Recent Developments in Codes and Standards for New and Advanced Reactors

- **Moderator:** Alexander Chereskin, Materials Engineer, NRR/DANU/UTB1

- **Panelists/Speakers:**
  - Sam Sham (INL) and Richard Wright (Structural Alloys LLC)
  - Amit Varma (Purdue University)
  - Augi Cardillo and Tom Ruggiero (ASME)
  - Samuel Johnson, Hasan Charkas, and Salvador Villalobos (EPRI)
  - Andrew Whittaker and George Abbat (ASCE), and Jim Xu (NRC)
  - Adeola Adediran (ACI)

September 15, 2021

Sam Sham, NST Directorate Fellow, INL

Richard Wright, President, Structural Alloys LLC

Qualification of High Temperature Materials and Their Incorporation into ASME Section III, Division 5

NRC Standards Forum

Qualification of High Temperature Materials for Section III, Division 5, Class A Construction

Section II, Part D

Over 100 alloys for Power Boilers (Section I) and Pressure Vessels (Section VIII) applications

Division 5, Class A

Only six and a half alloys for Section III

- Type 304 & 316 stainless
- Alloy 800H
- Grade 91
- 2.25Cr-1Mo
- Alloy 617
- SA 508, 533B pressure vessel steels (short-term elevated temperature excursions)

- Why there is such a large discrepancy
- What can be done to increase the availability of high temperature alloys for advanced reactors
  - To provide design flexibility
  - To accelerate advanced reactor deployment schedule
- Why not just use non-nuclear codes
- What is the inside scoop

ASME Section III, Rules for Construction of Nuclear Facility Components - Division 5, High Temperature Reactors

- ASME Section III Division 5 Scope
  - Division 5 rules govern the construction of vessels, piping, pumps, valves, supports, core support structures and nonmetallic core components for use in high temperature reactor systems and their supporting systems
    - Construction, as used here, is an all-inclusive term that includes material, design, fabrication, installation, examination, testing, overpressure protection, inspection, stamping, and certification
- High temperature reactors include
  - Gas-cooled reactors (HTGR, VHTR, GFR)
  - Liquid metal reactors (SFR, LFR)
  - Molten salt reactors, liquid fuel (MSR) or solid fuel (FHR)

Division 5 - A Component Code

- Division 5 is organized by Code Classes:
  - Class A and Class B* for metallic coolant boundary components
  - Class SM for metallic core support structures
  - Class SN for nonmetallic components
- The Code Classes allow a choice of rules that provide a **reasonable assurance of structural integrity and quality** commensurate with the relative importance **assigned** to the individual components of the advanced reactor plant

* Class B rules are similar to the Section VIII, Division 1, design-by-rules approach

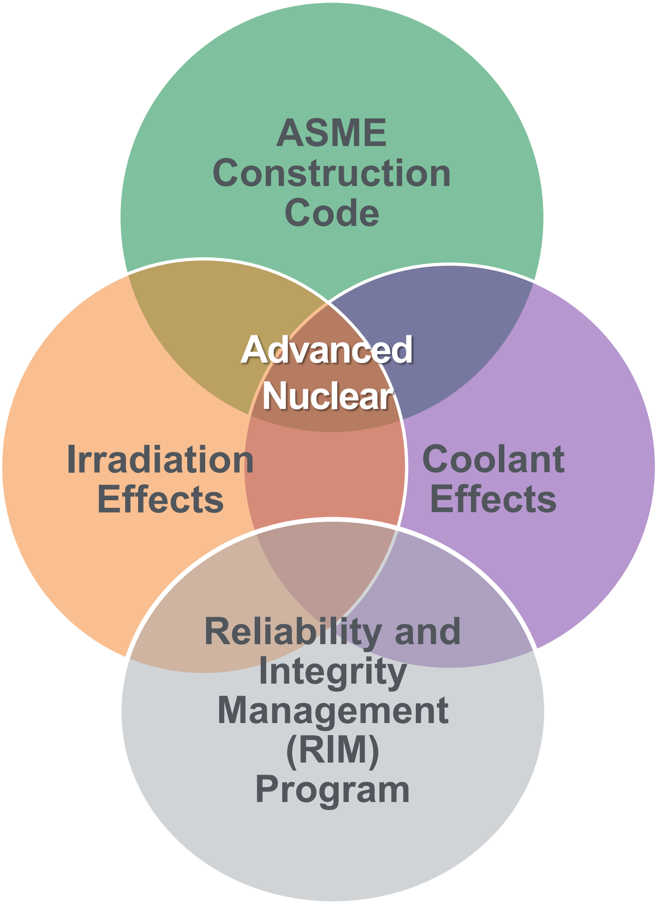
Section III, Division 5 Organization

Code Class	Sub-section	Subpart	ID	Title	Scope
General Requirements					
Class A, B, & SM	HA	A	HAA	Metallic Materials	Metallic
Class SN		B	HAB	Graphite and Composite Materials	Nonmetallic
Class A Metallic Coolant Boundary Components					
Class A	HB	A	HBA	Low Temperature Service	Metallic
Class A		B	HBB	Elevated Temperature Service	Metallic
Class B Metallic Coolant Boundary Components					
Class B	HC	A	HCA	Low Temperature Service	Metallic
Class B		B	HCB	Elevated Temperature Service	Metallic
Class A and Class B Metallic Supports					
Class A & B	HF	A	HFA	Low Temperature Service	Metallic
Class SM Metallic Core Support Structures					
Class SM	HG	A	HGA	Low Temperature Service	Metallic
Class SM		B	HGB	Elevated Temperature Service	Metallic
Class SN Nonmetallic Core Components					
Class SN	HH	A	HHA	Graphite Materials	Graphite
Class SN		B	HHB	Composite Materials	Composite

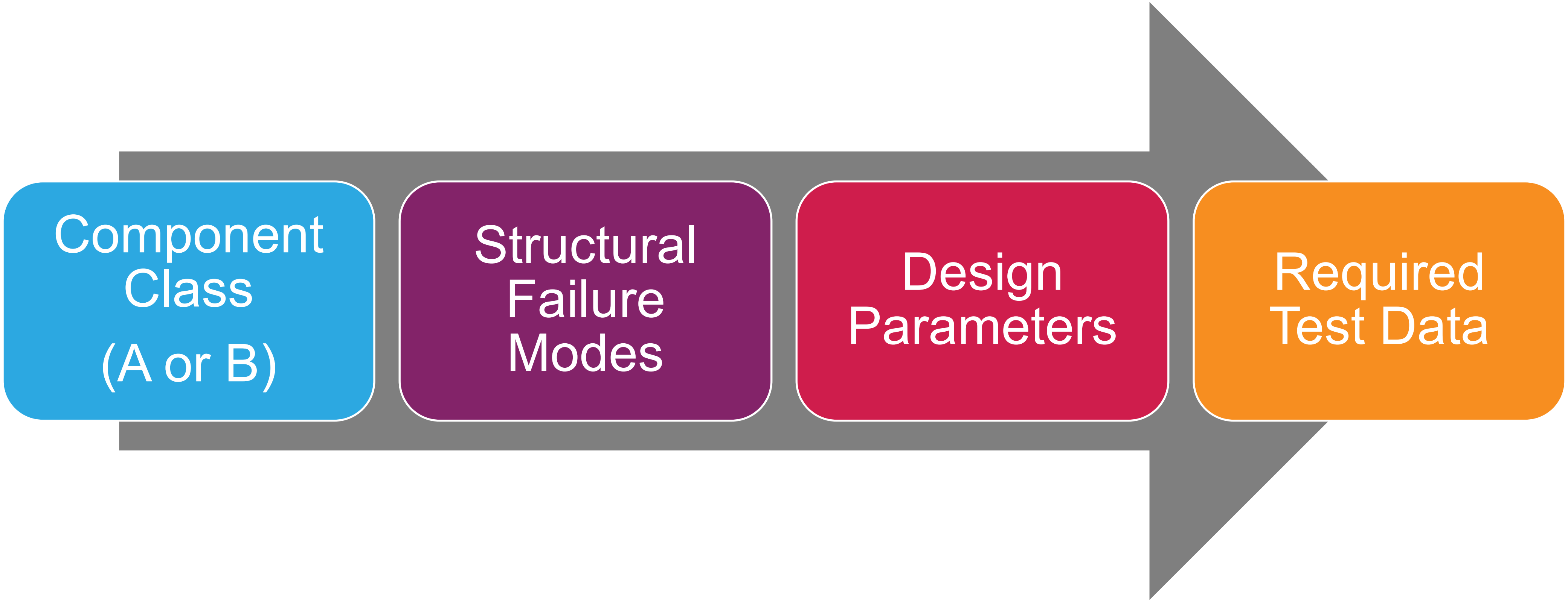
Advanced Reactors Under Development Have Drastically Different Characteristics

Different design and operational characteristics	Section III, Division 5 covers construction	Additional topics to support licensing & plant operations

• Inlet/outlet temperatures
• Thermal transients
• Coolants
• Solid fuel vs liquid fuel
• Neutron spectrum and dose
• Design lifetimes
• Safety characteristics
	• Metallic
	  • High temperature design methodology
	  • Alloy qualification
	  • Fabrication & examination
	• Graphite
	  • Qualification and codification
		• Corrosion effects
		  • Gases (He, N, CO_2), liquid metals, molten salts
		• Irradiation effects
		• Materials degradation management
		• Flaw evaluations



Materials Data Requirements for Section III, Division 5 Components



Structural Failure Modes for Division 5 Class A Components

- Class A design rules are based on design-by-analysis approach
  - Sought to provide a reasonable assurance of adequate protection of structural integrity
  - Based on design against structural failure modes; four design evaluation checks

