural members designed to resist impulse loads and dynamic effects in the abnormal, extreme environmental, and abnormal and extreme environmental categories are allowed to exceed yield strain and displacement values. Design adequacy is controlled by limiting the ductility assumed in evaluating the energy absorption capability or resistance function of the structure.

CC-3922 Stress Allowables

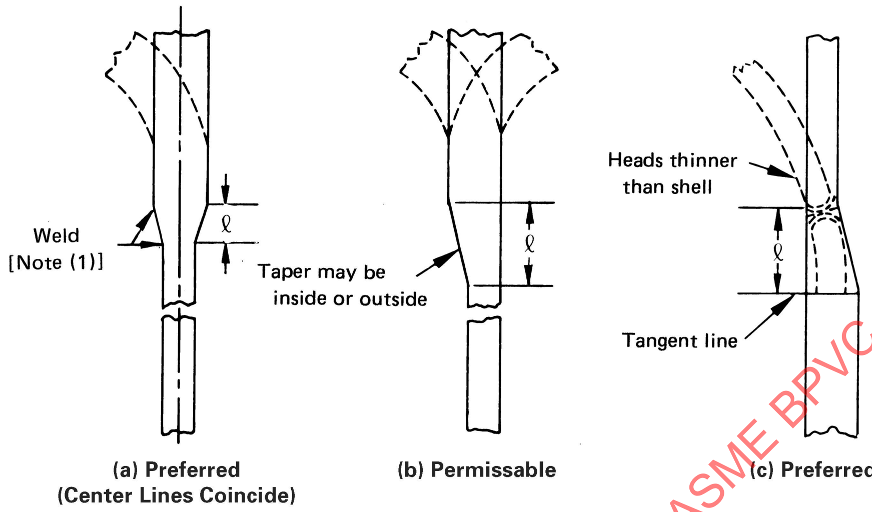
The allowables applicable to the determination of section strength are given in CC-3400 and CC-3700. In determining f_y values, the dynamic effect of the loading may be considered.

CC-3923 Ductility Limits

CC-3923.1 Impulse Loads. The ductility limits used in design for impulse load shall not exceed one-third the ductility determined at failure.

CC-3923.2 Impact Effects. The ductility limits used in design for impact load shall not exceed two-thirds the ductility determined at failure.

Figure CC-3840-1
Tapered Transition Sections



NOTE: (1) Length of taper may include the width of the weld.

CC-3930 DESIGN ASSUMPTIONS

CC-3931 Penetration Equations and Impulse or Impact Effects

Empirical penetration equations are assumed to govern design local to the missile impact area. Missile penetration shall be limited to 75% of total section thickness. Local areas for missile impact are defined as having a maximum diameter equal to 10 times the mean diameter of the impacting missiles, or $5\sqrt{t}(2.76\sqrt{t})$ plus the mean diameter of the impacting missile where t is defined as the total section thickness in feet (meter), whichever is smaller. The effect of damage in the local missile impact area shall be considered in the overall structural integrity of the section.

CC-3932 Effective Mass During Impact

For a concrete section, the effective diameter of the section to be used in determining the kinetic energy transferred on missile impact or the dynamic characteristics of the structural response shall be equal to the mean diameter of the missile plus one section thickness t. Larger values of effective mass may be used if a test or analytical verification is available to substantiate the use of larger values.

ARTICLE CC-4000
FABRICATION AND CONSTRUCTION

CC-4100 GENERAL REQUIREMENTS

CC-4110 INTRODUCTION

Concrete containments shall be fabricated and constructed in accordance with the requirements of this Article. The requirements apply whether performed in a shop or at the field site. Unless otherwise indicated, throughout this Article the term *component* shall be understood to include parts and appurtenances. The fabrication of parts and appurtenances designated to meet the requirements for Class MC and that are not backed up by concrete for load-carrying purposes shall meet the requirements of Article NE-4000 and Subsection NCA. Attachments to parts fabricated to the requirements of Division 1 shall meet the requirements of this Article.

CC-4120 CERTIFICATION OF MATERIAL AND FABRICATION OR CONSTRUCTION BY COMPONENT FABRICATOR OR CONSTRUCTOR

CC-4121 Means of Certification

The Fabricator or Constructor of a concrete containment or component shall certify, by application of the appropriate Certification Mark and completion of the appropriate Data Report in accordance with Article NCA-8000, that the materials used comply with the requirements of Article CC-2000 and that the fabrication and construction complies with the requirements of Article CC-4000.

CC-4121.1 Certification of Treatments, Tests, and Examinations. If the Fabricator or Constructor performs treatments, tests, repairs, or examinations required by other Articles of this Division, the Fabricator or Constructor shall certify that these requirements have been fulfilled (NCA-3862 or NCA-8410). Reports of all required treatments and of the results of all required tests, repairs, and examinations shall be available to the Authorized Inspector.

CC-4121.2 Repeat of Tests. If, during the fabrication or construction of the component, the material is subjected to conditions that cause a change in principal characteristics that has not been accounted for in the Design Report and that may change properties from the specified values, the tests shall be repeated or additional tests made by the Fabricator or Constructor for verification of acceptability.

CC-4122 Material Identification

CC-4122.1 Concrete. Each *concrete placement* (defined as a placement made continuously between construction joints) shall be identified on the as-built sketch, and records maintained of the date, concrete batch tickets with traceability to the information required in CC-4220, and testing performed in accordance with CC-5230.

CC-4122.2 Reinforcing Material. Reinforcing steel, by groups of bars or shipments, shall be identifiable by documentation, tags, or other means of control to a specific heat number or heat code until review of the CMTR has been performed. After acceptance of the reinforcing steel, adequate documentation, tags, or other means shall be provided to ensure traceability to an accepted shipment or to groups of accepted shipments of reinforcing steel.

CC-4122.3 Prestressing System Material. Material for prestressing systems shall carry identification markings or tags that shall remain distinguishable until the tendon assembly is completed. If the original identification markings are cut out or the material is divided into two or more pieces, the markings shall be accurately transferred to the pieces prior to cutting, or a coded marking or other means of control shall be used to ensure identification of each piece of material during the subsequent assembly. A tabulation shall be made of the CMTR for the materials used in an assembly or group of assemblies.

CC-4122.4 Liner Material. Material for liners (excluding leak-chase system materials, embedments, and attachment material) shall carry identification markings that will remain distinguishable until the liner is assembled. If the original identification markings are cut out or the material is divided into two or more pieces, the marks shall either be accurately transferred to all pieces prior to cutting or a coded marking shall be used to ensure identification of each piece of material during subsequent fabrication or installation. In either case, an as-built sketch or a tabulation of materials shall be made identifying each piece of material with the CMTR and the coded marking. Welding and brazing materials shall be identified and controlled so that they can be traced to each liner, or else a control procedure shall be employed that ensures that the specified materials are used.

CC-4122.5 Control of Material. Material shall be controlled, marked, and identification maintained in accordance with NCA-4134.7 and NCA-4134.8.

CC-4123 Examinations

Visual examination activities that are not referenced for examination by Article CC-5000 and are performed solely to verify compliance with requirements of Article CC-4000 are not required to be performed by personnel and procedures qualified to Article CC-5000 unless so specified.

CC-4200 CONCRETE

CC-4210 GENERAL

The Construction Specification shall specify the requirements for stockpiling, batching, mixing of concrete constituents, conveying, depositing, consolidating, and curing of concrete and construction joint preparation. The Construction Specification shall specify any requirements or special procedures to be followed to limit concrete temperature. Concrete batching and mixing facilities shall be certified in accordance with the requirements of the National Ready Mixed Concrete Association Plant Certification Check List. Inspection and certification shall be conducted by either the Society or the Constructor or Fabricator of the concrete component.

CC-4220 STORING, BATCHING, MIXING, AND PLACING

CC-4221 Stockpiling and Storing

CC-4221.1 Aggregates. Aggregates shall be handled, transported, and stockpiled in a manner that will minimize segregation and ensure that the fineness moduli and gradation are maintained within the range specified. Intermixing between stockpiles shall be prevented. Suitable storage facilities shall be provided to ensure that the above requirements are met. Aggregates shall be sampled and tested in accordance with the requirements of CC-5223.

CC-4221.2 Moisture Control. Cement, admixtures, and other concrete and grout constituents that are adversely affected by moisture before mixing shall be stored, handled, and transported in a manner that will prevent the introduction of moisture. If the above materials are exposed to moisture after testing, they shall be resampled and tested before use in accordance with the requirements of CC-5220.

CC-4222 Batching

CC-4222.1 General. The Construction Specification for batching of constituents for concrete manufacture shall be based on ACI 304R. Only constituents from stockpiles or storage containers that have been accepted shall be used. Constituents shall be removed from storage in a manner such that the distribution of particle sizes remains within the ranges specified. Aggregate shall be rescreened if necessary to maintain specified gradation.

CC-4222.2 Measuring. Aggregates, cements, ice, and mineral admixtures shall be measured by weight. Liquids may be measured by volume or weight. Free moisture content of aggregates and admixtures shall be determined and accounted for as corrections to the amount of added mixing water as differentiated from total mixing water requirements. The measurement accuracy and precision shall be such that the proportion of constituents stays within the ranges established in ASTM C94/C94M. The ±1% tolerance for water specified in ASTM C94/C94M may be modified to ±2% if permitted in the Construction Specification and if the plant can demonstrate a standard deviation less than 400 psi (3 MPa) as determined by ACI 214R. Records shall be maintained of the constituent quantities in each batch. Recording paper divisions or digital printout records shall be capable of verifying conformance to ±1% for the measurements of cement, total aggregates, mineral admixtures and water, and to ±3% for liquid admixture.

CC-4223 Mixing

CC-4223.1 General. All concrete shall be mixed in accordance with the requirements set forth in ASTM C94/C94M and any additional requirements of the Construction Specification.

CC-4223.2 Operation of Mixers. The range of mixing capacities and corresponding mixing times for all mixers shall be determined by the performance of mixer uniformity tests as specified in ASTM C94/C94M. Mixers shall be used only within the range of capacities and mixing times qualified by mixer uniformity tests.

CC-4224 Conveying

CC-4224.1 General. Concrete shall be conveyed from the mixer to final placement by methods that will prevent the separation or loss of materials.

CC-4224.2 Conveying Equipment. Conveying equipment shall be capable of providing a supply of concrete at the site of placement without separation of constituents and without interruptions that cause loss of plasticity between successive increments. The delivery rate shall be such that unconsolidated material is not covered by newly deposited concrete, and new material is not placed on concrete that has hardened unless the surface of the hardened material has been properly prepared as a construction joint. Performance of all conveying equipment including hoppers, buckets, conveyors, pumps, and chutes shall be selected and employed so that the concrete shall meet the specified characteristics. Concrete, during conveyance, shall not come in contact with aluminum.

CC-4225 Depositing

CC-4225.1 General. Concrete shall be deposited as near as practicable to its final position to avoid segregation due to rehandling or flowing. The placing operation shall be conducted at such a rate that the concrete is at all times plastic and flows readily into forms and around reinforcement and embedments. Concrete that is partially hardened or contaminated shall not be deposited in the structure. Retempered concrete shall not be used.

CC-4225.2 Continuity. Concreting shall be a continuous operation until the placement is completed. The top surfaces of vertically formed lifts shall be generally level. Location and preparation of construction joints shall be in accordance with CC-4252.

CC-4226 Consolidation

CC-4226.1 General. Concrete shall be thoroughly worked around the reinforcement and embedments and into corners of the forms. ACI 309R shall be used as a guide to develop suitable consolidation techniques.

CC-4226.2 Use of Mortar. Where placement and consolidation conditions are difficult, or where reinforcement is congested, batches of mortar containing the same proportions of cement and sand as used in the concrete shall first be deposited in the forms to the depth specified. Sufficient water shall be added to the mortar to provide necessary workability, but the water–cement ratio shall not exceed the water–cement ratio of the specified concrete design mix.

CC-4226.3 Placeability Tests. When required by the Construction Specification, one or more mockups shall be prepared and filled with the specified concrete to demonstrate that the concrete can be properly placed and consolidated under field conditions. The mockup shall contain representative amounts of reinforcing steel, tendon tubes, and embedments. Vibrators, equipment, and procedures used in the tests shall be representative of those that will be used in the actual construction.

CC-4230 PREPLACED AGGREGATE CONCRETE

CC-4231 General

The Construction Specification shall prescribe complete specifications for materials, locating and placing grout pipes, preplacing and compacting coarse aggregates, grout pumps and equipment, preparation for grouting, completing the top surface, and the grout mix design, fluidity, and temperature. Specifications and procedures shall be based on ACI 304R.

CC-4240 CURING

(a) The concrete shall be cured and protected against thermal and physical damage from the time of placement until the end of the minimum curing period specified in the Construction Specification.

(b) Special requirements on the type and duration of the curing process shall be established in the Construction Specification together with the details of any special conditions to be maintained during the curing period.

(c) During cold weather, the surfaces of the concrete placement shall be maintained above 40°F (5°C) for a minimum period of the first three days. Cold weather is defined as a period when for more than three successive days, the average daily outdoor temperature drops below 40°F (5°C). The average daily temperature is the average of the highest and lowest temperature during the period from midnight to midnight. When temperatures above 50°F (10°C) occur for more than half of any 24-hr duration, the period should no longer be regarded as cold weather.

(d) The period for protection against freezing may be reduced if it can be demonstrated that the compressive strength of the concrete is at least 500 psi (3.5 MPa) and the structure has no early strength requirements.

CC-4250 FORMWORK AND CONSTRUCTION JOINTS

CC-4251 Formwork Design

CC-4251.1 General. Forms shall result in a final structure which conforms to the shape, lines, and dimensions required by the Design Drawings and shall be substantial and sufficiently tight to prevent leakage of mortar. They shall be properly braced, tied, or supported to maintain position and shape within the limits prescribed by the Construction Specification.

CC-4251.2 Design of Formwork. The Construction Specification for the design of formwork shall be based on ACI 347, and shall include consideration of the following factors:

(a) rate and method of placing concrete

(b) density of concrete

(c) construction loads, including vertical, horizontal, and impact loads

CC-4251.3 Use of the Liner as Formwork. In using the steel containment liner as formwork, special attention shall be given to liner supports and the height of lifts to prevent exceeding the tolerance requirements of CC-4522.

CC-4252 Construction Joints

Construction joints shall be located only as shown on the Design Drawings. The Construction Specification shall specify the method of their preparation. Specific attention shall be given to ensure that before concrete is placed, all debris, water, and ice are removed from the space to be occupied by the concrete. Joint preparation shall include removal of all laitance and other unsound material from hardened concrete surface, and saturating of the surface before additional concrete is placed. Provision shall be made for transfer of shear and other forces through construction joints. Refer to CC-3424 for details.

CC-4253 Precast Concrete Segments

Where precast concrete segments will be used as forms, the Construction Specification shall specify the alignment tolerance, the type of joints between elements, the surface preparation, and ties required to ensure attachment to the containment concrete. Precast concrete segments shall be supported adequately to prevent displacement during concreting.

CC-4260 COLD AND HOT WEATHER CONDITIONS

Cold and hot weather procedures shall be in accordance with the Construction Specification. The Construction Specification shall establish a permissible range of as placed temperatures for the concrete and may specify the preheating or precooling of the concrete constituents, or the use of ice or other means to control the temperature of the concrete, including maximum rate of cooling to prevent thermal shock. Such procedures shall be based on the information provided in ACI 305R and 306R.

CC-4270 REPAIRS TO CONCRETE

Honeycombed or defective concrete shall be repaired or removed and replaced as directed by the Designer. Adjoining surfaces shall be prepared as specified for construction joints (see CC-4252).

CC-4280 GROUT FOR GROUTED TENDON SYSTEMS

CC-4281 Location of Grout Inlets and Outlets

Location of grout inlets and outlets shall be included in the Construction Specification drawings. All grout inlets and outlets shall contain positive shut-off devices. Grout inlets and outlets shall be placed at the top of grout caps at high and low points at a distance not to exceed 3 ft (0.9 m) in both directions and at major changes in cross sections of the duct to facilitate straight bores into anchorage/ducts for post-grouting inspection. Mandrels shall be used to keep grout holes straight during concrete placement.

CC-4282 Grout Production

CC-4282.1 Storage of Materials. The cement and other prepackaged materials shall be stored in locations that are weatherproof. Storage of all admixtures and additives shall be as recommended by the manufacturer.

CC-4282.2 Equipment for Measuring and Mixing. Equipment for measuring and batching grout constituents shall be accurate to ±3%. The capacity of the equipment shall be sufficient to ensure that post-tension ducts will be filled and vented without interruption at the required rate of injection. The mixer shall be capable of producing homogeneous and stable grout free of lumps and undispersed cement and able to deliver continuous supply of grout.

CC-4282.3 Grout Injection Equipment. The injection equipment shall be capable of continuous operation and include a system for recirculation of the grout while grouting. The use of compressed air to aid pumping shall not be permitted. Pumps shall be constructed to prevent oil, air, or other substances from entering the grout and to prevent loss of grout. The Construction Specification shall stipulate the pressure necessary to deliver the grout that assures adequate grout placement and necessary gauges required. The piping to the grout shall incorporate a sampling access. Oil and water-free compressed air shall be available to check free passage of the ducts and blow out excess water and assure that no leaks occur.

CC-4282.4 Equipment for Thixotropic Grout. The required grout equipment shall be included in the Construction Specification. It shall provide for a high speed shear (colloidal) mixer and pump and pressure controls.

CC-4282.5 Mixing and Injecting of Grout. The batching and mixing of grout shall be performed within accuracies required by the Construction Specification.

(a) Proportions of materials shall be based on previous testing of the grout. They may be selected based on prior documented experience with identical materials and similar equipment and under comparable field conditions.

(b) The materials shall be mixed to produce a homogeneous grout. The grout shall be continuously agitated until it is pumped. Water shall not be added to increase fluidity that has decreased by delayed use of grout.

(c) The fluidity of the grout shall be tested in accordance with ASTM C939. The efflux time of the grout sample immediately after mixing shall be as established by testing at the minimum and maximum water amounts. It shall be no less than 5 sec and no more than 30 sec.

(d) After mixing and resting without agitation for a period of 30 min, the efflux time shall not exceed 30 sec following 30 sec of remixing.

CC-4282.6 Grouting. The Construction Specification shall specify procedures for grouting that shall contain the following:

(a) The temperature at any point in the tendon duct during grouting shall be above 40°F (5°C). The end anchorages and tendon duct shall be maintained above 40°F (5°C) for a period of 48 hr after grouting or until the grout reaches a minimum of 800 psi (5.5 MPa) compressive strength. The grout temperature shall not exceed 100°F (38°C) during mixing and pumping.

(b) The grout shall be injected from near the lowest end of tendons in an uphill direction and used within 30 min of the first addition of water to ensure the flowability of the grout.

(c) The method of injecting grout shall ensure complete filling of the ducts and complete surrounding of the tendon with grout.

(d) Grout rate that is slow enough to avoid air entrapment and avoid segregation of the grout shall be specified.

(e) Means to maintain a continuous one-way flow of the grout shall be provided.

(f) Grouting of a tendon (or designated group of tendons) shall be performed in one operation.

(g) The pumping pressure at the inlet shall not exceed 245 psi (1.7 MPa) for steel ducts. Higher pressures may be employed if demonstrated to be satisfactory in field mock-up trials.

(h) When one-way flow of grout cannot be maintained, or when grouting is interrupted, the Construction Specification shall provide procedures to assure complete filling.

CC-4282.7 Vertical Grouting. The Construction Specification shall provide procedures to assure that bleed water is removed from the grout. It shall provide devices and means to assure that bleeding will not cause the grout to drop below the highest point of the anchorage device and complete filling is achieved.

CC-4300 FABRICATION OF REINFORCING SYSTEMS

CC-4310 GENERAL

This subarticle covers the fabrication requirements for the reinforcing systems of concrete containments.

CC-4320 BENDING OF REINFORCING BAR

CC-4321 Standard Hooks

CC-4321.1 Definition. The term *standard hook* as used herein shall mean either

(a) a semicircular turn plus an extension of at least 4 bar diameters, but not less than $2\frac{1}{2}$ in. (60 mm) at the free end of the bar or

(b) a 90 deg turn plus an extension of at least 12 bar diameters at the free end of the bar or

(c) for stirrup and tie anchorages

(1) for No. 5 (16) bar and smaller, a 90 deg turn plus an extension of 6 bar diameters

(2) for Nos. 6 (19) through 8 (25) bar, a 90 deg turn plus an extension of 12 bar diameters

(3) for No. 8 (25) bar and smaller, a 135 deg turn plus an extension of 6 bar diameters

CC-4321.2 Diameter. The diameter of bend measured on the inside of the bar for standard hooks shall not be less than the values of Table CC-4322-1, except for stirrups and ties in sizes Nos. 3 (10) through 5 (16).

CC-4322 Stirrups, Tie Hooks, and Bends Other Than Standard Hooks

(a) Inside diameter of bends for stirrups and ties shall not be less than 4 bar diameters for No. 5 (16) bar and smaller.

(b) Bends for all other bars shall have diameters on the inside of the bar not less than allowed by Table CC-4322-1.

CC-4323 Bending

CC-4323.1 Fabrication of Bars. When bending is required, it shall be performed prior to embedding the bars in the concrete except as permitted in CC-4323.2. All bars to be bent shall be cold bent prior to embedment in concrete, except as permitted in CC-4323.2.

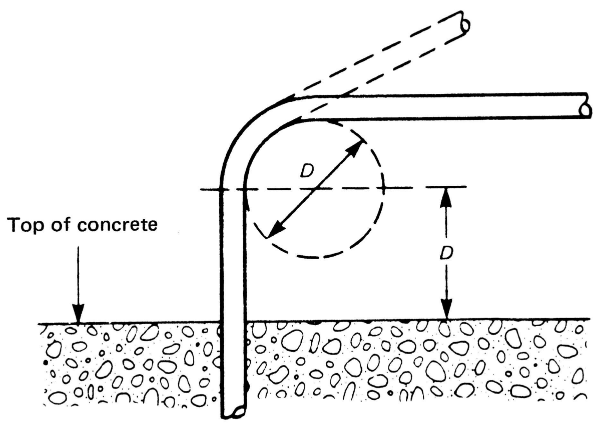
CC-4323.2 Bending of Bars Partially Embedded in Set Concrete. Bending or straightening of bars partially embedded in set concrete shall not be permitted, except in isolated cases where corrective action or a field change is required and is specifically approved by the Designer. The bend diameters shall conform to the requirements of Table CC-4322-1. In addition, the beginning of the bend shall not be closer to the existing concrete surface than is shown in Figure CC-4323-1. The following requirements shall be adhered to for individual bar sizes:

(a) Bar Nos. 3 (10) through 5 (16) may be cold bent once. Preheating in accordance with CC-4323.3 is required for subsequent straightening or bending.

Table CC-4322-1
Minimum Diameter of Bend

Bar Size	Minimum Diameter, bars
No. 3 (10) to No. 8 (25)	6
No. 9 (29) to No. 11 (36)	8
No. 14 (43) to No. 18 (57)	10

Figure CC-4323-1
Allowable Bend Configuration



GENERAL NOTE: D = minimum diameter of bend from Table CC-4322-1.

(b) Bar No. 6 (19) and larger shall be preheated in accordance with CC-4323.3.

(c) Examination of all bends shall be in accordance with CC-5340.

CC-4323.3 Preheating. Preheating prior to bending or straightening, when required, shall be in accordance with the following rules:

(a) Preheating may be applied by any method which does not harm the bar material or cause damage to the concrete.

(b) The preheat shall be applied to a length of bar equal to 5 bar diameters each way from the center of the bend, except that preheat shall not extend below the surface of the concrete. The temperature of the bar at the concrete interface shall not exceed 500°F (260°C).

(c) The preheat temperature shall be 1,100°F to 1,200°F (595°C to 650°C).

(d) The preheat temperature shall be maintained until bending or straightening is complete.

(e) The preheat temperature shall be measured by temperature measurement crayons or contact pyrometer.

CC-4323.4 Tolerances. Bars used for concrete reinforcement shall meet fabricating tolerance requirements specified in the Construction Specification.

CC-4330 SPLICING OF REINFORCING BARS AND ANCHORING OF MECHANICALLY HEADED DEFORMED BARS

CC-4331 Introduction

CC-4331.1 General. Splicing of reinforcing bars and anchoring of mechanically headed deformed bars shall be made only as required or permitted by the Designer.

CC-4331.2 Permitted Types of Splices and Joints. The types of splices and joints listed in (a), (b), and (c) below are permitted within the limitations described in the following:

(a) lap splices

(b) mechanical splices of the following types:

(1) sleeve with ferrous filler metal splices

(2) taper threaded splices

(3) swaged splices

(4) threaded splices in thread deformed reinforcing bars

(5) sleeve with cementitious grout

(6) cold roll formed parallel threaded splices

(c) arc-welded joints

CC-4331.3 Permitted Types of Mechanically Headed Deformed Bars Systems. The following types of mechanically headed deformed bar assemblies are permitted within the limitations described:

(a) head with ferrous filler metal systems

(b) taper threaded systems

(c) cold swaged on sleeve systems

(d) threaded heads in thread deformed reinforcing bars

(e) cold roll formed parallel threaded systems

CC-4332 Lap Splices

Lap splice requirements are stated in CC-3532.

CC-4333 Mechanical Splices and Mechanically Headed Deformed Bar Systems

CC-4333.1 Qualifications, Records, and Identifying Stamps.

CC-4333.1.1 Required Qualifications. Each Constructor or Fabricator is responsible for the mechanical splice and mechanically headed deformed bar system made by his organization and he shall conduct the tests required by this subarticle in order to qualify the mechanical splicing procedure, mechanically headed deformed bar attachment procedure, and the installers.

CC-4333.1.2 Maintenance and Certification of Records. The Constructor or Fabricator shall maintain a record of the splicing procedure, mechanical anchorage device installation procedure, and the installers qualified and employed by him, showing the date and results of tests, and the identification mark or marks assigned to each installer. These records shall be reviewed, verified, and signed by an authorized individual assigned by the Constructor. The records shall be accessible to the Owner and to the Authorized Inspector.

CC-4333.1.3 Splicing and Mechanical Anchorage Device Installation Prior to Qualification. No splicing or installation of mechanical anchorage devices shall be undertaken until an installer has been qualified.

Only installers who are qualified in accordance with CC-4333.4 shall be used.

CC-4333.2 Splice and Mechanically Headed Deformed Bar System Qualification Requirements.

CC-4333.2.1 General Requirements. Each splice and mechanically headed deformed bar system Manufacturer shall conduct a series of performance tests in order to qualify his splice and mechanically headed deformed bar system for use.

CC-4333.2.2 Materials to Be Used for Performance Tests. The types of materials to be used for the performance test specimens shall be the same as those intended for use in production splices and production mechanically headed deformed bar systems. The actual materials used and the necessary dimensions of all test specimens shall be documented.

CC-4333.2.3 Type and Number of Performance Tests.

(a) Static Tensile Tests. Six splice specimens for each bar size and splice type to be used in construction shall be tensile tested in accordance with the monotonic test method of ASTM A1034/A1034M. Six mechanically headed deformed bar specimens for each bar size, head type, and head size to be used in construction shall be tensile tested to failure using the loading rate set forth in SA-370. For swaged or sleeve with cementitious grout splices, three different deformation patterns shall be used for each bar size tested. The static tensile tests shall be repeated for each bar grade to be used in construction for taper threaded splices, cold roll formed parallel threaded splices, and threaded splices in thread deformed reinforcing bars. For taper threaded splices and cold roll formed parallel threaded splices and headed bar systems, one of the six specimens shall be tested at 20°F (−7°C) or less. Two additional specimens may be tested at 20°F (−7°C) or less for taper threaded splices and cold roll formed parallel threaded splices and mechanically headed deformed bar systems to waive the tensile test requirements of production splice and mechanically headed deformed bar samples at 20°F (−7°C) or less required by CC-4333.5.4. A tensile test on a specimen from the same bar used for the spliced and mechanically headed deformed bar specimens shall be performed to establish actual tensile strength. The average tensile strength of the splices and mechanically headed deformed bars shall not be less than 90% of the actual tensile strength of the reinforcing bar being tested, nor less than 100% of the specified minimum tensile strength. The tensile strength of an individual splice and mechanically headed deformed bar system shall not be less than 125% of the specified minimum yield strength of the reinforcing bar. Each individual test report on the splice, mechanically headed deformed bar, and unspliced specimen shall include at least the following information:

(1) tensile strength

(2) total elongation

(3) load–extension curve to the smaller of 2% strain or the strain of 125% of the specified minimum yield strength of the reinforcing bar

The gage length for each pair of spliced and un-spliced specimens shall be the same, and equal to the length of splice sleeve, plus not less than 1 bar diameter nor more than 3 bar diameters at each end. The minimum length of a mechanically headed deformed bar test specimen shall be the greater of 10 in. (250 mm) or ten times the nominal diameter of the bar. For taper threaded and cold roll formed parallel threaded and mechanically headed deformed bar systems, the splice and mechanically headed deformed bar specimens being tested at 20°F (−7°C) or less shall be cold soaked for a minimum of 24 hr prior to testing at a temperature equal to or less than the temperature required for this test. The test temperature at the root of the critical thread shall be 20°F (−7°C) or less and maintained until the specimen reaches yield level load.

