Meeting to Discuss the Provisions on Steel and Modular Composite Construction in the American Institute of Steel Construction (AISC) Specification N690-2012, Supplement 1, Dated 2015

Jose Pires and Marcos Rolon

Nuclear Regulatory Commission

Office of Nuclear Regulatory Research

Rockville, MD

November 23, 2015

Contact:

Marcos Rolon, 301-415-2208, Marcos.Rolon@nrc.gov

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Agenda

TIME	***TOPIC***	***SPEAKER***
8:00-8:30 AM	***Introduction, and placeholder for meeting specifics***	
	- Introduction and meeting logistics	NRC
	- Background and objective of the meeting	NRC
8:30-10:00 AM	Discussion Topics on AISC N690 Excluding App. N9 (Steel-Plate Composite Walls)*	
	- AISC Presentation – Overview and Technical Bases	AISC
	- NRC / Brookhaven National Laboratory (BNL) comments	NRC/BNL
10:00-10:15 AM	***BREAK***	
10:15-11:15 AM	Discussion Topics on AISC N690 Excluding App. N9 (Cont'd)*	
	- AISC Presentation – Technical Bases	AISC
	- NRC / BNL comments	NRC/BNL
11:15AM - 12:15PM	Discussion Topics Related to App. N9*	
	- AISC Presentation – Overview and Technical Bases	AISC
	- NRC / BNL comments	NRC/BNL
12:15 noon – 1:00 PM	***LUNCH BREAK***	
1:00-2:30 PM	Discussion Topics Related to App. N9 (Cont'd)*	
	- AISC Presentation – Technical Bases	AISC
	- NRC / BNL comments	NRC/BNL
2:30 - 2:45 PM	***BREAK***	
2:45-4:00 PM	Discussion Topics Related to App. N9 (Cont'd)*	
	- AISC Presentation – Technical Bases	AISC
	- NRC / BNL comments	NRC/BNL
4:00-4:30 PM	Other Issues*	NRC

* Opportunity for public comment at the conclusion of each topic area.

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Objective

- Public meeting to discuss and gather information on
  - Provisions for safety-related steel structures for nuclear facilities in ANSI/AISC N690-12
  - Provisions for safety-related steel plate and concrete composite modular structures (SC) in ANSI/AISC N690-12, Supplement 1, Dated 2015 (N690s1-15)
- This is a category 2 meeting*. The public is invited to participate in this meeting by discussing regulatory issues with the NRC at designated points on the agenda

Reference (available for distribution):
ANSI/AISC N690, "Specification for Safety-Related Steel Structures for Nuclear Facilities, Including Supplement No. 1," Chicago, Illinois
January 31, 2012 (ANSI/AISC N690-12)
August 11, 2015 (ANSI/AISC N690s1-15)

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

ANSI / AISC N690

- The Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition (NUREG-0800), 2010 (SRP), refers to N690-1994 including Supplement 2 (2004) in:
  - Section 3.8.3 – Concrete and Steel Internal Structures of Steel or Concrete Containments
  - Section 3.8.4 – Other Seismic Category I Structures

- The Standard Review Plan for the Review of an Application for a Mixed Oxide (MOX) Fuel Fabrication Facility (NUREG-1718), 2000, refers to N690-1984 in
  - *Section 11.4.6.1 Regulatory Guidance*

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

ANSI/AISC N690

- SRP (3.8.3 and 3.8.4) refers to N690 in relation to the following for steel structures
  - Applicable codes, standards and specifications
  - Loads and load combinations
  - Design and analysis procedures
  - Structural acceptance criteria
  - Materials, quality control, special construction techniques and quality assurance
- Example - SRP 3.8.4 - II
  - Structural Acceptance Criteria (Steel Structures) – For each of the loading combinations delineated in Subsection II.3 of this SRP section, the structural acceptance criteria appear in ACI 349 and RG 1.142 for concrete structures, and AISC N690-1994, including Supplement 2 (2004), for steel structures.

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

ANSI/AISC N690

- SRP references (additional examples)
- SRP 3.8.4 – II
  - Loads and Load Combinations (Steel Structures) – All loads and load combinations are to be in accordance with AISC N690-1994 including Supplement 2 (2004). This specification uses the allowable stress design (ASD) method. The supplemental criteria on the use of loads and load combinations presented above for concrete structures also apply to steel structures.
- SRP 3.8.3 - II
  - Structural Acceptance Criteria (Steel Structures) – ANSI/AISC N690-1994 including Supplement 2 (2004) defines the structural acceptance criteria for steel structures. This specification uses the ASD method. Use of the LRFD version of the specification (N690L) is reviewed on a case-by-case basis.

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Why Review N690-12?

- Current staff guidance addresses the 1994 standard
  - Includes the 2004 supplement 2 to the 1994 edition
  - Still used by end users (licensees and applicants)
- Examples of technical / regulatory issues
  - Understanding of relevant phenomena and technologies evolved (e.g., design approaches, characterization of loads and load combinations, materials and construction technologies)
  - Use of LRFD approach (with ASD as an alternative) which is consistent with the standard for safety-related concrete structures
  - Changes in the ASD approach
  - N690-12 uses ANSI/AISC 360-10, *Specification for Structural Steel Buildings*, as the baseline document (instead of standalone document)
    - This approach also provides links to other AISC provisions
  - Discontinuation of supplements to the 1994 edition

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Why Review N690s1-15?

- Steel plate and concrete composite modular structures (SC) have been adopted for safety-related structures of new reactor designs
  - E.g., containment internal structures, auxiliary buildings
- N690s1-15 is the first U.S. standard for safety-related SC structures
- Case-by-case review has been done and is done for current applications and license amendments

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Review of N690-12 and N690s1-15

Contract to DOE National Laboratory (BNL) on

- Review of provisions for safety-related steel structures in ANSI/AISC N690-12
- Review of provisions for safety-related SC structures in the October 2014, public review draft of N690s1-15
  - Will update review to address published N690s1-15
- To inform NRC staff review

NRC Staff and BNL Reviews Inform

- New regulatory guide (RG)
  - Draft Regulatory Guide (DG-1304) and RG 1.225 “Safety-Related Steel and Steel-Concrete Composite Structures (Other than reactor vessels and containments)
- SRP update

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Review of N690-12 and N690s1-15

- RG Development
  - NRC staff review (including NRC contractors/consultants)
  - Draft RG (DG-1304)
    - Not earlier than FY16 Q3
  - NRC staff concurrence
  - Publish DG-1304 for a 30-60 day comment period
    - Not earlier than FY16 Q4
  - Incorporation of comments and ACRS review
  - Issue RG

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Review of SC Standard

- Resulting designs must satisfy regulations
- Would designs (as examples)
  - Provide adequate strength and stiffness
  - Prevent non-ductile failure modes
  - Provide clear load paths avoiding load path discontinuities
  - Provide durability through the use of adequate materials, control of concrete cracking, prevention of steel and reinforcement corrosion
  - Be based on sound engineering principles and validated methods?
- Challenges (examples)
  - Loads and load combinations
  - Design criteria for connections and connections to other construction types, e.g. reinforced concrete
  - Experimental database
  - Methods of analysis

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Abbreviations

- ACRS – Advisory Committee on Reactor Safety
- AISC – American Institute of Steel Construction
- ANSI – American National Standards Institute
- ASD – Allowable Stress Design
- BNL – Brookhaven National Laboratory
- DG – Draft Guide
- DOE – Department of Energy
- FY – Fiscal Year
- LRFD – Load and Resistance Factor Design
- RG – Regulatory Guide
- SC – Steel Plate and Concrete Composite Modular Structures
- SRP – Standard Review Plan

Review of ANSI/AISC N690s1-15 "Specification for Safety-Related Steel Structures for Nuclear Facilities, Including Supplement No. 1"

Presentation Prepared by:

Joseph Braverman, Charles Hofmayer and Richard Morante

Brookhaven National Laboratory

November 23, 2015

BROOKHAVEN NATIONAL LABORATORY

a passion for discovery

Office of Science
U.S. DEPARTMENT OF ENERGY

Presentation Outline

- Program Summary
- Background
- General Comparison of ANSI/AISC N690-12 to N690-1994 (R2004)
- Assessment Summary for N690-12
- Assessment Summary for N690s1, Draft 2014 containing App. N9
- Backup Slides for Specific Assessments of N690-12 Chapters/Appendices

Program Summary

- **Objective**
  - Review ANSI/AISC N690s1-15 Specification for Safety-Related Steel Structures for Nuclear Facilities, including Supplement No. 1
  - NOTE: Since N690s1-15 was published in August 2015, the review presented herein is based on the review of the previous versions of N690 listed below:

    N690-12, January 31, 2012

    N690s1, Draft Dated October 1, 2014 for the inclusion of SC walls

- **Use of results**
  - Support NRC development of regulatory guidance regarding the use of AISC N690s1-15, for design of nuclear safety-related steel structures at nuclear power plants