Time Independent Failure Mode	Category	Design Evaluation Procedure	Time Dependent Failure Mode	Category	Design Evaluation Procedure
Ductile rupture from short-term loading	Load-controlled	Primary load check	Creep rupture from long-term loading	Load-controlled	Primary load check
Gross distortion due to incremental collapse and ratcheting (low temperatures)	Deformation-controlled	Strain limits check	Creep ratcheting due to cyclic service	Deformation-controlled	Strain limits check
Loss of function due to excessive deformation	Deformation-controlled	Strain limits check	Creep-fatigue failure due to cyclic service	Deformation-controlled	Creep-fatigue check
Buckling due to short-term loading	Deformation-controlled	Buckling Check	Creep-buckling due to long-term loading	Deformation-controlled	Buckling Check

Design Parameters Required to Address Failure Modes for Class A Components

Design Parameters	Required Test Data
Allowable Stresses	
• S_m: based on yield and ultimate strengths at temperature	Tensile data at temperature (time-independent)
• S_t: based on time to 1% total strain, time to onset of tertiary creep, time to rupture • S_r: based on stress to rupture	Creep rupture data with full creep curves (time-dependent)
• S_{mt}: lesser of (S_m, S_t) • S_0: lesser of $(S, S_{mt}@300{,}000h)$	Derived design parameters
• R: Stress rupture factor - based on rupture strengths of base metal and weldment	Stress rupture data from base metal and weldment (time dependent)
Thermal aging factors on yield and ultimate	Tensile data of aged material (time-dependent)
Isochronous stress-strain curves constructed based on creep tests	Tensile stress-strain curves (time-independent), and creep strain data up to 3% (time-dependent)

Design Parameters	Required Test Data
Fatigue design curves	Strain-controlled continuous cycling tests
Creep-fatigue interaction diagram	Strain-controlled cyclic tests with hold times
EPP design parameters	Two-bar and SMT tests; cyclic stress-strain curves
Inelastic material model parameters	Test data for other design parameters; and strain rate change and thermomechanical cycling
Huddleston effective stress parameters	Multiaxial creep rupture data
External pressure charts	Tensile stress-strain curves (time-independent)
Time-temperature limits for external pressure charts	Isochronous strain-strain curves

Design Parameters Required to Address Failure Modes for Class A Components

Design Parameters	Required Test Data
Allowable Stresses	
• S_m: based on yield and ultimate strengths at temperature	Tensile data at temperature (time-independent)
• S_t: based on time to 1% total strain, time to onset of tertiary creep, ti… • S_r: based on str…	Creep rupture dat…
• S_{mt}: lesser of (S_m… • S_0: lesser of (S, S_r…	
• R: Stress rupture … strengths of base…	
Thermal aging factor…	…ensile data of aged material (time-dependent)
Isochronous stress-strain curves constructed based on creep tests	Tensile stress-strain curves (time-independent), and creep strain data up to 3% (time-dependent)

Design Parameters	Required Test Data
Fatigue design curves	Strain-controlled continuous cycling tests
Creep-fatigue interaction diagram	Strain-controlled cyclic tests with hold times
	Two-bar and SMT tests; cyclic stress-strain curves
	Test data for other design parameters; and strain rate change and thermomechanical cycling
	Multiaxial creep rupture data
	Tensile stress-strain curves (time-independent)
Time-temperature limits for external pressure charts	Isochronous strain-strain curves

Some design parameters are for setting design limits; some are for providing behavioral trends to support design evaluations

Required Testing to Support Design Parameters Development for Class A Components

- Refer to Section II Materials and Section III, Division 5 “Nonmandatory Appendix HBB-Y, Guidelines for design data needs for new materials”
- Required Tests
  - Tensile, creep rupture, fatigue, creep-fatigue, constitutive, multiaxial creep rupture, EPP
- Time dependent data (creep rupture) dominates the test times for data generation
  - Allow limited extrapolation of time for creep properties
    - Well-behaved, solid-solution alloys may extrapolate in time of no more that a factor of 5 to reach **intended life**
    - Metastable alloys, such as the creep strength enhanced ferritic/martensitic steels may extrapolate with a factor of 3
      - Require metallurgical justification for 3 < extrapolation factor ≤ 5

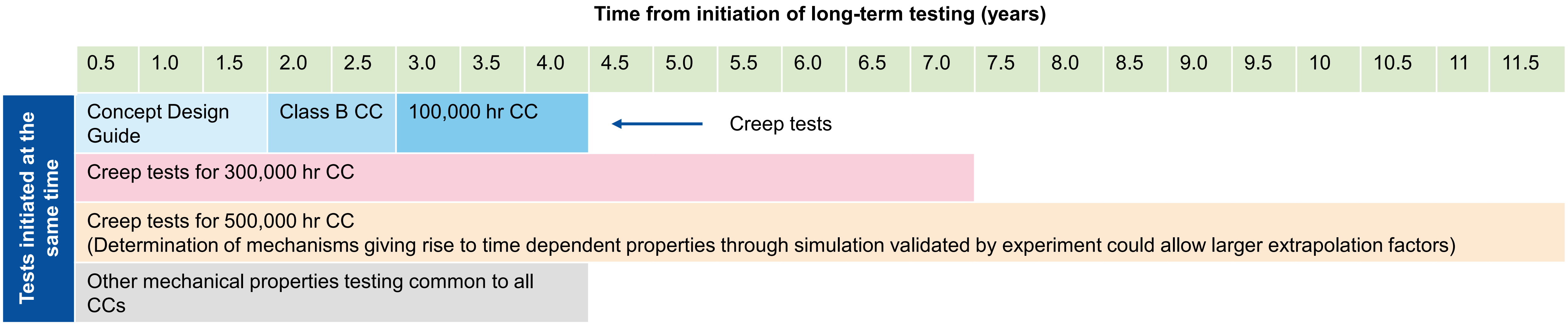
Design Life (hours)	Minimum Time to Complete Creep Rupture Testing (years)	
	Solid Solution Alloys	Ferritic-Martensitic Steels
100,000	2.3	3.8
300,000	6.8	11.4
500,000	11.4	19.0

A long and arduous process!

New Materials Data Generation Strategy for Class A Components

- Should we qualify new Class A materials for 500,000-hour design life from the get-go?
  - An emphatic NO
  - We have never done that historically
  - No reason to do so now
- Instead, a “staged” or “phased” new materials qualification strategy is employed
- For example, the current code qualification effort undertaken by the DOE Advanced Reactor Technologies (ART) Program for an advanced austenitic stainless steel, Alloy 709, follows such a strategy

A "Staged" Qualification Approach for Alloy 709



A four-year testing program, without resource constraints, would generate data package to support:

- Conceptual design
  - Conceptual Design Guide for 500,000-hour lifetime
- Preliminary design
  - 100,000-hour Class A code case
  - Class B material code case

Additional creep data at 7-year mark from start:

- Final design
  - 300,000-hour Class A code case

Additional creep data at 12-year mark from start:

- Nth-of-a-kind
  - 500,000-hour Class A code case

Incorporate Class A Material Code Cases into Section III, Division 5

- Once the design parameters are developed, the code case together with supporting data package can be submitted for approval using a balloting plan similar to that established for the Alloy 617 code case

RC #	Topics	ASME Code Committees									
16-994	Permissible base and weld materials, allowable stress values	WG-ASC	SG-ETD	SG-HTR	SG-MFE	II-SG-NFA	II-SG-SW	BPV-II			
16-995	Physical properties and extension of modulus values to higher temperatures	WG-ASC	SG-ETD	SG-HTR	SG-MFE	II-SG-NFA	II-SG-PP	BPV-II			
16-996	Temperature-time limits for NB buckling charts	WG-AM	SG-ETD	SG-HTR	SG-MFE	II-SG-EP	II SG-NFA	BPV-II	SC-D		
16-997	Huddleston parameters, ISSCs	WG-ASC	SG-ETD	SG-HTR	II-SG-NFA	BPV-II	SC-D				
16-998	Negligible creep, Creep-Fatigue: D-diagram and EPP	WG-CFNC	SG-ETD	SG-HTR	SC-D						
16-999	EPP strain limits	WG-AM	SG-ETD	SG-HTR	SC-D						
16-1000	Fatigue design curves	WG-CFNC	WG-FS	SG-ETD	SG-HTR	SG-DM	SC-D				
16-1001	Alloy 617 Overall Code Case	WG-ASC	WG-AM	WG-CFNC	WG-FS	SG-ETD	SG-HTR	SG-MFE	SC-D	BPV-II	BPV-III

Contacts for Questions on Class A Materials Qualification and Incorporation into Division 5

- Working Group Allowable Stress Criteria
  - Richard Wright (structural.alloys@gmail.com)
- Working Group Analysis Methods
  - Mark Messner (messner@anl.gov)
- Working Group Creep-Fatigue and Negligible Creep
  - Yanli Wang (wangy3@ornl.gov)
- Special Working Group High Temperature Reactor Stakeholders
  - Mike Cohen (micohen@terrapower.com)
- Subgroup High Temperature Reactors
  - Sam Sham (tingleung.sham@inl.gov)

Presenters Contact Information

- Sam Sham
  - Idaho National Laboratory
  - Email: TingLeung.Sham@inl.gov
- Richard Wright
  - Structural Alloys LLC
  - Email: structural.alloys@gmail.com

ASME Code Case: Steel Plate Composite Containment Vessel (SCCV)

Amit H. Varma
Karl H. Kettelhut Professor of Civil Eng.
Purdue University

OUTLINE

- INTRODUCTION & BACKGROUND
- ASME CODE CASE FOR SCCV
  - Overall Layout / Structure
  - Highlights / Details
  - Design Example