(b) Cyclic Tensile Tests. Three specimens of the bar-to-bar splice and three specimens of the bar-to-head attachment for each reinforcing bar size [and grade for taper threaded systems, cold roll formed parallel threaded systems, and threaded sleeves or mechanical anchorage devices (heads) in thread deformed reinforcing bar], splice type, and head type to be used in construction shall be subjected to a low cycle tensile test. Each specimen shall withstand 100 cycles of stress variation from 5% to 90% of the specified minimum yield strength of the reinforcing bar. One cycle is defined as an increase from the lower load to the higher load and return.

(c) Slip Test. Two of the six static tensile test mechanical splice samples noted in (a) shall be evaluated for slip prior to completing the static tensile test given in (a). The slip test shall be conducted in accordance with the ASTM A1034 slip test procedure to a predetermined load equal to one-half the specified yield strength ($0.5f_y$) of the reinforcing steel bar. After completion of the test cycle, the measured slip shall not exceed the total slip specified in Table CC-4333.2.3-1. If only one of the two samples meets the slip acceptance criteria, a retest may be allowed in which all remaining static tensile test specimens shall be evaluated for slip prior to static tensile testing and shall meet the slip acceptance criteria, otherwise the splices shall be rejected.

NOTE: Taper threaded splices conforming to CC-4331.2(b)(2) do not require a slip test.

CC-4333.2.4 Essential Variables. The performance tests must be completely reconducted when any of the applicable changes listed below are made.

Table CC-4333.2.3-1
Total Slip Acceptance Criteria for Mechanical Reinforcing Bar Splices

Reinforcing Bar Size	Total Slip, in. (mm)
No. 4 (13) through No. 6 (19)	0.020 (0.51)
No. 7 (22) through No. 9 (29)	0.028 (0.71)
No. 10 (32) through No. 11 (36)	0.036 (0.91)
No. 14 (43)	0.048 (1.22)
No. 18 (57)	0.060 (1.52)

Changes other than those listed may be made without the necessity for repeating the performance tests.

(a) for all splice and mechanically headed deformed bar systems

(1) a change in splice sleeve material or grade, or head material or grade

(2) a reduction in the cross-sectional area of the splice sleeve or mechanical anchorage device

(3) a reduction in the bar engagement length

(4) an increase in reinforcing bar grade

(5) a change in mechanical anchorage device (head) geometry

(b) for sleeve with ferrous filler metal splices and mechanically headed deformed bar systems with filler metal, a change in the filler metal

(c) for taper threaded splices and mechanically headed deformed bar systems with taper threads

(1) a change in thread geometry

(2) a change in torque

(d) for swaged splices and cold swaged mechanically headed deformed bar systems

(1) a change in swaging pressure

(2) a change in die geometry

(3) a change in stud material

(4) a change in outside or inside diameter of sleeve, mechanical anchorage device (head), or attachment device

(5) for heated splices, a change in the required minimum temperature of the sleeve at the time of swaging and maximum time and temperature that sleeves may be held in the heating oven

(e) for threaded splices and threaded mechanical anchorage devices in thread deformed bar

(1) a change in thread geometry

(2) a change in torque

(3) a reduction in the minimum required length of the locknuts used

(f) for sleeve with cementitious grout splices

(1) a change in the cementitious grout formulation

(2) a change in the deformation pattern inside the sleeve

(3) a change in the reinforcing steel deformation pattern

(4) a change in temperature limits for the splice system (bar, sleeve, grout) during placement and curing of grout

(g) for cold roll formed parallel threaded splices and cold roll formed parallel mechanically headed deformed bar systems

(1) a change in thread geometry

(2) a change in torque

(3) a change in roll forming pressures

(4) a reduction in the minimum required length of the locknuts used

CC-4333.3 Requirements for Production Splicing Procedures or Mechanical Anchorage Device (Head) Attachment Process. All production splicing and mechanical anchorage device (head) attachment shall be performed in accordance with a written procedure that shall include, as a minimum, the procedures used for the performance tests in CC-4333.2.3, with the following additional information:

(a) for sleeve with ferrous filler metal splices and mechanically headed deformed bar systems with ferrous filler

(1) bar end preparation

(2) cleanliness requirements

(3) bar end location tolerances

(4) permissible gap between reinforcing bar ends for splices only

NOTE: The permissible gap requirement is not applicable to mechanical devices as they are single-sided.

(5) allowable voidage in the filler metal

(b) for taper threaded splices and mechanically headed deformed bar systems with taper threads

(1) type of equipment and methods used to verify bar thread acceptability

(2) cleanliness requirements

(3) type of equipment and methods used for torquing

(4) required force and method of measurement

(5) method of mechanically locking the position splices

(6) method used to verify the final alignment and engagement of the coupler on both bars for splices or one bar for mechanically anchored headed deformed bars

(c) for swaged splices and mechanically cold swaged headed deformed bar systems

(1) cleanliness requirements

(2) type of equipment and methods used for swaging

(3) required swaging pressure, method of measurement, pressure tolerance, and frequency of calibration of the hydraulic system

(4) method used to verify final alignment and engagement of the coupler on both bars for splices or one bar for mechanically anchored headed deformed bars

(5) bar end preparation

(6) minimum and maximum number of swaging operations per sleeve and mechanically anchored headed deformed bars

(7) method used to ensure sleeve and mechanical anchorage device is swaged along full length

(8) limits of die wear and frequency of checking

(9) for heated sleeves, limits and methods used to measure duration and temperature of heating cycle and temperature of sleeve at time of swaging

(10) method used to ensure that stud is locked to swaged sleeve

(d) for threaded sleeves and mechanically headed deformed bar anchorage devices in thread deformed bar

(1) type of equipment and methods used to verify bar thread acceptability

(2) cleanliness requirements

(3) type of equipment and methods used for torquing

(4) required torque, tolerance on required torque, and method of measurement

(5) method used to verify the final alignment and engagement of the coupler on both bars for splices and for one bar for mechanically anchored headed deformed bars

(6) method used to lock the coupling in position to prevent loosening of the splice or mechanically headed deformed bar

(e) for sleeve with cementitious grout splices

(1) bar end preparation

(2) cleanliness requirements

(3) bar end location tolerances

(4) bar and sleeve centering tolerances

(5) permissible gap between reinforcing bar ends

(6) allowable voidage in the grout

(7) procedures for storing, mixing, placing, and curing the grout

(8) maximum and minimum temperature of the splice system during placement and curing of grout

(9) restriction to prevent relative bar movement during setting and strength development of the grout

(f) for cold roll formed parallel threaded splices and cold roll formed mechanically headed deformed bar systems

(1) type of equipment and methods used to verify bar thread acceptability

(2) cleanliness requirements

(3) type of equipment and methods used for torquing

(4) required torque, tolerance on required torque, and method of measurement

(5) method used to lock the coupling in position to prevent loosening of the splice or mechanical anchorage device (head)

(6) method used to verify the final alignment and engagement of the coupler on both bars for splices and on one bar for mechanically anchored headed deformed bar anchorage devices

CC-4333.4 Initial Qualification Tests. Each installer shall prepare two qualification splices or mechanically headed deformed bar samples on the largest bar size to be used. In addition, for ferrous filler metal systems, cementitious grouted splices, and swaged systems only, each of the splice or mechanical anchorage device positions to be used (e.g., horizontal, vertical, diagonal) shall be qualified. The qualification splice or mechanically headed deformed bar specimens shall be made using reinforcing bar of the same specification and grade as those to be used in construction. The completed qualification splices shall be tensile tested in accordance with the monotonic test method of ASTM A1034/A1034M. The completed mechanically headed deformed bar specimens shall be tensile tested using the loading rate set forth in SA-370. The tensile strength of each sample shall equal or exceed 125% of the specified yield strength as shown in Table CC-4333-1, column titled "Minimum Single Mechanical Splice, Mechanically Headed Deformed Bar, or Welded Joint Tensile Strength."

CC-4333.5 Continuing Splice and Mechanically Headed Deformed Bar Performance Tests.

CC-4333.5.1 Introduction. A continuing series of tests shall be made to ensure that production splices and mechanically headed deformed bars meet the tensile requirements. Nondestructive examination requirements are specified in CC-5320.

CC-4333.5.2 Splice and Mechanically Headed Deformed Bar Samples. Splice and mechanically headed deformed bar samples may be production splices and mechanically headed deformed bars (cut directly from in-place reinforcement) or straight sister splices and mechanically headed deformed bars (removable splices or mechanically headed deformed bar samples made in place next to production splices or mechanically headed deformed bar samples and under the same conditions), in accordance with the schedule established in CC-4333.5.3.

CC-4333.5.3 Testing Frequency. Splice and mechanically headed deformed bar samples shall be tensile tested in accordance with the following schedule for the appropriate splice and mechanically headed deformed bar system.

(a) Separate test cycles shall be established for sleeve and mechanical anchorage device with ferrous filler metal systems, sleeve with cementitious grout splices, and swaged systems in horizontal, vertical, and diagonal bars. Straight sister splices may be substituted for production test samples on radius bent bars and for splicing sleeves arc welded to structural steel elements or the liner.

(1) For sleeve and mechanically headed deformed bar anchorage devices with ferrous filler metal systems, one splice and one mechanically headed deformed bar shall be tested for each unit of 100

Table CC-4333-1
Tensile Requirements for Mechanical Reinforcing Bar Splices, Mechanically Headed Deformed Bars, and Welded Joints (23)

	Reinforcing Bar Properties			Splice, Mechanically Headed Deformed Bar, or Joint Strength Requirements	
Specification	Bar Grade	Minimum Yield Strength, psi (MPa)	Minimum Tensile Strength, psi (MPa)	Minimum Average Mechanical Splice, Mechanically Headed Deformed Bar, or Welded Joint Tensile Strength, psi (MPa) [Note (1)]	Minimum Single Mechanical Splice, Mechanically Headed Deformed Bar, or Welded Joint Tensile Strength, psi (MPa) [Note (2)]
ASTM A615	Grade 40	40,000 (280)	70,000 (480)	70,000 (480)	50,000 (350)
ASTM A615	Grade 60	60,000 (420)	80,000 (550)	80,000 (550)	75,000 (520)
ASTM A706	...	60,000 (420)	80,000 (550)	80,000 (550)	75,000 (520)
ASTM A615	Grade 80	80,000 (550)	100,000 (690)	100,000 (690)	100,000 (690)
ASTM A706	Grade 80	80,000 (550)	100,000 (690)	100,000 (690)	100,000 (690)

NOTES:
(1) See CC-4333 and Mandatory Appendix D2-VIII.
(2) These values are equivalent to 125% of the yield strength of each bar grade.

production splices and mechanically headed deformed bars, as applicable.

(2) For swaged splices, cold swaged mechanically headed deformed bar systems, and sleeve with cementitious grout splices, test cycles shall be established as follows:

(-a) If only production splices and production mechanically headed deformed bars are tested, the sample frequency shall be as follows:

(-1) 1 of the first 10 production splices and 1 of the first 10 mechanically headed deformed bars, as applicable

(-2) 1 of the next 90 production splices and 1 of the next 90 mechanically headed deformed bars, as applicable

(-3) 2 of the next units and each subsequent unit of 100 production splices and 100 mechanically headed deformed bars, as applicable

(-b) If production and sister splices and production and sister mechanically headed deformed bars are tested, the sample frequency shall be as follows:

(-1) 1 production splice and 1 production mechanically headed deformed bar of the first 10 production splices and 10 production mechanically headed deformed bars, as applicable

(-2) 1 production and 3 sister splices and 1 production and 3 sister mechanically headed deformed bars for the next 90 production splices and 90 mechanically headed deformed bars, as applicable

(-3) 3 splices and 3 mechanically headed deformed bars, either production or sister samples, for the next and each subsequent unit of 100 production splices and 100 production mechanically headed deformed bars, as applicable. At least one-fourth of the total number of splices and mechanically headed deformed bar assembles shall be production splices and production mechanically headed deformed bars, as applicable.

(b) For taper threaded systems, cold roll formed parallel threaded systems, and threaded sleeves and mechanical anchorage devices (heads) in thread deformed reinforcing bar. Separate test cycles shall be established for each bar size and grade, using straight sister samples as follows:

(1) 1 of the first 10 splices and 1 of the first 10 mechanically headed deformed bars, as applicable

(2) 1 of the next 90 splices and 1 of the next 90 mechanically headed deformed bars, as applicable

(3) 2 of the next and subsequent units of 100 splices and 100 mechanically headed deformed bars, as applicable

In addition, for taper threaded systems and cold roll formed parallel threaded systems, a minimum of three tests shall be made for each bar heat.

CC-4333.5.4 Tensile Testing Requirements. Splice samples shall be tensile tested in accordance with the monotonic test method of ASTM A1034/A1034M. Mechanically headed deformed bar samples shall be tensile tested using the loading rate set forth in SA-370. All taper threaded and cold roll formed parallel threaded sample splice and mechanically headed deformed bar samples shall be tensile tested at 20°F (−7°C) or less. The tensile tests for taper threaded and cold roll formed parallel threaded splice and mechanically headed deformed bar systems at 20°F (−7°C) or less may be replaced with tensile tests at ambient temperature provided that the tensile strength results of three individual splice and three individual mechanically headed deformed bar sample tensile tests at 20°F (−7°C) or less exceed the specified tensile strength during system qualification test phase per CC-4333.2.3. The following shall constitute the acceptance standards:

(a) The tensile strength of each sample shall equal or exceed 125% of the specified yield strength as shown in Table CC-4333-1.

(b) The moving average tensile strength of 15 consecutive samples shall equal or exceed the specified minimum tensile strength as shown in Table CC-4333-1.

If any sample tested fails to meet the provisions of (a) or (b) above, the requirements of CC-4333.5.5 shall be followed.

CC-4333.5.5 Substandard Tensile Test Results.

(a) If any splice or mechanically headed deformed bar used for testing fails to meet the strength requirement of Table CC-4333-1 and failure occurs in the bar, the cause of the bar break shall be investigated by the Constructor or Fabricator. Any necessary corrective action affecting splice or mechanically headed deformed bar samples shall be implemented prior to continuing the testing frequency of CC-4333.5.3.

(b) If any splice used for testing fails to meet the strength requirement of Table CC-4333-1 and failure does not occur in the bar, two additional splices shall be tested. If any mechanically headed deformed bar used for testing fails to meet the strength requirement of Table CC-4333-1, and failure does not occur in the bar, two additional mechanically headed deformed bar samples shall be tested. If either of these retests fails to meet the strength requirement of Table CC-4333-1, splicing or mechanical anchorage device (head) attachment shall be halted. Splicing or mechanical anchorage device attachment shall not be resumed until the cause of failures has been corrected and resolved.

(c) If the moving average tensile strength of 15 consecutive splice samples fails to meet the tensile requirement of Table CC-4333-1, splicing shall be halted. The Constructor or Fabricator shall investigate the cause and make the necessary corrective action.

(d) If the moving average tensile strength of 15 consecutive mechanically headed deformed bar samples fails to meet the tensile requirement of Table CC-4333-1, head attachment shall be halted. The Constructor or Fabricator shall investigate the cause and make the necessary corrective action.

(e) When splicing or mechanical anchorage device attachment is resumed, the testing frequency shall be started anew.

CC-4333.6 Recording of Tensile Test Results. The results of all tensile tests obtained from the tests prescribed by CC-4333.4 and CC-4333.5, along with all other pertinent data, shall be recorded.

CC-4333.7 Welding. Welding of splice sleeves to parts shall be performed using welding procedures and welders qualified in accordance with AWS D1.1 or Section IX.

CC-4333.8 Impact Requirements. When reinforcing bar or mechanical splices are to be welded to material that requires impact testing, the following shall apply:

(a) The weld filler metal shall be impact tested in accordance with the requirements of the material that the reinforcing bar is attached to.

(b) The acceptance criteria of the material requiring impact testing shall be met.

CC-4334 Arc Welded Joints

Refer to Mandatory Appendix D2-VIII for qualification requirements.

CC-4340 PLACING REINFORCEMENT

CC-4341 General

The placement of reinforcing steel shall comply with the Design and Construction Drawings and the placing tolerances specified in the Construction Specification.

CC-4342 Supports

Reinforcement shall be accurately placed and adequately supported before concrete is placed and shall be secured against displacement beyond permitted tolerances. Welding of crossing bars shall not be permitted.

CC-4343 Tolerances

The tolerances for the placement of reinforcement shall be specified in the Construction Specification.

CC-4350 SPACING OF REINFORCEMENT

CC-4351 Layers

The clear distance between parallel bars in a layer and the clear distance between parallel layers of reinforcement shall not be less than that required by the Construction Specification to properly place and consolidate concrete.

CC-4352 Splices

The clear distance limitation between bars shall also apply to the clear distance between a contact (lap) splice and adjacent splices or bars.

CC-4360 SURFACE CONDITION

(a) Reinforcing bars at the time concrete is placed shall be free from mud, oil, ice, snow, or other coatings that adversely affect bonding.

(b) Reinforcing bars with rust, mill scale, or a combination of both shall be considered satisfactory provided the minimum dimensions, including height of deformations and weight of a hand wire brushed test specimen, are not less than ASTM A615 requirements.

CC-4400 FABRICATION AND INSTALLATION OF PRESTRESSING SYSTEMS

CC-4410 GENERAL

This subarticle covers the requirements for the fabrication, installation, tensioning, and protection of prestressing tendons.

CC-4411 Responsibilities

The Construction Specification shall designate and assign the responsibilities for all post-tensioning activities.

CC-4420 RECEIVING, STORING, AND HANDLING OF MATERIAL

The construction procedures shall specify the manner in which material is to be received, stored, and handled in the Fabricator's plant and at the construction site. The Constructor's, Fabricator's, or Material Organization's Quality Assurance Program shall provide for material identification and segregation in accordance with CC-2152. The handling shall not cause detrimental mechanical damage to the material. The Construction Specification shall establish requirements for storage of all material to ensure that it is protected from detrimental corrosion. Limits of detrimental corrosion shall be specified in the Construction Specification.

CC-4430 TENDON FABRICATION

CC-4431 Anchorage Components

CC-4431.1 Bearing Plate — Trumpet Assembly. All welding shall be performed using welding procedures and welders qualified in accordance with Section IX. The suggested preheat schedules of Nonmandatory Appendix D2-B of this Division shall be taken into account.

CC-4431.2 Anchor Assemblies, Couplings, Wedge Blocks, Shims, Wedges, and Anchor Nuts. The construction procedures shall set forth the manufacturing limits and tolerances applicable to these items.

CC-4432 Tendon Assembly

CC-4432.1 Introduction. The following subparagraphs apply to both shop and field assembly operations.

CC-4432.2 Cutting. The construction procedures shall specify the methods and procedures for cutting and cutting tolerances of prestressing elements.

CC-4432.3 Assembly Procedures. A detailed fabrication procedure, including a checklist of work and information as required by the construction procedures, shall be prepared before tendon fabrication. The checklist information for each tendon shall include traceability data such as heat number or element coil number, anchorage component serial numbers, etc. It shall also include length, location, numerical designations of the tendons, and the temporary corrosion protection of the tendon.

CC-4432.4 Details. Attention shall be given to specific aspects such as dimensions, geometry, concentricity, alignment, angularity, and surface conditions. Limits and tolerances of these aspects shall be specified in the construction procedures.

CC-4432.5 Twisting and Coiling.

(a) Prestressing tendons composed of multiple elements shall be twisted, as necessary, to minimize differential length of the individual prestressing steel elements. Twisting is mandatory for all horizontal circumferential tendons composed of multiple elements stressed simultaneously as a group. The amount of twist shall be specified in the construction procedure. However, intentional twisting of tendons composed of multiple elements stressed simultaneously as a group may be waived for horizontal circumferential tendons as well as other configurations of tendons meeting all other requirements of CC-4430 provided the conditions in (1), (2), and (3) are met or the conditions in (4) are met:

(1) Tendons shall be maximum of 0.63 in. (16 mm) strands (ASTM A416) that are prefabricated and pulled into the duct at one time (complete tendon). All strands shall be the same hand lay.

(2) Provisions shall be made to keep strands in the tendon bundle parallel as the tendon is pulled into the duct.

(3) The uncoiler shall allow individual strands to move against each other as the tendon is pulled in. The tendon shall be pulled from a cage versus being pre-tied and pulled in from a rotating table (lazy susan).

(4) Tendons shall be maximum of 0.63-in. (16-mm) strands (ASTM A416). All strands shall be the same hand lay. After the tendon is installed and prior to performing the conventional full stressing operation, each strand of every tendon shall be stressed individually, at the same time, at the same force (5% to 10% of the specified strand ultimate strength) with independent individual strokes to remove the slack between the strands.

(b) Coiling, when required for transportation, shall be performed in a manner not to cause damage to the tendon. Coil diameter shall be specified in the construction procedures.

CC-4432.6 Corrosion Protection Applied During Fabrication. The type of corrosion protection, the detailed procedure for its application, and the pertinent time limitations shall be specified in the construction procedures.

CC-4440 TENDON IDENTIFICATION

Upon completion of fabrication into a whole or partial tendon, the tendon shall be identified with a tendon number. The materials in the tendon shall be recorded so that they can be traced to the tests that have determined their quality.

CC-4450 TENDON INSTALLATION

CC-4451 Installation Drawings and Stressing Calculations

CC-4451.1 General. Installation drawings for all post-tensioning shall be prepared in accordance with the Construction Specification. Installation drawings shall be approved by the Designer prior to commencing post-tensioning materials installation.

CC-4451.2 Geometry and Components. The Construction Specification shall include drawings that define the tendon duct and anchorage geometry with respect to the concrete outline. Post-tensioning system drawings shall include components required for the tendon installation, both temporary and permanent. They shall include all material composites of all components to be used. They shall show post-tensioning ducts in the final position with required tolerances as approved by the Designer.

CC-4452 Stressing Data

The Construction Specification shall provide tendon stressing data and sequences in table form. It shall indicate single-end or double-end stressing and define stressing sequences that minimize eccentric loads on the containment structure and minimize the chance of crushing adjacent ducts.

CC-4453 Stressing Calculation

The Construction Specification shall require stressing calculations for all tendons and target stressing forces expected along with elongations based on normal prestressing steel properties (area and modulus of elasticity). It shall include provisions for field-adjustments for actual area and E value (modulus of elasticity). Calculations shall include short-term losses due to friction and wobble coefficients. Elongations shall be given to the nearest $\frac{1}{16}$ in. (1.5 mm) and shall include elongations before and after seating.

CC-4454 Installation Procedure

All prestressing steel shall be protected from physical damage and corrosion at all times, as defined by the Construction Specification.

CC-4455 Strand

The Construction Specification shall define the method of assembly and installation of strands. Welding of tendon prestressing steel shall not be permitted. Strands shall be permitted to be brazed together for pulling as described in the Construction Specification.

CC-4460 POST-TENSIONING

Stress tendons only after concrete has attained the specified compressive strength, as determined by cylinder testing or other approved testing method. Stress all prestressing steel with hydraulic jacks of sufficient capacity to the forces shown on the approved installation drawings or as otherwise approved by the Designer. Do not use single-strand jacks to stress tendons.

CC-4461 Supervision

Prestressing operations shall be under the direction of an experienced supervisor and shall be carried out only by trained operators.

CC-4462 Permissible Intervals

Permissible intervals between prestressing steel installation and grouting shall be in accordance with Table CC-4462-1.

CC-4463 Maximum Stress at Jacking

The maximum stress in the prestressing steel at time of stressing shall not exceed $0.80f_{pu}$. Strands stressed past $0.80f_{pu}$ shall either be replaced or specifically approved by the Designer. This maximum stress shall not exceed lower limits that may be specified in the Construction Specification.

CC-4464 Stressing Sequences

Post-tensioning tendons shall be stressed in the sequences indicated in the Construction Specification.

CC-4465 Stressing Jacks and Gauges

Use equipment furnished or approved for use by the Post-Tensioning System (PTS) supplier. Pressure gauges or electronic pressure transducers with digital

Table CC-4462-1
Permissible Intervals Between Prestressing Steel Installation and Grouting Without Use of Corrosion Protection

Humidity	Time
Very damp atmosphere, or over or near salt water (humidity >70%)	7 days
Moderate atmosphere (humidity 40% to 70%)	20 days
Very dry atmosphere (humidity <40%)	30 days

indicators shall indicate the load directly within 1% of the maximum gauge or sensor/indicator capacity or within 2% of the maximum load applied, whichever is smaller.

CC-4466 Calibration of Jacks and Gauges

Calibrate each jack and two gauges as a unit. Separate calibrations shall be performed as defined in the Construction Specification. The PTS supplier, or an independent laboratory, if required by the Construction Specification, shall perform the initial calibration of jacks and gauge(s) and prepare the calibration report(s).

(a) Submit documentation showing the date and result for the most recent calibration, together with traceability to a national standards institute.

(b) Provide certified calibration reports prior to the start of stressing and every 6 months as required by the Construction Specification.

CC-4467 Elongation and Agreement With Forces

During tendon stressing, the forces applied to the tendon and the elongation of the tendon shall be measured and recorded.

CC-4467.1 Procedure. All tendons shall be stressed to the corresponding forces shown on the approved installation drawing(s). The Construction Specification shall contain procedures for achieving the required elongation. Do not stress tendons by matching the theoretical elongations. Tendon elongations shall be read and recorded to the nearest $^1/_{16}$ in. (1.5 mm). The true elongations, free of all system effects, shall fall within 7% of the theoretical elongations shown on the approved installation drawings, modified if necessary, for the actual modulus of elasticity and prestressing steel areas shown on the prestressing CMTRs.

(a) Where strands in a tendon are stressed individually, the average strand elongation shall be computed and compared to the theoretical elongation.

(b) If actual elongations fall outside the allowable range, the entire operation shall be checked, and the source of error determined and remedied before proceeding further. Do not exceed the specified jacking force to achieve theoretical elongations.

(c) Deviations of calculated versus measured elongations shall be corrected or compensated for in a manner proposed by the Contractor in consultation with the PTS supplier and as reviewed and approved by the Designer.

CC-4467.2 Data Acquisition. The Construction Specification shall require that a data acquisition system be employed for automatic collection of tendon forces and elongation data during stressing. The system shall record all stressing parameters required by the Construction Specification.

CC-4468 Wire Failures in Strand Tendons

Multistrand post-tensioning tendons with wire failures by breaking or slippage shall be evaluated for acceptance by the PTS supplier and submitted to the Designer for approval.

CC-4469 Cutting of Post-Tensioning of Steel

The procedure for cutting of post-tensioning (PT) steel shall be defined in the Construction Specification.

CC-4470 RECORD OF STRESSING OPERATIONS

Maintain a record of each tendon installed and submit daily to the Designer for review. At a minimum, record the following information:

(a) project name and ID
(b) contractor and/or subcontractor
(c) approved PT installation drawing date and revision number
(d) tendon location, size, and type
(e) date tendon installed in duct
(f) reel number(s) for strands and heat number for bars
(g) actual tendon cross-sectional area, based on mill certificates
(h) actual modulus of elasticity, based on mill certificates
(i) date stressed
(j) stressing operator(s) name
(k) jack and gauge numbers for each stressing end
(l) required jacking force
(m) target and actual gauge pressures
(n) elongations (theoretical and actual)
(o) anchor sets (anticipated and actual)
(p) stressing mode (one end/two ends/simultaneous)
(q) witnesses to stressing operation (contractor and inspector)
(r) stressing sequence (i.e., identify tendon stressed before and after)
(s) daily temperature and relative humidity
(t) use of temporary corrosion inhibitor, if applicable

CC-4480 PROTECTION OF POST-TENSIONING ANCHORAGES AND PRESTRESSING STEEL

CC-4481 Protection Requirements

(a) Install permanent grout caps and seal all other tendon openings within 1 day following cutting of strand tails unless specified otherwise.

(b) Within 7 days of completion of grouting, initiate protection of the anchorages of post-tension bars and tendons as required by the Construction Specification.

(c) Construct pourbacks located at the anchorage pockets and blockouts in accordance with the Construction Specification. Use an approved epoxy grout.

(d) If the tendon is not stressed and grouted within the time limits of Table CC-4462-1, CC-2438.2 shall apply. Flushing tendons or ducts with water is not permitted at any time.

(e) The Construction Specification shall specify the permanent corrosion protection system, if any, and the construction procedures shall define the method for its application. Material shall conform to the requirements of CC-2438.

CC-4500 FABRICATION OF LINERS

CC-4510 GENERAL REQUIREMENTS

CC-4511 Introduction

(a) The rules in the following paragraphs apply specifically to the fabrication and construction of metal liners.

(b) Each Fabricator or Constructor shall be responsible for the quality of the welding done by his organization and he shall conduct tests not only of the welding procedure to determine its suitability to ensure welds will meet the required tests, but also of the welders and welding operators to determine their ability to apply the procedure properly.

(c) No production work shall be undertaken until both the welding procedure and the welders or welding operators have been qualified in accordance with Section IX.

CC-4512 Elimination and Repair of Defects

Defects in materials may be eliminated or repaired by the Constructor or Fabricator by welding provided the defects are removed, repaired, and examined in accordance with the requirements of CC-2530 for the applicable product form.

CC-4520 FORMING, FITTING, AND ALIGNING

CC-4521 Cutting, Forming, and Bending

CC-4521.1 Cutting. Liner material, edges of heads, and other parts may be cut to shape and size by mechanical means, such as machining, shearing, grinding, or by oxygen or arc cutting. After oxygen cutting, all slag, dross, or other foreign material shall be removed by mechanical means prior to further fabrication or use.

CC-4521.1.1 Preheating Prior to 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 Nonmandatory Appendix D2-B.

CC-4521.2 Forming and Bending Processes. Any process may be used to hot or cold form or bend liner plate materials, including weld metal, provided the notch toughness properties of the materials, where 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 (38°C) below the lower critical temperature of the material.