- **BNL team members: J. Braverman, C. Hofmayer*, R. Morante**

*consultant

Background

- **Current NRC Acceptance Criteria for Design of Safety-Related Steel Structures**
  - **SRP 3.8.3, 3.8.4, and 3.8.5, all Revision 4, September 2013, refer to ANSI/AISC N690-1994 (R2004): "Specification for the Design, Fabrication and Erection of Steel Safety-Related Structures for Nuclear Facilities"**
  - **Use of allowable stress design (ASD) method in AISC N690-1994 (R2004) is acceptable**
  - **Use of load and resistance factor design (LRFD) version of the specification (N690L) is reviewed on a case-by-case basis**
  - **No specific guidance for steel concrete composite sections – reviewed on a case-by-case basis**

Background (Cont'd)

- **Need to update NRC Acceptance Criteria for Design of Safety-Related Steel Structures**
  - **Periodic update to NRC guidance is needed to reflect new revisions to industry codes and standards**
  - **Updating NRC guidance to incorporate revised industry codes and standards will support efficient review of new applications, including those anticipated for small modular reactors**
  - **N690-2012 and N690-2012s1 represent a major revision to N690-1994 (R2004), and incorporates (1) developments in the design of conventional steel structures (i.e., AISC 360-10) by reference and (2) design of steel-plate composite (SC) walls**

General Comparison

N690-1994 (R2004)	N690-2012
Stand alone document	Incorporates AISC 360-10 (herein also referred to as *Specification*) by reference, and identifies additions, deletions, or replacements to the *Specification*
Relatively short and simple to use. Specification = 69 pages (not including plastic design which is typically not used for NPPs)	Use of N690-12 requires the use of 360-10 which is more complex. N690-12 is 63 pages, and 360-10 is 239 pages [excluding the Commentaries]
Provisions based on prior AISC steel design specifications for ASD, which are referred to in the NRC SRP.	By reference to 360-10, incorporates both LRFD and updated ASD methods; covers some design considerations (e.g., stability) in much greater detail; substantially revised and new provisions compared to N690-1994 (R2004)
Does not address steel-plate composite (SC) walls	New Appendix N9 inserted along with updates of other related chapters for the use of SC walls.

Assessment Summary for N690-12

- Numerous new and revised provisions developed by the non-nuclear structural design community (based on prior studies, operating experience, testing, consensus of experts) are incorporated in AISC 360-10. By reference to 360-10, these have been incorporated in AISC N690-12.
- The review of N690-12 is also a de facto review of 360-10. To evaluate in detail all of the referenced provisions of 360-10 that are different from the content of N690-1994 (R2004) would require significant resources. Therefore, the approach to the review of N690-12 and the referenced sections of 360-10 has been to identify key differences from N690-1994 (R2004), to evaluate the significance, and to propose a course of action.

Assessment Summary for N690-12

A. LOAD COMBINATIONS, DESIGN BASIS AND LIMIT STATES

- **A.1.** For Sections NB2, Loads and Load Combinations, and NB3, Design Basis, the evolution of changes from N690-1994 (2004 revision) to N690-2012 is not straightforward. Implications of these on the designs produced need clarification for resolution of their acceptance with or without potential exceptions. Design examples would be useful in identifying these implications. [See Backup Slides 25-29]
- **A.2.** For Chapter NF, Design of Members for Flexure, the most significant change appears to be the use of the plastic section modulus in the allowable strength equations (ASD). 360-2010 would allow increase in stress above the N690-1994 (2004 revision) allowable (e.g., up to an 18% (1.3/1.1) increase for W shapes, bending about the major axis). Implications of this (jointly with the factors of safety and load combinations used) in the designs provided need clarification for resolution of their acceptance with or without potential exceptions. [Slide 35]

Assessment Summary for N690-12

B. CLARIFICATIONS AND POTENTIAL EXCEPTIONS TO AISC N690-2012

- **B.1. Appendix N1 - Design by Inelastic Analysis**

Chapter A1 of ANSI/AISC 360-10 states that Appendix 1 (Design by Inelastic Analysis) shall not apply to seismic design. Chapter NA does not make a similar statement. Does this imply that Appendix N1 (Design by Inelastic analysis) could be applied to seismic design? Clarification is needed for commercial NPPs. [Slide 43]

- **B.2. Appendix N4 - Structural Design for Fire Conditions**

Appendix N4, STRUCTURAL DESIGN FOR FIRE CONDITIONS, states that this Appendix does not address "Important to Safety" steel members. Clarification is needed as to what nuclear structures are meant to be covered by this appendix. [Slide 45]

- **B.3. Appendix N5 - Evaluation of Existing Structures**

Appendix N5, EVALUATION OF EXISTING STRUCTURES, does not address seismic and other dynamic loads. Clarification is needed as to the applicability of Appendix N5 to N690-12 for commercial NPPs since it does not address seismic and other dynamic loads. [Slide 45]

Assessment Summary for N690-12

C. NEED CLARIFICATION OF INTENT

- **C.1.** Section NA1 states that it applies to "design". N690-1994 (2004 revision) also included fabrication, erection, and composite structures. Section A1 of ANSI/AISC 360-10 also includes these items. The scope of N690-2012 needs to be clarified. [Slide 23]
- **C.2.** Section NA1 specifically excludes pressure retaining components (pressure vessels, valves, pumps and piping). It should be clarified in Section NA1 that this exclusion also applies to all types of supports for pressure retaining components. The Commentary directs the reader to ASME Section III, Subsection NF for plate and shell component supports. This could imply that linear supports are covered by N690. [Slide 24]
- **C.3.** Section NA1 states that the AISC Seismic Provisions (ANSI/AISC 341), in general, are not applicable. However, it also states that the detailing requirements of Sections A3 and D2 "shall be appropriately considered when designing for inelastic behavior." It is appropriate to consider these detailing requirements to provide margin for beyond design basis seismic loads. However, it should be made clear that inelastic behavior is not acceptable for design to withstand the design basis seismic loads. [Slide 23]

Assessment Summary for N690-12

C. NEED CLARIFICATION OF INTENT (Cont'd)

- **C.4.** Section NA1 recommends the provisions of AISI North American Specification for the Design of Cold-Formed Steel Structural Members for "… other than hollow structural sections (HSS) that are cold-formed to shapes with elements not more than 1 in." Does this imply that N690 covers HSS less than 1 in. thickness? Text needs clarification. [Slide 24]
- **C.5.** For Chapter NG, Design of Members for Shear, the 360-10 Commentary notes that Eq. G2-6 of Chapter G applies as long as there are flanges on both edges of the web, and further states that for tee-shaped beams, Kv=1.2. Should this be a User Note or provision in the N690 Specification? The Commentary also states that Section G2.1 assumes monotonically increasing loads, and for members subjected to load reversals, such as earthquakes, special design considerations may apply. Should this be a User Note or provision in the N690 Specification? [Slide 36]
- **C.6.** Chapter NI, Design of Composite Members, apparently only requires the use of steel anchors for encased composite members when using Method (c) of Section I.3.3 of 360-2010. Section I.6.4a of 360-2010 appears to require steel anchors both within and outside the load introduction length. N690-1994 (2004 revision) did not require anchors, provided specific restrictions imposed on encasement are met. AISC 360-2010 does not include these restrictions. The use of steel anchors for encased composite members needs to be clarified. [Slide 38]

Assessment Summary for N690-12

D. FURTHER REVIEW NEEDED

- **D.1.** The review encompassing Chapter C and Appendices 6, 7, and 8 of 360-2010, related to evaluation for stability, is ongoing. In addition to the Direct Method, several approaches have been included in 360-2010 without clear guidance on their applicability and limitations. See more detailed discussion under "Specific Assessments". [Slide 31]
- **D.2.** For Section NJ3, Bolts and Threaded Parts, a thorough comparison of Table J3.2 in 360-2010 with Table Q1.5.2.1 in N690-1994 (2004 revision) is recommended, to better understand any differences between the new criteria and the earlier accepted criteria. See more detailed discussion under "Specific Assessments". [Slide 39]
- **D.3.** Section NM3, Shop Painting, is similar to Q1.24 in N690-1994 (2004 revision) except that Q.1.24.1 also states "… all other steel work shall be given one coat of shop paint." Need to understand the basis for eliminating this provision and whether an exception is warranted. [Slide 41]
- **D.4.** For Appendix N3, Design for Fatigue, the initial review is complete with no issues identified. Additional confirmatory review is needed before finalizing the conclusions. [Slide 44]

Assessment Summary for N690-12

E. FURTHER REVIEW FOR CONSISTENCY WITH QA STAFF GUIDANCE

- **E.1.** Section NA5 discusses 10 CFR 50 Appendix B and NQA-1, and specifically references the use of NQA-1, requirement 3, for calculations pertinent to the design and NQA-1, Subpart 2.7, for computer programs used in analysis and design. It is not clear why reference is made only to these parts of NQA-1. The Section NA2 references include NQA-1. Section NA5 will be further reviewed for consistency with current staff guidance. [Slide 24]
- **E.2.** Chapter NN of N690-12 replaces the information in Chapter N of 360-10, but follows Chapter N of 360-10 closely. There is no reference in Chapter NN to 10 CFR 50 App. B or ANSI/ASME NQA-1. The Commentary for Chapter NN does discuss NQA-1 and NQA-1a. Chapter NN will be further reviewed for consistency with current staff guidance. [Slide 42]

Assessment Summary for N690s1, Draft 2014

- Chapters NA, NM, NN – minor revisions
- Chapter NB - Introduced soil load H and fluid load F into load combinations
- Appendix N9: Steel-Plate Composite (SC) Walls
  - Scope: steel-plate composite (SC) walls
  - Two steel faceplates with concrete infill and steel anchors, connected with ties
  - Sub-Sections:
    - N9.1 Design Requirements
    - N9.2 Analysis Requirements
    - N9.3 Design of SC Walls
    - N9.4 Design of SC Wall Connections
- Specific assessments - listed on following slides

Assessment Summary for N690s1, Draft 2014

- **Appendix NB: Some Specific Assessments**
  - For load combinations (LCs), adds F (fluid) and H (soil) loads into LCs presented in N690-12. The addition of F and H in LCs appear to be acceptable; however, the appropriateness of LC's under N690-12 still needs to be addressed as discussed previously.
  - Some questions exist with treating F as D (dead load) and H as L (live load) when "stability evaluations" are performed; e.g., should F be reduced below 0.9 X F and why is H treated as L which is set to 0.0 X H (refer to Section NB2.5d (4))?
  - LCs containing H imply that the steel faceplates of SC walls can be located below grade which could be exposed to water and potentially aggressive environment; no guidance is provided.
  - Commentary Section NB2.5, regarding the use of SRSS for LCs with LOCA and SSE, appears to refer to the wrong equation.