STEEL-PLATE COMPOSITE WALLS

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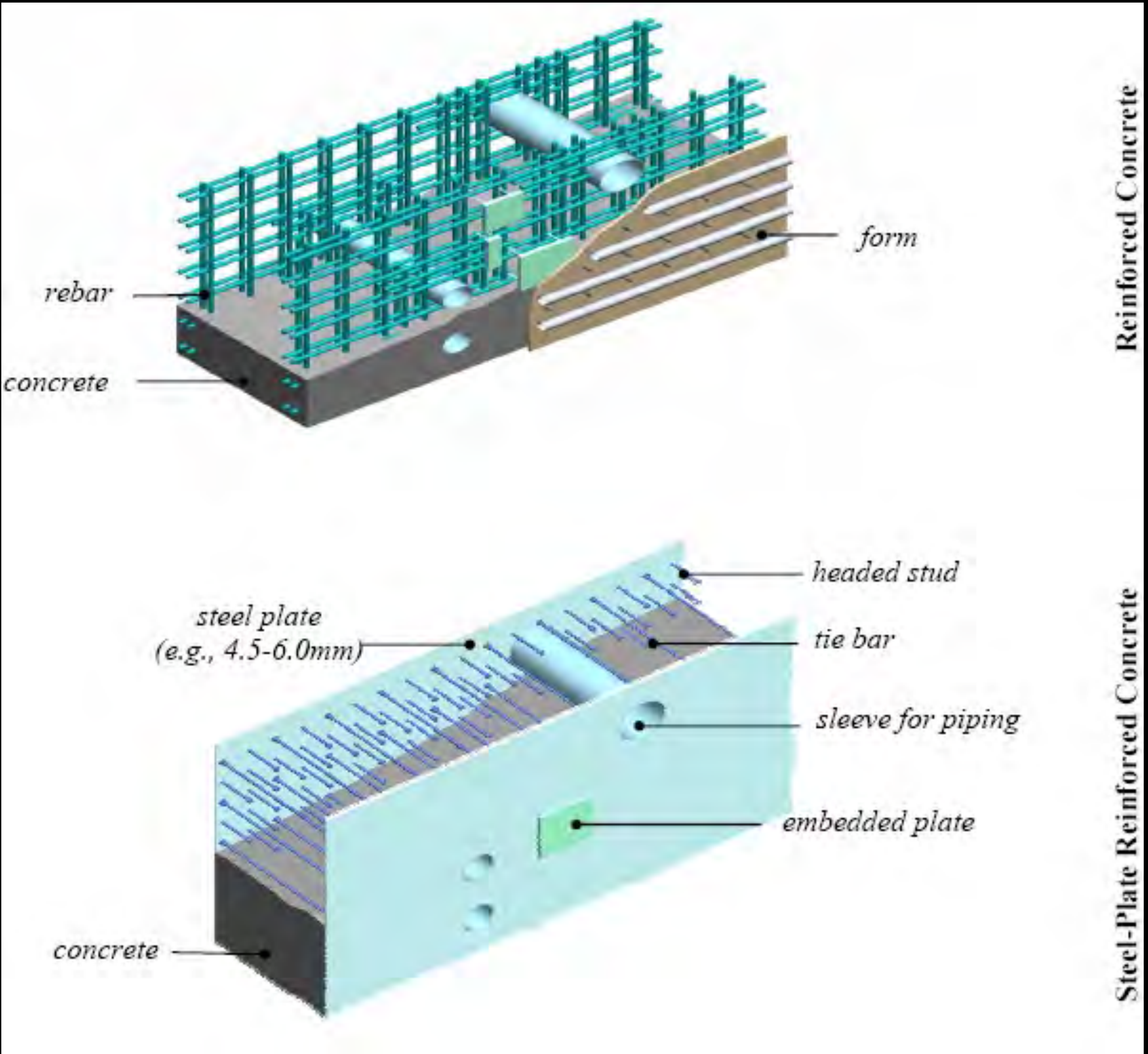
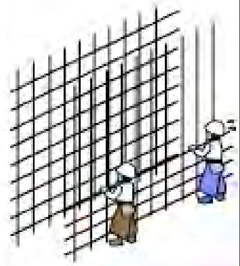
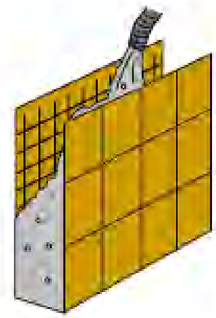
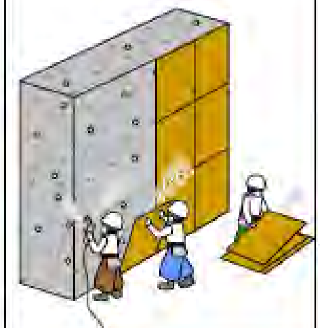
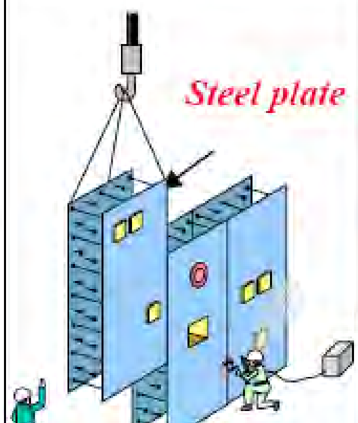
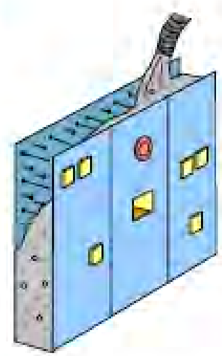
- Modular vs. Conventional RC Construction
  - Eliminates Rebar cages, assembly, formwork, removal
  - Eliminates rebar congestion
  - Shop fabrication of steel modules
  - Concrete flowability –self-consolidating concrete
  - Missile / Aircraft Impact

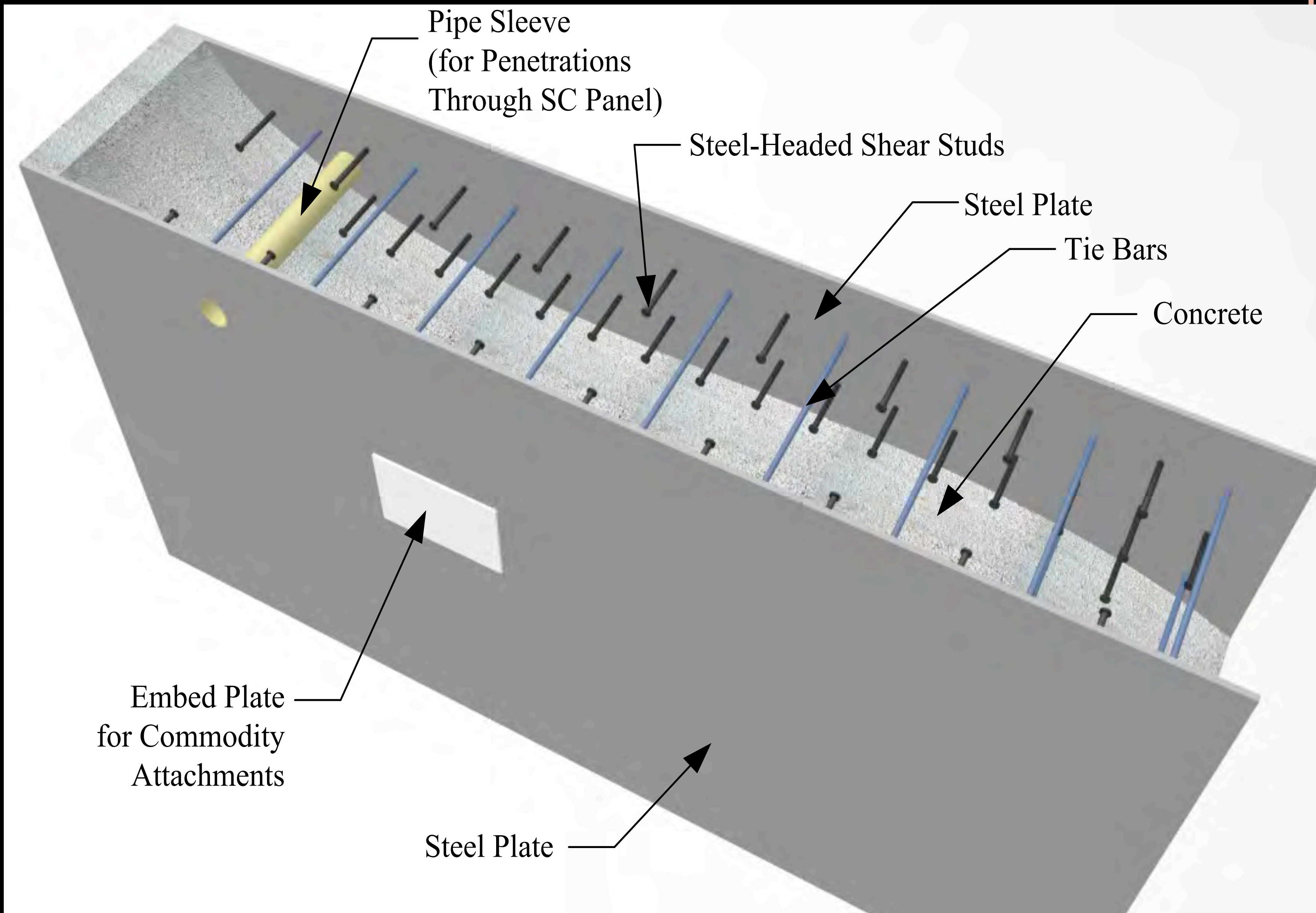
STEEL-PLATE COMPOSITE WALLS



STEEL-PLATE COMPOSITE WALLS

Work / Structure	Rebar arrangement	Form work (assembling	Placing concrete	Form work (removal)
RC				
28days	*13days*	*7days*	*4days*	*4days*
SC	—			—
14days	–	*10days*	*4days*	–