CC-4521.2.1 Required Postweld Heat Treatment. Cold-formed shell sections and heads of P-No. 1 materials shall be postweld heat treated when the resulting maximum extreme fiber elongation is more than 5%.

CC-4521.3 Qualifications of Forming and Bending Processes. A procedure qualification test shall be conducted on specimens taken from coupons of the same material specification, grade or class, heat treatment, and similar impact requirements as employed for the material of the component involved. These coupons shall be subjected to the equivalent forming or bending process and heat treatment as the material of the component involved. Applicable tests shall be conducted to determine that the required impact properties are met after straining.

CC-4521.3.1 Exemptions. Procedure qualification tests are not required for the following:

(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 that have been subjected to heat treatment representing the hot-forming procedure and the heat treatments to be applied to the parts

(c) material that does not require impact testing in accordance with CC-2500

(d) material that has a final strain after forming of less than 0.5%

(e) material where the final strain is less than that of a previously qualified procedure for the material

(f) material from which the impact testing is required by CC-2522 to be performed on each heat and lot, as applicable, after forming

CC-4521.3.2 Procedure Qualification Test. The procedure qualification test shall be performed in the following manner:

(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 this Division and shall be taken from the tension side of the strained material.

(c) The percent strain shall be established by the following equations:

(1) for cylinders

$$\%\ \text{strain} = \frac{50t}{R_f}\left(1 - \frac{R_f}{R_o}\right)$$

(2) for spherical or dished surfaces

$$\%\ \text{strain} = \frac{75t}{R_f}\left(1 - \frac{R_f}{R_o}\right)$$

(3) for pipe

$$\%\ \text{strain} = \frac{100r}{R}$$

where

R = nominal bending radius to the center line of the pipe
r = nominal radius of the pipe
R_f = final radius to center line of shell
R_o = original radius (equal to infinity for a flat part)
t = nominal thickness

(d) The procedure qualification shall simulate the maximum percent surface strain employing a bending process similar to that used in the fabrication of the material or by direct tension on the specimen.

(e) Sufficient Charpy V-notch impact test specimens shall be taken from each of the three heats of material to establish a transition curve showing both the upper and lower shelves. Tests consisting of three impact specimens taken from each of three heats shall be conducted at a minimum of five different temperature distributions throughout the transition range. The upper and lower shelves may be established by the use of individual test specimens. As an alternative to the transition curve, drop weight tests may be used, or one set of Charpy V-notch impact test specimens tested after forming at the specified temperature may be used if performed on each heat or lot, as applicable, of formed material.

(f) From the impact test transition curves or drop weight tests from each of the three heats, both before and after straining, determine either:

(1) the maximum change in temperature considering various energy levels when transition curves are used, or the change in nil-ductility transition (NDT) temperature as determined by the drop weight tests; or

(2) the maximum loss of impact energy for the material considering each temperature increment of 10°F (6°C).

CC-4521.3.3 Acceptance Standards. To be acceptable, the material used in the liner must have impact properties sufficient to compensate for the maximum change in temperature or energy levels established by the qualification procedures for all material subjected to the equivalent strain used in the liner.

CC-4521.3.4 Requalification. A new procedure qualification test is required when any of the following changes are made:

(a) where the postweld heat treatment time at temperature is greater than previously qualified. (If the material is not postweld heat treated, the procedure must qualify without postweld heat treatment.)

(b) where 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.

CC-4521.4 Minimum Thickness of Fabricated Material. If any fabrication operation reduces the thickness below the minimum required to satisfy the rules of Article CC-3000, the material may be repaired in accordance with CC-2530.

CC-4522 Forming Tolerances

CC-4522.1 Tolerances for Liner Shells and Heads. The following subarticles define the requirements for liner tolerances. The Construction Specification shall state any additional requirements. A guide for dimensional tolerances for liners is provided in Nonmandatory Appendix D2-D.

CC-4522.1.1 Tolerances for Liner Shells. At the specified increments of elevation, the difference between the maximum diameter and the minimum shall not exceed $\frac{1}{2}$ of 1%. This requirement will be satisfied by measuring diameters spaced approximately 30 deg (0.52 rad) apart for each 12 ft (3.7 m) of height. The overall containment plumbness of the liner cylinder between the springline (start of dome) and the bottom shall be 1 in 200 based on the total height of the cylinder.

CC-4522.1.2 Tolerance for Liner Heads. The inner surface of the liner head shall not deviate from the specified shape by more than $1\frac{1}{4}$% of the inside diameter of the liner shell.

CC-4522.2 Localized Thin Areas. Forgings are permitted to have small areas thinner than required if the adjacent areas surrounding each has sufficient thickness to provide the necessary reinforcement.

CC-4522.3 Tolerance Deviations for Liner Parts Fabricated From Pipe. Liner parts fabricated from pipe meeting all other requirements of this subarticle may have variations of diameter and deviations from circularity permitted by the material specification for such pipe.

CC-4523 Fitting and Aligning

CC-4523.1 Fitting and Aligning Methods. Parts that are to be joined by welding may be fitted, aligned, and retained in position during the welding operation by the use of bars, jacks, clamps, tack welds, or temporary attachments.

Table CC-4523-1
Maximum Allowable Offset in Final Welded Joints

Section Thickness, in. (mm)	Offset
Up to $^3\!/\!_4$ (19), incl.	$^1\!/\!_4t$
Over $^3\!/\!_4$ to $1^1\!/\!_2$ (19 to 38), incl.	$^3\!/\!_{16}$ in. (5 mm)
Over $1^1\!/\!_2$ (38)	$^1\!/\!_8t$ to $^1\!/\!_4$ in. (6 mm) max.

CC-4523.1.1 Tack Welds. Tack welds shall be made by qualified welders using qualified welding procedures. Tack welds used to secure alignment shall either be removed completely when they have served their purpose; or when the tack welds are to become part of the finished weld, their stopping and starting ends shall be properly prepared by grinding or other suitable means so that they may be satisfactorily incorporated into the finished weld.

CC-4523.2 Maximum Offset of Aligned Sections.

(a) Alignment of sections shall be such that the maximum offset of the finished weld will not be greater than the applicable amount listed in Table CC-4523-1, where t is the nominal thickness of the thinner section of the joint.

(b) Joints in spherical liners and within heads and joints between cylindrical shells and hemispherical heads shall meet the requirements of Table CC-4523-1.

CC-4523.2.1 Fairing of Offsets. Any offset within the allowable tolerance provided above shall be faired to at least a three to one taper over the width of the finished weld or, if necessary, by adding additional weld metal beyond what would otherwise be the edge of the weld.

CC-4523.3 Support During Concreting. The liner shall be adequately supported, braced, and tied to prevent displacement beyond the tolerances set forth in CC-4522.

CC-4530 WELDING QUALIFICATIONS

CC-4531 General Requirements

CC-4531.1 Types of Processes Permitted. Only those welding processes that are capable of producing welds in accordance with the welding procedure qualification requirements of Section IX and this Division may be used for welding liners or attachments thereto, except as otherwise permitted by CC-4333.7. Any process used shall be such that the records required by CC-4532.2 can be made.

CC-4531.1.1 Capacitor Discharge Welding. The capacitor discharge method of welding may be used for temporary attachments directly to the liner, provided any surface defects found upon removal are eliminated in accordance with CC-4545.2.

CC-4531.1.2 Low Energy Capacitor Discharge Welding. The low energy capacitor discharge method of welding may be used for permanent nonstructural attachments such as strain gages and thermocouples, provided

(a) the power output is limited to less than 125 W/sec

(b) a Welding Procedure Specification describing the capacitor discharge equipment, the combination of materials to be joined, and the techniques of application is prepared; qualification of the welding procedure is not required

(c) the minimum thickness of the material to which the attachment is made exceeds $^3\!/\!_{32}$ in. (2.5 mm)

CC-4532 Welding Qualifications, Records, and Identifying Stamp

CC-4532.1 Required Qualifications.

(a) Each Fabricator or Constructor is responsible for the welding done by his organization and he shall establish procedures and conduct the tests required by this subarticle and by Section IX in order to qualify both the welding procedures and the performance of welders and welding operators who apply these procedures.

(b) Procedures, welders, and welding operators used to join permanent or temporary attachments to liners and to make permanent or temporary tack welds used in such welding shall also meet the qualification requirements of this subarticle.

(c) When making procedure test plates for butt welds, it is recommended that consideration be given to the effect of angular, lateral, and end restraint on the weldment. The addition of restraint during welding may result in cracking difficulties that otherwise might not occur.

CC-4532.2 Maintenance and Certification of Records. The Fabricator or Constructor shall maintain a record of his qualified welding procedures and of the welders and welding operators qualified and employed by him, showing the date and results of tests and the identification mark assigned to each welder. These records shall be reviewed, verified, and signed by any authorized individual assigned by the Fabricator or Constructor and shall be accessible to the Owner or his agent and to the Authorized Inspector.

CC-4532.2.1 Identification of Joints by Welder or Welding Operator. The welder or welding operator making permanent welded joints shall be identified by one of the following methods:

(a) The welder or welding operator making a joint shall apply the identification mark assigned by the Fabricator or Constructor on or adjacent to all permanent welded joints. The marking shall be at intervals of 3 ft (1 m) or less and shall be done with either blunt nose continuous or blunt nose interrupted dot die stamps.

(b) The Fabricator or Constructor shall keep a record of permanent welded joints in a component and of the welders and welding operators making each joint.

(c) When a multiple number of permanent welded joints are made, the Fabricator or Constructor need not maintain a record to identify the welder or welding operator who welded each individual joint provided

(1) the Fabricator or Constructor maintains a system that will identify the welders or welding operators who made such welds so that the Inspector can verify that the welders or welding operators were properly qualified

(2) the welds in each category are all of the same type and configuration and are welded using the same welding procedure specification

(d) The identification of welders or welding operators making tack welds that become part of a permanent weld is not required provided the Fabricator or Constructor maintain a system to permit the Inspector to verify that such tack welds were made by qualified welders or welding operators.

(e) The identification of welders or welding operators is not required for attachment welds provided the Fabricator or Constructor maintains a system to permit the Inspector to verify that all such attachment welds were made by qualified welders or welding operators.

CC-4532.3 Welding Prior to Qualifications. No welding shall be started until after the welding procedures that are to be used have been qualified. All welders and welding operators shall be qualified in accordance with CC-4534 and Section IX.

CC-4532.4 Transferring Qualifications. The performance qualification tests for welders and welding operators conducted by one Fabricator or Constructor shall not qualify welders or welding operators to weld for any other Fabricator or Constructor.

CC-4533 General Requirements for Welding Procedure Qualification Tests

CC-4533.1 Conformance to Section IX Requirements. All welding procedure qualification tests, including stud welding, shall be in accordance with the requirements of Section IX as supplemented by the requirements of this Article.

CC-4533.2 Base Material to Be Employed. Welding procedure qualifications for materials that have specified impact test requirements shall be made using base materials in accordance with the applicable requirements of Section IX, QW-403.4 and QW-403.5.

CC-4533.3 Heat Treatment of Qualification Welds for Ferritic Materials. Postweld heat treatment of procedure qualification welds shall conform to the applicable requirements of CC-4550 and Section IX. The postweld heat treatment time at temperature shall be at least 80% of the maximum time to be applied to the weld material. The postweld heat treatment total time may be applied in one heating cycle.

CC-4533.4 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 the removal of impact test coupons and the dimensions of impact test specimens shall be in accordance with CC-4533.4.1, CC-4533.4.2, and (b) below.

(b) Weld deposit of each process in a multiple process weld shall, where possible, be included in the impact test specimens. When each process cannot be included in the full-size impact test specimen at the $\frac{1}{4}t$ location required by this Section, additional full-size specimens shall be obtained from locations in the test weld that will assure 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.

CC-4533.4.1 Coupons Representing the Weld Deposits. Impact test specimens and testing shall conform to the applicable requirements of CC-2522.1. 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 CC-4552 and the test assembly is cooled at an accelerated rate, the longitudinal axis of the specimen shall be a minimum of t from the edge of the test assembly. The specimen shall be transverse to the longitudinal axis of the weld with the area of the notch located in the weld. The length of the notch of the Charpy V-notch specimen shall be normal to the surface of the weld. Where drop weight specimens are required, the tension surface of the specimen shall be oriented parallel to the surface of the test weld assembly.

CC-4533.4.2 Coupons Representing the Heat-Affected Zone. Where impact tests of the heat-affected zone are required by CC-4533.5.2, specimens shall be taken from the welding procedure qualification test assemblies in accordance with (a) through (c) below.

(a) If the qualification test material is in the form of a plate or a forging, the axis of the weld shall be oriented either parallel to or perpendicular to the principal direction of rolling or forging.

(b) The heat-affected zone impact test specimens and testing methods shall conform to the requirements of CC-2522.1.2. The specimens shall be removed from a location as near as practical to a depth midway between the surface and center thicknesses. 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 CC-4533.5.2(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) **CC-4533.5 Impact Test Requirements.** Impact tests of the weld metal and the heat-affected zone are required when impact tests are required for either of the base materials being joined (see CC-2521). Exemption from impact testing under CC-2521.1(h) does not apply to weld metal. Exemption from impact testing of the heat-affected zone of those base materials exempted by CC-2521.1(h) is not permitted. The welding procedure qualification impact test specimens shall be prepared and tested in accordance with the applicable requirements of CC-2524 and CC-4533.4. Acceptance standards and exceptions to test requirements shall be in accordance with the following subparagraphs. Retests in accordance with the provisions of CC-2527 are permitted.

(23) **CC-4533.5.1 Impact Tests of Weld Metal.**

(a) Impact tests of the weld metal shall be required for welding procedure qualification tests for production weld joints exceeding $^5/_8$ in. (16 mm) in thickness when the weld will be made on the surface or will penetrate the base material that requires impact testing in accordance with CC-2521. 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 CC-2521, regardless of the depth of the repair. Exemption from impact testing under CC-2521.1(h) does not apply for weld metal of welding procedure qualification tests 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 CC-2524 for the base material to be welded or repaired. When two materials having 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-2143 or other parts of this Section.

(c) Impact tests are not required for austenitic weld metal.

(d) A Welding Procedure Specification qualified to the impact testing requirements of Subsection NB, Subsection NCD (Class 2 only), or Subsection NE may be accepted as an alternative to the Welding Procedure Specification impact testing requirements of this Subsection.

CC-4533.5.2 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 the base materials require impact testing in accordance with the rules of CC-2521. Exemption of base materials by CC-2521.1(h) does not apply to the welding procedure qualification heat-affected zone or unaffected base material for such materials. The only exceptions to the requirements are the following:

(1) the qualification for welds in P-No. 1 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 on any base material

(b) Impact testing of the procedure qualification test heat-affected zone, where required by CC-4533.5.2, shall be conducted in accordance with (1) through (3), or (4) through (6) and (c), if applicable.

(1) For tests of welding procedure qualifications for materials that require tests in accordance with CC-2524.2.1 and CC-2524.4.1, when applicable, three Charpy V-notch heat-affected zone specimens and three Charpy V-notch unaffected base material specimens shall be tested at a temperature in accordance with CC-2524.1(a)(1). The Charpy V-notch test of the unaffected base material shall meet the requirements of Table CC-2524.2-1 or Table CC-2524.2-2, and Table CC-2524.4-1, if applicable. If the average toughness value of the three heat-affected zone specimens is equal to or greater than the average value of the unaffected base material Charpy V-notch specimen, the qualification test shall be considered acceptable and the values and testing temperature shall be recorded on the Welding Procedure Qualification Record. The production base material impact tests may be conducted at temperatures in accordance with CC-2524.1.

(2) If the heat-affected zone Charpy V-notch average toughness value of (1) above is less than the unaffected base material value, and the qualification test meets the other criteria of acceptance, the Charpy V-notch test results may be recorded on the Welding Procedure Qualification Record. In this case, either production base material impact tests shall be conducted 30°F (17°C) lower than required by CC-2524.1; or data that will provide a testing temperature reduction for the production base material

below that of CC-2524.1, or an increase in the permissible lowest service metal temperature for the base material for which the welding procedure is being qualified, shall be obtained in accordance with (3) below and included. Alternatively, the welding procedure qualification may be rewelded and retested.

(3) The data for use in (2) above shall be developed by performing additional Charpy V-notch tests on either or both of the welding procedure qualification test heat-affected zone and the unaffected base material at temperatures that provide toughness values that meet or exceed those required for the thickness or thickness–strength combination of the material to be welded in production. The average toughness values for the heat-affected zone and unaffected base material shall be plotted on a property–temperature chart. The temperature at which these two sets of data exhibit a common acceptable value of toughness for the production thickness or thickness–strength combination involved shall be determined. The determined temperature for the unaffected base material shall be subtracted from the similarly determined temperature for the heat-affected zone. This difference, if a positive number, shall be used in (2) above as the adjustment temperature. The welding procedure adjustment temperature shall be added to the highest lowest service metal temperature (LSMT) established by the tests of CC-2524.2.1 for all of the base material to be welded by this procedure in production. If the temperature difference is zero or a negative number, no adjustment is required for the base material to be welded in production, and the minimum temperature established by the tests for CC-2524.2.1 will still apply as stated in (1) above. Where the actual lowest service metal temperature is not required for the production material to be welded (for example, where a testing temperature is established by the Design Specification to determine that the material has adequate toughness to meet the requirements at the specified test temperature) the adjustment temperature determined by the curve shall be used to establish a reduction in the specified testing temperature for the production material. The adjustment temperature shall be used to lower the specified testing temperature for any production material upon which the procedure will be used.

(4) For tests of welding procedure qualifications for materials that require tests in accordance with CC-2524.2.2, three Charpy V-notch heat-affected zone specimens and three Charpy V-notch unaffected base material specimens shall be tested at a temperature lower than or equal to the lowest service metal temperature. The Charpy V-notch impact tests of the unaffected base material shall each meet or exceed the applicable over $2\frac{1}{2}$ in. (64 mm) thickness requirements of Table CC-2524.2-1 or Table CC-2524.2-2, and Table CC-2524.4-1, if applicable. If the average toughness value of the three heat-affected zone specimens is equal to or greater than the average value for the unaffected base material Charpy V-notch specimens, the qualification test shall be considered acceptable. The values and testing temperature shall be recorded on the Welding Procedure Qualification Record.

(5) If the heat-affected zone Charpy V-notch average toughness value of (4) above is less than the unaffected base material value, and the qualification test meets the other criteria of acceptance, the Charpy V-notch test results may be recorded on the Welding Procedure Qualification Record. In this case, either production base material impact tests shall be conducted 30°F (17°C) lower than required by CC-2524.1; or data that will provide a testing temperature reduction for the production base material below that of CC-2524.1, or an increase in the permissible lowest service metal temperature for the base material for which the welding procedure is being qualified, shall be obtained in accordance with (6) below and included. Alternatively, the welding procedure qualification may be rewelded and retested.

(6) The data for use in (5) above shall be developed by performing additional Charpy V-notch tests on either or both of the welding procedure qualification heat-affected zone or unaffected base material at temperatures which provide values equal to or greater than the applicable Over $2\frac{1}{2}$ in. (64 mm) thickness requirements of Table CC-2524.2-1 or Table CC-2524.2-2, and Table CC-2524.4-1, if applicable. The average toughness values for the heat-affected zone and the unaffected base material shall be plotted on a property–temperature chart. The temperature at which these two sets of data exhibit a common toughness value equal to or greater than the applicable Over $2\frac{1}{2}$ in. (64 mm) thickness requirements of Table CC-2524.2-1 or Table CC-2524.2-2, and Table CC-2524.4-1, if applicable, shall be determined. The determined temperature for the unaffected base material shall be subtracted from the similarly determined temperature for the heat-affected zone. This difference, if a positive number, shall be used in (5) above as the adjustment temperature. The adjustment temperature shall be added to the highest T_{NDT} established by the tests of CC-2524.2.2 for all of the base material to be welded by this procedure in production. If the temperature difference is zero or a negative number, no adjustment is required for the base material to be welded in production, and the minimum temperature established by the tests for CC-2524.2.2 will still apply as stated in (4) above. Where the actual T_{NDT} is not required for the production material to be welded (for example, where a testing temperature is established by the Design Specification to determine that the T_{NDT} is at or below the specified temperature) the adjustment temperature determined by the curves shall be used to establish a reduction in the specified testing temperature for the production material. The adjustment temperature shall be used to lower the specified testing temperature

for any production material upon which the procedure will be used.

(c) Should the unaffected base material Charpy V-notch impact test results fail to meet the applicable requirements referenced in (b)(1) or (b)(4) above, additional unaffected base material Charpy V-notch impact tests shall be tested at higher temperatures until the applicable requirements are met. Charpy V-notch impact tests of the heat-affected zone shall be tested at the same temperature at which acceptable unaffected base material properties were achieved. The rules governing the average toughness of the heat-affected zone relative to the average toughness of the unaffected base material shall be followed as in (b)(1) through (b)(3) or (b)(4) through (b)(6) above, as applicable, to determine the data to be recorded on the Welding Procedure Qualification Record.

(d) A Welding Procedure Specification qualified to the impact testing requirements of Subsection NB, NC, or NE may be accepted as an alternative to the Welding Procedure Specification impact testing requirements of this Subsection.

CC-4533.6 Qualification Requirements for Built-Up Weld Deposits. Built-up weld deposits for base metal compensation shall be qualified in accordance with the requirements of CC-4533.1 through CC-4533.5, inclusive.

Table CC-4534-1
Required Torque for Testing Studs

Nominal Stud Diameter, in. (mm)	Thread/in. and Series Designated	Testing Torque, ft-lb (N·m)
1/4 (6)	28 UNF	5.0 (6.8)
1/4 (6)	20 UNC	4.2 (5.7)
5/16 (8)	24 UNF	9.5 (12.9)
5/16 (8)	18 UNC	8.6 (11.7)
3/8 (10)	24 UNF	17.0 (23.0)
3/8 (10)	10 UNC	15.0 (20.3)
7/16 (11)	20 UNF	27.0 (36.6)
7/16 (11)	14 UNC	24.0 (32.5)
1/2 (13)	20 UNF	42.0 (56.9)
1/2 (13)	13 UNC	37.0 (50.2)
9/16 (14)	18 UNF	60.0 (81.3)
9/16 (14)	12 UNC	54.0 (73.2)
5/8 (16)	18 UNF	84.0 (113.9)
5/8 (16)	11 UNC	74.0 (100.3)
3/4 (19)	10 UNF	147.0 (199.3)
3/4 (19)	10 UNC	132.0 (179.0)
7/8 (22)	14 UNF	234.0 (317.3)
7/8 (22)	9 UNC	212.0 (287.4)
1 (28)	12 UNF	348.0 (471.8)
1 (28)	18 UNC	218.0 (295.6)

CC-4534 Continuing Performance Test for Stud Welding

(a) For each operator, one stud in every 100 production studs shall be tested as follows:

(1) Unthreaded Studs. The test studs shall be tested by bending to an angle of 15 deg by striking with a hammer. The test studs may be welded to a plate attached to the liner adjacent to a stud from the lot under consideration. The plate shall be of the same type and thickness as the liner with dimensions equal to at least four times the diameter of the stud. The temporarily attached plate shall be adequately supported during testing so as to develop the 15 deg bend in the stud.

(2) Threaded Studs. The test studs shall be torque tested with a calibrated torque wrench to the value shown in Table CC-4534-1 for the corresponding diameter and thread of the stud in a device similar to that shown in Figure CC-4534-1.

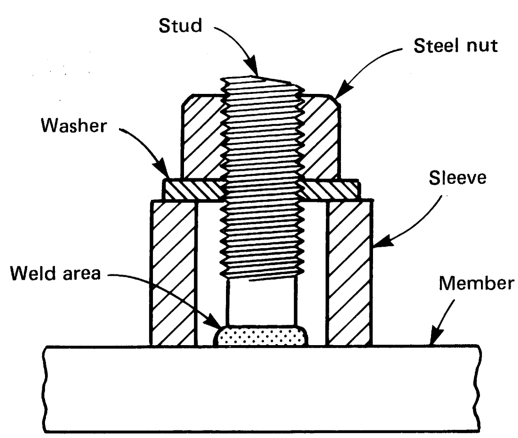
(b) If the studs fail, two more of the existing studs from 100 shall be bent or torque tested. If either of these two studs fails, all of the studs represented by the tests shall be torque tested, bend tested, or rejected.

CC-4540 RULES GOVERNING MAKING, EXAMINING, AND REPAIRING WELDS

CC-4541 Precautions to Be Taken Before Welding

CC-4541.1 Identification, Storage, and Handling of Welding Materials. The Fabricator or Constructor is responsible for control of the welding electrodes and other materials that are used in the fabrication and installation of components (see CC-4120). Suitable

Figure CC-4534-1
Typical Torque Testing Device



GENERAL NOTES:
(a) Dimensions are appropriate to the size of the stud.
(b) Threads of the stud shall be clean and free of lubricant other than residual cutting oil.

identification, storage, and handling of electrodes, flux, and other welding materials shall be maintained. Precautions shall be taken to minimize absorption of moisture by electrodes and flux.

CC-4541.2 Cleanliness and Protection of Welding Surfaces. The method used to prepare the base metal shall leave the weld preparation with reasonably smooth surfaces. The surfaces for welding shall be free of scale, rust, oil, grease, and other deleterious material. The work shall be protected from deleterious contamination and from rain, snow, and wind during welding. Welding shall not be performed on wet surfaces.

CC-4542 Rules for Making Welded Joints

CC-4542.1 Category A and B Joints.

(a) All welded joints of Category A and B shall be full penetration butt joints. The joints may be single or double welded.

(b) Backup bars, if used, shall be continuous and any joints in the backup bars shall be made with full penetration welds. When structural shapes are used as backups, these requirements shall apply.

CC-4542.2 Other Category Joints. Welded joints of Categories D, E, F, G, H, and J shall be single or double welded. Backup bars are permitted except when the weld is to be radiographed. Backup bars, when allowed, shall be continuous and any joints in the backup bars shall be made with full penetration welds. When structural shapes are used as backups, these requirements shall apply. See Figures CC-4542.2-1 through CC-4542.2-7 for typical joint details.

CC-4542.3 Double-Welded Joints. Before applying weld metal on the second side to be welded, the root of 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.

CC-4542.4 Single-Welded Joints. Where single-welded joints are used, particular care shall be taken in aligning and separating the components to be joined so that there will be complete penetration and fusion at the bottom of the joint for its full length.

CC-4542.5 Surfaces of Welds. The surface of welds shall be free from coarse ripples or grooves, overlaps, and abrupt ridges or valleys. Abrupt changes in section thickness, such as undercuts which do not exceed $^1/_{32}$ in. (0.8 mm) for liner plate $^1/_4$ in. (6 mm) nominal thickness and greater, are permitted. The surface condition of the finished weld shall be suitable for the proper interpretation of nondestructive examinations of the weld. If the surface of the weld requires grinding, care shall be taken to avoid reducing the weld or base material below the required thickness.

CC-4542.6 Welding Components of Different Thicknesses. When materials or parts of different thicknesses are welded together, there shall be a gradual transition between the two surfaces. The length of the transition may include the weld. The slope of the transition shall be such that the length–offset ratio shall not be less than 3:1.

CC-4542.7 Peening. Controlled peening may be performed to minimize distortion. Peening shall not be used on the initial layer (root) of the weld nor on the final layer unless the weld is postweld heat treated.

CC-4542.8 Reinforcement of Welds.

CC-4542.8.1 Finished Surfaces of Welds and Thickness of Weld Reinforcement. Welds which are to be radiographed shall be prepared as follows:

(a) The weld ripples or weld surface irregularities on both the inside and outside shall be removed by any suitable mechanical process to such a degree that the resulting radiographic image, due to any irregularities, cannot mask or be confused with the image of any unacceptable discontinuity.

(b) The finished surface of the reinforcement of all butt-welded joints may be flush with the base material or may have reasonably uniform crowns, the maximum on each side not to exceed the thicknesses of Table CC-4542.8.1-1.

CC-4542.9 Fillet Welds. Fillet welds may vary from convex to concave. The size of the weld shall be determined in accordance with Figure CC-4542.9-1.

CC-4543 Welding of Attachments

CC-4543.1 Material for Permanent Structural Attachments. Material for lugs, brackets, stiffeners, and other permanent structural attachments that are permanently welded to liners shall meet the requirements of liner material (see CC-2500 except CC-2530). If the welds are exempt from postweld heat treatment (see CC-4552), the attachments shall meet the fracture toughness requirements of CC-2520 if required by CC-2521.1.

CC-4543.2 Welding of Permanent Structural Attachments. The rules of CC-4532.1 governing welding qualifications shall apply to the welding of both internal and external permanent structural attachments to liner material. Welds shall meet the postweld heat treatment requirements of CC-4552.

CC-4543.3 Lugs and Fitting Attachments. All lugs, brackets, saddle type nozzles, manhole frames, reinforcement around openings, and other appurtenances shall conform reasonably to the curvature of the shell or surface to which they are attached.