Assessment Summary for N690s1, Draft 2014

- **Appendix N9: Some Specific Assessments / Clarifications**
  - Only applies to walls; what about slabs?
  - How are construction loads addressed?
  - Clarification needed on why Commentary Section N9.1.3 indicates that for faceplates with a minimum yield stress greater than or equal to 50 ksi, no additional limits are imposed on the locked-in stresses or displacements as a result of concrete casting.
  - Section N9.1.1(l): Clarification needed on wording for using complete joint penetration groove welds to develop the nominal yield strength of the two spliced faceplates if the two faceplates have different yield strengths.
  - Section N9.1.1: User Note discusses effects of curved SC walls. User Notes are not considered part of the nuclear specification. Commentary provides some additional guidance but it is not part of the specification provisions. These would be useful as part of the specification.

Assessment Summary for N690s1, Draft 2014

- **Appendix N9: Some Specific Assessments / Clarifications (Cont'd)**
  - Section N9.1.2b Design for Stability, and User Note: basis why ACI 318 is referred to rather than ACI 349.
  - Section N9.1.6b, ductility ratio limits are similar in most cases to ACI 349-06, but some differences exist with ACI 349, and also with NRC RG 1.142 Rev 2.
  - Section N9.1.6c, methods for evaluation of impulsive loads (e.g., LOCA) similar to ACI 349-06 but some requirements in ACI 349-06 are not addressed in N690s1.
  - Some questions on the design and detailing requirements at boundaries of openings; e.g.,
    - N9.1.7a Item (b)(4) – for flange around opening, in addition to thickness and yield strength why not also match/exceed rupture strength?
    - Item (b)(5) - Does the weld connection develop the full strength of the faceplate?
    - Figure C-A-N9.1.21 in Commentary – Should (a) sleeve thickness be shown ≥ faceplate thickness and (b) title be corrected to be "<" rather than ≤?

Assessment Summary for N690s1, Draft 2014

- **Appendix N9: Some Specific Assessments / Clarifications (Cont'd)**
  - Provisions do not indicate that aircraft missile impact is outside the scope of App. N9 (Commentary does so).
  - Clarifications needed on concrete cracking, e.g.,
    - For LCs with To, do all loads in these LCs use cracked transformed properties and for LCs with Ta, do all loads in these LCs use fully cracked properties?
    - If criteria in RG 1.61 Rev 1 and SRP 3.7.2 Rev 4 for generation of ISRS have been captured?
  - Clarification needed on derivation of some equations discussed in the Commentary (e.g., Eqn C-A-N9-7 and C-A-N9-8 versus referenced papers).
  - For Section N9.2.3, clarification needed on why matching is done for flexural and in-plane shear stiffnesses but not membrane stiffness.
  - For Section N9.2.5, clarification needed on basis for determining required strengths by averaging demand over 2 times the section thickness.

Assessment Summary for N690s1, Draft 2014

- **Appendix N9: Some Specific Assessments / Clarifications (Cont'd)**
  - **Section N9.3.2 Compressive Strength**
    - The Section indicates that the available compressive strength shall be determined in accordance with Specification Section I2.1b. Clarification needed on why N9.3.2 uses the *Specification* section applicable to encased composite members rather than that for concrete-filled composite members.
    - N9.3.2 replaces the definitions of some variables in *Specification* Section I2.1b. An example is Asn = net area of faceplates per unit width. Should this be As, which appears in the Specification Sections I2.1b and I2.2b? Asn is not in the *Specification*.
    - Clarification needed on the derivation of the effective stiffness, EIeff. Is it derived from EIeff in Section I2.1b or from Section I2.2b? Clarification also needed on why the Commentary allows using a more accurate equation in the *Specification,* which is a function of the reinforcement ratio, while this is not stated in the provisions.

Assessment Summary for N690s1, Draft 2014

- **Appendix N9: Some Specific Assessments / Clarifications (Cont'd)**
  - **Section N9.3.4, In-Plane Shear Strength**
    - ACI 349 places an upper bound limit of 10 SQRT of f'c. Clarification on why this limit does not apply to SC walls.
    - Clarification on why Phi = 0.90 is specified instead of Phi = 0.85 as in ACI 349-97.
  - **Section N9.3.5, Out-of-plane Shear Strength**
    - Clarification on the basis for the equation for the concrete contribution Vconc = 0.05 Sqrt(f'c) (tc) (l)
    - Clarification on how to address concrete in tension or compression, if applicable
    - For contribution from ties, clarification needed on the use of tensile strength rather than yield strength
    - Clarification on need for additional restrictions, e.g., for non-yielding ties, demonstration of the adequacy of the provision equations by testing.
  - **Section N9.3.6 – Strength under Combined Forces, 6a**
    - For out-of-plane-shear forces, clarification needed on the development of the expression in the second square bracket.

Assessment Summary for N690s1, Draft 2014

- **Appendix N9: Some Specific Assessments / Clarifications (Cont'd)**
  - **Additional review is warranted in several areas:**
    i. **Compare and review against the published version of N690s1-15 for further revisions that may have been made**
    ii. **Clarification of selected formulations in N690s1**
    iii. **Extent to which experimental data and analysis supports design approach**
    iv. **Where feasible comparison to other international design standards or approaches**

Backup Slides

Specific Assessments of N690-12

Chapter NA – General Provisions

- N690-12 applies to "design of safety-related steel structures…," whereas N690-94(R2004) as well as 360-10 indicate that scope also includes fabrication and erection. Clarification needed.
- Sub-Section A1.1 of 360-10 indicates that App. 1 – Design by Inelastic Analysis does not apply to seismic design. Clarify why this statement is not included in N690-12.
- Section NA1 states that AISC Seismic Provisions (ANSI/AISC 341), in general, are not applicable. However, it also states that the detailing requirements of Sections A3 and D2 of the Seismic Provisions "shall be appropriately considered when designing for inelastic behavior." The concept of designing for ductile behavior should be maintained; however, this sentence should not imply that the design acceptance criteria for design-basis seismic loading can consider inelastic behavior.

Specific Assessments of N690-12

Chapter NA – General Provisions (Cont'd)

- Section NA1 specifically excludes pressure retaining components (pressure vessels, valves, pumps and piping). It should be clarified in Section NA1 that this exclusion also applies to all types of supports for pressure retaining components. The Commentary directs the reader to ASME Section III, Subsection NF for plate and shell component supports. This could imply that linear supports are covered by N690.
- Section NA1 recommends the provisions of AISI North American Specification for the Design of Cold-Formed Steel Structural Members for "… other than hollow structural sections (HSS) that are cold-formed to shapes with elements not more than 1 in." Does this imply that N690 covers HSS less than 1 in. thickness? Text needs clarification.
- Section NA5 (and Chapter NN) discusses quality assurance program, with reference to ASME NQA-1. Chapter NN will be further reviewed for consistency with current staff guidance.

Specific Assessments of N690-12

Chapter NB – Design Requirements

- **Section NB2 - Loads and Load Combinations**
  - Substantial changes have been made in the load combinations
  - Sub-Section NB2.5 covers LRFD and Sub-Section NB2.6 covers ASD
  - Two examples showing comparisons of the new load combinations in N690-12 versus N690-94 (R2004), where LOCA and SSE loads are combined:

ASD

- Eqn NB2-18 from N690-12:
  D + L + Pa + Ra + Ta + Yr + Yj + Ym + 0.7Es

- Eqn 11 from N690-04:
  D + L + Pa + Ra + Ta + Yr + Yj + Ym + Es

LRFD

- Eqn NB2-9 from N690-12:
  D + 0.8L + (Pa + Ra + Ta) + (Yr + Yj + Ym) +0.7Es

- ACI 349-97, Ch. 9, Eqn 8: Comparison is made to ACI 349-97 because there is no LRFD approach in the current NRC endorsed N690-94 (R2004), and ACI 349-97 is based on the strength design approach.
  D + F + L + H + Ta + Ra +1.0Pa + 1.0(Yr + Yj + Ym) + 1.0Es

Specific Assessments of N690-12

Chapter NB – Design Requirements (Cont'd)

- **Section NB2 - Loads and Load Combinations (cont'd)**
  - **N690-12, Commentary states: "The load combinations stem from a probability-based study of load combinations for design of nuclear power plants (Hwang et al., 1987). The probabilistic methodology in that study is consistent with that used to develop the probability-based load combination requirements appearing in ASCE/SEI 7-10 (ASCE, 2010), Galambos et al. (1982), and Ellingwood et al. (1982)."**
  - **N690-12 provisions and commentary do not explain why these specific load factors are used; but ASCE/SEI 7-10 (which is referenced in the above statement) has some discussion in the Commentary which may apply. It states for earthquake load E:**

    "The earthquake load effect is multiplied by 0.7 to align allowable stress design for earthquake effects with the definition of E in Section 11.3 of this Standard, which is based on strength principles."