STEEL-PLATE COMPOSITE WALLS



SC Walls: Structural Performance

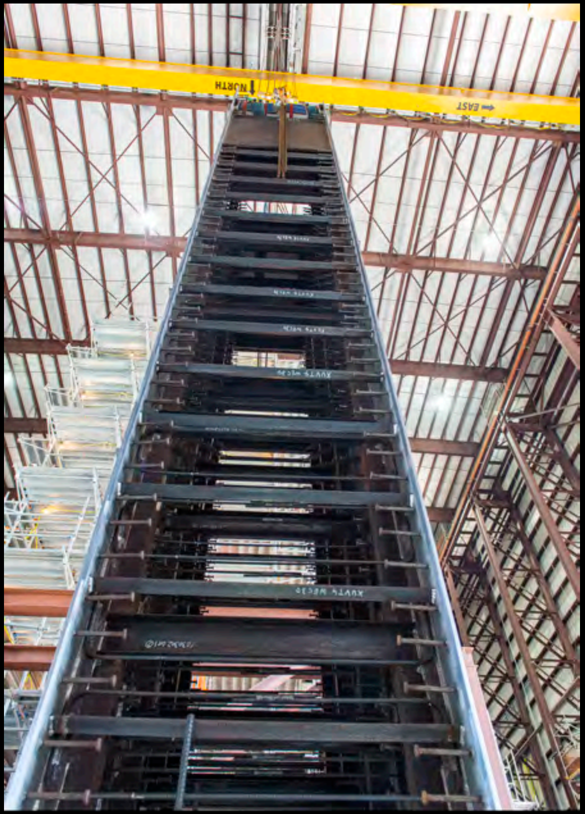
- Excellent seismic strength and ductility
  - Basis: Testing and Analysis
- Better than conventional RC Walls…
  - Primarily shear wall structures with excellent stiffness, strength, and deformation capacity
- Excellent strength for impact and blast loads
  - Basis: Testing and Analysis
- Excellent behavior for accident thermal loading
  - Basis: Testing and Analysis

SC Walls: Used in Nuclear Industry

- GE – Hitachi- Toshiba (ABWR) Kashiwazaki-Kariwa 6 and 7 (1996)
- Extensive use in AP1000(R) plants being built in China, South Carolina, and Atlanta
- US-APWR plant designed by the Japanese, MHI
- APR+ designed by the Koreans
- All use SC construction because of modularity, strength, construction schedule, and impact resistance

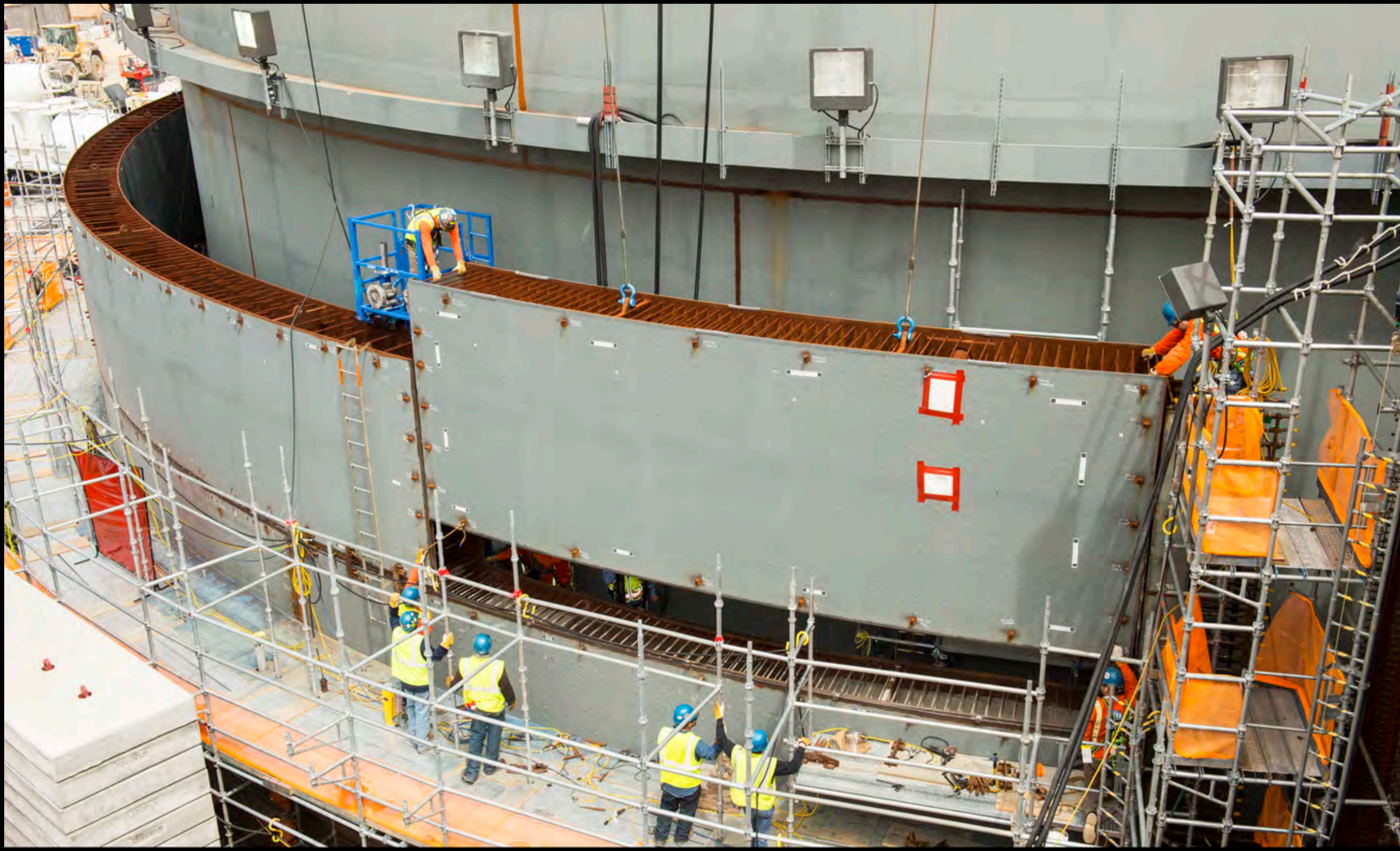
SC Walls and Designs in Nuclear Structures

Vogtle Unit 3 CA20 Module June 2014 © Georgia Power Company



Sub-module inside the Module Assembly Building
May 2015 © Georgia Power Company

Accessed from: https://vogtlegallery.georgiapower.com



Workers placed all six of the third course shield building panels for Unit 3

April 2016

Accessed From: https://vogtlegallery.georgiapower.com

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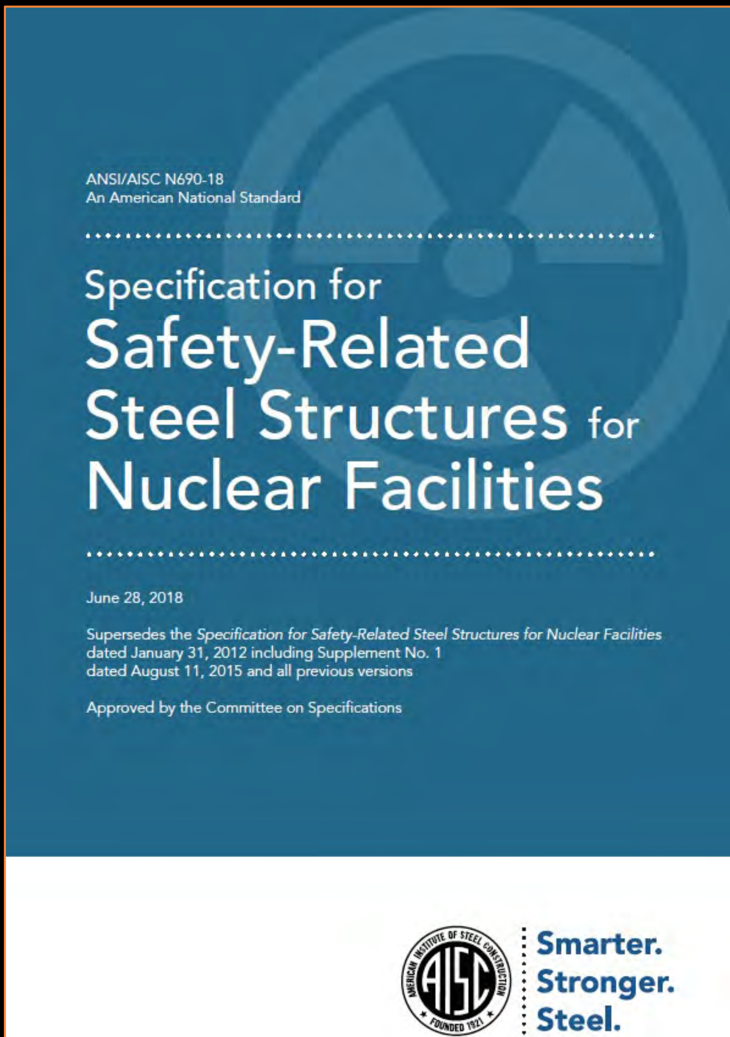
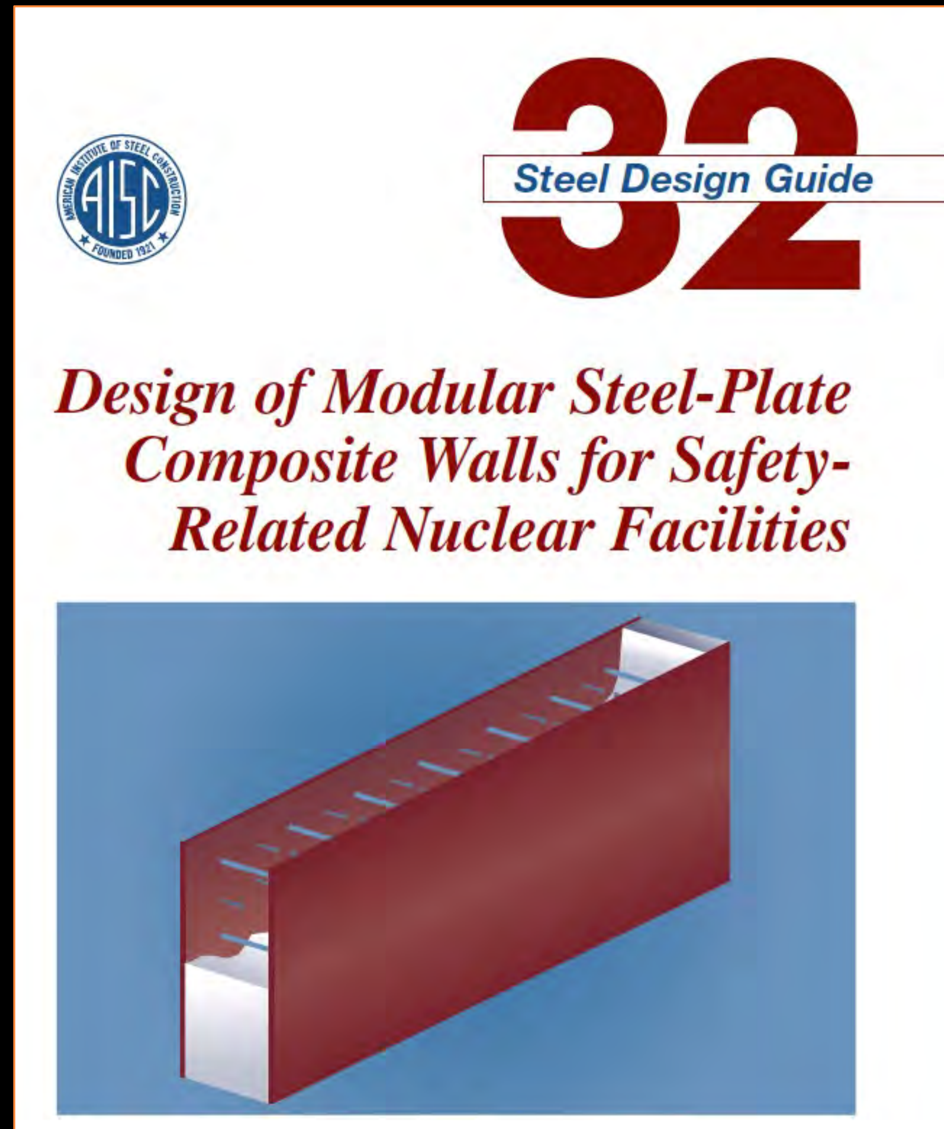
Steel-Plate Composite (SC) Walls : Evolution