Figure CC-4542.2-1
Typical Category D Joints for Nozzle Diameters Over NPS 3 (DN 80)

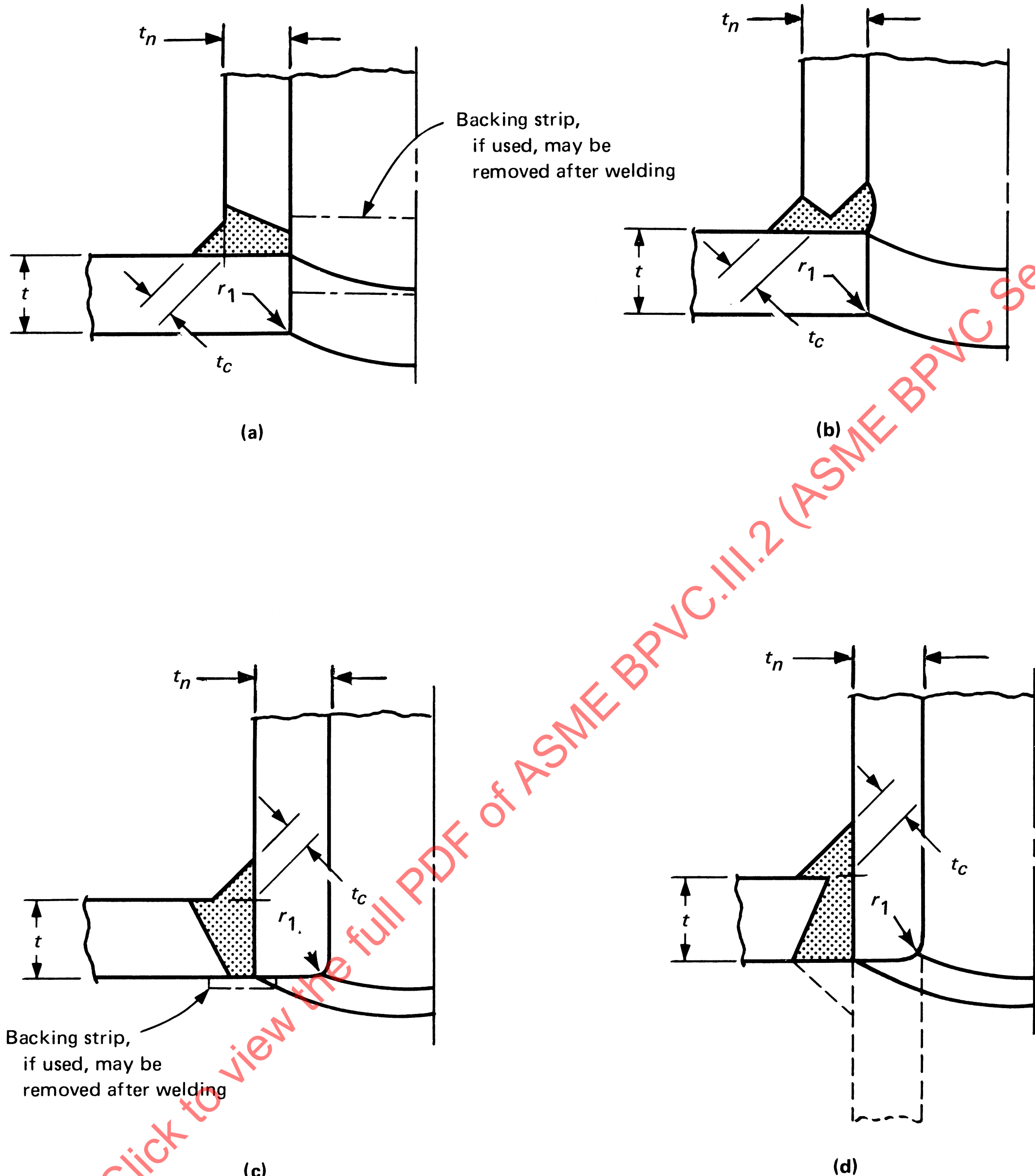
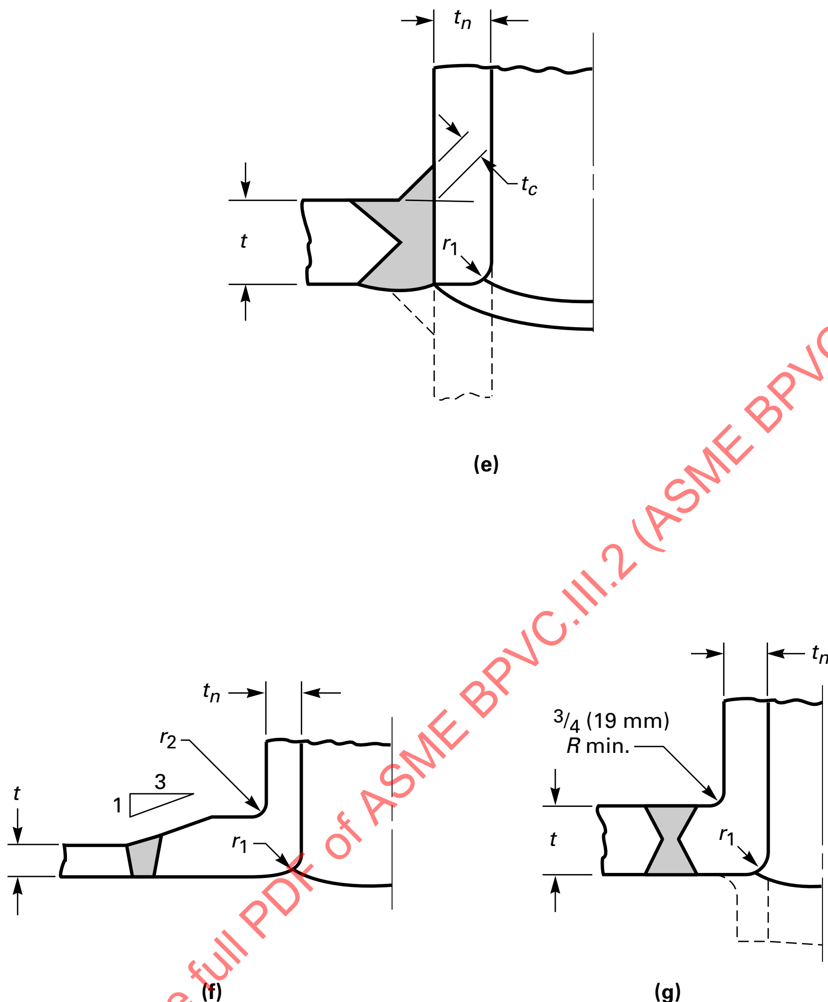


Figure CC-4542.2-1
Typical Category D Joints for Nozzle Diameters Over NPS 3 (DN 80) (Cont'd)



GENERAL NOTE: For definition of symbols, see CC-3842.10.

Figure CC-4542.2-2
Typical Category D Joints for Nozzle Diameters NPS 3 (DN 80) and Less

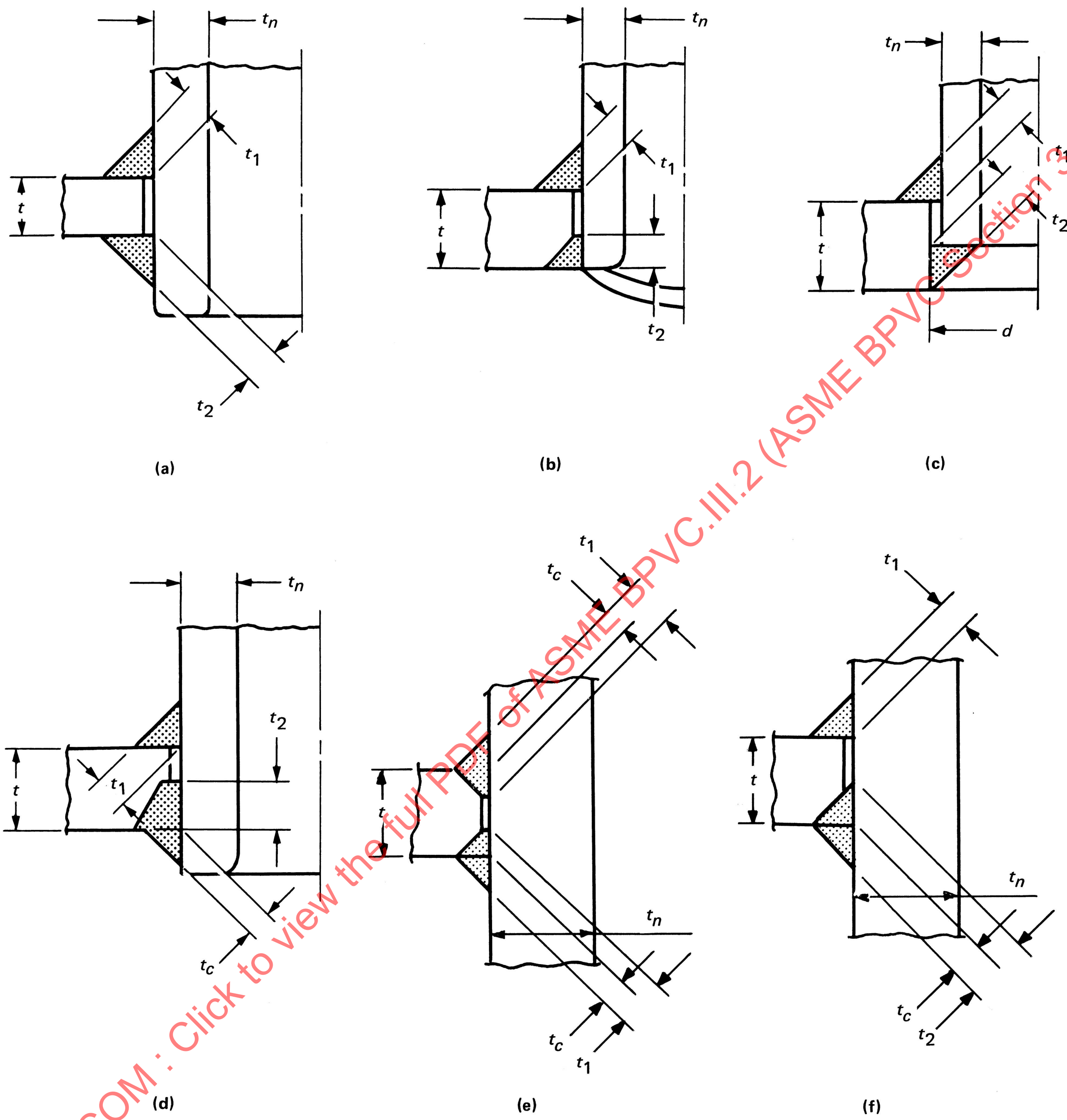
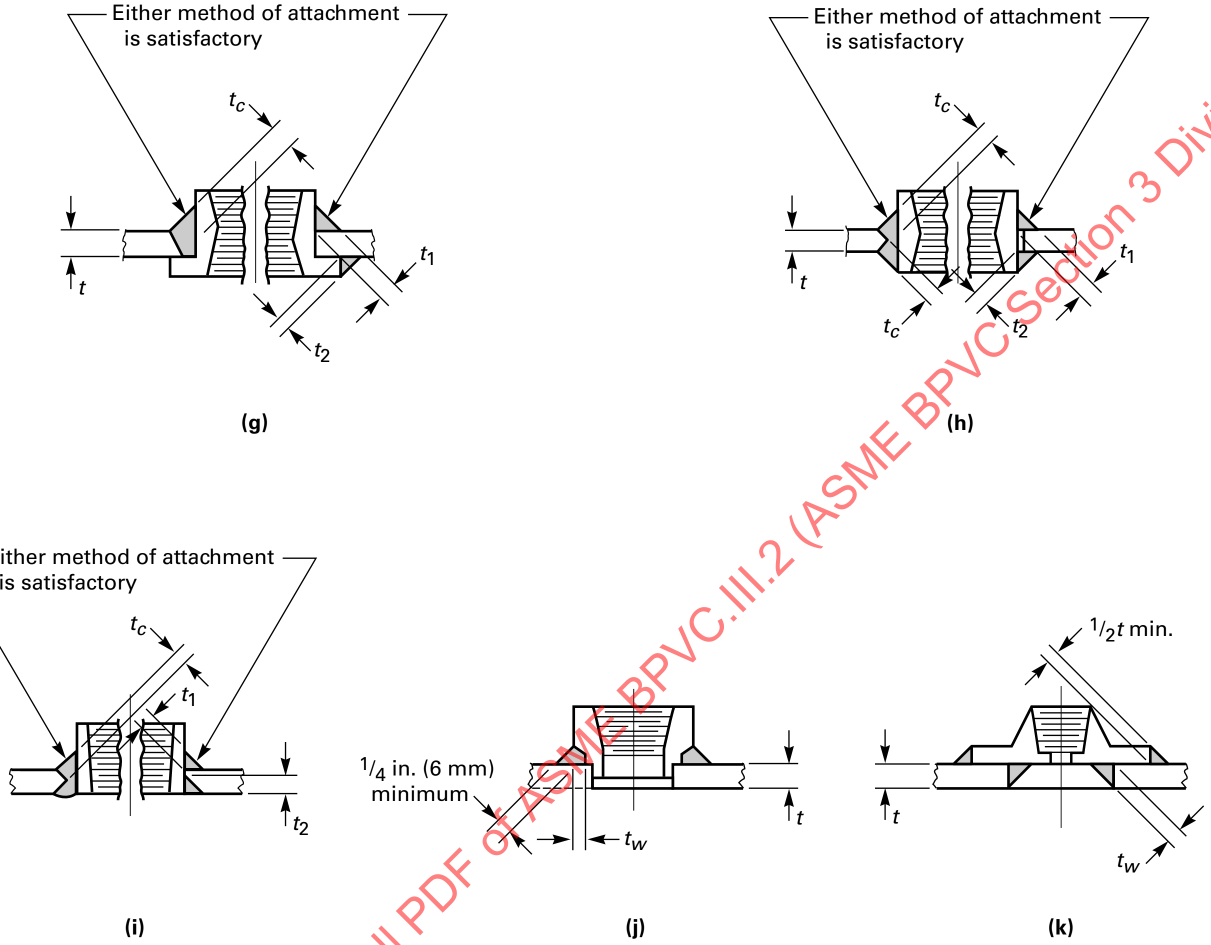
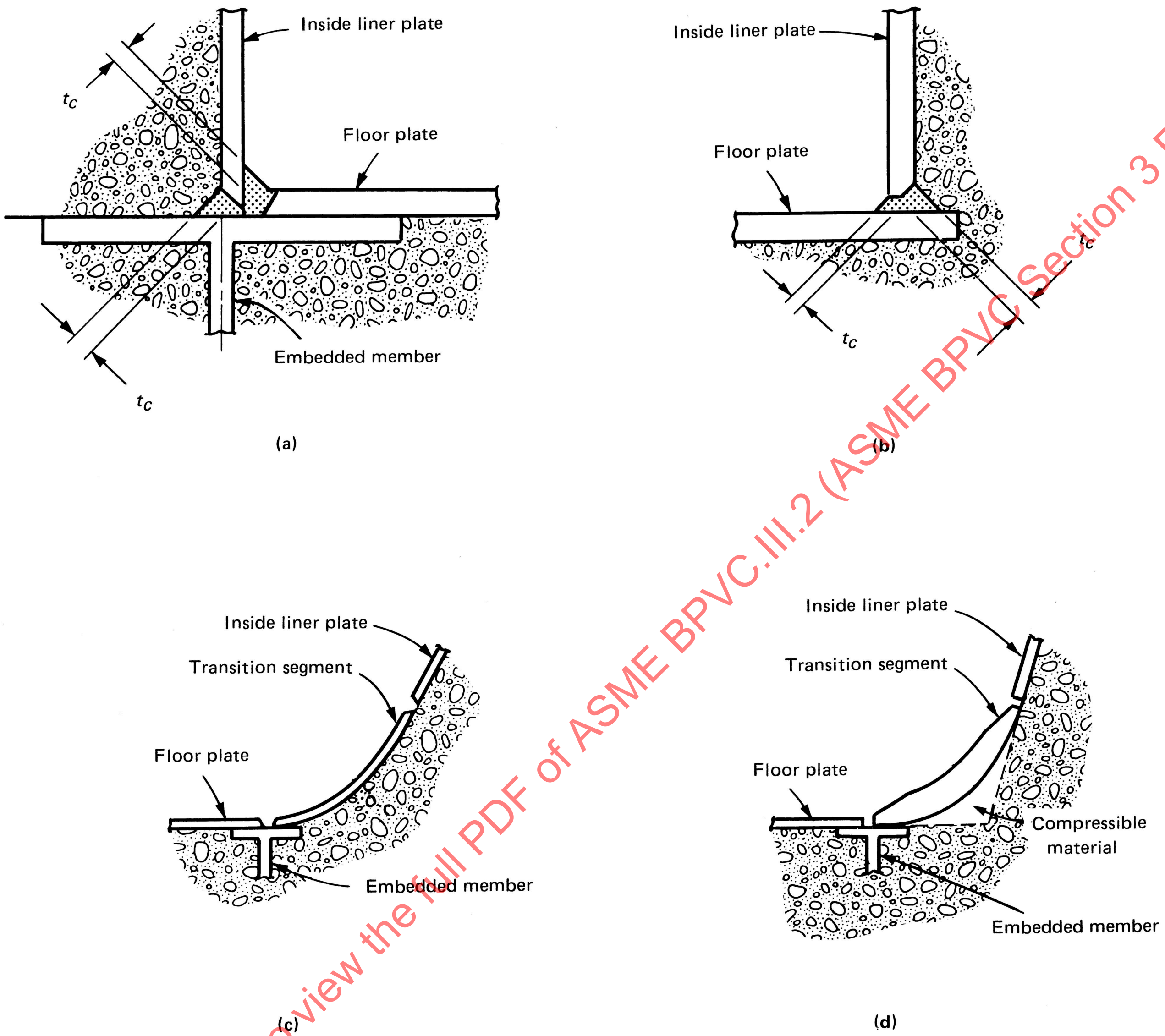


Figure CC-4542.2-2
Typical Category D Joints for Nozzle Diameters NPS 3 (DN 80) and Less (Cont'd)



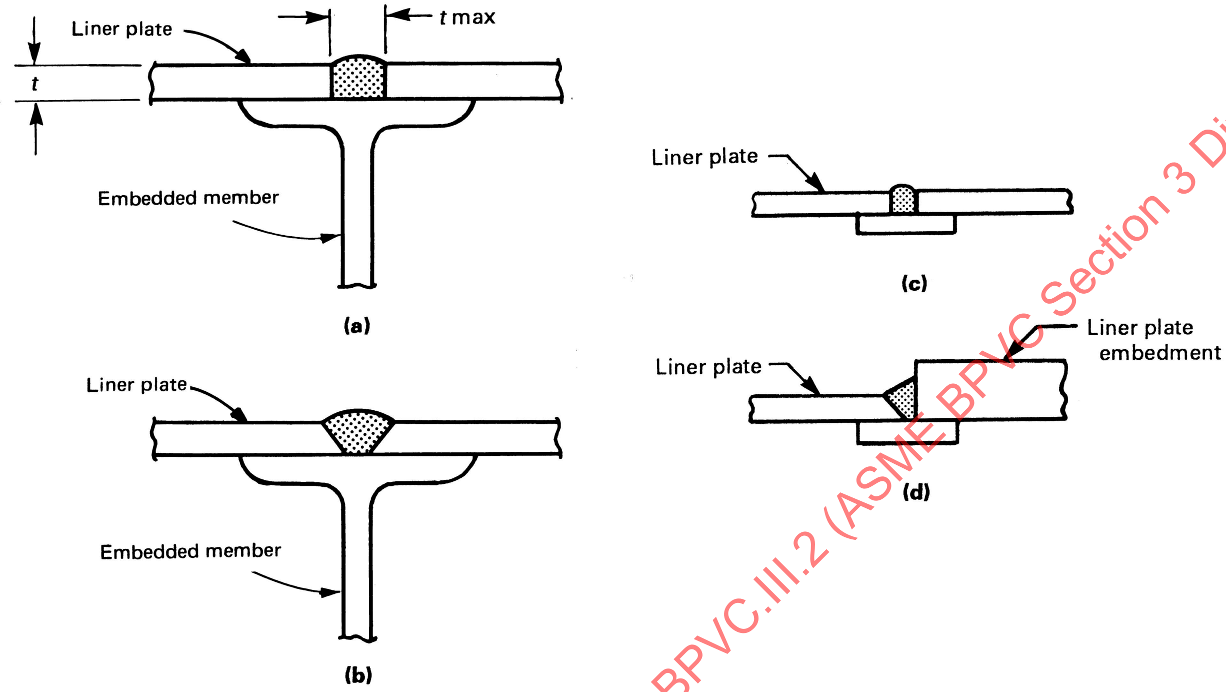
GENERAL NOTE: For definition of symbols, see CC-3842.10.

Figure CC-4542.2-3
Typical Category E Joints



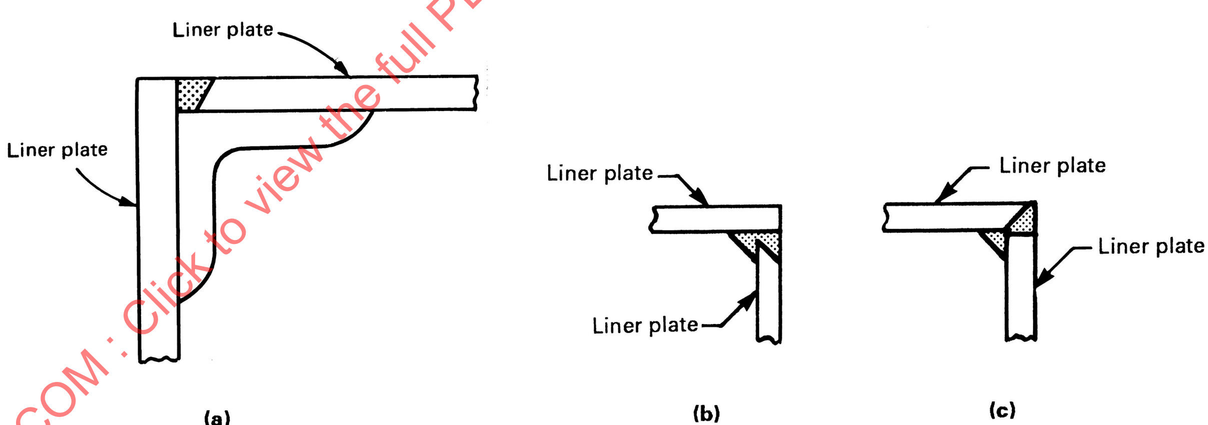
GENERAL NOTE: For definition of symbols, see CC-3842.10.

Figure CC-4542.2-4
Typical Category F Joints



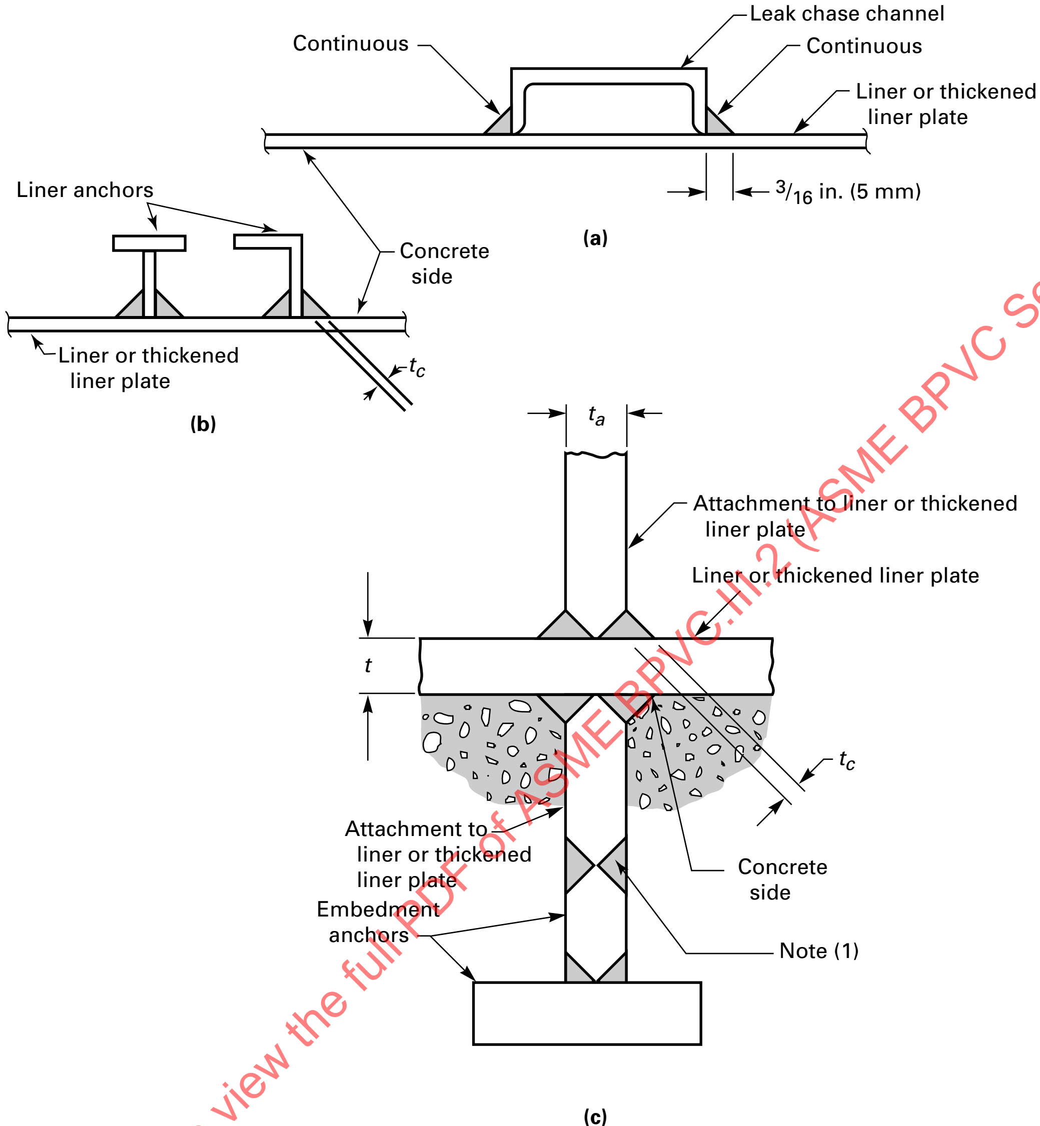
GENERAL NOTE: For definition of symbols, see CC-3842.10.

Figure CC-4542.2-5
Typical Category G Joints



GENERAL NOTE: For definition of symbols, see CC-3842.10.

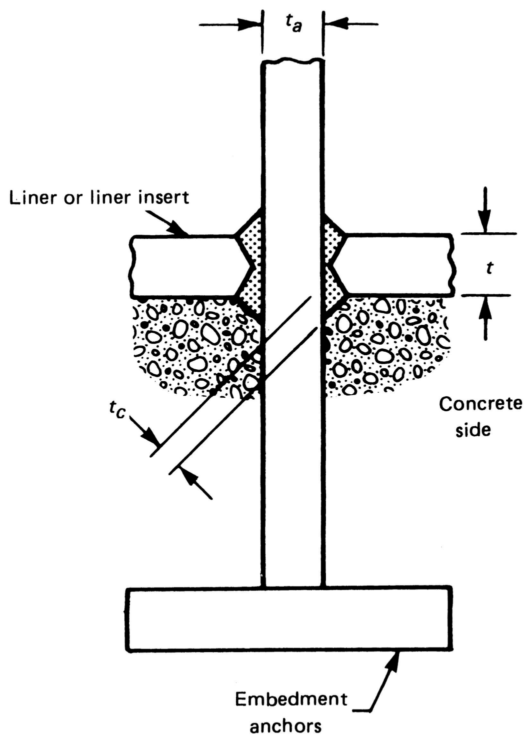
Figure CC-4542.2-6
Typical Category H Joints



GENERAL NOTES:
(a) For definition of symbols, see CC-3842.10.
(b) Welds are fillet, partial penetration, or full penetration, as required.
(c) For illustrations (b) and (c), regardless of the type of weld, a fillet weld with an effective throat equal to or larger than t_c shall be provided.

NOTE: (1) If the material of attachment is in accordance with Table D2-I-2.2, and the material of attachment and embedment anchor is the same, this welding joint can be deleted.

Figure CC-4542.2-7
Typical Category J Joints



GENERAL NOTE: For definition of symbols, see CC-3842.10.

Table CC-4542.8.1-1
Maximum Thicknesses Permitted

Material Nominal Thicknesses, in. (mm)	Maximum Reinforcement on Each Side, in. (mm)
Up to $^1/_2$ (13), incl.	$^3/_{32}$ (2.5)
Over $^1/_2$ to 1 (13 to 25)	$^1/_8$ (3)
Over 1 to 2 (25 to 50)	$^3/_{16}$ (5)

CC-4543.4 Welding of Nonstructural and Temporary Attachments. Nonstructural attachments, such as lifting lugs, insulation supports, nameplates, locating lugs, and temporary attachments may be noncertified material and may be welded directly to the liner with continuous or intermittent fillet or partial penetration welds, provided the requirements of (a) through (e) below are met.

(a) The welding procedure and the welders have been qualified in accordance with CC-4532.1.

(b) The material is identified and suitable for welding.

(c) The material is compatible with the material to which it is attached.

(d) The welding material is identified and compatible with the materials joined.

(e) The welds are postweld heat treated when required by CC-4552.

CC-4543.5 Stud Welding. When stud welding is employed to attach shear connectors or other connectors or other attachment to the liner, the following rules apply:

(a) Studs shall be welded to steel members with automatically timed stud welding equipment connected to a suitable power source.

(b) If two or more stud welding guns are to be operated from the same power source, they shall be interlocked so that only one gun can operate at a time and so that the power source has fully recovered from making one weld before another weld is started.

(c) While in operation, the welding gun shall be held in position without movement until the weld metal has solidified.

(d) At the time of welding, the studs shall be free from rust, rust pits, scale, oil, or other deleterious matter that would adversely affect the welding operation.