- **The load factors, load combinations, and some definition of loads warrant more detailed review**

Specific Assessments of N690-12

- **Chapter NB – Design Requirements (Cont'd)**

The following is a list of items for discussion based on a review of NB2 and NB3 of ANSI/AISC N690-12. It is not meant to be a complete list of all potential questions related to these sections.

- **NB2.5a – Use of 1.2D + 1.6L…**
- **NB2.5b – Change from 1.6W to W in Eq NB2-4**
- **NB2.5c – Use of 1.2Pa in Eq NB2-8 and 0.7Es in Eq NB2-9**
- **NB2.5d(8) – Use of probability of Es and C at same time to waive load C**
- **NB2.6a – Use of 0.75L in Eq NB2-12**
- **NB2.6b – Use of factors in both equations. In particular change from W to 0.6W in Eq NB2-13**
- **NB2.6c – Why 0.7Es in Eq NB2-18**

Specific Assessments of N690-12

- **Chapter NB – Design Requirements (Cont'd)**

The following is a list of items for discussion based on a review of NB2 and NB3 of ANSI/AISC N690-12 (Cont'd):

- **NB2.6d(6) – Reference should be to Section NB3.15 not NB3.14**
- **NB2.6d(8) – Use of 1.5 increase for members in tension or shear. Table Q1.5.7.1 of N690-1994 uses 1.4 and also has limit of 1.5 for cases where axial compression is greater than 20% of allowable.**
- **NB2.6d(9) – Use of probability is new for ASD.**
- **NB3.1 – Need caveat on use of inelastic analysis. Maybe OK for impulsive and impactive loads, but not in general. Also check User Note.**
- **NB3.15 – Further review of this section is warranted. Some of it is like Q1.5.8 of N690-1994, including Table NB3.1 which is similar to Table Q1.5.8.1. Table NB3.2 is difficult to compare to N690-1994.**

Specific Assessments of N690-12

- **Chapter NB – Design Requirements (Cont'd)**

By reference, Chapter NB uses Chapter B. Discussion items for Chapter B3 are as follows:

- **B3.2 – What is the second paragraph of this section saying regarding nominal strength vs design or allowable strength?**
- **B3.6 – Permitting self-limiting inelastic deformations of connections**
- **B3.7 – Provisions for moment distribution in beams**
- **B3.10 – Use of slope of ¼ in per ft to preclude ponding conditions**
- **B3.11 – Not considering fatigue for seismic or wind**
- **B3.12 – Does this section make use of Appendix 4 moot?**

Specific Assessments of N690-12

Chapter NB – Design Requirements (Cont'd)

- **Section NB3 – Design Basis**

  Sub-Section NB3.1 states: "Design by elastic, inelastic or plastic analysis is permitted. Provisions for inelastic and plastic analysis are as stipulated in Appendix N1, Design by Inelastic Analysis."

  Since the current SRP acceptance criteria for safety-related structures is based on elastic analysis, clarify why inelastic or plastic analysis is permitted. Inelastic analyses have been used to address II/I issues (SRP 3.7.2.8).

- **Remainder of NB - reviewed; more detailed evaluation of several provisions may be needed to determine acceptability**

Specific Assessment of N690-12

Chapter NC – Design for Stability

- Same as Chapter C of 360-10. One minor sentence added. No counterpart in N690-1994 (R2004).

- Review encompasses Chapter C and Appendices 6, 7, and 8 of 360-10. Several optional approaches are included, without clear guidance on applicability and limitations.

- The "direct method" for evaluating stability explicitly includes all potentially important nonlinear effects in a computer analysis, including construction tolerances, component fabrication tolerances, other geometric imperfections, material nonlinearity, P-delta effects (overall and between floors), and stiffness reduction. The Commentary warns that many software packages will be unsuitable for such analysis, and provides 2 relatively simple benchmark problems for verification. The Commentary also recommends that additional, more realistic benchmark problems be taken from the referenced studies. This is acceptable, provided adequate benchmarking exists for the software used.

Specific Assessment of N690-12

Chapter NC – Design for Stability (cont'd)

- It is likely that most designer/analysts will implement the alternate guidance for checking stability. The alternate guidance (1) relies on approximation using various factors to account for the nonlinear effects, and/or (2) justifies not considering certain nonlinear effects based on linear analysis results. There is considerable judgment in the guidance, based on discussion in the Commentary. There is also a degree of uncertainty. Example: "If ….., then the results should be within 3-5%."

- The "direct method" appears to be acceptable, if adequately benchmarked.

- Determining the range of applicability and acceptability of the alternate methods would warrant additional detailed evaluation (e.g., example implementations to better understand their effect on the design).

Specific Assessment of N690-12

Chapter ND – Design of Members for Tension

- No changes from Chapter D of 360-10
- Several differences were identified compared to N690-1994 (2004).
- However, they do not appear to warrant more detailed review.

Specific Assessment of N690-12

Chapter NE – Design of Members for Compression

- No changes from Chapter E of 360-10
- There are similarities and differences compared to N690-1994 (2004).
- Comparison between the older and new spec are difficult. The newer spec also has much more information, much of which can be traced back to earlier LRFD Specs or other earlier standards.
- Per AISC 2005 Commentary on E3, Flexural Buckling of Members Without Slender Limits, for both LRFD and ASD, the new column equations give somewhat more economy than previous editions of the Spec.
- Further review does not appear to be warranted

Specific Assessment of N690-12

Chapter NF – Design of Members for Flexure

- No changes from Chapter F of 360-10
- As stated in the 360-10 Commentary, for most designs, the engineer need seldom go beyond Section F2, Doubly Symmetric Compact I-Shaped Members and Channels Bent About their Major Axis. Therefore, further review of the other sections does not appear to be warranted.
- The most significant change appears to be the use of the plastic section modulus in the allowable strength equations. Depending upon the section used, N360-10 would allow an increase in stress above the N690-1994 allowable (e.g., up to 18% (1.3/1.1) for W shapes, bending about the major axis). The increase in allowable stress would be even greater for members bent about their minor axis.

Specific Assessment of N690-12

Chapter NG – Design of Members for Shear

- No changes from Chapter G of 360-10
- There do not appear to be any significant differences in 360-10 with the shear provisions in N690-1994 (Q1.5.1.2 Shear, and Q1.10.5.2, Allowable Shear Based on Stiffener).
- There are differences compared to N690-1994 (2004) (e.g. Q1.10.5.3 and 1.10.5.4). Comparison between the older and new spec are difficult. The newer spec also has much more information, much of which can be traced back to earlier LRFD Specs or other earlier standards. Further review does not appear to be warranted.
- It is noted that some guidance in the 360-10 Commentary should be discussed in the Specification. The Commentary states that Section G2.1 assumes monotonically increasing loads and that for members subjected to load reversals, such as earthquakes, special design considerations may apply (Popov, 1980). It would appear that such guidance should also be in the Specification.

Specific Assessment of N690-12

Chapter NH – Design of Members for Combined Forces and Torsion

- No changes from Chapter H of 360-10
- The 360-10 provisions provide simplifications and clarifications of similar equations used in ASD since 1961. They also provide updated and expanded coverage of areas not previously addressed.
- As noted in the 360-10 Commentary, some of the newer provisions are less conservative, than the previous ASD Spec.
- Further review does not appear to be warranted.

Specific Assessment of N690-12

Chapter NI – Design of Composite Members

- Applicable to composite members such as rolled or built-up structural steel shapes and concrete acting together, not applicable for steel-plate composite (SC) members. Design of SC walls has been added to N690s1-15.
- Same as Chapter I of 360-10, with substitution of ACI-349 for ACI-318 in 2 places.
- There are differences compared to N690-1994 (2004). Comparison between the older and new spec are difficult.
- 360-10 includes new material and significant changes compared to 360-05. 360-05 already had extensive technical and format changes and new material compared to previous editions such as the 1999 and 1986 LRFD Spec.
- Clarification of the requirements for steel anchors for concrete-encased beams is needed.
- Further review does not appear to be warranted.