- Extensive research, testing, and development
- AISC N690 Nuclear Specification, Appendix N9
- AISC Design Guide 32
- NUREG coming soon !
- Under consideration for SMRs – e.g., BWRX-300
- Significant interest in using SC design for containment vessel / structure


ANSI/AISC N690-18
An American National Standard
Specification for
Safety-Related
Steel Structures for
Nuclear Facilities
June 28, 2018
Supersedes the Specification for Safety-Related Steel Structures for Nuclear Facilities
dated January 31, 2012 including Supplement No. 1
dated August 11, 2015 and all previous versions
Approved by the Committee on Specifications
AISC
Smarter.
Stronger.
Steel.


AISC
32
Steel Design Guide
Design of Modular Steel-Plate
Composite Walls for Safety-
Related Nuclear Facilities

MOTIVATION

- Steel liner plates already needed !
- Expedite construction and reduce time spent in the pit by leveraging factory pre-fabrication, modularity
- Two steel plates
  - Double leak tight barriers
  - Pressure boundary
  - Excellent structural performance for impulsive loading
- *No governing or applicable design code or standard*
- *ASME Code Case needed*

MOTIVATION

- Preliminary design and cost benefit analysis conducted by GEH team for their own BWRX-300 application

- Construction schedule and economic benefits justify the pursuit of an ASME Code Case

- Can help the industry and profession at the same time

- Vendor, Utility, Regulator → all eyes on the Code Case and the potential for innovation, economy of scale, and the next step in evolution for the Containment Vessel

CHALLENGE

- Several considerations for SCCV
  - Design, design checks, fabrication, material, examination…
  - Not all information available
  - Need to rely on what is available

- Leverage existing knowledge and information
  - AISC N690
  - AISC Design Guide 32
  - ASME Division 2 Code for Concrete Containment
  - ASME Division 1 – Subsection NE Class MC Components

ASME Code Case for SCCV

- Existing knowledge:
  - AISC N690 and Design Guide 32
    - Overall design, available strength, analysis approach, penetration
  - ASME Division 2 Code for Concrete Containment
    - Allowable stress, examination, materials
  - ASME Division 1 – Subsection NE Class MC Components
    - Examination, materials

ASME Code Case for SCCV
Overall Structure

- 8 Articles
  - Article – 1000 Introduction
  - Article – 2000 Material
  - Article – 3000 Design
  - Article – 4000 Fabrication and Construction
  - Article – 5000 Construction Testing and Examination
  - Article – 6000 Testing
  - Article – 7000 Overpressure Protection
  - Article – 8000 Nameplates, Stamping with Certification Mark, and Report

ASME Code Case for SCCV
Overall Structure

CASE N-XXX
USE OF STEEL PLATE COMPOSITE STRUCTURES FOR NUCLEAR CONTAINMENT

Inquiry: What provisions are required to make a nuclear containment using steel plate composite structures?

Response: It is the opinion of this committee that this Code Case provides for alternative requirements to use a steel plate and concrete composite containment in lieu of a traditional reinforced or prestressed concrete containment. Sections CC-1000 through CC-8000 and the Division 2 Appendices were reviewed for changes or additions that need to be made to allow and provide appropriate requirements for the use of a steel plate and concrete composite containment in lieu of a concrete containment. The proposed modified sections are included in the attachment to this Code Case as Sections -1000 to -8000. All Division 2 Appendices shall be followed to the extent they apply to a steel plate and concrete composite containment without reinforcing steel or tendons.

The containment would still be considered a Division 2 containment. The applicable sections of the remaining ASME B&PV Code, such as Section II; Section III, Subsection NCA; Section V: and Section IX would be followed to the extent they apply to a steel plate and concrete composite containment without reinforcing steel or tendons. ASME Section XI, Section IWE would be followed considering the faceplates are acting as the liner.

ASME Code Case for SCCV
Overall Structure

9/13/21

ASME Code Case for SCCV Highlights

- Analysis Procedure

  -3320 Effective Stiffness for analysis (flexural and in-plane shear)

$$EI_{eff} = (E_s I_s + c_2 E_c I_c)\left(1 - \frac{\Delta T_{savg}}{150}\right) \geq E_s I_s$$

$$GA_{eff} = GA_{uncr} - \frac{GA_{uncr} - GA_{cr}}{S_{cr}}(S_{rxy} - S_{cr})$$

  -3320 Geometric and material properties for finite element analysis

  ν_m E_m ρ_m

  -3350 Analysis involving accidental thermal conditions

ASME Code Case for SCCV Highlights

- Available Strength
  - -3520 Design for individual loads
    - Axial compression $\phi P_n = \left(F_y A_s + 0.85 f'_c A_c\right)$
    - Axial tension $\phi P_n = \phi\left(F_y A_s\right)$
    - Flexure load $\phi M_n = \phi\left(F_y\, A_s^F\, T_{sc}\right)$
    - Out-of-plane shear $\phi V_n = \phi(V_c + V_s)$
    - In-plane shear $\phi V_n = \phi \kappa f_y A_s$
  - -3530 Design for combined loads
    - Interaction of out-of-plane shear demands

$$\left[\left(\frac{V_u - V_{c\,conc}}{V_c - V_{c\,conc}}\right)_x + \left(\frac{V_u - V_{c\,conc}}{V_c - V_{c\,conc}}\right)_y\right]^2 + \left[\frac{\frac{\sqrt{V_{ux}^2 + V_{uy}^2}}{0.9T_{sc}}}{\left(\frac{lQ_{cv}^{avg}}{s^2}\right)}\right]^2 \leq 1.0$$

ASME Code Case for SCCV Highlights

- Steel and Concrete Stresses

  -3422 Allowable stress for factored loads

Table -3422-1
Allowable Stresses for Factored Loads

Material	Force Classification	Type of Force Action	Criteria for Factored Loads: Stress Limit	Criteria for Factored Loads: Strain Limit, if any
Concrete	Primary	Membrane	$0.60f_c'$	-
		Membrane + Bending	$0.75f_c'$	-
	Primary + Secondary	Membrane	$0.75f_c'$	-
		Membrane + Bending	$0.85f_c'$	0.002
Steel Plates	Primary	Membrane or Membrane + Bending	$0.90F_y$	-
	Primary + Secondary	Membrane or Membrane + Bending	-	$2\varepsilon_y$*

ASME Code Case for SCCV Highlights

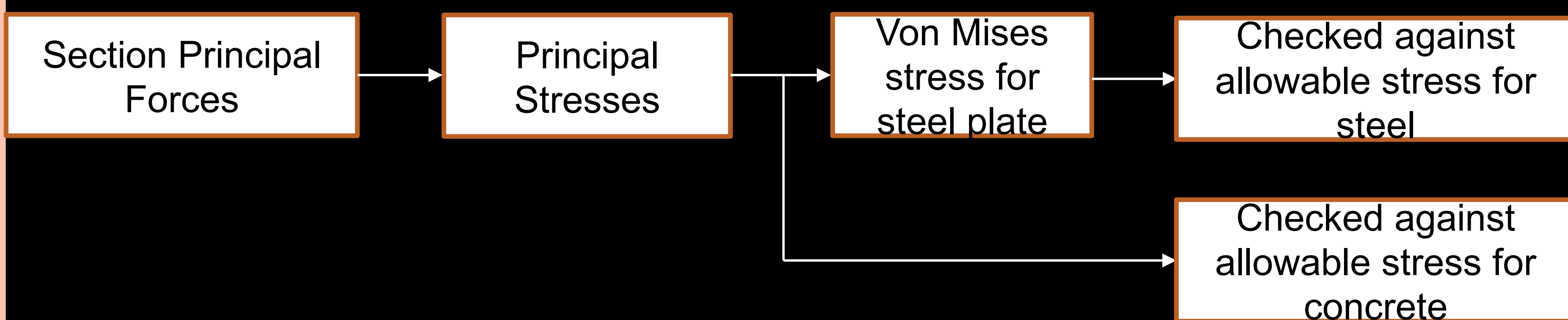
- Steel and Concrete Stresses
  - -3430 Allowable stress for service loads