(e) The areas on the member to which the studs are to be welded shall be free of scale, rust, or other injurious material to the extent necessary to obtain satisfactory welds. These areas may be cleaned by wire brushing, peening, prick punching, or grinding.

(f) Arc shields shall be broken free after welding from shear connector and anchor studs and, where practicable, from all other studs.

(g) The studs, after welding, shall be free from any defect or substance that would interfere with their intended function.

(h) If the reduction in the length of studs as they are welded becomes less than normal (e.g., the length of stud after welding is more than $^1/_{16}$ in. (1.5 mm) longer than specified), welding shall be stopped immediately and not resumed until the cause has been corrected.

(i) Stud size shall be $^3/_4$ in. (19 mm) diameter maximum when stud welding is to be performed in any position other than downflat.

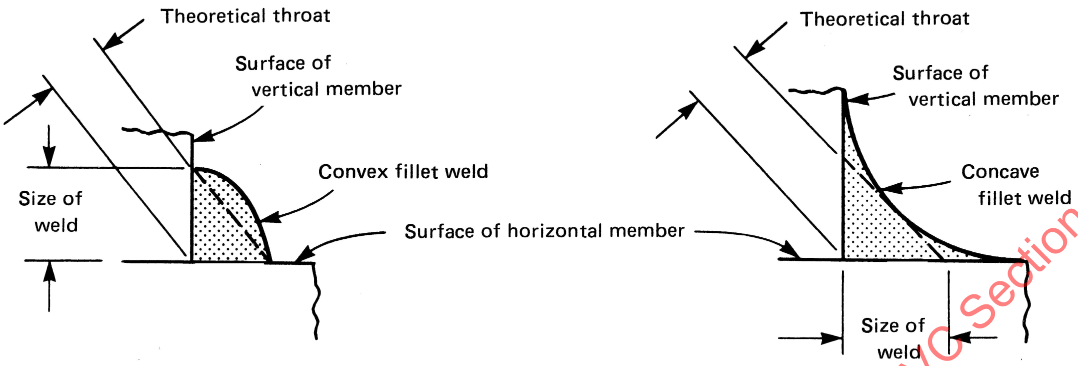
CC-4543.6 Special Requirements for Welding. When a portion of the liner transmits loads in the through thickness direction, one of the following requirements shall be met if the plate subjected to through thickness loading is 1 in. (25 mm) and greater in thickness:

(a) After completion of welding, the base material directly underneath the attachment shall be ultrasonically examined in accordance with the requirements of CC-5500.

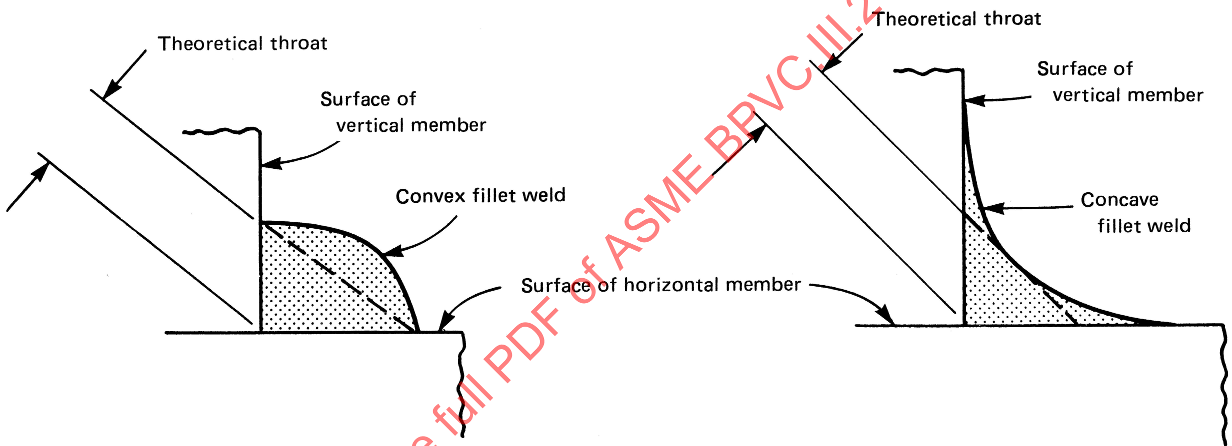
(b) A weld metal inlay or overlay shall be made in accordance with Figure CC-4543.6-1 and ultrasonically examined in accordance with CC-5500, prior to making the weld joining the attachment member to the inlay or overlay.

(c) Special deposition techniques, as illustrated in Figure CC-4543.6-2, may be used as an alternative to inlay or overlay. Such techniques shall be demonstrated to meet the requirements of (a) above on material

Figure CC-4542.9-1
Fillet and Socket Weld Dimensions

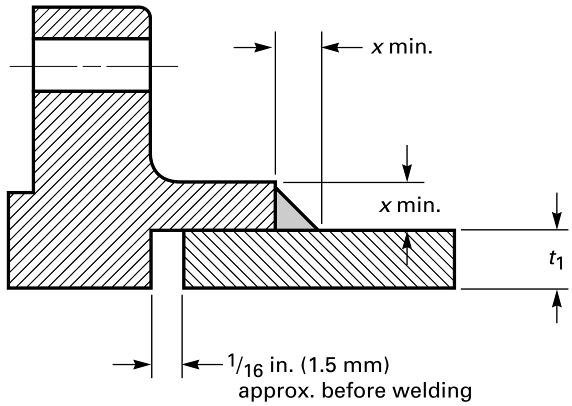


Equal Leg Fillet Weld [Note (1)]



Unequal Leg Fillet Weld [Note (2)]

Figure CC-4542.9-1
Fillet and Socket Weld Dimensions (Cont'd)

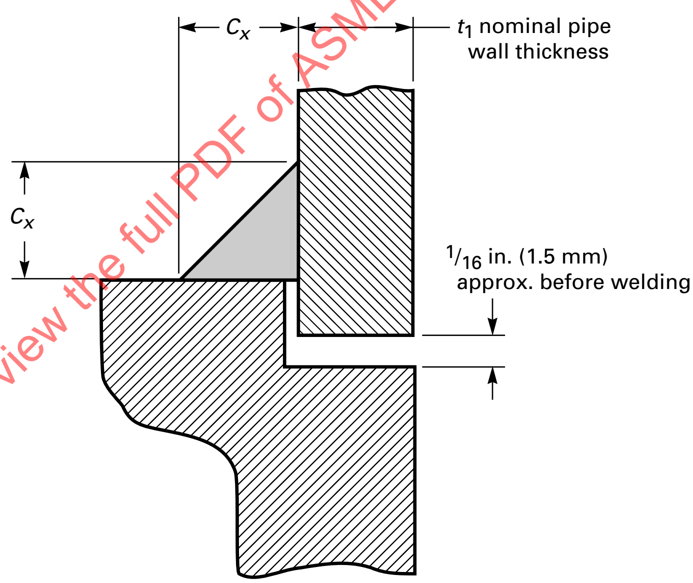


Socket Welding Flange

t_1 = nominal pipe wall thickness

x min. = 1.4t or the thickness of the hub, whichever is smaller, but not less than 1/8 in. (3 mm)

Size of Fillet Welds



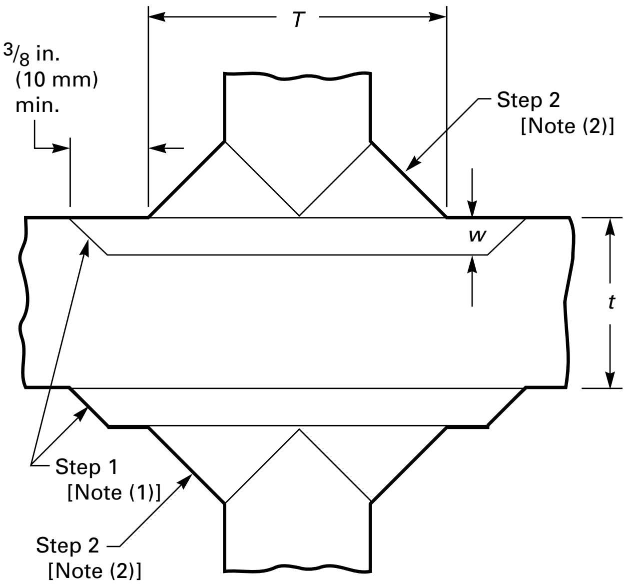
C_x min. = 1.09t, but not less than 1/8 in. (3 mm)

Welding Details for Socket Welding Flanges [Note (3)]

GENERAL NOTE: Not permitted for connections over NPS 2 (DN 50).

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.
(2) The "size" of an unequal leg fillet weld is the shorter leg length of the largest right triangle that can be inscribed within the fillet weld cross section.
(3) Not permitted for socket weld connections over NPS 4 (DN 100).

Figure CC-4543.6-1
Weld Joint Producing Through-Thickness Loading



GENERAL NOTES:

(a) Members may be welded on one side only, or from both sides.

(b) Inlay or overlay thickness shall be $^1/_4$ in. (6 mm) min. for t = 1 in. (25 mm) and shall be increased $^1/_{16}$ in. (1.5 mm) for each additional $^3/_8$ in. (10 mm) of t, but need not exceed $^1/_2$ in. (13 mm).

(c) When T exceeds t, w shall be increased by an additional $^1/_{16}$ in. (1.5 mm) for each $^3/_8$ in. (10 mm) of T over t, to a maximum of $^1/_2$ in. (13 mm).

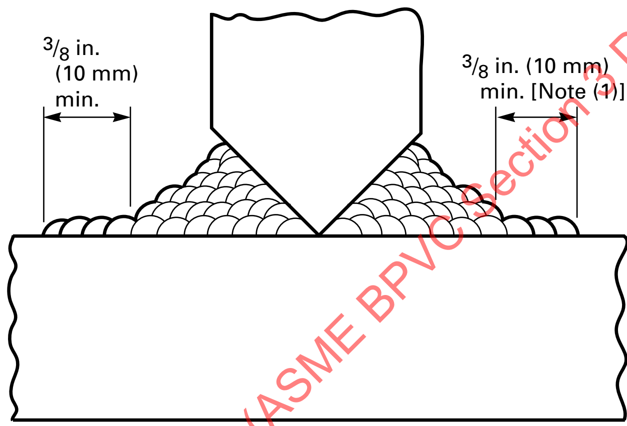
(d) The minimum specified tensile strength of the electrodes used for inlay or overlay shall not exceed the minimum specified tensile strength of the base material by more than 12 ksi (83 MPa).

NOTES:

(1) Step 1 — inlay or overlay weldment.

(2) Step 2 — completion of weldment.

Figure CC-4543.6-2
Special Deposition Technique for Weld Joint Producing Through-Thickness Loading (Typical)



GENERAL NOTE: Members may be welded on one side only, or from both sides.

NOTE: (1) The initial layer(s) shall extend a minimum of $^3/_8$ in. (10 mm) beyond the toe of the fillet.

thickness equal to or greater than the production thickness but need not be more than 4 in. (100 mm), and on material of the same type and grade as the production material.

(d) The material shall meet the acceptance standards of SA-770, Through-Thickness Tension Testing of Steel Plates for Special Applications.

CC-4544 Examination of Welds

All welds shall be examined in accordance with the requirements of CC-5500.

CC-4545 Repair of Weld Metal Defects

CC-4545.1 General Requirements. Discontinuities (23) detected in weld metal by examination (see Article CC-5000) or testing (see Article CC-6000) and classified as defects shall be reduced to imperfections of acceptable size and, if necessary, repaired by welding.

CC-4545.2 Elimination of Surface Defects. Weld metal surface defects may be removed by grinding or machining and not repaired by welding, provided the following requirements are met:

(a) The remaining thickness of the section is not less than that required by Article CC-3000.

(b) The thickness of the section is not reduced more than $^1/_{16}$ in. (1.6 mm).

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

(d) The area is examined after blending by a magnetic particle or liquid penetrant method meeting the requirements of CC-5500 to ensure that the defect has been removed or the indication reduced to an acceptable limit.

CC-4545.3 Requirements for Making Repairs to Welds. Excavated cavities in weld metal, when repaired by welding, shall meet the requirements of the following subparagraphs.

CC-4545.3.1 Defect Removal. Unacceptable defects detected visually or by the examinations required by CC-5500 shall be removed by mechanical means or by thermal gouging processes. The area prepared for repair shall be examined and comply with the requirements of CC-5533 or CC-5534.

CC-4545.3.2 Requirements for Welding Materials, Procedures, and Welders. The weld repair shall be made using welding materials, welders, and welding procedures in accordance with CC-4530.

CC-4545.3.3 Blending of Repaired Welds. After repair the surface shall be blended uniformly into the surrounding surface.

CC-4545.3.4 Examination of Repair Welds. The examination of weld repairs shall be repeated as required for the original weld except that repair of defects originally detected by magnetic particle or liquid penetrant methods, when the repair cavities do not exceed the lesser of $^3\!/_8$ in. (10 mm) or 10% of the thickness, need only be reexamined by a magnetic particle or liquid penetrant method.

CC-4545.3.5 Heat Treatment of Repaired Areas. The area shall be heat treated in accordance with CC-4550 when the original weld required heat treatment.

CC-4545.4 Repair of Defective Areas Resulting From Stud Removal.

(a) The areas of liners where defective studs have been removed shall be made smooth and flush by grinding.

(b) Where in such areas base metal has been pulled out in the course of stud removal, a shielded metal-arc welding process with low hydrogen electrodes in accordance with the requirements of CC-4545.3 shall be used to fill the pockets and the weld surface ground flush.

(c) Where a replacement stud is to be placed in the defective area, the above repair shall be made prior to welding the replacement stud.

CC-4550 HEAT TREATMENT

CC-4551 Welding Preheat Requirements

CC-4551.1 When Preheat Is Necessary. The need for preheat and the required temperature of preheat are dependent on a number of factors, such as the chemical analysis, degree of restraint of the parts being joined, temperature elevation, physical properties, and material thicknesses. Some practices used for preheating are given in Nonmandatory Appendix D2-B as a general guide for the materials listed by P-Number of Section IX. It is cautioned that the preheating suggested in Nonmandatory Appendix D2-B does not necessarily ensure satisfactory completion of the welded joint and that the requirements for individual material within the P-Number listing may have preheating more or less restrictive than this general guide. The Welding Procedure Specification for the material being welded shall specify the minimum preheating requirements under the welding procedure qualification requirements of Section IX.

CC-4551.2 Preheating Methods. Preheat for welding or thermal cutting, when employed, may be applied by any method that does not harm the base material or any weld metal already applied, or that does not introduce deleterious material into the welding area that is harmful to the weld.

CC-4552 Postweld Heat Treatment Requirements

CC-4552.1 Means of Heating and Cooling. Postweld heat treatment (PWHT) may be accomplished by any suitable means of heating and cooling provided the required heating and cooling rates, metal temperature, metal temperature uniformity, and temperature control are maintained.

CC-4552.2 PWHT Time and Temperature Requirements.

CC-4552.2.1 Requirements for PWHT. Except as otherwise permitted in CC-4552.2.7, 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 minimum holding times specified in Table CC-4552-1, except as otherwise permitted by CC-4552.2.4(c). P-Number groups in Table CC-4552-1 are in accordance with Section IX, QW-420. Except as provided in CC-4552.4.3, 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. Unless exempted in CC-4552.2.7, all nozzles and penetrations shall be welded into a portion of the liner plate or plates and postweld heat treated as complete subassemblies prior to welding into the liner.

CC-4552.2.2 Time–Temperature Recordings. Time–temperature recordings of all PWHT shall be made available for review by the Authorized Inspector. Identification on the time–temperature recording shall be to the weld or item as applicable. A summary of the time–temperature recording may be provided for permanent records in accordance with NCA-4134.17(e)(9).

CC-4552.2.3 Definition of Nominal Thickness Governing PWHT. (23) Nominal thickness in Table CC-4552-2 is the thickness of the weld, the liner material, or the thinner of the materials being joined, whichever is least. It is not intended that nominal thickness include material provided for forming allowance, thinning, or mill overrun when excess material does not exceed $^1\!/_8$ in. (3 mm). For fillet welds, the nominal thickness is the throat thickness, and for partial penetration and repair welds, the nominal thickness is the depth of the weld groove or preparation.

(23)

Table CC-4552-1
Mandatory Requirements for Postweld Heat Treatment of Welds

P-No. (Section IX, QW-420)	Holding Temperature Range, °F (°C) [Note (1)]	Minimum Holding Time at Temperature for Nominal Thickness of the Weld		
		$^{1}/_{2}$ in. (13 mm) or Less	Over $^{1}/_{2}$ in. to 2 in. (13 mm to 50 mm)	Over 2 in. (50 mm)
1	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)
8		PWHT neither required nor prohibited		

GENERAL NOTE: Exceptions to the mandatory requirements of this table are defined in Table CC-4552-2.

NOTE: (1) All temperatures are metal temperatures.

Table CC-4552-2
Exemptions to Mandatory PWHT

P-No. (Section IX, QW-420)	Type of Weld	Nominal Thickness (See CC-4552.2.3)	Properties of Pressure-Retaining Material(s) Being Joined	
			Max. Reported Carbon, %	Min. Preheat Required, °F (°C)
1	All welds, including repair welds, in material $1\frac{1}{2}$ in. (38 mm) and less	$1\frac{1}{4}$ in. (32 mm) or less	0.30 or less	...
		Over $1\frac{1}{4}$ in. (32 mm) to $1\frac{1}{2}$ in. (38 mm)	0.30 or less	200 (95)
		$\frac{3}{4}$ in. (19 mm) or less	Over 0.30	...
		Over $\frac{3}{4}$ in. (19 mm) to $1\frac{1}{2}$ in. (38 mm)	Over 0.30	200 (95)
	All fillet, partial penetration, and repair welds in material over $1\frac{1}{2}$ in. (38 mm)	$\frac{3}{4}$ in. (19 mm) or less	...	200 (95)
	All welds, including repair welds, in material greater than $1\frac{1}{2}$ in. (38 mm) but equal to or less than $1\frac{3}{4}$ in. (44 mm) [Note (1)]	$1\frac{3}{4}$ in. (44 mm) or less	0.24	200 (95)
	Repairs to welds in subassemblies postweld heat treated as required by CC-4552.2.1, with the total accumulated repair length of any weld not exceeding 25% of the original weld length	$\frac{3}{4}$ in. (19 mm) or less	...	200 (95)

GENERAL NOTE: The exemptions shown in this table do not apply to electron beam welds in ferritic materials over $\frac{1}{8}$ in. (3 mm) in thickness.

NOTE:
(1) This exemption is limited to SA-299, SA-516, and SA-537 under the following conditions:
(a) the impact test temperature is 40°F (22°C) below the lowest service temperature;
(b) the C_v energy value is increased by 5 ft-lb (7 J) over that shown in Table CC-2524.2-2;
(c) exemption from impact testing as provided in Table CC-2521.1-1.

Table CC-4552-3
Alternative PWHT Temperatures

Alternative Holding Temperature Range, °F (°C)	Alternative Minimum [Note (1)] Holding Time, hr/in. (min/mm) Thickness
1,050–1,200 (565–650)	2 (5)
1,000–1,150 (540–620)	3 (7)
950–1,000 (510–540)	5 (12)
900–1,050 (480–565)	10 (24)

NOTE: (1) All other requirements of CC-4552.2 shall apply.

CC-4552.2.4 Holding Temperatures and Times.

(a) The holding time at temperature as specified in Table CC-4552-1 need not be continuous. It may be an accumulation of time of multiple postweld heat treat cycles.

(b) Holding time at temperatures in excess of the minimum requirements of Table CC-4552-1 may be used, provided specimens are tested in accordance with CC-2526, CC-2600, and CC-4530.

(c) Alternatively, when it is impractical to postweld heat treat at the temperature range specified in Table CC-4552-1, it is permissible to perform the postweld heat treatment of P-No. 1 material at lower temperature ranges for longer periods of time in accordance with Table CC-4552-3 and (1) below.

(1) Base materials certified in accordance with CC-2526 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.

CC-4552.2.5 PWHT Requirements When Differing P-Number Materials Are Joined. PWHT is not required when joining P-No. 1 material $1^1/_2$ in. (38 mm) or less in thickness to P-No. 8 materials with electrodes that produce austenitic or non-air-hardening nickel–chrome–iron deposits.

CC-4552.2.6 PWHT Requirements for Material Welded to Liners. When materials are welded to liner materials, the PWHT temperature range of the liner materials shall control.

CC-4552.2.7 Exemptions to PWHT Mandatory Requirements. PWHT is not required for the following:

(a) nonferrous material

(b) welds exempted in Table CC-4552-2

(c) welds subjected to temperatures above the PWHT temperature range specified in Table CC-4552-1, provided the Welding Procedure Specification is qualified in accordance with Section IX

CC-4552.3 Heating and Cooling Rate Requirements. Above 800°F (425°C), the rate of heating and cooling over 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 (55°C) over any hourly interval. During the heating and cooling period, there shall not be a greater variation in temperature than 250°F (140°C) within any 15 ft (4.6 m) interval of the weld length.

CC-4552.4 Methods of PWHT. The PWHT shall be performed in accordance with the requirements of one of the following subparagraphs.

CC-4552.4.1 Furnace Heating — One Heat. Heating the 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; direct impingement of flame on the component or assembly is prohibited.

CC-4552.4.2 Furnace Heating — More Than One Heat. The item may be heated in more than one heat in a furnace, provided the furnace atmosphere control requirements of CC-4552.4.1 apply and the overlap of the heated sections of the item is at least 5 ft (1.5 m). When this procedure is used, the portion of the item outside the furnace shall be shielded so that the temperature gradient is not harmful. The cross section where the item projects from the furnace shall not intersect a nozzle or other structural discontinuity.

CC-4552.4.3 Local Heating. Welds may be locally postweld heat treated when it is not practical to heat treat the entire item. Local PWHT shall consist of heating a circumferential band at temperatures within the ranges specified in Table CC-4552-1 or Table CC-4552-3. The width of the controlled band at each side of the weld, on the face of greatest weld width, shall be not less than the thickness of the weld or 2 in. (50 mm), whichever is less. The temperature of the item shall be gradually diminished from the edge of the controlled band outward so as to avoid harmful thermal gradients. This procedure may also be used for PWHT after repairs.

CC-4552.4.4 Heating Components Internally. The item may be heated internally by 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 vessel. Previous to this operation, the item shall be fully enclosed with insulating material.

CC-4553 Intermediate PWHT

The temperature, time at temperature, and heating and cooling rate requirements of CC-4552 are not mandatory for intermediate heat treatments.

CC-4554 Heat Treatment After Repairs by Welding

CC-4554.1 Rules Governing Heat Treatment After Repair by Welding. Liners or portions of liners, including materials that have been repaired by welding, shall be postweld heat treated in accordance with the requirements of CC-4552.

CC-4555 Heat Treatment During Fabrication

When material is subjected to heat treatment during fabrication, the test specimens required by the applicable SA material specification shall be obtained from the sample coupons which have been heat treated in the same manner as the material, including such heat treatments as were applied by the producer before shipment. The required tests may be performed by the material producer or the Fabricator or Constructor. When plate specification heat treatments are not performed by the mill, they shall be performed by or under the control of the Fabricator or Constructor, who shall then place the letter "T" following the letter "G" in the mill plate marking (SA-20) to indicate that the material specification heat treatments have been performed. The Fabricator or Constructor shall also show by a supplement to the appropriate Certified Material Test Report that the specified heat treatment has been performed.

CC-4560 PROTECTION OF ATTACHMENTS

All attachments and penetrations shall be protected against entry of deleterious materials or dislodgement during construction operations.

CC-4600 FABRICATION OF EMBEDMENT ANCHORS

CC-4610 GENERAL REQUIREMENTS

CC-4611 Introduction

(a) The rules in the following paragraphs apply specifically to the fabrication and construction of embedment anchors.

(b) Each Certificate Holder shall be responsible for the quality of the welding done by his organization, and shall conduct tests of the welding procedure to determine its suitability and also of the welders and welding operators to determine their ability to apply the procedure properly.

(c) No production work shall be undertaken until both the welding procedure and the welders or welding operators have been qualified in accordance with Section IX.

CC-4612 Elimination and Repair of Defects

CC-4612.1 Repair of Material. Material originally accepted on delivery in which defects exceeding the limits of CC-2730 are known or discovered during the process of fabrication or installation is unacceptable. The material may be used provided the condition is corrected in accordance with the requirements of CC-2730 for the applicable product form except

(a) the limitation on the depth of the weld repair does not apply; and

(b) the time of examination of the weld repairs to weld edge preparations shall be in accordance with CC-5500.

CC-4620 FORMING, FITTING, AND ALIGNING

CC-4621 Cutting, Forming, and Bending

CC-4621.1 Cutting. Cutting of material shall be in accordance with CC-4521.1.

CC-4621.2 Forming and Bending Processes. Forming and bending processes shall be in accordance with CC-4521.2.

CC-4621.3 Qualification of Forming Processes and Acceptance Criteria for Formed Material. Qualification of forming and bending processes shall be in accordance with CC-4521.3.

CC-4621.4 Minimum Thickness of Fabricated Material. If any fabrication operation reduces the thickness below the minimum required to satisfy the rules of Article CC-3000, the material may be repaired in accordance with CC-4612.

CC-4622 Forming Tolerances

CC-4622.1 Tolerances for Embedment Anchors. Tolerances for embedment anchors shall be specified in the Design Specifications.

CC-4623 Fitting and Aligning

CC-4623.1 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.

CC-4623.1.1 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.

CC-4623.1.2 Temporary Attachments and Their Removal. Attachments that are welded onto the embedment anchors or parts during the process of manufacture or installation but that are not incorporated into the final support are permitted provided the requirements of (a) through (e) below are met.

(a) The material is identified and is suitable for welding but need not be certified material.

(b) The material is compatible for welding to the embedment anchor material to which it is attached.

(c) The welding material is compatible with the base material and is certified in accordance with CC-2130.

(d) The welder and welding procedure are qualified in accordance with CC-4532.

(e) The temporary attachment is completely removed in accordance with the procedures of CC-4621.1.

CC-4623.2 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 CC-4523-1, where t is the nominal thickness of the thinner section of the joint.

CC-4623.2.1 Fairing of Offsets. Any offset within the allowable tolerance of Table CC-4523-1 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.

CC-4630 WELDING QUALIFICATIONS

CC-4631 General Requirements

CC-4631.1 Types of Processes Permitted. Only those welding processes that are capable of producing welds in accordance with the welding procedure qualification requirements of Section IX and this Subsection shall be used for welding embedment anchor material or attachments thereto. Any process used shall be such that the records required by CC-4632 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.

CC-4631.1.1 Stud Welding. Stud welding shall be in accordance with CC-4543.5.

CC-4632 Welding Qualification and Records

CC-4632.1 Required Qualifications.

(a) Each Certificate Holder is responsible for the welding done by his organization and shall establish the procedure and conduct the test required by this Article and Section IX in order to qualify both the welding procedures and the performances of welders and welding operators who apply these procedures.

(b) Procedures, welders, and welding operators used to join permanent or temporary attachments to embedment anchors 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. The addition of restraint during welding may result in cracking difficulties that otherwise might not occur.

CC-4632.2 Maintenance and Certification of Records. Maintenance and certification of records shall be in accordance with CC-4532.2.

CC-4632.2.1 Identification of Joints.

(a) For partial penetration welds with a depth less than 1 in. (25 mm), fillet welds with a throat dimension less than 1 in. (25 mm), and stud welds, 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 so that the Inspector can verify that the welders or welding operators were all properly qualified

(2) the welds in each category are all of the same type and configuration and are welded with the same Welding Procedure Specification

(b) the identification of welder or welding operator is not required for tack welds

(c) the Certificate Holder shall certify that only welders and welding operators qualified in accordance with CC-4632.1 and Section IX were used in making all welds

CC-4632.3 Welding Prior to Qualification. No welding shall be undertaken until after the welding procedures which are to be used have been qualified.

CC-4632.4 Transferring Qualifications. The welding procedures qualification 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, QW-201 and QG-106.2.

CC-4633 General Requirements for Welding Procedure Qualification Test

The requirements for welding procedure qualification tests shall be in accordance with CC-4533.

CC-4634 Continuing Performance Test for Stud Welding

Continuing performance test for stud welding shall be in accordance with CC-4534.

CC-4640 RULES GOVERNING MAKING, EXAMINING, AND REPAIRING WELDS

CC-4641 Precautions to Be Taken Before Welding

Precautions to be taken before welding shall be in accordance with CC-4541.

CC-4642 Rules for Making Welded Joints

CC-4642.1 Welded Joints. The materials for backing strips, when used, shall be compatible with the base metal. Backing strips shall be continuous and any joints shall be made with full penetration welds.

CC-4642.2 Peening. The weld metal may be peened when it is deemed necessary or helpful to control distortion. Peening is prohibited on root pass and final pass.

CC-4642.3 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 to sound metal except for those processes of welding by which proper fusion and penetration are otherwise obtained and demonstrated to be satisfactory by welding procedure qualification.

CC-4642.4 Surfaces of Welds. As-welded surfaces are permitted. However, the surfaces of welds shall be sufficiently free from coarse ripples, grooves, overlaps, abrupt ridges, and valleys to meet the requirements of (a) through (e) below.

(a) The surface condition of the finished weld shall be suitable for the proper interpretation of radiographic and other required nondestructive 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) Reinforcements are permitted in accordance with CC-4642.5.

(c) Undercuts shall not exceed $^1/_{32}$ in. (0.8 mm).