Specific Assessment of N690-12

Chapter NJ – Design of Connections

- Same as Chapter J of 360-10, with replacements/additions to J1.9, J1.10, J2.2b, J2.6, J3.8, J3.10
- J1 of 360-10, General Provisions, are similar to J1 of the 1986 LRFD Spec and Q1.15, Connections, of N690-1994.
- J2 of 360-10, Welds, states that all provisions of AWS D1.1/D1.1M apply with the exceptions listed. Commentary does not discuss the basis for exceptions listed. Earlier versions of the Spec also referenced AWS with exceptions and no discussion.
- J3 of 360-10, Bolts and Threaded Parts, is like 360-05 with some additions. It is expanded and updated compared the 1986 LRFD and N690-1994 Specs. To better understand the difference, it might be worthwhile to do a more thorough comparison of Table J3.2 in 360-10 with Table Q1.5.2.1 in N690-1994.
- No specific issues have been identified with J4 through J10 that warrant further review of these sections.

Specific Assessment of N690-12

Chapter NK – Design of HSS and Box Member Connections

- Same as Chapter K of 360-10, except replace preamble's second User Note
- Subject not addressed in N690-1994. The provisions of this Chapter are based on international research by CIDECT and the recommendations of the International Institute of Welding (IIW) Subcommission XV-E on Tubular Structures. Further review of this Chapter does not appear to be warranted.

Chapter NL – Design for Serviceability

- Same as Chapter L of 360-10, with replacement for L1,
- There is no comparable information in N690-1994 (2004).
- The information in 360-10 Chapter L is general and qualitative and there is nothing in this chapter that relaxes any other design guidance contained in 360-10.
- The value of including this in N690-12 is not obvious. However, inclusion does not create any technical issues requiring detailed evaluation and reconciliation.

Specific Assessment of N690-12

Chapter NM – Fabrication and Erection

- Modifies Chapter M of 360-10 with replacements for M1 and M3, extensive changes and additions to M2, and replacements and additions to M4.

- More thorough review of other reference documents would be needed to track down all the differences with N690-1994 for NM2, Fabrication and NM4, Erection. This activity does not appear to be warranted since these sections may simply represent updated current practice or old provisions now incorporated in other updated referenced standards.

- NM3, Shop Painting, is similar to Q1.24 in N690-1994 S2. However, Q.1.24.1 says "… all other steel work shall be given one coat of shop paint." M3 (1) says it is not required unless specified. Q1.24.1 refers to RG1.54. This covered in general by new User Note. Also new Subsection 4 takes exception to stainless steel and adds approval by engineer of record.

Specific Assessment of N690-12

Chapter NN – Quality Control and Quality Assurance

- Completely replaces Chapter N of 360-10
- Section Q1.0.1 Scope of N690-1994 referenced 10CFR50 Appendix B. Supplement 2 expanded this to include reference to Independent Spent Fuel Facilities and DOE Nuclear Facilities. Supplement 2 also adds ANSI/ASME NQA-1 to the referenced Codes and Standards and discusses the use of this standard in CQ1.29 of the Commentary.
- The QC/QA information in Chapter NN of N690-12 says it replaces the information in N of 360-10, but it closely follows what is in Chapter N of 360-10. No mention is made of 10CFR50 App B nor ANSI/ASME NQA-1.
- Section NA2 adds NQA-1 as a reference, and the Commentary for NN discusses NQA-1 and NQA-1a. Section NA5 discusses Appendix B and NQA-1.
- Section NA5 and Chapter NN should be further reviewed for consistency with current staff guidance.

Specific Assessment of N690-12

Appendix N1 – Design by Inelastic Analysis

- Same as Appendix 1 of 360-10, plus addition to the last paragraph of Appendix.
- Current SRP does NOT permit use of inelastic analysis for the overall structural response of Seismic Cat I SSCs. Limited use is permitted for localized effects, such as missile penetration resistance.
- SRP 3.7.2.8 allows limited use of inelastic analysis for Seismic II/I evaluations. The Seismic Cat II (or Non-Seismic) SSC is allowed to deflect beyond linear elastic limits, provided (1) there is ample clearance to accommodate the increased deflection, and (2) structural integrity is assured.
- The use of Appendix N1 for commercial NPPs should not be permitted for seismic loading, or the limits for its use should be appropriately defined.

Specific Assessment of N690-12

Appendix N2 – Design for Ponding

- No changes from Appendix 2 of 360-10
- Appendix 2 of 360 is very similar to previous provisions of N690-1994 and the 1986 LRFD Spec. No specific issues have been identified that warrant further review of Appendix 2.

Appendix N3 – Design for Fatigue

- No changes from Appendix 3 of 360-10
- The current Appendix 3 appears to be very close to Appendix K3 of the 1999 LRFD spec. There are some additions which appear to be improvements. Table A-3.1, Fatigue Design Parameters appears to be the same as Table A-K3.1 of the 1999 LRFD spec.
- Appendix QB, Fatigue, of N690-1994, including the tables, is similar to the 1986 LRFD Spec. Apparently the 2004 Supplement to the 1994 spec did not incorporate the changes made in 1999 to the LRFD Spec. There does not appear to be any explanation as to why these changes were not included in the 2004 Supplement to N690-1994.
- In summary, Appendix 3 is very similar to the changes made to the 1999 LRFD Spec, which appear to have a sound technical basis. Further review of the differences between Appendix QB of the 1994 Spec and Appendix 3 do not appear to be warranted.

Specific Assessment of N690-12

Appendix N4 – Structural Design for Fire Conditions

- Replacements and modifications to Appendix 4 of 360-10
- It is not clear why N4.1 states that the Appendix does not address "Important to Safety" steel members. It should be clarified as what nuclear structures are meant to be covered by this appendix.
- Chapter B3.12 appears to make the guidance in Appendix 4 moot, although one could always choose to use it.
- Further discussion is needed as to the applicability of Appendix N4 to commercial NPPs.

Appendix N5 – Evaluation of Existing Structures

- Clarification is needed as to the applicability of Appendix N5 to N690-12 for commercial NPPs since it does not address seismic and other dynamic loads.

Specific Assessment of N690-12

Appendix N6 – Stability Bracing for Columns and Beams

- No changes from Appendix 6 of 360-10
- Evaluation included with Chapter NC, above.

Appendix N7 – Alternative Methods of Design for Stability

- No changes from Appendix 7 of 360-10
- Evaluation included with Chapter NC, above.

Appendix N8 – Approximate Second Order Analysis

- No changes from Appendix 8 of 360-10
- Evaluation included with Chapter NC, above.

Overview and Comparison of AISC N690-12, AISC 360-10 and AISC ASD 1989

Sanj Malushte, Bechtel Power Corporation

Amit H. Varma, Purdue University

Saahas Bhardwaj, Purdue University

Table of Contents

- AISC N690-12: Overview and Comparison with AISC 360-10
- AISC 360-05 &10: Overview & comparison with ASD 1989
  - Comparison of Effective Length Method and Direct Analysis Method

AISC N690-12 Specification for Safety-Related Steel Structures for Nuclear Facilities

Why the need for a separate nuclear standard?

- For non-nuclear structures (falling under AISC 360-10), loading requirements and corresponding performance requirements follow from ASCE 7-10
- For safety-related nuclear structures, loading and performance requirements need to meet applicable regulatory expectations (and a commensurate "higher standard of care" / due diligence)
- Both nuclear power plants (NPPs) and DOE nuclear facilities have special loading and acceptance requirements
- AISC N690 is thus a separate, yet dependent standard written against AISC 360. This is analogous to ACI 349 v/s ACI 318 for concrete structures

Applicable Regulatory Landscape for AISC N690

- For NPPs, the governing design and quality requirements come from GDC 1, 2, and 4 in 10CFR50 Appendix A

- GDC 1: *Quality standards and records*

- GDC 2: *Design bases for protection against natural phenomena*

- GDC 4*: Environmental and dynamic effects design bases*

A Note about Seismic Performance/Detailing

- N690 does not call out for seismic design/detailing per AISC 341
- NPPs are designed to remain essentially elastic with probability of unacceptable performance below 10^{-5} per year… This results in a mean return interval between 10,000 to 100,000 years
- N690 provisions are appropriate for R=1 design (e.g., NPPs) since ordinary detailing practices of AISC 360 are deemed to provide a sufficient measure of overstrength and some ductility for this case
- NPPs are required to show additional margin by a factor of 1.67 against this rare earthquake

Development/Format of a Dependent Standard

- A dependent standard such as AISC N690 and ACI 349 follows the reference (parent) standard (e.g., AISC 360 and ACI 318, respectively, in this case), and only provides the changes (i.e., additions, deletions, and exceptions) relative to the same

- The structure of the reference standard is preserved, and the user needs has to read/interpret the dependent standard in conjunction with the reference standard

- The committee goes through the reference standard and carefully identifies areas where changes are warranted due to nuclear-specific issues, and develops the necessary changes

Areas where AISC N690-12 Differs from AISC 360-10

Nuclear-specific considerations that warrant changes to AISC 360:

- Expanded Glossary/Definitions for nuclear-related terminology
- Inclusion of additional referenced standards
- Inclusion of additional materials/steel grades
- Need for additional safeguards against lamellar tearing
- Unique load cases and load combinations
- Design for impulsive and impactive loads
- Effect of elevated service temperature on steel properties
- Connection design based on reduced slip against reversible loads
- Improved CVN requirements for filler metals in ”critical” welds
- Limited yielding due to bolt bearing (See Eq. J3-6)
- Need for more stringent QA/QC requirements during design process and fabrication/erection process

Overview of AISC 360-05, 360-10 and differences relative to older AISC 1989 ASD Spec