Table -3422-2
Allowable Stresses for Service Loads

Material	Force Classification	Type of Force Action	Criteria for Service Loads: Stress Limit	Criteria for Service Loads: Strain Limit
Concrete	Primary	Membrane	$0.30f_c'$	-
		Membrane + Bending	$0.45f_c'$	-
	Primary + Secondary	Membrane	$0.45f_c'$	-
		Membrane + Bending	$0.60f_c'$	-
Steel Plates	Primary	Membrane <u>or</u> Membrane + Bending	$0.50F_y$	-
	Primary + Secondary	Membrane <u>or</u> Membrane + Bending	$0.67F_y$	-

ASME Code Case for SCCV
Highlights

- Calculation of Steel and Concrete Stresses
  - 3420 Allowable stress for factored loads
  - 3430 Allowable stress for service loads



ASME Code Case for SCCV Highlights

- Miscellaneous
  - -3630 Missile impact design for local failure
  - -3510 General provisions for SC containment design

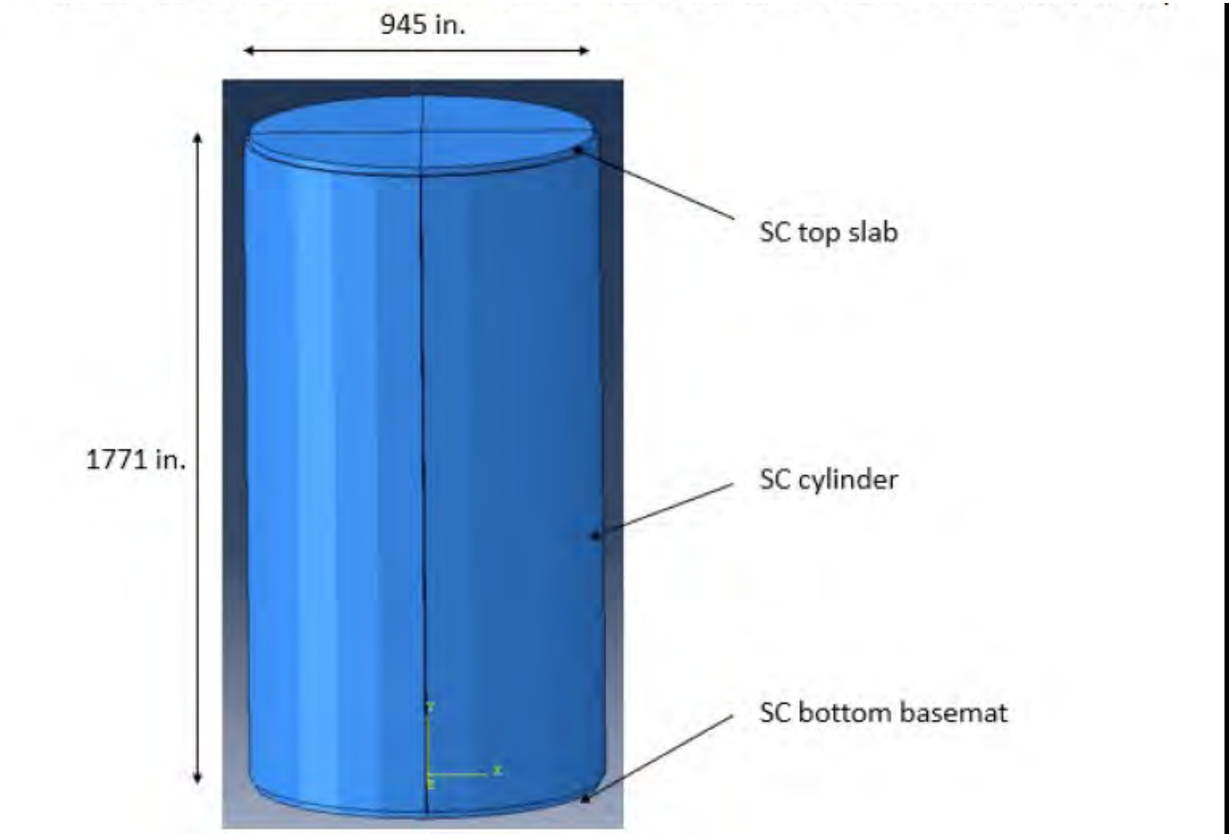
- Article-6000 Testing
  - NE Article-6000 adopted

ASME Code Case : Design Example

- Supplementary Documents

OBJECTIVE

The objective of this calculation is to provide insights into the design of steel-plate compsite containement structures described in the ASME code case. The design of a sample SC containment structure is provided in this calculations based on the requirements of the code case. For the purpose of this calculation, a simplified SC containment structure is assumed.



ASME Code Case : Design Example

The calculation can be categorized into the following steps:

Step 0: Preliminary details of SC containment

Step 1: Minimum requirements per SCC-3511

Step 2: Faceplate slenderness requirement per SCC-3512

Step 3: Shear connector and tie detailing per SCC-3513 and SCC-3514

Step 4: Stiffness and other parameters for modeling per SCC-3300

Step 5: Analysis results and demand summary

Step 6: Individual design available strengths per SCC-3520

Step 7: Interaction design available strengths per SCC-3530

Step 8: Demand to capacity ratios (DCR)

Step 9: Stress checks per SCC-3400

Step 10: Impactive and impulsive loading design per SCC-3600

ACKNOWLEDGMENTS

- GE Hitachi Technical and Management Team
- AISC, ACI, ASME Teams and Committees
- Neb Orbovic, CNSC
- Sanj Malushte, Bechtel
- John McLean, SGH
- ASME Working Group Modernization

OM-2
Inservice Testing for Gen-4 and Beyond

A. Cardillo
Chairman ASME O&M SC New Reactors
T. Ruggiero, PE
Member ASME O&M, ASME Fellow

Current OM Code for IST
Background

- Current O&M is a “Mature” code.
- The code is “fully developed” additional requirements have been driven by adverse industry events
- The code is written to Water Cooled Reactor Plants.
- There is currently no consideration of Small Modular Reactors (SMR) in the current code.
- Several sections of OM Code require verification of component design basis.
  - This is beyond the original charter for OM.

A Component Code

- The original concept of OM was to ensure operational readiness and be able to monitor and detect degradation.
- OM is not to ensure operability
- Purpose is to ensure operational readiness.
  - detect degradation
- Trend so that the component(s) can be reworked before they fail

Accommodations due to Plant Design

- Current OM Code is directed squarely at Light Water Reactor Plants.
- System design issues caused several accommodations.
  - Plants were designed before the need for In Service Testing was understood, or the requirements written down.
  - PWRs had pumping systems that did nor have full flow test loops, while BWR did.
  - Valve exercise testing interval based on when the system can be made available for testing.

ASME
SETTING THE STANDARD

Accommodations due to Plant Design

- Nothing in a code to verify operational readiness can correct poor system design, incorrect equipment sizing, or use of a type of component that is inappropriate for its required function.
- Verification that the component type is appropriate for the service and that it provides the functions and parameters for which were specified is in QME, not in O&M.

ASME
SETTING THE STANDARD

IST Scope of Components

- Scoping Issues continue to arise
  - Components that are not ASME 1, 2 & 3
  - Emergency power
  - Significant number of new SMR designs

- A scope statement that encompasses all of the components that are important to safety is virtually impossible.

- Designs of the Light Water Reactors are well understood by both the writers of the Code, and the regulators, that is not the case for the SMR.

- OM is a component code.
  - The question of importance to safety need not rest with the code writers.
  - Instead, it should be with the plant designer and their regulator.

A New OM Code

- Start with a clean slate.
- Consider what the function of a component is..
- Determine what needs to be done to periodically verify that the component is not degrading in service to a point where it cannot provide that function.

A New OM Code

- OM-2 structured so that it is directly usable for any type of Small Modular Reactor Plant.
  - Avoid scoping based on any particular system
  - IST based only on the function of the component and not the system function in any particular NSSS.

Questions?