(d) Concavity on the root side of a single-welded circumferential butt weld is permitted when the resulting thickness of the weld is at least equal to the thickness of the thinner member of the two sections being joined.

(e) If the surface of the weld required grinding to meet the above criteria, care shall be taken to avoid reducing the weld or base material below the required thickness.

CC-4642.5 Reinforcement of Butt Welds. The surface of the reinforcement of all butt-welded joints may be flush with the base material or may have uniform crowns. The height of reinforcement on each face of the weld shall not exceed the following thickness:

Nominal Thickness, in. (mm)	Maximum Reinforcement, in. (mm)
Up to 1 (25), incl.	$^3/_{32}$ (2.5)
Over 1 to 2 (25 to 50), incl.	$^1/_8$ (3)
Over 2 to 3 (50 to 75), incl.	$^5/_{32}$ (4)
Over 3 to 4 (50 to 100), incl.	$^7/_{32}$ (5.5)
Over 4 to 5 (75 to 125), incl.	$^1/_4$ (6)
Over 5 (125)	$^5/_{16}$ (8)

CC-4642.6 Shape and Size of Fillet Welds. Fillet welds may vary from convex to concave. The size of the weld shall be in accordance with the requirements of Figure CC-4542.9-1. A fillet weld in any single continuous weld may be less than the specified fillet weld dimension by not more than $^1/_{16}$ in. (1.5 mm), provided that the total undersize portion of the weld does not exceed 10% of the length of the weld. Individual undersize weld portions shall not exceed 2 in. (50 mm) in length. 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. In making fillet welds, the weld metal shall be deposited in such a way that adequate penetration into the base metal at the root of the weld is secured.

CC-4642.7 Plug Welds. When plug welds are used on embedment anchors, a fillet weld shall first be deposited around the circumference at the bottom of the hole.

CC-4642.8 Stud Welding. Stud welding shall be in accordance with the requirements of CC-4543.5.

CC-4644 Examination of Welds

All welds shall be examined in accordance with the requirements of CC-5500.

CC-4645 Repair of the Weld Metal Defects

Repair of weld metal defects shall be in accordance with CC-4545.

CC-4650 HEAT TREATMENT

Heat treatment of concrete embedment material shall be in accordance with CC-4550.

CC-4660 BOLTED CONSTRUCTION

Requirements for bolted construction shall be defined in the Construction Specification.

ARTICLE CC-5000
CONSTRUCTION TESTING AND EXAMINATION

CC-5100 GENERAL REQUIREMENTS FOR EXAMINATION

CC-5110 PROCEDURES, QUALIFICATION, AND EVALUATIONS

CC-5111 General Requirements

Nondestructive examinations, except leak testing by the vacuum box technique, shall be in accordance with the examination procedures of Section V. Leak testing by the vacuum box technique shall be in accordance with Mandatory Appendix D2-VI. For radiography, geometric unsharpness shall not exceed the limits of Section V, Article 2, T-274.2. The examinations shall be performed by personnel who have been qualified as required in this Article. The results of the examinations shall be evaluated in accordance with the acceptance standards of this Article. The examination of parts and appurtenances meeting the requirements for Class MC and which are not backed up by concrete for load carrying purposes shall meet the requirements of Article NE-5000 and Subsection NCA. Examination of embedded attachments to parts examined to the requirements of Division 1 shall meet the requirements of this Article.

CC-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 the Inspector. Section V Special configurations and materials may require modified methods and techniques. In these cases, special procedures which are at least equivalent to the methods and techniques described in shall be developed. Written procedures and records of demonstration of procedure capability and personnel qualification shall be made available to the Inspector upon request. At least one copy of each procedure shall be readily available to all appropriate nondestructive examination personnel for reference and use.

CC-5113 Post-Examination Cleaning

Following any nondestructive examination in which examination materials are applied to the piece, the piece shall be thoroughly cleaned in accordance with procedure specifications.

CC-5120 QUALIFICATION AND CERTIFICATION OF NONDESTRUCTIVE EXAMINATION PERSONNEL

CC-5121 General Requirements

Organizations performing Code required nondestructive examinations shall use personnel competent and knowledgeable to the degree specified by CC-5122. When these services are subcontracted by the Certificate Holder or Quality System Certificate Holder, he shall verify the qualification of personnel to the requirements of CC-5122. All nondestructive examinations required by this Subsection shall be performed by and the results evaluated by qualified nondestructive examination personnel.

CC-5122 Personnel Qualification, Certification, and Verification

CC-5122.1 Qualification Procedure.

(a) Personnel performing nondestructive examinations shall be qualified in accordance with the recommended guidelines of SNT-TC-1A. Personnel qualified by examination and certified to an earlier edition of SNT-TC-1A are considered to be qualified to the edition referenced in Table NCA-7100-3 when the recertification is based on continuing satisfactory performance. All reexaminations and new examinations shall be in accordance with the edition referenced in Table NCA-7100-3. 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 written practice required by para. 5 of SNT-TC-1A shall identify his requirements relative to the recommended guidelines. "Employer" as used in this Article shall include N, NPT, or NA Certificate Holders; Quality System Certificate Holders; Material Organizations who are qualified in accordance with NCA-3842; and organizations who provide subcontracted nondestructive examination services to organizations

described above. The recommended guidelines of SNT-TC-1A shall be considered minimum requirements, except as modified in (1) through (5) below.

(1) Qualification of Level III nondestructive examination personnel shall be by examination.

(-a) The basic and method examinations, paragraphs 8.8.1 and 8.8.2 of SNT-TC-1A, may be prepared and administered by the Employer, ASNT, or an outside agency.

(-b) The specific examination, paragraph 8.8.3 of SNT-TC-1A, shall be prepared and administered by the Employer or an outside agency. The Employer or outside agency administering the specific examination shall identify the minimum grade requirement in the written program when the basic and method examinations have been administered by ASNT, which issues grades on a pass/fail basis. In this case, the minimum grade for the specific examination may not be less than 80%.

(2) The written practice identified in paragraph 5 of SNT-TC-1A and the procedures used for examination of personnel shall be referenced in the Employer's Quality Program.

(3) The number of hours of training and experience for nondestructive examination personnel who perform only one operation of a nondestructive examination method that consists of more than one operation, or perform nondestructive examination of limited scope, may be less than that recommended in Table 6.3.1 A of SNT-TC-1A. The training and experience times shall be described in the written practice, and any limitations or restrictions placed on the certification shall be described in the written practice and on the certificate. The minimum classroom training times 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.

(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.

CC-5122.2 Certification of Personnel.

(a) The Employer retains responsibility for the adequacy of the program and is responsible for certification of Levels I, II, and III nondestructive examination personnel.

(b) When ASNT is the outside agency administering the Level III basic and method examinations CC-5122.1(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.

CC-5122.3 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 and qualified by them in accordance with NCA-3820 and subcontractors who provide nondestructive examination services to them.

CC-5122.4 Records. Personnel qualification records identified in paragraph 9.4 of SNT-TC-1A shall be retained by the Employer.

CC-5130 QUALIFICATION OF CONCRETE INSPECTION AND TESTING PERSONNEL

CC-5131 General Requirements

It shall be the responsibility of each organization (see Article NCA-3000) to ensure that all personnel performing concrete inspection and testing functions under this Division are competent and knowledgeable of the applicable requirements to the degree specified in CC-5132. All concrete inspection and testing required by this Division shall be performed and the results evaluated by qualified concrete inspection and testing personnel. The assignment of responsibilities to individual personnel will be at the discretion of the responsible organization.

CC-5132 Personnel Qualification

Personnel performing concrete inspection and testing functions shall be qualified in accordance with Mandatory Appendix D2-V of this Division.

CC-5133 Verification by Authorized Inspectors

The Authorized Inspector has the duty to verify the organization's certification of concrete inspection and testing personnel in accordance with Mandatory Appendix D2-V, and has the prerogative to audit the program and require requalification of any concrete inspection and testing personnel when the Authorized Inspector has reason to question the performance of that individual.

CC-5140 RECORDS

Personnel qualification records shall be retained in accordance with NCA-4134.17.

CC-5200 CONCRETE EXAMINATION

CC-5210 GENERAL

Concrete and concrete constituents shall be examined and tested in accordance with the rules established herein. The results of these tests shall not represent constituents previously used, but will be used only to qualify or disqualify the lot of concrete constituents represented. The examinations and tests required by this subarticle shall be performed by the Constructor, Fabricator, or Manufacturer of Nonmetallic Materials and monitored by the Authorized Inspector in accordance with Article NCA-5000. If the examinations and tests are performed by the Manufacturer of Nonmetallic Materials, provisions shall be made for the Authorized Inspector of the Constructor or Fabricator, as applicable, to make the necessary inspections to ensure compliance with this subarticle. The results shall be verified by the Fabricator or Constructor.

CC-5211 Laboratory Qualification

The tests required by CC-5200 shall be performed by an accredited laboratory that complies with ASTM C1077, except that testing personnel shall be qualified in accordance with CC-5132. Such laboratory tests may be provided by the Cement and Concrete Reference Laboratory of the National Institute of Standards and Technology, with accreditation programs provided by the National Voluntary Laboratory Accreditation Program, American Association for Laboratory Accreditation, and Construction Materials Engineering Council.

CC-5220 CONCRETE CONSTITUENTS

CC-5221 Cementitious Materials

CC-5221.1 Requirements. Quality control testing shall be performed by the Constructor to ascertain conformance of cementitious materials to applicable requirements of ASTM C150/C150M, ASTM C595/C595M, ASTM C618, ASTM C989, ASTM C1157/C1157M, and ASTM C1240, as shown in Table CC-5200-1.

CC-5221.2 Testing Frequency. The frequency of testing shall be as shown in Table CC-5200-1.

CC-5221.3 Uniformity Requirements. The quality control testing for fly ash and pozzolan shall be evaluated to ascertain conformance with ASTM C618 uniformity requirements for

(a) specific gravity (density)
(b) fineness

CC-5222 Admixtures

CC-5222.1 Air-Entraining Admixtures.

CC-5222.1.1 Requirements. In addition to the testing required by ASTM C260 of the admixture Manufacturer, the following quality control tests shall be performed using procedures recommended by the Manufacturer: infrared analysis, pH, and solids content. Additionally, the optional uniformity requirements of ASTM C260 shall apply — pH, specific gravity, and air content.

CC-5222.1.2 Testing Frequency. Quality control tests shall be conducted on the air-entraining admixture prior to use in accordance with Table CC-5200-1.

CC-5222.2 Chemical Admixtures.

CC-5222.2.1 Requirements. In addition to the testing required of the admixture Manufacturer by ASTM C494/C494M, the following quality control tests shall be performed using procedures recommended by the Manufacturer and as stipulated in ASTM C494/C494M to ensure uniformity: infrared analysis, specific gravity (liquids singly), and residue by oven drying.

CC-5222.2.2 Testing Frequency. Quality control tests shall be conducted on the admixture prior to use in accordance with Table CC-5200-1.

CC-5222.3 Grout Fluidifier.

CC-5222.3.1 Requirements. Quality control testing shall be performed to ascertain conformance to ASTM C937.

CC-5222.3.2 Testing Frequency. Quality control tests shall be conducted on the fluidifier in accordance with Table CC-5200-1.

CC-5223 Aggregates

CC-5223.1 Requirements. Quality control tests shall be as shown in Table CC-5200-1. Aggregate samples for gradation, moisture content, and material finer than #200 sieve tests shall be obtained from conveyors, bins, or chutes at the batch plant. Aggregate samples for other quality control tests may be obtained from these same locations, at the point of delivery, or from stockpiles.

Table CC-5200-1
Minimum Testing Frequencies for Concrete Constituents and Concrete

Material	Requirements	Test Method	Frequency [Note (1)] Initial [Note (2)]	Frequency [Note (1)] After Field Experience [Note (3)]
Portland Cement and Blended Hydraulic Cement	Standard chemical properties	ASTM C114	Each 1,200 tons (1 100 t)	Each 1,200 tons (1 100 t)
	Fineness	ASTM C204 or ASTM C115	Each 1,200 tons (1 100 t)	Each 1,200 tons (1 100 t)
	Autoclave expansion	ASTM C151/C151M	Each 1,200 tons (1 100 t)	Each 1,200 tons (1 100 t)
	Compressive strength	ASTM C109/C109M	Each 1,200 tons (1 100 t)	Each 1,200 tons (1 100 t)
	Time of setting	ASTM C266 or ASTM C191	Each 1,200 tons (1 100 t)	Each 1,200 tons (1 100 t)
Fly Ash and Pozzolan	Loss on ignition	ASTM C311	Each 400 tons (360 t)	Each 400 tons (360 t)
	Fineness (No. 325 sieve analysis)	ASTM C311	Each 400 tons (360 t)	Each 400 tons (360 t)
	Specific gravity	ASTM C311	Each 400 tons (360 t)	Each 400 tons (360 t)
	Reactivity with cement alkalies [Note (4)]	ASTM C441	Each 2,000 tons (1 800 t)	Each 2,000 tons (1 800 t)
	Available alkalies [Note (4)]	ASTM C311	Each 2,000 tons (1 800 t)	Each 2,000 tons (1 800 t)
GGBF-Slag	Fineness (No. 325 sieve analysis)	ASTM C430	Each 2,500 tons (2 250 t)	Each 2,500 tons (2 250 t)
	Specific surface	ASTM C204	Each 2,500 tons (2 250 t)	Each 2,500 tons (2 250 t)
	Slag activity index	ASTM C989	Each 2,500 tons (2 250 t)	Each 2,500 tons (2 250 t)
Silica Fume	Oversize (No. 325 sieve analysis)	ASTM C430	Each 3,500 tons (3 150 t)	Each 3,500 tons (3 150 t)
	Density	ASTM C1240	Each 3,500 tons (3 150 t)	Each 3,500 tons (3 150 t)
	Specific surface	ASTM C1069	Each 3,500 tons (3 150 t)	Each 3,500 tons (3 150 t)
	Accelerated activity index	ASTM C1240	Each 3,500 tons (3 150 t)	Each 3,500 tons (3 150 t)
Air-Entraining Admixtures	Uniformity	Infrared spectrophotometry, pH, and solids content in accordance with ASTM C260	Composite of each shipment or production lot	Composite of each shipment or production lot
Chemical Admixtures	Uniformity	Infrared analysis, specific gravity (liquids singly), and residue by oven drying in accordance with ASTM C494/C494M	Composite of each shipment or production lot	Composite of each shipment or production lot
Grout Fluidifier	Physical properties	ASTM C937	Composite of each shipment or production lot	Composite of each shipment or production lot

Table CC-5200-1
Minimum Testing Frequencies for Concrete Constituents and Concrete (Cont'd)

Material	Requirements	Test Method	Frequency [Note (1)]	
			Initial [Note (2)]	After Field Experience [Note (3)]
Aggregate	Gradation	ASTM C136	Each 1,000 yd^3 (760 m^3) concrete	Each 2,000 yd^3 (1 500 m^3) concrete
	Moisture content	ASTM C566	Twice daily during production	Twice daily during production
	Material finer than No. 200 sieve	ASTM C117	Each 1,000 yd^3 (760 m^3) concrete	Each 2,000 yd^3 (1 500 m^3) concrete
	Organic impurities [Note (5)]	ASTM C40	Each 1,000 yd^3 (760 m^3) concrete	Each 2,000 yd^3 (1 500 m^3) concrete
	Flat and elongated particles	ASTM D4791	Monthly	Every 6 months
	Friable particles [Note (5)]	ASTM C142	Monthly	Every 6 months
	Lightweight particles [Note (5)]	ASTM C123	Monthly	Every 6 months
	Specific gravity and absorption	ASTM C127 or ASTM C128	Monthly	Every 6 months
	Los Angeles abrasion	ASTM C131 or ASTM C535	Every 6 months	Every 6 months
	Water-soluble chloride [Note (6)]	ASTM D1411	Every 6 months	Every 6 months
	Petrographic examination [Note (7)]	ASTM C295	Every 6 months	Every 6 months
Water and Ice (if not potable)	Effect on compressive strength	ASTM C31/C31M, C39/C39M	Per ASTM C1602/C1602M	Per ASTM C1602/C1602M
	Time of set deviation	ASTM C403/C403M	Per ASTM C1602/C1602M	Per ASTM C1602/C1602M
	Chloride	ASTM C114	Per ASTM C1602/C1602M	Per ASTM C1602/C1602M
	Sulfate	ASTM C114	Per ASTM C1602/C1602M	Per ASTM C1602/C1602M
	Alkalies	ASTM C114	Per ASTM C1602/C1602M	Per ASTM C1602/C1602M
	Total solids	ASTM C1603	Per ASTM C1602/C1602M	Per ASTM C1602/C1602M
	Density	ASTM C1603	Per ASTM C1602/C1602M	Per ASTM C1602/C1602M
Concrete	Mixer uniformity	ASTM C94/C94M	Initially and every 6 months	Initially and every 6 months
	Compressive strength	ASTM C39/C39M or ASTM C943	One set of cylinders from each 100 yd^3 (76 m^3) per day [Notes (8), (9)]	One set of cylinders from each 200 yd^3 (150 m^3) with a minimum of one set per day [Notes (8), (9)]
	Slump	ASTM C143/C143M	First batch placed each day and every 50 yd^3 (38 m^3) placed [Note (8)]	First batch placed each day and every 100 yd^3 (76 m^3) placed [Note (8)]
	Slump flow	ASTM C1611/C1611M	First batch placed each day and every 50 yd^3 (38 m^3) placed [Note (8)]	First batch placed each day and every 100 yd^3 (76 m^3) placed [Note (8)]
	Air content	ASTM C173/C173M or ASTM C231	First batch placed each day and every 50 yd^3 (38 m^3) placed [Note (8)]	First batch placed each day and every 100 yd^3 (76 m^3) placed [Note (8)]
	Temperature	ASTM C1064/C1064M	First batch placed each day and every 50 yd^3 (38 m^3) placed [Note (8)]	First batch placed each day and every 100 yd^3 (76 m^3) placed [Note (8)]
	Density (unit weight)	ASTM C138/C138M	Test in conjunction with each set of compressive strength cylinders [Note (8)]	Daily [Note (8)]
	Static segregation (rapid test)	ASTM C1712/C1712M	First batch placed each day and every 50 yd^3 (38 m^3) placed [Note (8)]	First batch placed each day and every 100 yd^3 (76 m^3) placed [Note (8)]
	Passing ability	ASTM C1621/C1621M	Once every 100 yd^3 (76 m^3) per day [Note (8)]	Once every 200 yd^3 (150 m^3) with a minimum of once per day [Note (8)]

Table CC-5200-1
Minimum Testing Frequencies for Concrete Constituents and Concrete (Cont'd)

Material	Requirements	Test Method	Frequency [Note (1)]	
			Initial [Note (2)]	After Field Experience [Note (3)]
General Purpose Grout	Compressive strength	ASTM C109 or ASTM C1107/C1107M	Daily	Daily

NOTES:
(1) Testing frequencies on a time basis apply only during production and placement of concrete or grout and when the constituent is being used.
(2) Initially during the development of the first 30 tests of production concrete and whenever the criteria for the alternate frequency [Note (3)] cannot be met.
(3) Field experience is satisfactory when the running average of all three consecutive strength test results for at least 30 consecutive tests meets or exceeds f'_c and no single result falls below f'_c by more than 500 psi (3.5 MPa) when f'_c is 5,000 psi (35 MPa) or less, or by more than $0.10f'_c$ when f'_c is greater than 5,000 psi (35 MPa).
(4) If required by the Construction Specification.
(5) Not required for crushed stone quarried from rock strata unless petrographic analysis indicates acceptable but significant quantities of these contaminants.
(6) The chloride content of the concrete shall be calculated in accordance with CC-2231.
(7) The report shall be evaluated by the Designer.
(8) Test frequencies apply to each concrete mix design placed each day.
(9) Set of cylinders shall be in accordance with CC-5232.3.2(a).

If the aggregate sampled for gradation and materials finer than #200 sieve tests are not within the specification limits, two additional samples shall be obtained from the same location and tested. If both of the retest samples are within specification limits, the aggregate is acceptable. If either or both of the retest samples is outside of the specification limits, the three test results shall be averaged. This test result shall be averaged with the previous five aggregate test results. If the average of the six tests is within specification limits, the remaining aggregate is acceptable. If the average of the six tests is outside specification limits, the remaining aggregate shall be adjusted to bring the aggregate within limits or the aggregate shall be rejected.

If the aggregate sampled for the other quality control tests is outside the specification limits, two additional aggregate samples shall be obtained from the same location and tested. If both samples are within the specification limits, the aggregate is acceptable.

CC-5223.2 Testing Frequency. The frequency of testing shall be as shown in Table CC-5200-1.

CC-5224 Mixing Water

CC-5224.1 Requirements. Quality control testing shall be performed to ensure conformity with the requirements of CC-2223.

CC-5224.2 Testing Frequency. The frequency of testing shall be as shown in Table CC-5200-1.

CC-5230 CONCRETE

CC-5231 Mixer Uniformity

Mixer uniformity tests shall be performed on stationary and truck mixers to determine that the mixers are capable of combining the concrete constituents into a thoroughly mixed and uniform mass.

CC-5231.1 Requirements. Mixer uniformity shall be established in accordance with ASTM C94/C94M.

CC-5231.2 Testing Frequency. The frequency of testing shall be as shown in Table CC-5200-1.

CC-5232 Concrete Properties

(a) Concrete slump, temperature, air content, unit weight, and physical properties examination shall be performed on a common sample to establish conformance with the provisions of the Construction Specification. The sampling of freshly mixed concrete for the above tests shall be in accordance with ASTM C172. For SCC mixtures, sampling shall be in accordance with ASTM C1758. This sampling shall take place after all material and water additions have been made.

(b) The chloride content of the concrete shall be calculated and evaluated each time chloride test results are received on any one of the constituents. The calculation shall be based on the most recent chloride test results of the other constituents.

CC-5232.1 Slump.

CC-5232.1.1 Requirements. Quality control testing in accordance with ASTM C143/C143M shall be performed to ensure conformity to the requirements of the Construction Specification. For SCC mixtures, slump flow according to ASTM C1611 shall also be used.

CC-5232.1.2 Testing Frequency. The frequency of testing shall be as shown in Table CC-5200-1.

CC-5232.2 Temperature, Air Content, and Unit Weight.

CC-5232.2.1 Requirements. Temperature, air content, and unit weight shall be measured to ensure conformance with the Construction Specification. Air content tests shall be made in accordance with ASTM C173/C173M or ASTM C231. Unit weight tests shall be made in accordance with ASTM C138/C138M.

CC-5232.2.2 Testing Frequency. The frequency of testing shall be as shown in Table CC-5200-1.

CC-5232.2.3 Evaluation and Acceptance. The concrete is acceptable if no more than one individual air content test result in a placement is outside the specified range of air content by more than 20%, provided the average of all air content test results in each placement is within the limits specified in CC-2231.7.5.

CC-5232.3 Physical Properties.

CC-5232.3.1 Requirements. Testing of concrete physical properties shall be performed for the purpose of establishing conformance with the provisions of the Construction Specification.

CC-5232.3.2 Evaluation and Acceptance.

(a) Samples for compressive strength tests of each class of concrete shall be taken at the frequency of testing shown in Table CC-5200-1. Concrete for compressive strength tests shall be sampled in accordance with ASTM C172. Cylinders for acceptance tests shall be molded and laboratory cured in accordance with ASTM C31/C31M and tested in accordance with ASTM C39/C39M. A strength test shall be the average of the strengths of at least two 6 in. × 12 in. (150 mm × 300 mm) cylinders or at least three 4 in. × 8 in. (100 mm × 200 mm) cylinders made from the same sample of concrete and tested at 28 days or at the test age designated for determination of specified strength, f'_c.

(b) When the frequency of testing will provide less than five tests for a given concrete mix for the containment, tests shall be made from at least five randomly selected batches, or from each batch if fewer than five are used.

(c) The strength level of the concrete will be considered satisfactory if the averages of all sets of three consecutive strength tests at "a" days equal or exceed the specified strength and no individual strength test result falls below the specified strength by more than500 psi (3.5 MPa).

(d) Supplementary compressive strength tests may be required to check the adequacy of curing and to determine form removal time. When such strength tests are required, the specimens shall be molded and cured under field conditions in accordance with ASTM C31/C31M and tested in accordance with ASTM C39/C39M. Such specimens shall be molded at the same time and from the same batch as the laboratory cured acceptance test specimens. Procedures for protecting and curing the concrete in the structure shall be improved when the strength of field cured cylinders at "a" days is less than 85% of that of the companion laboratory cured cylinders. When the laboratory cured cylinder strengths are appreciably higher than the specified strengths, the field cured cylinder strengths need not exceed the specified strength by more than 500 psi (3.5 MPa) even though the 85% criterion is not met.

(e) If verification of tensile strength is required, eight sets of four test specimens shall be prepared for each type of concrete throughout the period of construction. They shall be molded and laboratory cured in accordance with ASTM C31/C31M and tested at "a" days in accordance with ASTM C78 or ASTM C496/C496M. For each set, three specimens shall be tested for flexure or splitting tensile strength and one for compression.

(f) If the test results do not satisfy the acceptance criteria, the Constructor or Fabricator shall prove to the satisfaction of the Designer that the load carrying capacity of the structure is not jeopardized. If the possibility of low strength concrete is confirmed and computations indicate that the load carrying capacity may have been significantly reduced, test of cores drilled from the area in question may be required in accordance with ASTM C42/C42M. Three cores shall be taken for each case of a cylinder test more than 500 psi (3.5 MPa) below the specified strength.

(g) Concrete in the area represented by the core will be considered structurally adequate if the average of the three strength values is equal to at least 85% of specified strength and if no single core is less than 75% of specified strength. To check testing accuracy, locations represented by the erratic core strengths may be retested. If the strength acceptance criteria are not met by the retests and if structural adequacy remains in doubt, the nonconforming concrete must be replaced. The structural adequacy shall be determined by the Designer.

CC-5233 Preplaced Aggregate Concrete

CC-5233.1 Aggregate.

(a) Tests for cleanliness, in accordance with ASTM C117, and gradation, in accordance with ASTM C136, shall be performed for each 200 tons (180 000 kg) of aggregate placed in the forms.

(b) Visual examination of aggregate for cleanliness shall be maintained while washing, transporting, and placing aggregate.

CC-5233.2 Cement, Mineral Filler, and Fluidifier.

(a) Material shall be tested in accordance with CC-5220.

(b) Grout fluidifier shall be tested in accordance with ASTM C937. In addition, the grout fluidifier shall be certified by the Constructor, Fabricator, Nonmetallic Material Manufacturer, or Nonmetallic Constituent Supplier to possess the same physical and chemical properties as the grout fluidifier developed and used in trial mix tests.

CC-5233.3 Intrusion Grout.

(a) The viscosity of each batch of intrusion grout shall be determined in accordance with ASTM C939. The Construction Specification shall establish the flow factor units to be used as the basis for acceptance, rejection, and adjustment of each grout batch mix.

(1) Prior to transferring grout from the mixer to the agitator (if no intermediate agitation is planned prior to pumping), at least one flow cone test for each mix shall fall within the specified limits. Grout not meeting the specified flow factors shall not be transferred to the agitator.

(2) During agitation, if the grout is stiffening, a flow cone test shall be performed just prior to pumping. If the flow cone test result falls outside the specified flow factor limits, the grout batch shall be discarded. Each flow cone test result shall be recorded and its time verified.

(b) The temperature of each grout batch shall be measured at the mixer, at the agitator, and after the grout has left the pump at the point of injection, and recorded. If the temperature of the grout at the place of entering the form is outside of the specified limits for more than one in five consecutive batches, corrective measures shall be taken.

(c) Expansion and bleeding tests shall be performed on a grout sample taken from an actual batch just prior to pumping in accordance with ASTM C940, as modified by the Construction Specification. Expansion and bleeding tests shall be made for each grout batch from which test cylinders are taken.

(d) The time of set shall be determined on a grout sample taken from an actual batch just prior to pumping in accordance with ASTM C953, or as modified by the Construction Specification.

CC-5233.4 Concrete. For each preplaced aggregate concrete placement, test cylinders shall be fabricated from each specified batch or each 100 yd^3 (76 m^3) of grout, or fraction thereof, pumped during the grouting operation. The number of test cylinders and their test age shall be as specified in the Construction Specification. The 6 in. × 12 in. (150 mm × 300 mm) heavy-duty test cylinder molds and casting procedures shall conform to the requirements of ASTM C943. Cylinders shall be moist-cured in accordance with ASTM C31/C31M until tested in accordance with ASTM C39/C39M.

CC-5234 General Purpose Grout

CC-5234.1 Constituents.

CC-5234.1.1 Requirements. Quality control tests shall be conducted on grout constituents in accordance with the requirements of CC-5220.

CC-5234.1.2 Test Frequency. The frequency of testing shall be as shown in Table CC-5200-1.

CC-5234.2 Physical Properties.

CC-5234.2.1 Requirements. Grout shall be tested in accordance with ASTM C109/C109M or ASTM C1107/C1107M for the purpose of establishing conformance of compressive strength to the requirements of the construction specifications.

CC-5234.2.2 Test Frequency. The frequency of testing shall be as shown in Table CC-5200-1.

CC-5240 GROUT FOR GROUTED TENDON SYSTEMS

CC-5241 General

Grout fluidity, temperature, and compressive strength shall be specified in the Construction Specification and determined on a common sample in accordance with CC-2243.

CC-5242 In-Process Testing Frequencies

CC-5242.1 Temperatures. Temperature of the air and combined grout constituents shall be measured and recorded hourly during the grouting operation to determine compliance with the Construction Specification.