History of AISC Specifications

ASD

1st Edition - 1923

7th Edition - 1969

8th Edition - 1978

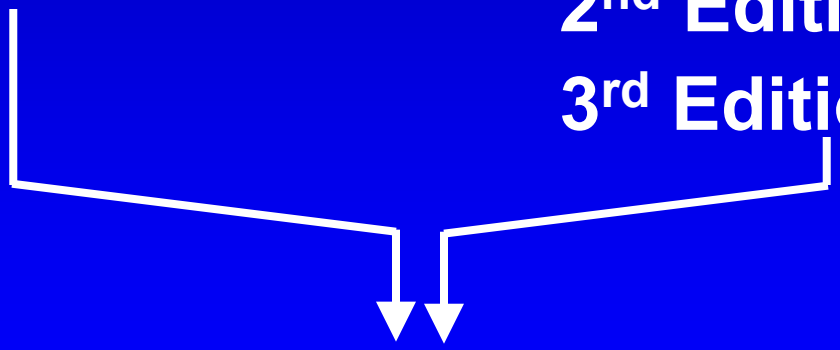
9th Edition - 1989

LRFD

1st Edition – 1986

2nd Edition – 1993

3rd Edition – 2001



13th Edition - 2005:
Combined ASD - LRFD

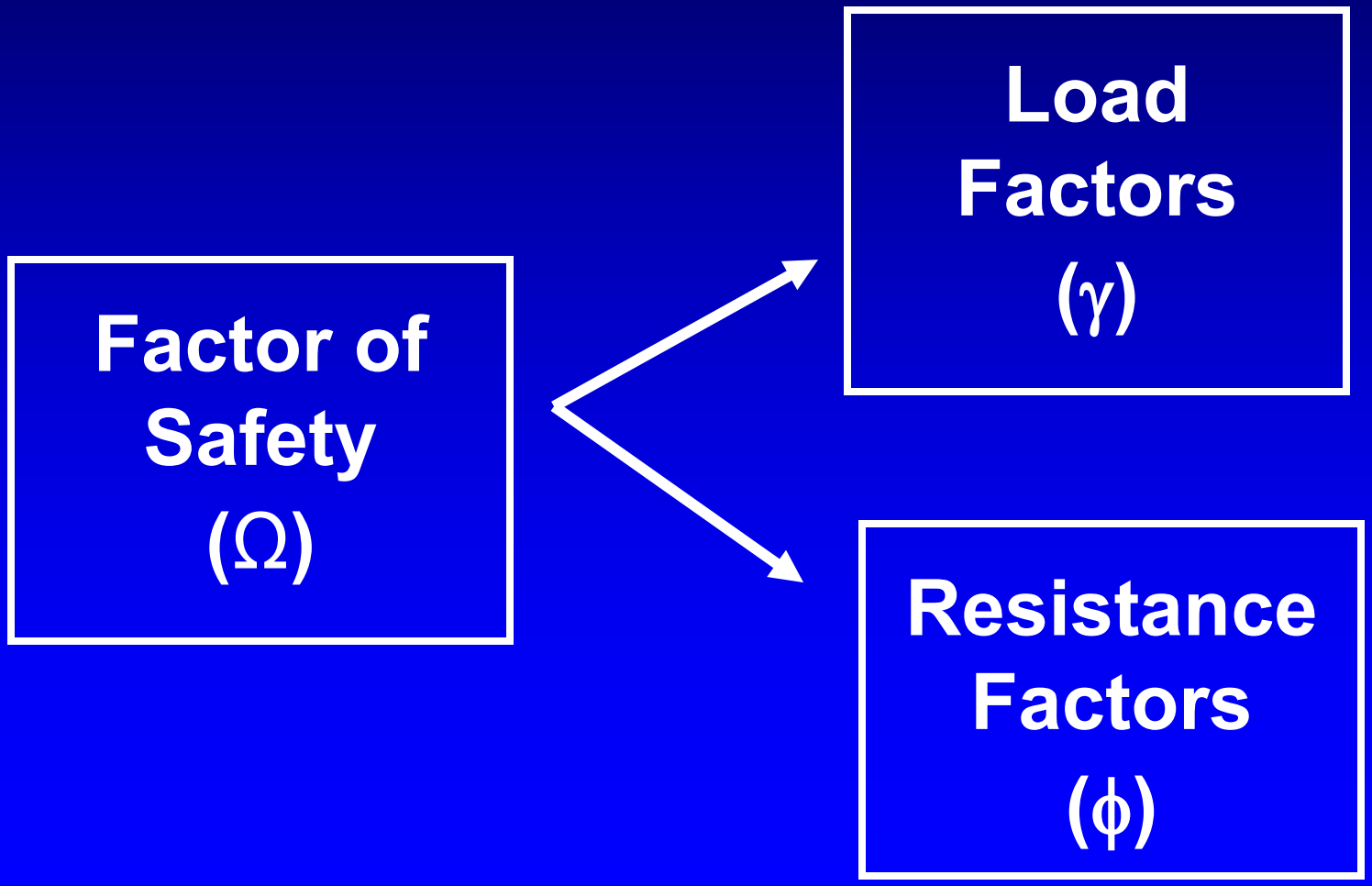
Differences Between ASD and LRFD Prior to 2005 Spec.

- Formatting of Factor of Safety
- Stress vs Force Format for Design Equations
- Nominal Strength Equations

Formatting of Factor of Safety

ASD

LRFD



Stress vs. Force Format

ASD

$$f_a \leq F_a$$

$$f_b \leq F_b$$

$$f_v \leq F_v$$

LRFD

$$P_u \leq \phi P_n$$

$$M_u \leq \phi M_n$$

$$V_u \leq \phi V_n$$

Equations for Nominal Strength

ASD and LRFD check the same limit states:

Columns:	Buckling
Tension Members:	Yield of Gross Section Fracture of Net Section Block Shear Fracture
Beams - Flexure:	Yielding (reaching M_p) Local Buckling Lateral Torsional Buckling
Beams - Shear:	Yielding (reaching V_p) Shear Buckling
Bolts and Welds:	Fracture
Etc...	

Equations for Nominal Strength

ASD and LRFD check the same limit states

But.....

ASD and LRFD check limit states using different nominal strength equations

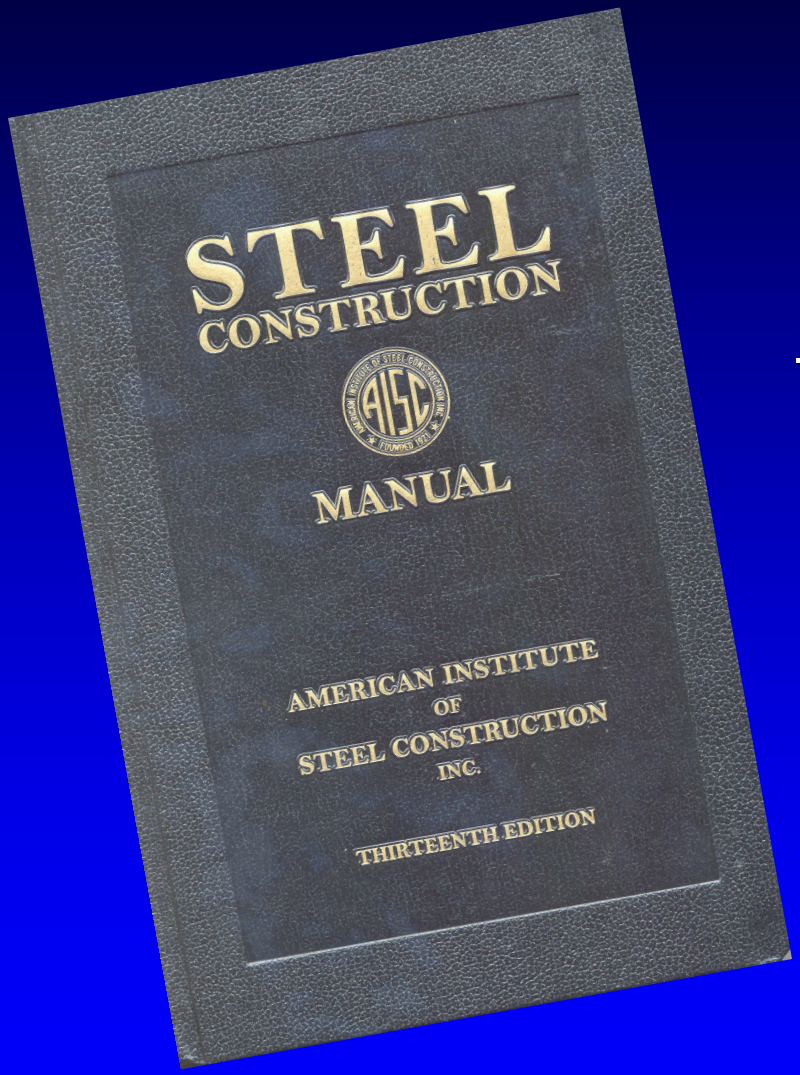
Why ?.....

ASD has not been updated in many years. All new developments have been put into LRFD

Differences Between ASD and LRFD in the *2005 AISC Spec*

- Formatting of Factor of Safety
- ~~Stress vs Force Format for Design Equations~~
- Nominal Strength Equations

2005 AISC Specification



Permits design using either....