EPRI Project Updates

Sam Johnson
Sr. Technical Leader

Hasan Charkas
Principal Technical Leader

Sal Villalobos
Sr. Technical Leader

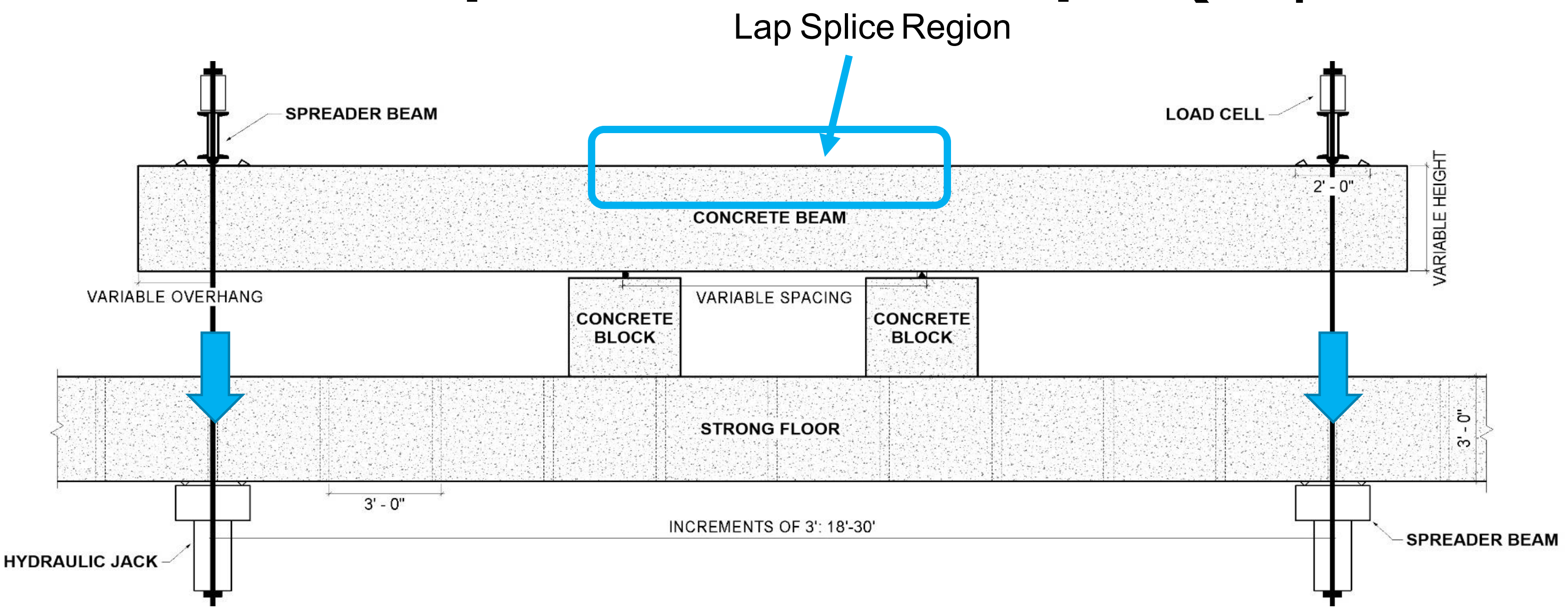
NRC Standards Forum
September 15th, 2021

Large High Strength Rebar – Lap Splices and Mechanical Couplers

Objectives

- Phase 1: Explore lap splice behavior of large high strength rebars (No. 14 and No. 18) for use in earthquake-resistant structures
- Phase 2: Investigate mechanical couplers use in anchoring high strength rebars at base of structural walls subjected to cyclic loading
- Phase 3: Examine the anchorage capacity of groups of large high strength rebars at column and wall foundation connections subjected to cyclic loading
- Propose design requirements based on experimental results and work to integrate them into design standards

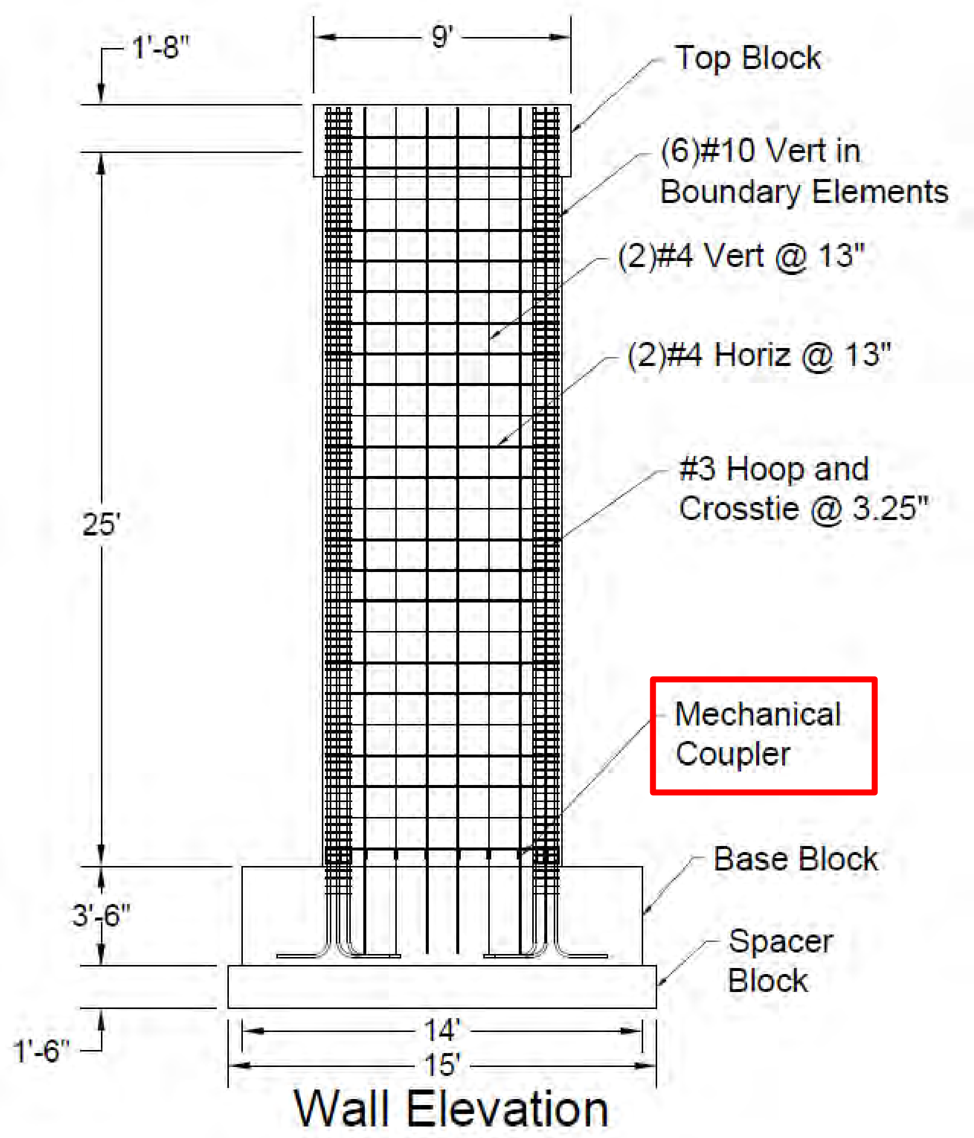
Phase 1: Experimental Setup...(4-point bending)



- Full series of 11 tests are complete
  - 7 No. 14 bar specimens
  - 4 No. 18 bar specimens
- Generally, the measured stress in the bars are less than the calculated stress based on the current ACI equation
- Research is on-going.

Phase 2 (Mechanical Splices of High-Strength Bars)

- Investigate the mechanical splices of high-strength bars
- Specimen construction is underway

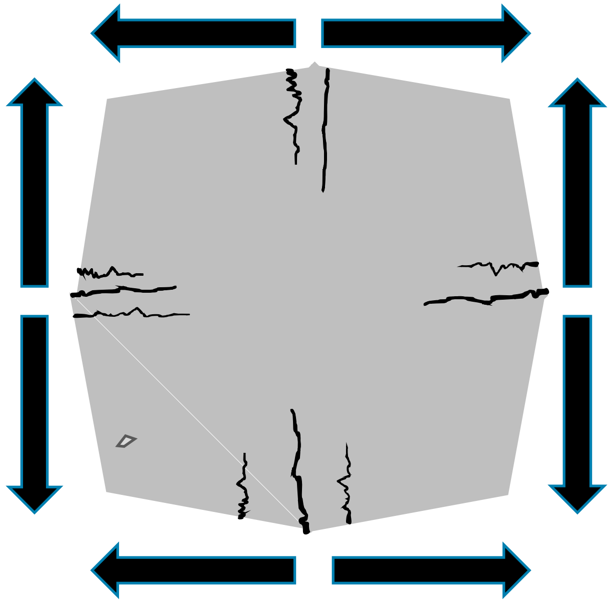


Best Practices for Self-Consolidating Concrete as Mass-Concrete Proportioning and Testing

Self Consolidating Concrete Used in Mass Concrete Structures

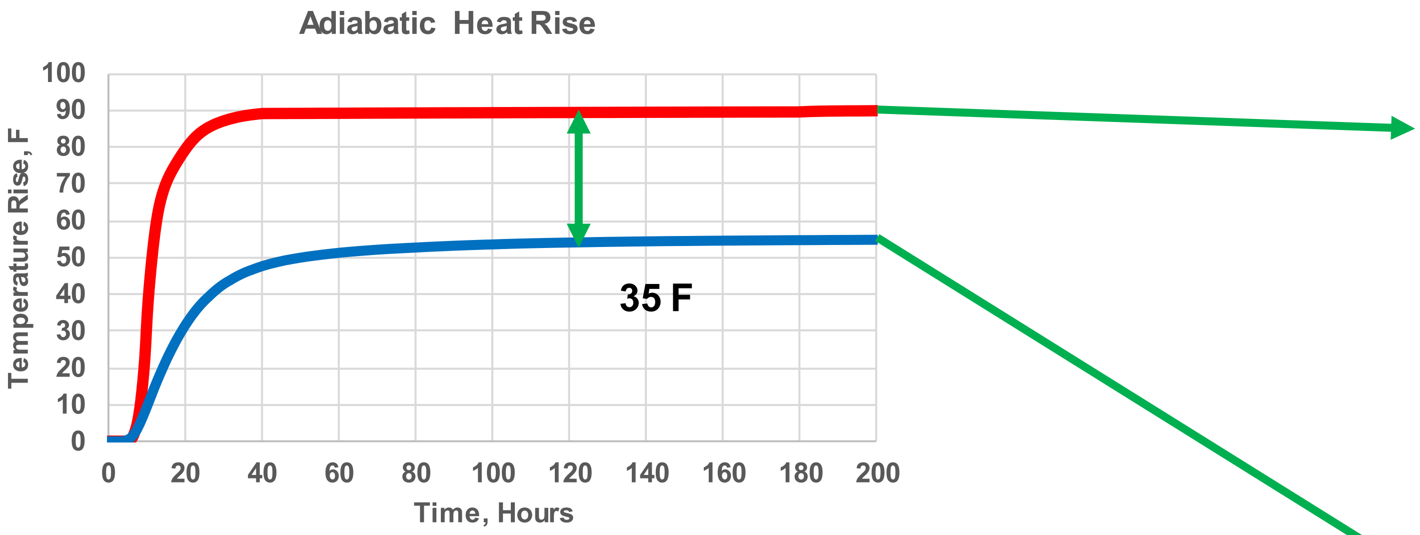
SCC is necessary for heavily congested concrete placements