CC-5242.2 Fluidity. The fluidity of the grout shall be measured prior to placement of the first batch each day. An additional test shall be made for each 20 subsequent batches but not less than one test for every fourth tendon grouted each day. Testing for fluidity shall be in accordance with CC-2243.3.2(e).

CC-5242.3 Compressive Strength. Grout strength tests consisting of a set of 3 cube specimens shall be made at the rate of one set for each 100 batches of grout, but not less than one set per day. Testing for compressive strength shall be in accordance with CC-2243.3.2(b).

CC-5242.4 Chloride Testing. During grouting, the amount of water-soluble chloride in the grout shall be determined on a weekly basis per ASTM C1218/C1218M for each lot or batch of constituents.

CC-5300 EXAMINATION OF REINFORCING SYSTEMS

CC-5310 GENERAL

This subarticle describes the requirements for the examination of reinforcing bars and their splices and joints.

CC-5320 EXAMINATION OF MECHANICAL SPLICES AND MECHANICALLY HEADED DEFORMED BARS

Acceptance criteria for all splicing and mechanically headed deformed bar systems shall be as described in the Construction Specification.

CC-5321 Sleeve With Ferrous Filler Metal Splices and Mechanically Headed Deformed Bars

(a) One sleeved connection from each day's work per splicing crew shall be examined daily for proper fit-up.

(b) All completed sleeved connections shall be visually examined after cooling for acceptable bar end locations. Filler metal shall be visible at accessible ends of the splice sleeve and at the tap hole. Each accessible end of the splice sleeve or mechanical anchorage device shall also be subjected to the maximum allowable void criteria as described in the Construction Specification. Splices and mechanically headed deformed bars not meeting these criteria shall be removed and replaced.

CC-5322 Taper Threaded Splices and Mechanically Headed Deformed Bars

(a) Bar ends, splice sleeves, and mechanical anchorage devices (heads) shall be visually examined prior to assembly for cleanliness.

(b) Threads shall be checked with a Manufacturer's thread gage.

(c) Bars shall be marked with a suitable marker to indicate depth of insertion into splice or mechanical anchorage device. After assembly, the actual depth of insertion shall be checked for compliance with CC-4333.3 by means of this mark.

(d) Proper assembly and torque shall be checked for compliance with the installation procedure described in the Construction Specification.

(e) One splice for each 100 production splices and one mechanically headed deformed bar for each 100 production headed bars shall be disassembled and inspected for

compliance with CC-4333.3, and all threads rechecked with the Manufacturer's thread gage.

CC-5323 Swaged Splices and Mechanically Headed Deformed Bars

(a) Bar ends, splice sleeves, and mechanically headed deformed bars shall be visually examined prior to assembly for cleanliness and proper end preparation.

(b) Bars shall be marked with a suitable marker to indicate depth of insertion into splice or mechanical anchorage device. After completion, the actual depth of insertion shall be checked for compliance with CC-4333.3 by means of this mark.

(c) Proper assembly and swaging pressure shall be checked for compliance with the installation procedure described in the Construction Specification.

CC-5324 Threaded Splices in Thread Deformed Reinforcing Bar and Mechanically Headed Deformed Bars

(a) Bar ends, splice sleeves, and mechanical anchorge devices (heads) shall be visually examined for damage, cleanliness, and proper end preparation prior to assembly.

(b) Threads shall be checked with a Manufacturer's thread gage.

(c) Bars shall be marked with a suitable marker to indicate depth of insertion into the splice or mechanical anchorage device. After assembly, the actual depth of insertion shall be checked for compliance with CC-4333.3 by means of this mark.

(d) Proper assembly and torque at both ends of coupling shall be checked for compliance with the installation procedure described in the Construction Specification.

(e) One splice and one mechanically headed deformed bar of each 100 production splices and mechanically headed deformed bars shall be disassembled and inspected for compliance with CC-4333.3, and all threads shall be rechecked with the Manufacturer's thread gage.

CC-5325 Cold Roll Formed Parallel Threaded Splices and Mechanically Headed Deformed Bars

(a) Bar ends, splice sleeves, and mechanically headed deformed bars shall be visually examined prior to assembly for cleanliness.

(b) Threads shall be checked with a Manufacturer's thread gage.

(c) Bars shall be marked with a suitable marker to indicate depth of insertion into splice or mechanically headed deformed bar anchorage device. After assembly, the actual depth of insertion shall be checked for compliance with CC-4333.3 by means of this mark.

(d) Proper assembly and torque shall be checked for compliance with the installation procedure described in the Construction Specification.

(e) One splice and one mechanically headed deformed bar of each 100 production splices and 100 mechanically headed deformed bars shall be disassembled and inspected for compliance with CC-4333.3, and all threads shall be rechecked with the Manufacturer's thread gage.

CC-5340 EXAMINATION OF BENDS

The bent or straightened surfaces of all reinforcing bars that are partially embedded in concrete and that are bent and/or straightened in the field shall be visually examined for indications of cracks.

(a) Bars exhibiting transverse cracks or fissures shall be rejected and the bent or straightened section shall be removed and replaced using a splice in accordance with CC-4330.

(b) The presence of longitudinal seams shall not be cause for removal.

CC-5400 EXAMINATION OF PRESTRESSING SYSTEMS

CC-5410 GENERAL

This subarticle describes the examination requirements for prestressing systems. Aspects of the systems that affect quality such as tendon fabrication, placement and tensioning of tendons, installation of ducts and bearing plates, and the application of the corrosion prevention materials shall be examined.

CC-5420 REQUIRED EXAMINATION

CC-5421 General

The design, fabrication, and installation of prestressing systems shall be in conformance with the Construction Specification. The Construction Specification shall include provisions to control and examine tendon length, twist, temporary protective coatings if required, anchorage hardware, conformance to Manufacturer's standards, coiling and packaging requirements, handling, shipping, and storage procedures.

CC-5422 Bearing Plates

CC-5422.1 Preplacement. Bearing plates shall be examined for dimensional accuracy, out-of-square, and surface smoothness in accordance with the criteria stated in the Construction Specification.

CC-5422.2 Post-Placement. Following installation, the position of all bearing plates shall be examined prior to concrete placement for proper location and orientation. Placement tolerances shall be in accordance with the

Construction Specification. If the orientation of the plate tends to inhibit concrete placement, a program shall be specified in the Construction Specification for the examination of the soundness of the concrete in the bearing zone.

CC-5423 Tendon Ducts

CC-5423.1 Preplacement. Tendon ducts shall be examined to ensure compliance with requirements of the Construction Specification as to type, diameter, and wall thickness. The frequency of examination shall be specified in the Construction Specification.

CC-5423.2 Post-Placement. Tendon ducts shall be examined for position and alignment in accordance with CC-4452. After installation, but prior to concrete placement, the ducts shall be visually examined for damage, including holes and cracks, and for dents and ovalling which may affect required minimum clear aperture. The criteria for the visual examination shall be given in the Construction Specification. Prior to and following concrete placement, all ducts shall be examined to ensure that minimum clear aperture is provided.

CC-5424 Prestressing Steel

(a) All tendons shall be examined to verify that proper element quantities are present. The elements shall be examined at the frequency defined in the Construction Specification to verify proper diameter.

(b) The exposed surfaces of the prestressing elements shall be visually examined upon shipping, receipt, and prior to installation to ensure that damage such as nicks, bends, or corrosion has not occurred to a detrimental degree. Criteria for acceptance shall be given in the Construction Specification. Tendons shall be examined for banding and twisting of the bundle to ensure compliance with the field drawings.

CC-5425 Anchorage Components

(a) Anchorage components shall be examined for dimensions, thread, and surface conditions. The frequency of such examinations, as well as tolerance and any other acceptance criteria, shall be in accordance with the Construction Specification.

(b) Following tensioning, all anchorage assemblies shall be visually examined. Broken tendon wires or components and out-of-tolerance values for elongation or tensioning shall be evaluated for acceptance per CC-4468.

CC-5426 Tensioning

The tensioning of tendons shall be examined for conformance with written procedures. Current calibration of stressing systems shall be verified. Examinations shall be made to verify proper application of stressing loads and measurement and recording of tendon elongations. The required frequency of examination shall be specified in the Construction Specification. Results of all stressing observations and data shall be reviewed by the Designer.

CC-5500 EXAMINATION OF WELDS

CC-5510 GENERAL

CC-5511 Scope

This subarticle contains the nondestructive examination requirements for the welding of liners and attachments thereto.

CC-5512 Time of Examination of Welds

Acceptance examination of welds shall be performed at the times stipulated in (a) through (d) below, except as otherwise specified in CC-5520.

(a) Radiographic examination of all welds in liners may be performed prior to any required postweld heat treatment for P-No. 1 material.

(b) Magnetic particle or ultrasonic examinations shall be performed after any required postweld heat treatment, except P-No. 1 materials may be examined prior to PWHT.

(c) All dissimilar metal weld joints shall be examined after final postweld heat treatment.

(d) Leak testing shall be performed after any required final PWHT.

CC-5520 REQUIRED EXAMINATION OF WELDS

CC-5521 Welding Categories

(a) Category A and B welds shall be radiographed in accordance with CC-5531, except where backup bars are used in accordance with CC-4542.1. Category A and B welds with backup bars shall be examined by the magnetic particle or ultrasonic examination method for the full length of the weld.

(b) Category D butt welds shall be examined in accordance with (a) above. Where the Category D weld around the insert plate is within a distance from the center of the opening equal to the diameter of the opening, the weld shall be 100% radiographed in that area. All butt welds in the insert plate shall be 100% radiographed.

(c) Other Category D welds and Category E, F, G, and J welds shall be examined by the magnetic particle or ultrasonic examination method for the full length of the weld.

(d) Full penetration Category H welds shall be examined by the magnetic particle or ultrasonic examination method for the full length of the weld.

Except for the exposed ends of welds, which require only visual examination, Category H permanent structural and nonstructural attachment welds to the liner or thickened liner plate shall be examined by the magnetic particle or liquid-penetrant method for the full length of the weld, with the following exceptions:

(1) Partial penetration welds to a thickened liner plate that have a groove depth or throat dimensions equal to or less than 1 in. (25 mm) need only be visually examined.

(2) Fillet welds to a thickened liner plate that have throat dimensions less than $\frac{1}{2}$ in. (13 mm) need only be visually examined.

(3) Liner anchor welds need only be visually examined.

Other Category H partial penetration welds that have a groove depth or throat dimension greater than 1 in. (25 mm) and fillet welds that have a throat dimension of $\frac{1}{2}$ in. (13 mm) or greater shall be examined by the liquid penetrant or magnetic particle method for the full length of the weld, except that the exposed ends of welds need only be visually examined. All Category H welds exclusive of those described above shall be visually examined.

(e) All welds, except attachment welds that do not penetrate the liner, shall be leak tested in accordance with CC-5536 for the full length of the weld.

(f) For all austenitic welds, liquid penetrant shall be substituted for magnetic particle examination.

(g) Temporary attachment weld removal areas shall be inspected and shall meet the requirements of CC-2533, and the removal area shall be examined by the magnetic particle or liquid-penetrant method.

CC-5522 Weld Joints in Backups

Weld joints in backup bars, and structural shapes used as backups, shall be examined by the magnetic particle, liquid penetrant, or ultrasonic examination method.

CC-5523 Splice Sleeve Welds

The surfaces of all welds between splice sleeves and the liner shall be visually examined.

CC-5524 Stud Welds

Stud welds shall be visually examined.

CC-5525 Leak-Chase Systems

All the welds in the leak-chase systems shall be leak tested.

CC-5526 Electroslag Welds

In addition to the requirements for the type of weld being examined, all complete penetration welds made by the electroslag welding process in ferritic materials shall be ultrasonically examined.

CC-5530 EXAMINATION PROCEDURES

CC-5531 Radiographic Examination

CC-5531.1 Examination Procedure. Radiographic examination as required by CC-5520 shall be performed in accordance with Section V, Article 2, except that the geometric unsharpness shall not exceed the limits of Section V, Article 2, T-251.

CC-5531.2 Extent of Examination. The first 10 ft (3 m) of weld and one spot (not less than 10 in. (250 mm) in length) in each additional 50 ft (15.2 m) increment of weld (weld test unit), or fraction thereof, shall be radiographed for each welder and welding position (flat, vertical, horizontal, and overhead). In any case, a minimum of 2%, by length, of all butt welds shall be radiographed. The 100% radiography required by CC-5521(b) shall not be included in determining the 2%. Where backup bars are used, the welds shall be examined in accordance with CC-5521.

CC-5531.3 Selection of Spots for Radiographic Examination. The spots of welds to be radiographically examined shall be randomly selected but no two spots in adjacent weld test units shall be closer than 10 ft (3 m). The location of all spots shall be recorded.

CC-5531.4 Time of Examination. Radiographic examination shall be performed prior to the placement of concrete or other obstructions.

CC-5531.5 Repair and Reexamination.

(a) The examination of the first 10 ft (3 m) of weld required by CC-5531.2 is acceptable when the aggregate length of unacceptable discontinuities is less than 10 in. (250 mm). If this requirement is not met, the welder's next 10 ft (3 m) of weld shall be radiographed and evaluated to the acceptance criteria above. All defective welding disclosed shall be repaired and reradiographed.

(b) When a radiographed spot meets the acceptance standards of CC-5542, the entire weld unit represented by the spot is considered acceptable. When a radiographed spot fails to meet the specified acceptance standards, two additional spots shall be radiographically examined in the same weld test unit at locations at least 1 ft (300 mm) removed on each side from the original spot. The locations of these additional spots shall be determined using the same procedure followed in the selection of the original spot for examination, and the examination results shall determine the corrective actions of (1) and (2) below.

(1) If the two additional spots examined meet the acceptance standards, the entire weld unit represented by the three spot radiographs is considered acceptable. However, the defective welding disclosed by the first of the three radiographs shall be repaired and reradiographed.

(2) If either of the two additional spots examined fails to meet the specified acceptance standards, the entire weld test unit is unacceptable. The entire unacceptable weld shall be removed and the joint shall be rewelded or, optionally, the entire weld unit may be completely radiographed and defective welding only need be repaired.

(c) Repair welding shall be performed using a qualified procedure. The weld repaired areas in each weld test unit shall be radiographed to meet the acceptance criteria specified in CC-5542.

CC-5533 Liquid Penetrant Examination

Liquid penetrant examination shall be performed in accordance with Section V, Article 6.

CC-5534 Magnetic Particle Examination

Magnetic particle examination shall be performed in accordance with Section V, Article 7.

CC-5535 Ultrasonic Examination

Ultrasonic examination shall be performed in accordance with Section V, Article 5.

CC-5536 Leak Testing

CC-5536.1 Liner Welds. Leak testing of liner welds shall be performed by one of the following techniques:

(a) vacuum box technique, in accordance with Mandatory Appendix D2-VI of this document

(b) bubble test — direct-pressure technique, in accordance with Section V, Article 10, Mandatory Appendix I

(c) halogen diode detector probe test, in accordance with Section V, Article 10, Mandatory Appendix III

(d) helium mass spectrometer test — detector probe technique, in accordance with Section V, Article 10, Mandatory Appendix IV

CC-5536.2 Leak-Chase Systems. Leak testing of leak-chase system welds shall be performed either by

(a) bubble test — direct-pressure technique in accordance with Section V, Article 10, Mandatory Appendix I, pressurized to a test pressure of at least 115% of the Design Pressure, but no less than 25 psi (170 kPa), or

(b) the channels shall be pressurized to a test pressure of at least 115% of the Design Pressure but no less than 25 psi (170 kPa). The pressure shall be gradually increased to no more than one-half of the test pressure, after which the pressure shall be increased in steps of approximately one-tenth of the test pressure until the required test pressure has been reached. The final test pressure shall not be applied until the leak chase channels and pressuring medium are approximately the same temperature.

The test gage shall conform to the requirements of CC-6222. The test pressure shall be held for a minimum of 60 min. The pressure decay shall not exceed $\frac{1}{2}$ of 1% of the test pressure.

CC-5537 Visual Examination

Visual examination shall be performed in accordance with Section V, Article 9.

CC-5540 ACCEPTANCE STANDARDS

CC-5541 General Requirements

Unacceptable weld defects shall be removed or reduced to an acceptable size, and, when required, the weld shall be repaired and reexamined in accordance with CC-4540. Acceptance standards for welds shall be as stated in CC-5540, while acceptance standards for material adjacent to the weld shall be as stated in CC-2530.

CC-5542 Radiographic Acceptance Standards (23)

Welds that are shown by radiography to have any of the following types of discontinuities are unacceptable:

(a) any type of crack or zone of incomplete fusion or penetration

(b) any other elongated indication that has a length greater than

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

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

(3) $\frac{3}{4}$ in. (19 mm) for t over $2\frac{1}{4}$ in. (57 mm)

where t is the thickness of the thinner portion of the weld

(c) any group of indications (excluding nonrelevant indications) in line that have an aggregate length greater than t in a length of $12t$, except where the distance between the successive indications exceeds $6L$, in which case the aggregate length is unlimited, L being the length of the largest indication

(d) porosity in excess of that shown as acceptable in Mandatory Appendix D2-VI

CC-5544 Liquid Penetrant Acceptance Standards

CC-5544.1 Evaluation of Indications.

(a) Mechanical discontinuities at the surface will be indicated by bleeding out of the penetrant; however, localized surface imperfections such as may occur from machining marks or surface conditions may produce similar indications that are nonrelevant to the detection of unacceptable discontinuities.

(b) Any indication that is believed to be nonrelevant shall be regarded as a defect and shall be reexamined to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation that would mask indications of defects are unacceptable.

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

CC-5544.2 Acceptance Standards.

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

(b) Unless otherwise specified in this Subsection, the following relevant indications are unacceptable:

(1) any cracks or linear indications

(2) rounded indications with dimensions greater than $\frac{3}{16}$ in. (5 mm)

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

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

CC-5545 Magnetic Particle Acceptance Standards

CC-5545.1 Evaluation of Indications.

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

(b) Any indication that is believed to be nonrelevant should be regarded as a defect and shall be reexamined by the same or other nondestructive examination methods to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. After an indication has been verified to be nonrelevant, it is not necessary to reinvestigate repetitive, nonrelevant indications of the same type. Nonrelevant indications that would mask indications of defects are unacceptable.

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

CC-5545.2 Acceptance Standards.

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

(b) Unless otherwise specified in this Subsection, the following relevant indications are unacceptable:

(1) any cracks or linear indications

(2) rounded indications with dimensions greater than $\frac{3}{16}$ in. (5 mm)

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

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

CC-5546 Ultrasonic Acceptance Standards

All indications that produce a response greater than 20% of the reference level shall be investigated to the extent that the operator can determine the shape, identity, and location of all such reflectors and evaluate them in terms of the acceptance rejection standards as given in (a) and (b) below.

(a) Indications are unacceptable if the amplitude exceeds the reference level and discontinuities have lengths that exceed

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

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

(3) $\frac{3}{4}$ in. (19 mm) for t over $2\frac{1}{4}$ in. (57 mm)

where t is the thickness of the weld being examined. If a weld joins two members having different thicknesses at the weld, t is the thinner of these two thicknesses.

(b) Where indications are interpreted to be cracks, lack of fusion, or incomplete penetration, they are unacceptable regardless of discontinuity or signal amplitude.

CC-5547 Leak Testing Acceptance Standards

CC-5547.1 Evaluation.

CC-5547.1.1 Vacuum Box and Bubble Testing. Through-thickness leaks will be indicated by the formation of a continuous stream of bubbles in the bubble-forming solution. The formation of small single bubbles that do not grow shall not be considered relevant.

CC-5547.1.2 Halogen Diode or Helium Mass Spectrometer Test. Through-thickness leaks will be indicated when the leakage rate exceeds that obtained from the applicable capillary leak calibration.

CC-5547.1.3 Pressure Decay Testing. Pressure decay in leak-chase systems shall not exceed the acceptance criterion of CC-5536.2.

CC-5547.2 Acceptance Standards. All through-thickness leaks are unacceptable and shall be repaired and retested. When pressure decay results are unacceptable, the leak path shall be determined, repaired, and the test repeated.

CC-5548 Visual Acceptance Standards

(a) All areas around each stud weld that indicate lack of fusion or absence of weld are unacceptable and shall be repaired.

(b) For welds between splice sleeves and the liner or structural element, and welds in embedment anchors (see CC-4600), the following imperfections are unacceptable:

(1) any crack.

(2) surface porosity, the sum of whose diameters exceeds $^3/_8$ in. (10 mm) in any linear inch of weld or $^3/_4$ in. (19 mm) in any 12 in. (300 mm) length of weld. As-welded surfaces are permitted; however, the surface of welds shall be free from coarse ripples and grooves and abrupt ridges and valleys. Unacceptable imperfections shall be removed or reduced in order to meet the above limits and reexamined.

(c) All welds described in CC-5521 shall conform to the following visual examination criteria:

(1) Weld surfaces shall comply with the requirements in CC-4542.5.

(2) Cracks are unacceptable.

(3) 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.

(4) 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.

(5) 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.

(6) 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

(-a) 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

(-b) four or more pores are aligned and the pores are separated by $^1/_{16}$ in. (1.5 mm) or less, edge to edge.

(7) The length and location of welds shall be as specified, except that weld lengths may be longer than specified. For weld lengths less than 3 in. (75 mm), the permissible underlength is $^1/_8$ in. (3 mm), and for welds 3 in. (75 mm) and longer, the permissible underlength is $^1/_4$ in. (6 mm). Intermittent welds shall be spaced within 1 in. (25 mm) of the specified location.

(8) Arc strikes and associated blemishes on the weld or in the base material are acceptable provided no cracking is visually detected.

(9) Slag whose major surface dimension is $^1/_8$ in. (3 mm) or less is irrelevant. Isolated surface slag that remains after weld cleaning and does not exceed $^1/_4$ 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.

(d) Unacceptable imperfections shall be removed or reduced to meet the above limits and reexamined.

ARTICLE CC-6000
STRUCTURAL INTEGRITY TEST OF CONCRETE CONTAINMENTS

CC-6100 GENERAL REQUIREMENTS

CC-6110 INTRODUCTION

This Article contains the requirements for structural integrity testing of concrete containments (CC). The CC shall be tested for structural acceptability as a prerequisite for Code acceptance and stamping. The test is performed at a test pressure of at least 1.15 times the containment design pressure to demonstrate the quality of construction and to verify the acceptable performance of new design features. The structural integrity test (SIT) shall include the differential pressure test of the boundary between the drywell and wetwell compartments of pressure suppression type containments if the boundary loading induces stresses in the containment structure. The differential pressure shall be at least 1.0 times the maximum design differential pressure. However, measurements made solely to demonstrate integrity of the compartment boundary, as distinct from the containment, are not subject to the requirements of this Article. The requirements for the structural test are contained in CC-6300. The test and instrumentation plan shall be defined by the Designer and implemented by the Constructor. The Designer or his designated representative shall witness the integrity test. Test results and conclusions shall be documented in the construction report. The duties of the Authorized Inspector with respect to this test are stipulated in NCA-5280 and NCA-5290.

CC-6120 TEST AND INSTRUMENT PLAN

CC-6121 Scope

The test and instrumentation requirements shall be defined in the Design Specification and included in the Construction Specification. The Construction Specification shall describe the type and location of instrumentation and shall also include a description of the method of applying the test pressure. This test plan shall be available prior to construction so that sufficient time will be available for the placement of any instrumentation to be embedded in concrete or otherwise installed during construction.

CC-6122 Alteration of Test Plan

The Designer may alter the test plan required by CC-6121 at any time prior to completion of the test.

CC-6123 Weather

The limits of design environmental conditions under which the test may be conducted shall be specified by the Designer. The test shall be postponed or interrupted if environmental conditions are not within the limits specified by the Designer or are such as to pose a safety hazard to test personnel.

CC-6130 TESTING OF DIVISION 1 PARTS, APPURTENANCES, AND COMPONENTS

If parts, appurtenances, and components designed under the rules of Division 1 are to be tested during the containment structural integrity test, they shall be examined in accordance with the rules of Division 1. Any examination required by Division 1 to be performed at elevated pressure shall be done at the structural integrity test pressure (1.15 × design pressure).

CC-6140 PRETEST CONDITIONS

The CC shall be structurally complete and equipped with the permanent access hatch covers and airlock doors. Piping and electrical penetrations shall either be complete or the penetration sleeves fitted with temporary closures which transfer the pressure load to the sleeve in a similar manner as the permanent penetration device.

CC-6150 CLASSIFICATION OF STRUCTURE

CC-6151 Prototype Containments

A CC incorporating new or unusual design features not yet confirmed by tests, as determined by the Designer, shall be designated a prototype containment.

CC-6152 Nonprototype Containments

A CC shall be designated a nonprototype containment when the Designer has determined that the design has been verified by previous tests on prototype containments.

CC-6160 STRUCTURAL RESPONSE PREDICTIONS

Predictions of displacements, and, in prototype containments, strains, shall be made prior to the start of the test.

CC-6200 TEST PROCEDURE

CC-6210 PRETEST EXAMINATION

Prior to pressure testing, a thorough visual examination of the accessible portions of the containment shall be made by the Designer or his designee. The object of such examination is to record conditions such as spalling or unusual cracking of the concrete, bulging, deformation, or other damage to the liner, and other data that may be needed to interpret the behavior of the containment.

CC-6220 INSTRUMENTATION

CC-6221 Purpose

Instrumentation shall be incorporated into the CC for measurement of displacements. Prototype containments shall also include provisions for strain measurements.

CC-6222 Pressure

Pressure gages used in pressure testing shall be connected directly to the internal environment of the containment, and measure the differential pressure between the internal and external environments.

CC-6222.1 Range of Pressure Gages. Pressure gages used in testing shall have a range of not more than four times the test pressure.

CC-6222.2 Calibration of Pressure Gages. Gages shall be calibrated against a deadweight tester or a calibrated master gage prior to and after each test.

CC-6222.3 Accuracy. Gages shall be accurate to within ±2% of test pressure.

CC-6223 Displacements

Displacement measuring instrumentation shall be attached directly to the containment shell. If the attachment is made to the liner, the Designer shall identify locations. Consideration shall be given to possible separation between the liner and the concrete. Devices may be connected either to two points on the containment or to one point on the containment and a point on a reference structure inside or outside of the containment.

CC-6223.1 Accuracy of Measurements. Specifications for displacement transducers shall provide for an accuracy of ±5% of the anticipated displacement at the point of maximum displacement as predicted or within 0.01 in. (0.25 mm), whichever is greater.

CC-6224 Strain

Strain measuring devices shall be appropriate for the material for which strain is to be measured.

CC-6224.1 Accuracy of Strain Measuring Devices. Devices used for strain measurements shall be specified to have an accuracy of ±5% of the maximum anticipated strain on the structure or 10 µin./in. (µmm/mm), whichever is greater. The minimum gage length shall be 4 in. (100 mm) for measurement of internal concrete strains or measurement of strains on concrete surfaces.

CC-6225 Crack Measurements

The widths of cracks shall be measured in the specified areas with optical comparators or wire gages. Lengths of cracks shall be measured with linear scales, or estimated if a grid is marked on the crack mapping area. Measuring devices used to measure cracks shall be capable of measuring a minimum width of 0.005 in. (0.13 mm) and have a resolution of 0.003 in. (0.076 mm).

CC-6226 Temperature

Concrete temperatures measured in conjunction with strains shall be measured with thermocouples or resistance elements. Standard thermometry devices may be used to measure ambient air temperature inside and outside the CC. Temperature measuring devices shall have an accuracy of ±2°F (±1.1°C) and a range sufficient to cover the range of temperatures expected at the device location during the test. Devices that are embedded in concrete shall be designed for long-term operation in the concrete environment.

CC-6230 PRETEST OF INSTRUMENTATION

Prior to the start of the test, the output of all instruments shall be recorded. Instruments that display undue drift or erratic readings shall be corrected, if possible, or noted. All malfunctioning instrumentation shall be reported to and evaluated by the Designer.

CC-6231 Instrument Malfunction During Test

Instruments that become erratic or inoperative during the test shall be reported to the Designer. If the Designer determines that data at this location is essential, alternate instrumentation shall be installed before proceeding with the test.

CC-6300 STRUCTURAL TEST REQUIREMENTS

CC-6310 INTRODUCTION

This subarticle contains the requirements for containment pressurization, measurements of structural response, and data collection during the SIT. These requirements apply to the containment configurations defined below. If containment configuration is such that these requirements cannot be implemented, the Designer shall specify alternative requirements. The following four containment configurations are addressed in this subarticle.

(a) Cylinder dome containments consist of a freestanding concrete cylinder, supported on a reinforced concrete base mat and closed by a concrete dome. The cylindrical wall and dome may be conventionally reinforced or prestressed. Cylinder dome containments may be of the pressurized water reactor (PWR) type or the boiler water reactor (BWR) type with a drywell structure supported by the base mat and enclosed by the containment.

(b) Cylinder cone containments consist of a concrete cylinder supported by a reinforced concrete base mat and topped by a concrete cone. The top of the cone is closed by a steel dome head. The cone and cylinder are the drywell and wetwell compartments of a BWR containment, respectively, and are separated by a diaphragm slab which may or may not transmit forces to the cylinder–cone juncture. The concrete cylinder and cone may be conventionally reinforced or prestressed.

(c) Hybrid containments consist of mixed construction of reinforced concrete and steel. The transition of steel to concrete may be at the cylinder-to-mat junction, the cylinder-to-dome junction, or at any location in between.

(d) Other containments are those with vertical and horizontal (including curved or dome type) pressure boundaries with configurations not defined above.