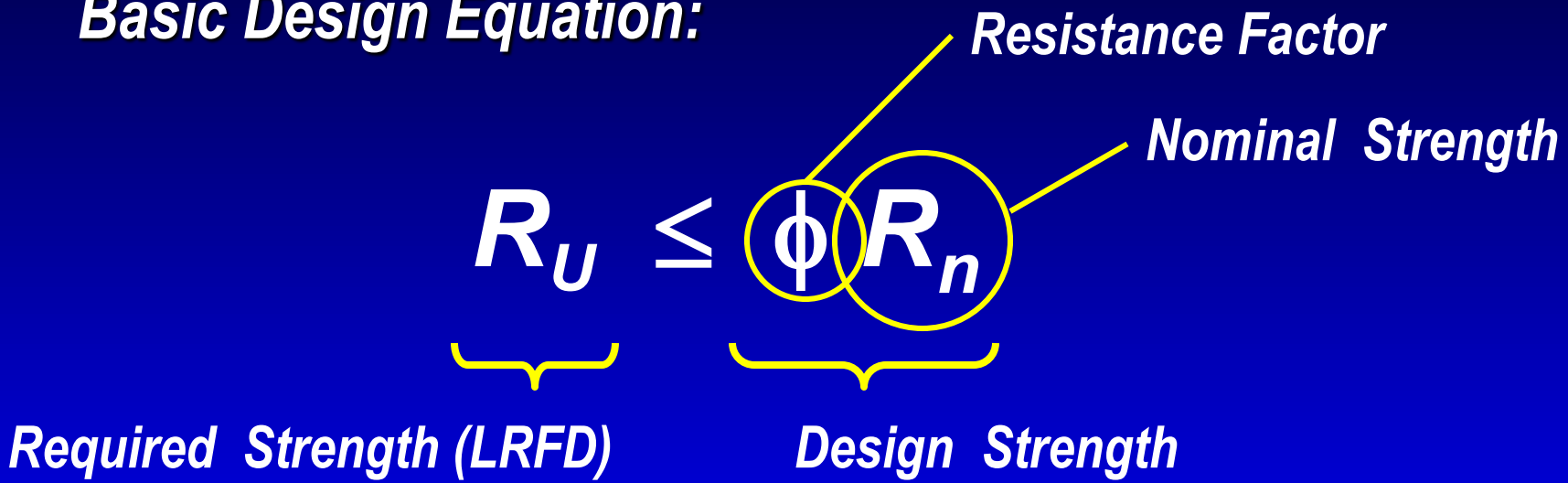
LRFD *Load and Resistance Factor Design*

- or -

ASD Allowable **Strength** Design

2005 AISC Specification - LRFD Option

Basic Design Equation:



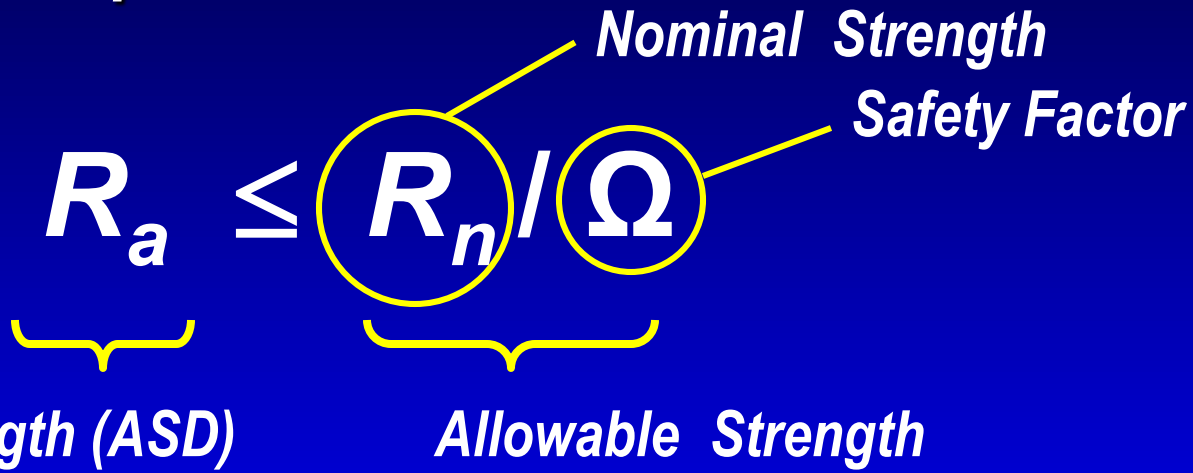
$$P_U \leq \phi P_n$$

$$M_U \leq \phi M_n$$

$$V_U \leq \phi V_n$$

2005 AISC Specification - ASD Option

Basic Design Equation:

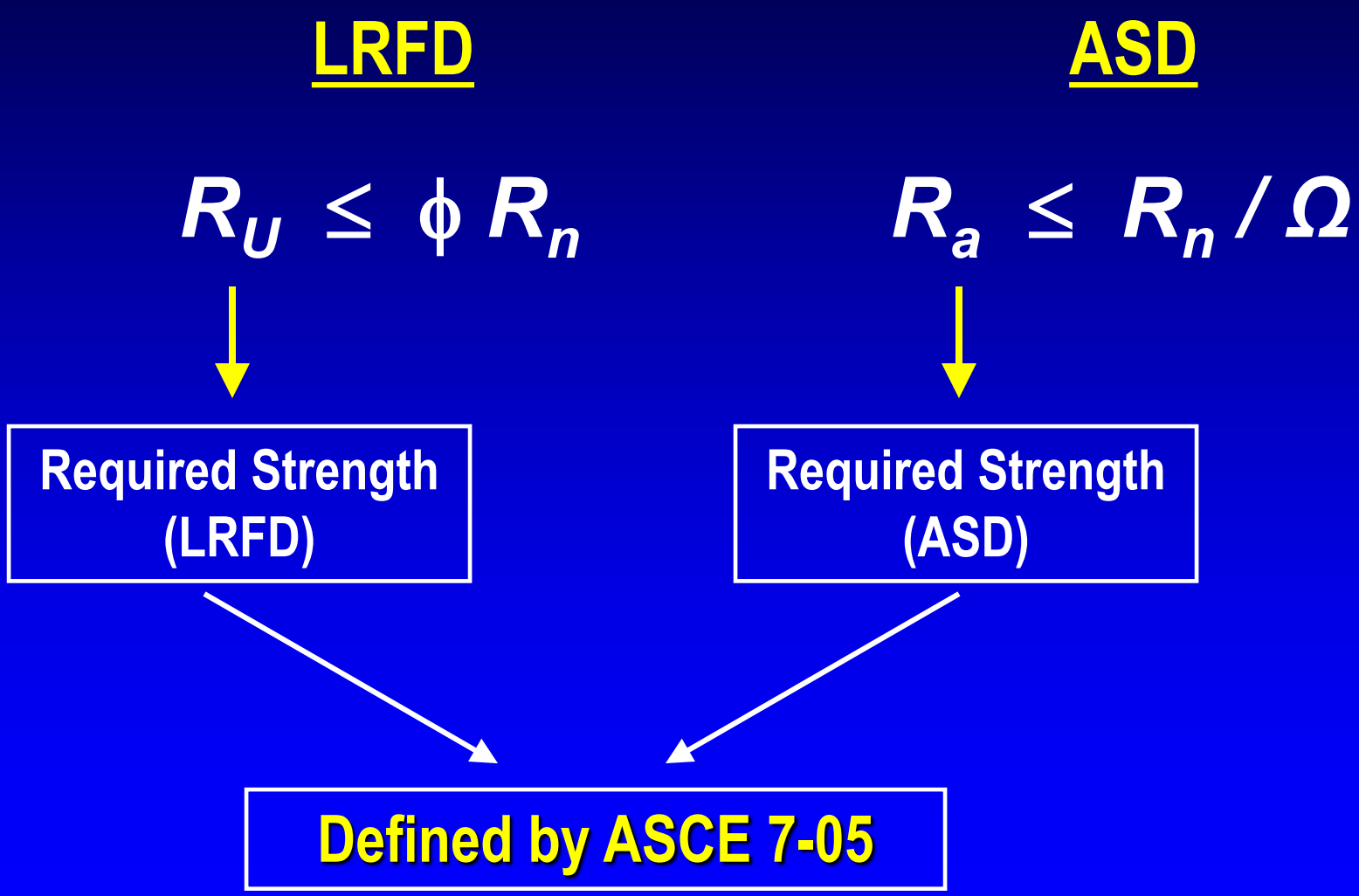


$$P_a \leq P_n / \Omega$$

$$M_a \leq M_n / \Omega$$

$$V_a \leq V_n / \Omega$$

2005 AISC Specification



ASCE 7-05 LRFD Load Combinations:

1. 1.4D
2. 1.2D + 1.6L + 0.5(L_r or S or R)
3. 1.2D + 1.6 (L_r or S or R) + (0.5L or 0.8W)
4. 1.2D + 1.6W + 0.5L + 0.5 (L_r or S or R)
5. 1.2D + 1.0E + 0.5L +0.2S
6. 0.9D + (1.6W or 1.0E)

ASCE 7-05 ASD Load Combinations:

1. D + L
2. D + (L_r or S or R)
3. D + 0.75 [L + (L_r or S or R)]
4. D + (W or 0.7 E)
5. D + 0.75 [L + (Lr or S or R) + (W or 0.7E)]
6. 0.6D + (W or 0.7E)

*(D+L)**

*(0.75D+0.75L+0.75W)**

*(0.75D+0.75L+0.75E)**

** 1989 ASD Load Combinations*

2005 AISC Specification

LRFD

$$R_U \leq \phi R_n$$

Required Strength (LRFD)

ASD

$$R_a \leq R_n / \Omega$$

Required Strength (ASD)

In general.... $R_U \cong (1.4 \text{ to } 1.6) \times R_a$

2005 AISC Specification

LRFD

$$R_U \leq \phi R_n$$

ASD

$$R_a \leq R_n / \Omega$$

Nominal Strength - Same in LRFD and ASD

2005 AISC Specification

LRFD

$$R_U \leq \phi R_n$$

Resistance Factor

ASD

$$R_a \leq R_n / \Omega$$

Safety Factor

$$\phi\Omega = 1.5$$

The available strength for LRFD is always 1.5 times that for ASD

Example: For $\Omega = 1.67$, $\phi = 0.90$
For $\Omega = 2$, $\phi = 0.75$

2005 AISC Specification

LRFD

$$R_U \leq \phi R_n$$

Design Strength

ASD

$$R_a \leq R_n / \Omega$$

Allowable Strength

Available Strength

2005 AISC Specification

LRFD and ASD

Required Strength $\leq$ Available Strength

Overview of AISC 360-10

History of AISC Specifications

ASD

1st Edition - 1923

7th Edition - 1969

8th Edition - 1978

9th Edition - 1989

LRFD

1st Edition – 1986

2nd Edition – 1993

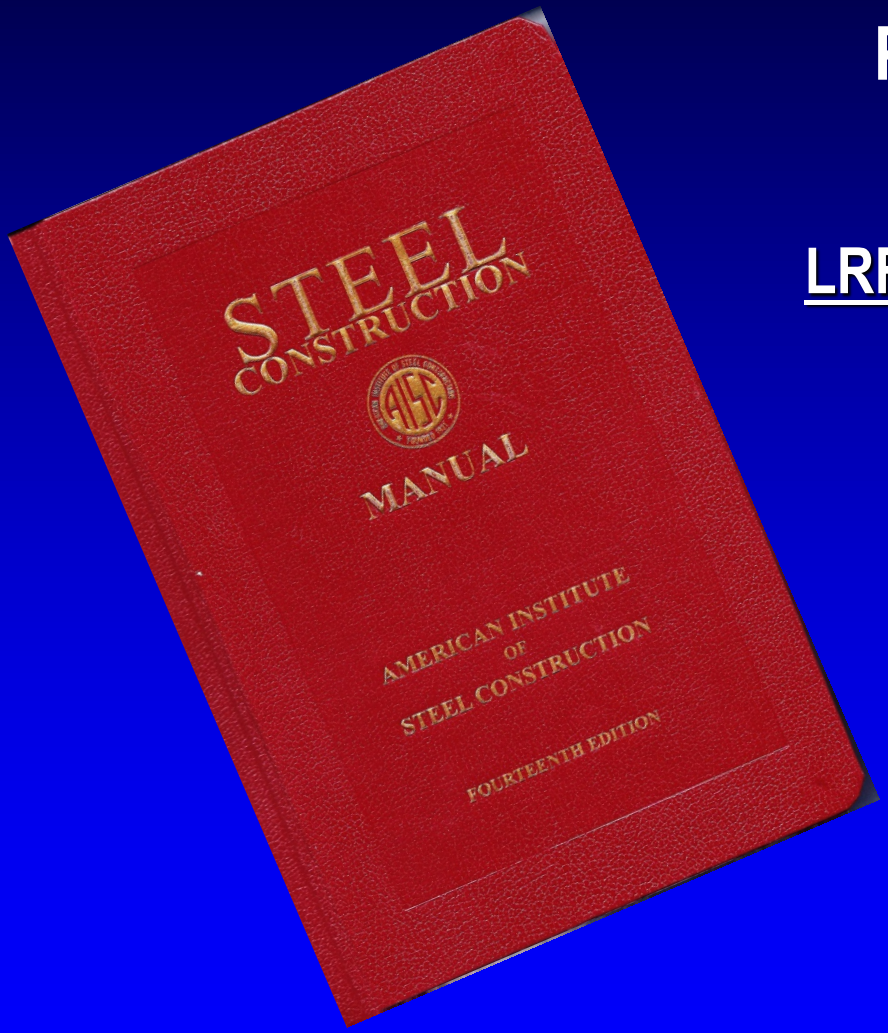
3rd Edition – 2001

Combined ASD-LRFD

13th Edition – 2005

14th Edition - 2010

2010 AISC Specification



Permits design using either....

LRFD *Load and Resistance Factor Design*

- or -

ASD Allowable **Strength** Design


ASCE STANDARD
ASCE/SEI
7–10
Minimum Design
Loads for Buildings
and Other Structures
This document uses both the
International System of Units (SI)
and customary units
SEI
ASCE
STRUCTURAL
ENGINEERING
INSTITUTE
ASCE

LRFD Load Combinations:

1. 1.4D
2. 1.2D + 1.6L + 0.5(L_r or S or R)
3. 1.2D + 1.6 (L_r or S or R) + (0.5L or 0.5W)
4. 1.2D + 1.0W + 0.5L + 0.5 (L_r or S or R)
5. 1.2D + 1.0E + 0.5L +0.2S
6. 0.9D + W
7. 0.9D + E

Note: The load factor on *L* in load combinations 3, 4 and 5 is taken as 1.0 if the service live load is greater than 100 psf

ASD Load Combinations:

1. D
2. D + L
3. D + (L_r or S or R)
4. D + 0.75 L + 0.75 (L_r or S or R)
5. D + (0.6 W or 0.7 E)

6a. D + 0.75 L + 0.75 (.6W) + 0.75 (L_r or S or R)

6b. D + 0.75 L + 0.75 (0.7E) + 0.75 S

7. 0.6 D + 0.6 W
8. 0.6 D + 0.7 E

2010 AISC Specification

LRFD

$$R_U \leq \phi R_n$$

Required Strength (LRFD)

ASD

$$R_a \leq R_n / \Omega$$

Required Strength (ASD)

In general.... $R_U \cong (1.4 \text{ to } 1.6) \times R_a$

2010 AISC Specification

LRFD

$$R_U \leq \phi R_n$$

ASD

$$R_a \leq R_n / \Omega$$

Nominal Strength - Same in LRFD and ASD

Comparison of Effective Length Method (ELM) and Direct Analysis Method (DAM)

AISC 360-10 adopts DAM in Ch. C and relegates ELM to App. 7

Limitations of Effective Length Method (ELM)

- Behavior is purely elastic
- All members have constant cross section
- All joints are rigid
- For braced frames, rotations at opposite ends of beams are equal in magnitude, producing single curvature bending
- For unbraced frames, rotations at opposite ends of restraining beams are equal in magnitude, producing reverse-curvature bending
- The stiffness parameters $L\sqrt{P/EI}$ of all columns are equal
- Joint restraint is distributed to the column above and below the joint in proportion to *I/L of the two columns.*
- *All columns buckle simultaneously.*
- *No significant axial compression force exists in the girders.*

Limitations of Effective Length Method (ELM)

- No real frame meets these assumptions behind ELM, and the resulting solution for column buckling strength is generally conservative.
- AISC and other codes have therefore embraced the notional load method (DAM) to determine the column buckling strength. The AISC version of the notional load method is called direct analysis method (DAM)

Stability Design Requirements

- Stability shall be provided for the structure as a whole and for each of its elements.
- Any method that considers the effects of the following on the stability of structure and elements is permitted:
  - Influence of second-order effects (P-Δ and P-δ) produced by flexural, shear, and axial deformations
  - Geometric imperfections
  - Member stiffness reduction due to residual stress
  - All component and connection deformations that contribute to lateral displacements must be considered in the analysis

These considerations are addressed in (Direct Analysis Method) DAM

Direct Analysis Method (AISC 360-10)

- Design for stability can be done by any rational method including DAM (Section C2) or alternate methods of design (effective length method and the first order analysis method in Appendix 7).
- For DAM, the required strengths are determined from:
  - Analysis conforming to Section C2.1
  - Initial imperfections according to Section C2.2
  - Stiffness according to Section C2.3
- The Available strengths are calculated in accordance with Section C3.
- The design of stability bracing of elements is per Appendix 6.

Direct Analysis Method: Analysis Requirements (C2.1)

- Account for member deformations and stiffness reductions
- Second order analysis considering P-Δ and P-δ effects
  - Approximate second-order analysis provided in App. 8 is permitted as an alternative
- Analysis shall consider all gravity and other loads
- For design by LRFD, the second order analysis shall be carried out under LRFD load combinations

Direct Analysis Method: Imperfections and Stiffness Reduction

- The effects of imperfections on the stability of the structure are accounted for by:
  - Directly modeling the imperfections (C2.2a)
  - Application of notional loads (C2.2b)
- The analysis of structures to determine reduced strengths shall use reduced stiffness by applying the factors of 0.8 and τ_b.

Thank You.