CC-6320 PRESSURIZATION

Containments shall be subjected to an integrity test during which the internal pressure is increased from atmospheric pressure to the test pressure and held for at least 1 hr. If the differential pressure test of the boundary between the drywell and wetwell compartments of pressure suppression type containments induces stresses in the containment shell, the differential pressure test sequence shall be included in the pressurization plan. The test requirements herein are based on the use of atmospheric air as the testing medium.

CC-6321 Rate

The CC shall be pressurized and depressurized at rates not to exceed 20% of test pressure per hour.

CC-6330 TEMPERATURE

The internal temperature shall be controlled as required for any Division 1 components, parts, or appurtenances that are pressurized during this test. Representative temperatures shall be measured if required for displacement and strain measurement corrections.

CC-6340 DATA REQUIRED

Strains, displacements, temperatures, and pressures shall be recorded at atmospheric pressure prior to starting pressurization, at reaching the test pressure, 1 hr after reaching test pressure, and upon completion of depressurization. In addition, at least five sets of readings shall be taken during pressurization and depressurization to monitor the containment response.

CC-6350 SURFACE CRACKING

The patterns of cracks that exceed 0.01 in. (0.25 mm) in width and 6 in. (150 mm) in length shall be mapped at specified locations before the test, at maximum pressure, and after the test. Locations shall be specified by the Designer and shall include areas where high surface tensile strain is predicted. At each location, an area of at least 40 ft^2 (3.7 m^2) shall be mapped.

CC-6360 DISPLACEMENT MEASUREMENTS

The Designer shall evaluate the recorded test data during the test as necessary to permit a determination that the test may proceed safely.

CC-6361 Cylinder Dome Containments

Displacement measurements of the CC as defined in CC-6310 shall meet the following provisions:

(a) Radial displacements of the cylinder at a minimum of five approximately equally spaced elevations located at 20%, 40%, 60%, 80%, and 100% of the distance between the base and the spring line. However, if the CC has a thickened lower wall section (thickness increase greater than 25% extending more than three nominal wall thicknesses in height above the base slab), one of the five displacement measurement elevations shall be at the discontinuity between the thickened wall and the nominal wall. The remaining elevations specified for radial displacements shall be readjusted to provide approximately equal spacing between the base slab and the discontinuity and between the discontinuity and the spring line. These measurements shall be made at a minimum of four approximately equally spaced azimuths. Measurement of the total displacement may be made between diametrically opposite locations on the containment wall. The radial displacement may be assumed to be equal to one-half of the measured change in diameter.

(b) Radial displacements of the containment wall adjacent to the largest opening, at a minimum of 12 points, four equally spaced on each of three concentric circles. The diameter of the inner circle shall be just large enough to permit measurements to be made on the concrete rather than on the steel sleeve; the middle approximately 1.75 times the diameter of the opening; and the outer approximately 2.5 times the diameter of the opening. For hatch designs with thickened wall sections, the concentric circle at 1.75 times the diameter shall be

relocated at the wall thickness discontinuity and the remaining circle shall be relocated approximately two wall thicknesses outside the discontinuity. The increase in diameter of the opening shall be measured in the horizontal and vertical directions. If other openings require structural verification as determined by the Designer, displacement measurements shall be made in the same manner as stipulated for the largest opening.

(c) Vertical displacement of the top of the cylinder relative to the base, at a minimum of four approximately equally spaced azimuths.

(d) Vertical displacements of the dome of the containment at a point near the apex and two other approximately equally spaced intermediate points between the apex and the spring line on at least one azimuth.

CC-6362 Cylinder Cone Containments

Displacement measurements of CC as defined in CC-6310 shall meet the following provisions:

(a) Radial displacement measurements at midheight of the cylinder, midheight of the cone, the top of the cone, and the cone–cylinder junction if the drywell floor is not constructed integral with the containment wall, shall be made at a minimum of four approximately equally spaced azimuths. Measurements should be perpendicular to the containment centerline or corrections made so these measurements refer to the containment centerline.

(b) Radial displacements of the containment wall adjacent to the largest opening, at a minimum of 12 points, four equally spaced on each of three concentric circles. The diameter for the inner circle shall be large enough to permit measurements to be made on the concrete rather than on the steel sleeve; the middle approximately 1.75 times the diameter of the opening; and the outer approximately 2.5 times the diameter of the opening. The change in diameter of the opening shall be measured on the horizontal and vertical axes. If other openings require structural verification as determined by the Designer, displacement measurements shall be made in the same manner as stipulated for the largest opening.

(c) Vertical displacement of the top of the cone relative to the base mat–wall junction shall be measured at a minimum of four approximately equally spaced azimuths.

CC-6363 Hybrid Containment

Displacement measurements of the CC as defined in CC-6310 shall meet the following provisions:

(a) Radial displacements of the concrete construction portion of the cylinder at a minimum of three elevations approximately equally spaced between the base slab and the steel–concrete juncture for containments in which the steel–concrete juncture is located in the upper one-third of the cylinder wall. For steel–concrete juncture locations in the mid one-third of the cylinder wall, radial displacements shall be measured in the concrete portion at two elevations approximately equally spaced. For steel–concrete juncture locations in the lower one-third of the cylinder wall, radial displacements shall be measured in the concrete portion at one elevation approximately equidistant between the base slab and the steel–concrete juncture. In addition, radial displacements shall be measured at the steel–concrete juncture for all juncture locations. These measurements shall be made at a minimum of four approximately equally spaced azimuths. For containments in which the steel–concrete juncture is at the cylinder–base mat intersection, no radial or vertical displacement measurements are required.

(b) Radial displacements of the containment wall adjacent to the largest opening if located in the concrete construction portion. The displacement measurements shall meet the provisions of CC-6361.

(c) Vertical displacement of the concrete portion of the cylinder at a minimum of four approximately equally spaced azimuths measured from the base slab to the wall steel–concrete juncture.

The steel shell shall be examined for leakage in compliance with NE-6224 except as noted in CC-6130.

CC-6365 Other Containments

Displacement measurement of containments as defined in CC-6310 that have vertical pressure boundaries and horizontal closures shall meet the following general provisions:

(a) Horizontal (radial) displacement of the primary vertical pressure-retaining walls at a minimum of three elevations approximately equally spaced between major load carrying restraints (base slab, diaphragm slabs, spring lines, etc.) or major discontinuities (wall thickness transitions, steel–concrete junctures, etc.), and at the elevations of major discontinuities. These measurements shall be made at a minimum of four approximately equally spaced azimuths.

(b) Vertical displacement of the primary pressure-retaining walls at a minimum of four locations nominally spaced to verify gross extension as determined by the Designer.

(c) Vertical displacement of horizontal primary pressure boundaries (domes, slabs, etc.) at a minimum of the structural centerline or as near as practical to the centerline (dome apex) and two other approximately equally spaced locations between the structural centerline and the vertical primary pressure-retaining walls on a common azimuth.

(d) Radial displacements of the pressure boundary adjacent to the largest opening. The displacement measurements shall follow the provisions of CC-6361 to the extent possible.

CC-6370 STRAIN MEASUREMENTS

Prototype containments shall be instrumented to measure strain. The strain measuring instrumentation shall be located so as to demonstrate the structural behavior of the prototypical features and the influence of these features on adjacent areas of the containment. The Designer shall, in selecting locations for strain measurement, give particular attention to the influence of the prototypical features on the following areas of the containment:

(a) the intersection of the wall and base slab

(b) the vicinity of the largest opening in the concrete construction portion

(c) other areas of major discontinuity in the curvature, slope, or thickness of the shell

(d) horizontally or vertically restrained areas

(e) steel-to-concrete transition areas

These areas shall be instrumented to measure strain if structurally influenced by the prototypical feature.

CC-6371 Baseline Measurements

Strains and associated temperatures shall be measured for a minimum period of 24 hr prior to the test to evaluate the strain variations resulting from temperature changes.

CC-6380 TEMPERATURE MEASUREMENTS

When strain measurements are to be made, temperatures shall be measured at containment shell locations as specified in the Design Specifications to establish representative temperatures for strain measurements. Temperature measurements shall be used to correct measured strain values for thermal effects.

CC-6390 POST-TEST EXAMINATION

A post-test examination shall be made within 1 week of depressurizing. The same examination made during the pretest required by CC-6210 shall be performed.

CC-6400 EVALUATION OF TEST RESULTS

CC-6410 ACCEPTANCE CRITERIA

The CC shall be considered to have satisfied the structural integrity test if the following minimum requirements are met:

(a) Yielding of conventional reinforcement does not develop as determined from analysis of crack width, strain, or displacement data.

(b) No visible signs of permanent damage to either the concrete structure or the steel liner are detected. Evidence, resulting from the test, of spalling, laminations, or voids behind the liner are pertinent considerations. Special care shall be exercised in the post-test examination (see CC-6390) to detect evidence of localized distress that may not be revealed by strain or displacement data. The significance of such distress, if detected, must be determined by the Designer and be acceptable to the Owner.

(c) Residual displacements at the points of maximum predicted radial and vertical displacement at the completion of depressurization or up to 24 hr later shall not exceed the following:

(1) For conventionally reinforced containments or conventionally reinforced directions of partially prestressed containments: 30% of measured or predicted displacement at maximum test pressure, whichever is greater, plus 0.01 in. (0.25 mm) plus measurement tolerance.

(2) For prestressed containments or prestressed directions of partially prestressed containments: 20% of measured or predicted displacement at maximum test pressure, whichever is greater, plus 0.01 in. (0.25 mm) plus measurement tolerance.

The above criteria shall be applied to the average of radial displacements measured at the same elevation.

(d) The measured displacements at test pressure at points of predicted maximum radial and vertical displacements do not exceed predicted values by more than 30% plus measurement tolerance. This criterion shall apply to the average of radial displacement measured at the same elevation. This requirement may be waived if the residual displacements within 24 hr are not greater than 10% for prestressed structures or 20% for conventionally reinforced concrete structures.

CC-6420 SURFACE CRACKS

Cracks data shall be reviewed by the Designer for evaluation of overall test results.

CC-6430 RETEST

If the measurements indicate that the requirements of CC-6410 are not met, further study by the Designer will be required. Consideration should be given to the possible effects of creep and temperature change, as well as possible inaccuracies in the measured quantities or the predicted values. If such studies still indicate that requirements of CC-6410 are not fulfilled, remedial measures shall be undertaken or a retest shall be conducted. If the containment experiences major structural changes or significant damage requiring repairs after the test, the integrity test shall be repeated following the completion of the corrective actions. In the areas where major structural repairs are performed, additional instrumentation shall be provided to determine whether the structural repair is providing suitable structural capability. Special attention shall be given to shrinkage and creep effects caused by variations in age and composition of the repaired area.

CC-6440 STRAINS

Strain measurements shall be reviewed by the Designer for evaluation of the overall test results.

CC-6500 ANALYSIS OF DATA AND PREPARATION OF REPORT

CC-6510 RESOLUTION OF TEST DATA

The results of the test shall be furnished to and examined by the Designer. Discrepancies between measured and predicted strain or deformation shall be resolved satisfactorily by review of the design, evaluation of measurement tolerances, material variability, and reexamination of the containment.

CC-6520 PRESENTATION OF DATA

Data shall be presented in the final report so that direct comparisons between predicted values and measured values may be made.

CC-6530 MINIMUM REPORT REQUIREMENTS

The following minimum information shall be included in the final test report:

(a) a description of the test procedure and the instrumentation

(b) a comparison of the measured displacements and strains with the predicted response including tolerance

(c) a summary and discussion of crack measurements

(d) an evaluation of the estimated accuracy of the measurements

(e) an evaluation of any deviation (such as test results that exceed the allowable limits), the disposition of the deviations, and the need for corrective measures

ARTICLE CC-7000
OVERPRESSURE PROTECTION

This Article does not provide specific rules for overpressure protection of concrete containments. However, when the use of pressure relief devices is specified by the Design Specification, the relief pressure shall be specified, and the rules of Article NE-7000 are applicable, except that Article CC-3000 shall apply rather than Article NE-3000 as required by NE-7220(k).

ARTICLE CC-8000
NAMEPLATES, STAMPING WITH CERTIFICATION MARK, AND REPORTS

CC-8100 GENERAL REQUIREMENTS

The requirements for nameplates, stamping with Certification Mark, and reports for components shall be as given in Article NCA-8000.

MANDATORY APPENDIX D2-I
TABLES OF PRESTRESSING AND LINER MATERIAL

Table D2-I-1.2
Material for Containment Prestressing Systems

ASME or ASTM Specification	Grade or Type	Product Form
ASTM A416	250	Strand
	270	Strand
ASTM A421	BA	Wire
ASTM A722	150	Bar
	160 [Note (1)]	Bar
ASTM A779	270	Strand
	260	Strand
	245	Strand

NOTE: (1) Bars of Grade 160 [minimum UTS of 160,000 psi (1 103 MPa)], not specifically itemized in ASTM A722, may be used provided they conform to all other requirements of the ASTM A722 specification.

Table D2-I-2.2
Material for Containment Liners and Liner Attachments

ASME Specification	Type, Grade, or Class	Welding P-No.
Plate		
SA-240	TP304, TP304L	8
	TP316, TP316L	8
SA-285	Gr. A	1
	Gr. B	1
	Gr. C	1
SA-299	...	1
SA-516	Gr. 55	1
	Gr. 60	1
	Gr. 65	1
	Gr. 70	1
SA-537	Cl. 1	1
	Cl. 2	1
SA-738	Gr. A	1
	Gr. B	1
	Gr. C	1
Pipe and Tube — Seamless		
SA-106	Gr. A	1
	Gr. B	1
	Gr. C	1
SA-210	Gr. A-1	1
	Gr. C	1
SA-213	TP304, TP304L	8
	TP316, TP316L	8
SA-312	TP304, TP304L	8
SA-333	Gr. 1	1
	Gr. 6	1
SA-334	Gr. 1	1
	Gr. 6	1
SA-376	TP304, TP304H	8
	TP316, TP316H	8
SA-430	FP304, FP304H	8
	FP316, FP316H	8
Pipe and Tube — Welded		
SA-178	Gr. A	1
SA-333	Gr. 1	1
	Gr. 6	1
SA-334	Gr. 1	1
	Gr. 6	1
SA-358	Gr. 304, Gr. 304L	8
	Gr. 316, Gr. 316L	8
SA-671	Cl. 12, 22, 32, 42, and 52	1
SA-691	Cl. 12, 22, 32, 42, and 52	1
Fittings, Forgings, Castings, Bars, and Shapes		
SA-36 [Note (1)]	...	1
SA-105	...	1
Fittings, Forgings, Castings, Bars, and Shapes (Cont'd)		
SA-181	Cl. 60	1
	Cl. 70	1
SA-216	Gr. WCA	1
	Gr. WCB	1
	Gr. WCC	1
SA-234	Gr. WPB	1
	Gr. WPBW	1
	Gr. WPC	1
	Gr. WPCW	1
SA-266	Cl. 1	1
	Cl. 2	1
	Cl. 3	1
SA-350	Gr. LF1	1
	Gr. LF2	1
SA-351	Gr. CF3	8
	Gr. CF3A	8
	Gr. CF8	8
	Gr. CF8A	8
	Gr. CF3M	8
	Gr. CF8M	8
SA-403	Gr. 304, Gr. 304L	8
	Gr. 316, Gr. 316L	8
SA-420	Gr. WPL-6	1
	Gr. WPL-6W	1
SA-508	Cl. 1	1
SA-541	Cl. 1	1
Reinforced Bar Splice Sleeves Attached to the Liner		
ASTM A108 (Grades as listed in ASTM A29/A29M)	1008	1
	1010	1
	1011	Not assigned
	1012	1
	1013	Not assigned
	1015	1
	1016	1
	1017	1
	1018	1
	1019	1
	1020	1
	1021	1
	1022	1
	1023	1
	1025	1
	1026	1
	1029	1
	1030	Not assigned

Table D2-I-2.2
Material for Containment Liners and Liner Attachments (Cont'd)

ASME Specification	Type, Grade, or Class	Welding P-No.
Reinforced Bar Splice Sleeves Attached to the Liner (Cont'd)		
ASTM A513	1008	1
	1009	Not assigned
	1010	1
	1012	1
	1015	1
	1016	1
	1017	1
	1018	1
	1019	1
	1020	1
	1021	1
	1022	1
	1023	1
	1024	Not assigned
	1025	1
	1026	1
	1027	Not assigned
	1030	Not assigned
ASTM A519	1008	1
	1010	1
	1012	1
	1015	1
	1016	1
	1017	1
	1018	1
	1019	1
	1020	1
	1021	1
Reinforced Bar Splice Sleeves Attached to the Liner (Cont'd)		
	1022	1
	1025	1
	1026	1
	1030	Not assigned
ASTM A576	1008	1
	1010	1
	1012	1
	1015	1
	1016	1
	1017	1
	1018	1
	1019	1
	1020	1
	1021	1
	1022	1
	1023	1
	1025	1
	1026	1
	1029	1
	1030	Not assigned
Studs		
ASTM A108 [Note (2)]	1010	1
	1015	1
	1016	1
	1018	1
	1020	1

NOTES:
(1) May also be used in the form of plate for load-bearing attachments.
(2) May also be used in the form of Type C studs in Table CC-2623.2-1.

Table D2-I-2.3
Material for Embedment Anchors

Anchorage Materials	Grade or Type
SA-36	...
SA-307	B
SA-325	1
	2
	3
SA-354	BC
	BD
SA-449	...
ASTM F3125, Grade A490	1
	3
SA-540	B21 (Cr-Mo-V)
	5
	4
	3
	2
	1
	B22 (4142-H)
	5
	4
	3
	2
	1
	B23 (E4340-H)
	5
	4
	3
	2
	1
	B24 (4340 MOD)
	5
	4
	3
	2
	1
SA-563	0
	A
	B
	C
	D
	DH
ASTM F436	...

MANDATORY APPENDIX D2-II GLOSSARY OF TERMS AND NOMENCLATURE

ARTICLE D2-II-1000 TERMS AND DEFINITIONS

For the terms related to concrete not defined herein, refer to ACI CT. Terms listed in this Article have a specific meaning applicable to the Code.

anchor, concrete: a member, usually a steel rod with a bend at one end or a headed bolt embedded in the concrete, to which a liner, embedment, or surface-mounted item is attached to prevent that item from pulling away from the hardened concrete.

auxiliary systems: features exclusively intended to control or monitor conditions affecting structural integrity that augment the concrete containment (e.g., vessel cooling and insulation, corrosion protection systems, and stress–strain instrumentation).

bending stress: bending stress is the variable component of normal stress; the variation may or may not be linear across the thickness.

bulk concrete temperature: the temperature of concrete sufficiently remote from thermal or geometric discontinuities as to be representative of the generalized temperature profile controlling overall structural response. Maximum values are established on the basis of acceptable material behavior for the load category under consideration.

channel: a circumferential recess or groove formed in the external surface of a containment for the purpose of retaining a circumferential prestressing system.

coating-tendon: material used to protect against corrosion or to lubricate the prestressing system.

component: a concrete containment that is governed by the rules of this Division (NCA-1210).

concrete placement: the deposition of concrete or the ingredients for concrete into forms or into members of a structure that serve as forms.

coupling: the means by which the prestressing force is permanently transmitted from one portion of the prestressing steel to another to form a complete tendon.

ductility: the ratio of the maximum deformation or deflection of the member at the point of collapse to the maximum elastic deformation or deflection at specified minimum yield in the member.

effective temperature at liner–concrete interface: the temperature obtained by geometrically projecting the temperature gradient in the bulk of the concrete to the liner–concrete interface.

embedment: an item such as an anchor bolt, screed, or conduit encased or partially encased in concrete. Reinforcing systems, liners, and structural members are not considered embedments.

guaranteed ultimate tendon strength (GUTS): GUTS is the lower of:

(a) the maximum tensioning force that can be applied without breaking more than 2% of the tendon tension members and that can be guaranteed for all tendons

(b) the minimum guaranteed wire, strand, or bar strength times the number of tendon wires, strands, or bars based on test conditions of 70°F (21°C), static loads, and unirradiated samples

leak-chase channel: a channel section permanently installed over a liner weld to permit leak testing of the weld.

leak-tight integrity: the ability of a component to maintain a prescribed maximum leakage rate under all service conditions.

liner: a permanent metal membrane attached to the surface of a concrete containment or penetration in order to form a leak-tight enclosure.

liner attachment: member or component welded to either the front or back surface of the liner plate, but not penetrating the liner, such as lugs, brackets, anchors, and leak chase channels.

local hot spots: the maximum local temperature at the liner in any part of the primary coolant due to either discontinuity in the thermal barrier and liner cooling system, or to attachments on the coolant side of the liner which penetrate the thermal barrier or at other locations within the bulk concrete due to radiation heating or other causes. It also includes liner areas subjected to high temperature jet impingement.

membrane stress: the component of normal stress, hoop or meridional, that is uniformly distributed and equal to the average of stress across the thickness of the section under consideration. As applied in this Division, membrane stress is not to be substituted for principal stress or stress intensity.

microindentation hardness test: a hardness test using a calibrated machine to force a diamond indenter of specific geometry into the surface of the test material being evaluated.

mineral admixture (fly ash and pozzolans): a siliceous or siliceous and aluminous material, which in itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties.

operating basis earthquake: for a site, that which produces the vibratory ground motion for which those features of the power plant necessary for continued operation without undue risk to the health and safety of the public are designed to remain functional.

operating basis wind: wind velocities and forces required for the design of a structure in accordance with the uniform building code.

peak stress: total stress due to local discontinuities or local thermal stress including the effects of stress concentrations. Its basic characteristic is that it does not cause any noticeable distortion and is objectionable only as a possible source of a fatigue crack or brittle fracture or a localized concrete crack. A stress that is not highly localized falls into this category if it is of a type that cannot cause noticeable distortion. Examples are stresses at a local discontinuity and thermal stresses produced by a local hot spot.

point stress: the maximum apparent stress calculated by adding the membrane stress and the maximum bending stress calculated by elemental beam equations. When advanced analytical methods (e.g., finite element analysis) are used for design, the point stress is defined as the maximum stress across the section under consideration.

prestressing element: an individual wire, strand, or bar in a single-wire or multiple-wire system, strand system, or bar system, respectively.

primary stress: any normal stress or a 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 in a steel member or gross cracking in concrete will result in failure or in gross distortion. A thermal stress is not classified as a primary stress. Examples are stresses due to internal pressure or to distributed live loads and bending stress in the central portion of a flat slab due to pressure.

safe shutdown earthquake: for a site, that which produces the vibratory ground motion for which those features of the power plant necessary to shut down the reactor and maintain the plant in a safe condition without undue risk to the health and safety of the public are designed to remain functional.

secondary stress: a normal stress or shear stress developed by the constraint of adjacent material or by self-constraint of the structure. Its basic characteristic is that it is self-limiting. Local yielding, minor distortions, and concrete cracking can satisfy the conditions that cause the stress to occur, and failure is not to be expected. Examples are general thermal stresses, bending stress at a gross structural discontinuity, and stresses induced by concrete shrinkage and creep.

shear connectors: general term for steel members attached to the liner and embedded in the concrete to provide general compatibility of strains between liner and concrete.

structural integrity: the ability of a structure or component to withstand prescribed loads.

tendon: the complete assembly consisting of pre-stressing steel and anchorages, and couplings. The tendons impart prestressing forces to the concrete.

tension tie member: a reinforced member having an axial tensile force sufficient to create tension over the entire cross section of the member and having limited concrete cover on all sides, such as an arch tie.

ARTICLE D2-II-2000
NOMENCLATURE

a = shear span, distance between concentrated load and face of support

A_1 = bearing area of the tendon anchor plate in contact with the concrete

A_2 = maximum area of the portion of the anchorage surface that is geometrically similar to and concentric with the area of the tendon anchor plate

A_b = area of individual reinforcement bar

A_g = gross area of section

A_s = area of tension reinforcement

A_v = area of shear reinforcement within a distance t_1

A_{vh} = area of shear reinforcement parallel to the main tension reinforcement

b_v = width of cross section being investigated for shear

D = dead loads, or their related internal moments and forces

d = distance from the extreme compression fiber to the centroid of the tension reinforcement

d_b = nominal diameter of deformed bars or wire

D_c = construction equipment loads

D_e = plant fixed equipment load

D_h = hydrostatic loads

D_i = weight of internals

= snow and ice load

D_r = restraint load

d_s = distance from the centroidal axis of gross section, neglecting the reinforcement, to the extreme fiber in tension

D_s = soil or embankment load

D_w = structure and vessel weight

E_c = modulus of elasticity, concrete

E_o = operating basis earthquake

E_q = earthquake loads

E_s = modulus of elasticity, steel

E_{ss} = safe shutdown earthquake

F = prestressing force loads

F_a = allowable liner anchor force capacity

F_c = prestressing force loads during construction staging

f_{cc} = apparent concrete compressive stress

f_{ci} = compressive strength of concrete at time of initial prestress

f_{ct} = apparent concrete tensile stress

f_{cua} = compressive strength of concrete at time of test

F_e = prestressing force loads at end of plant operational life

f_h = tensile stress developed by a standard hook

F_j = initial prestressing force loads upon completion of stressing

f_{pe} = compressive stress in concrete due to prestress only after all losses, at the extreme fiber of a section at which tensile stresses are caused by applied loads

f_{pu} = ultimate tensile strength of prestressing steel

f_{py} = specified tensile yield strength of prestressing or liner steel

f_s = steel stress

f_{sc} = allowable liner plate compressive stress

f_{st} = allowable liner plate tensile stress

F_t = prestressing force loads at time of consideration

F_u = liner anchor ultimate force capacity

f_y = specified tensile yield strength of reinforcing steel

F_y = liner anchor yield force capacity

f'_c = specified compressive strength of concrete

f'_{cr} = required average compressive strength of concrete used as the basis for selection of concrete proportions

h = total depth of section or thickness of wall

I_g = moment of inertia of gross concrete section about the centroidal axis, neglecting the reinforcing steel

K = wobble friction coefficient per ft of prestressing steel

l_x = length of prestressing steel element from jacking end to any point x

L = live load, or the related internal moments and forces

L_c = construction live load

l_d = reinforcement development length

L_m = live load

l_v = shear span, distance between concentrated load and face of support

M_u = applied design load moment at a section

N_u = design axial load normal to the cross section occurring simultaneously with V_u to be taken as positive for compression and negative for tension, and to include the effects of tension due to shrinkage and creep

= design tensile force on bracket or corbel acting simultaneously with V_u

P = pressure load

p = pressure, psi (kPa)

P_a = accident/incident maximum pressure load

p_a = accident/incident maximum pressure

P_c = pressurized crack pressure load

p_c = pressurized crack pressure

P_d = differential flow pressure load

p_d = differential flow pressure

P_l = local pressure buildup load

p_l = local pressure buildup

P_m = maximum cavity pressure load

p_m = maximum cavity pressure

P_o = operational maximum pressure load

p_o = operational maximum pressure

P_s = steel force at jacking end

P_t = test pressure load

p_t = test pressure

P_v = subatmospheric minimum pressure load

p_v = subatmospheric minimum pressure

P_x = steel force at any point x

Q = plant movable equipment loads

R_a = piping loads due to increased temperature resulting from the design accident

R_o = piping loads during operating conditions

R_r = local effects on the containment due to the design basis accident as defined in U.S. NRC Regulatory Guide 1.70. The local effects shall include the following:

- R_{rj} = load on the containment generated by the design basis accident (for example, jet impingement from a ruptured high energy pipe during the postulated event). The time-dependent nature of the load and the ability of the structure to deform beyond yield shall be considered in establishing the structural capacity necessary to resist the effects of R_{rj}.
- R_{rm} = effects resulting from the impact of a ruptured high energy pipe on the containment during the design basis accident. The type of impact (e.g., plastic, elastic) together with the ability of the structure to deform beyond yield shall be considered in establishing the structural capacity necessary to resist the impact.
- R_{rr} = load on the containment generated by the design basis accident (for example, reaction of a ruptured high energy pipe during the postulated event). The time-dependent nature of the load and the ability of the structure to deform beyond yield shall be considered in establishing the structural capacity necessary to resist the effects of R_{rr}.

S = standard deviation

s = spacing of shear reinforcement in a direction parallel to the longitudinal reinforcement

T_a = accident/incident temperature effects

T_o = operating temperature effects

T_p = preoperational heatup temperature effects

T_t = test temperature effects

v_c = nominal permissible shear stress carried by concrete

V_s = membrane shear force

V_u = total applied design shear force at section

v_u = nominal total design shear stress

W = wind loads

W_t = tornado load

W_{tm} = tornado-generated missile impact effects. The type of impact (for example, plastic, elastic) together with the ability of the structure to deform beyond yield shall be considered in establishing the structural capacity necessary to resist the impact.

W_{tp} = differential pressure loads due to rapid atmospheric pressure

W_{tq} = loads due to tornado wind pressure

x = distance from extreme compression fiber to neutral axis

Y = dynamic force loads

Y_j = jet impingement due to fluid discharge

Y_m = missile impingement load

Y_r = reaction load due to fluid discharge

Y_w = water force dynamic load

α = angle between inclined shear reinforcement and longitudinal axis of member

α_x = total angular deviation of prestressing steel profile in radians from jacking end to any point x

δ_a = allowable displacement for liner anchors

δ_u = ultimate displacement capacity for liner anchors

μ = coefficent of friction

μ_p = curvature friction coefficient

ρ = A_s/bd

ϵ_{sc} = allowable liner plate compressive strain

ϵ_{st} = allowable liner plate tensile strain