NPPs are notorious for heavily congested concrete placements



- Traditional self consolidating concrete mixture generates excessive heat
- High quantities of cementitious materials means hotter concrete mixtures
- More cracking
- Potential loss of durability

Self Consolidating Concrete Used in Massive Concrete Structures

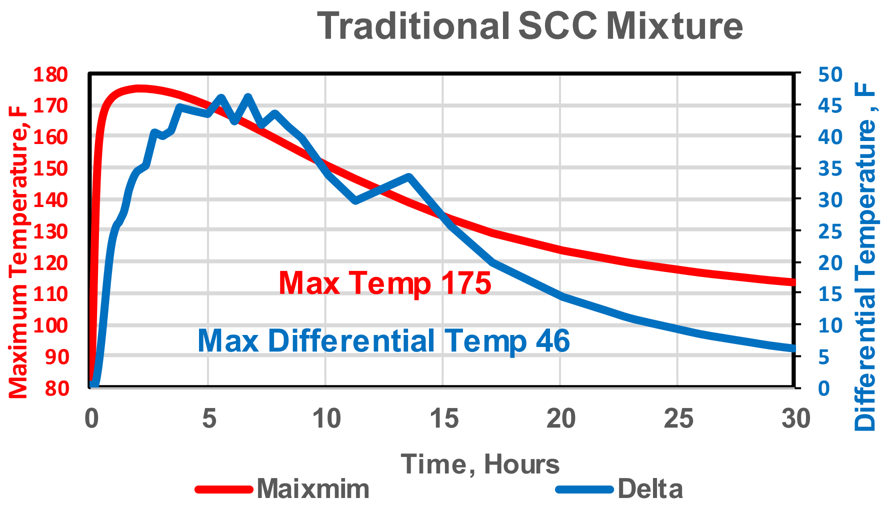


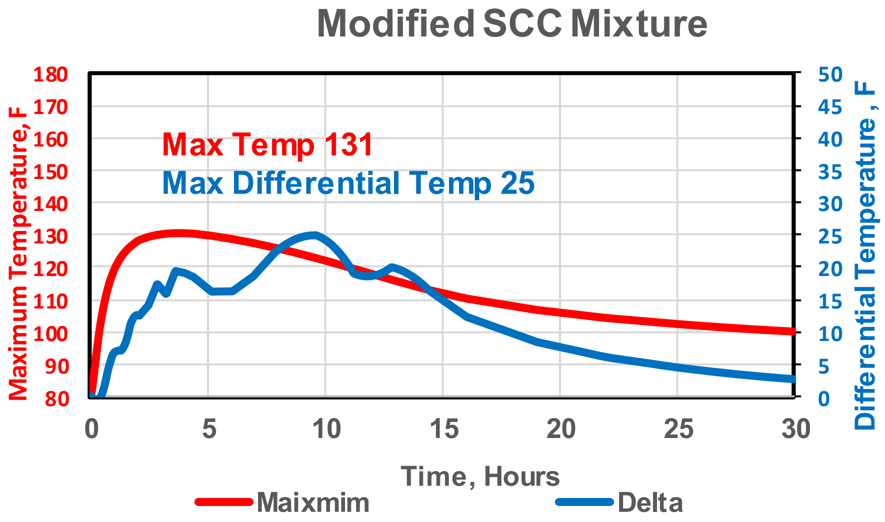
Traditional SCC mixture—adiabatic heat rise 90 F

Modified SCC mixture– adiabatic heat rise 55 F

<u>Major Benefits:</u>

- **Less cracking potential**
- **Less Risk of Delayed Ettringite Formation**
- **Shorter protection cycles—reduces construction time**
- **Permits larger concrete placements**

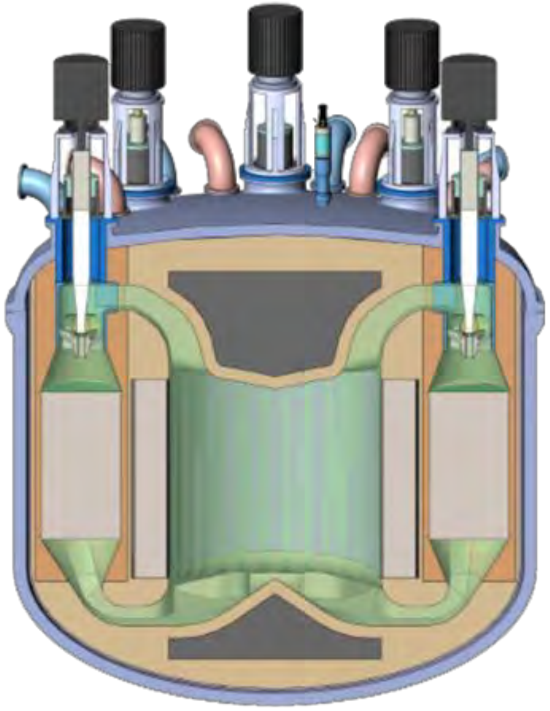




Temperature profile chart for an 8 foot thick wall cast with concrete at temperature of 80 degrees

Concrete Strength at Elevated Temperatures

Concrete Temperature Limitations



Maximum concrete temperature are limited by ACI 349:

Concrete surface temperature to 150 F

Localized areas to 200 F

Higher temperatures are permitted if supported by test data

Challenge:

Advanced Reactors need to Operate at Higher Temperatures

Evaluate Different Concrete Mixtures at Different Temperatures

Six different concrete mixtures are currently being tested

Four more to be batched and tested

The Process Begins

Making Test Specimens

Water Cured for 28 Days

Air Dried for an Additional 28 Days

Concrete Heated to 400 to 800 F

Record Temperatures


Together…Shaping the Future of Energy™

ASCE 1, 4, and 43

Risk-informed, Performance-based Standards

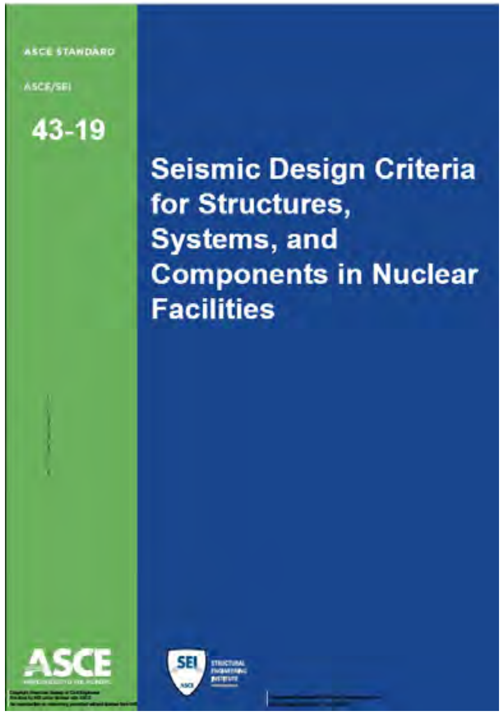
F George Abatt, Ph.D., P.E., F.ASCE
Andrew Whittaker, Ph.D., P.E., S.E., F.ASCE, F.SEI

September 15, 2021

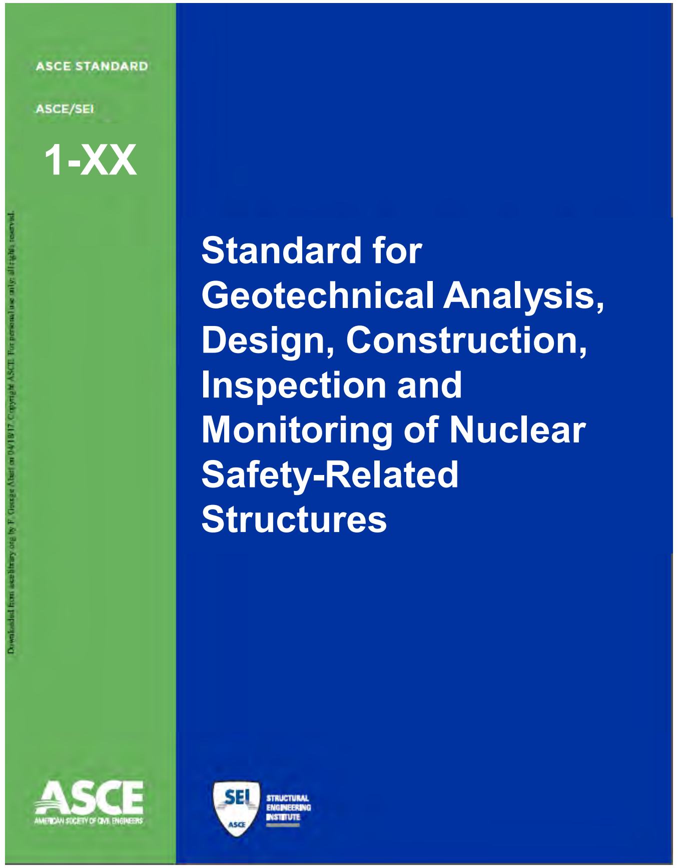
STRUCTURAL ENGINEERING INSTITUTE

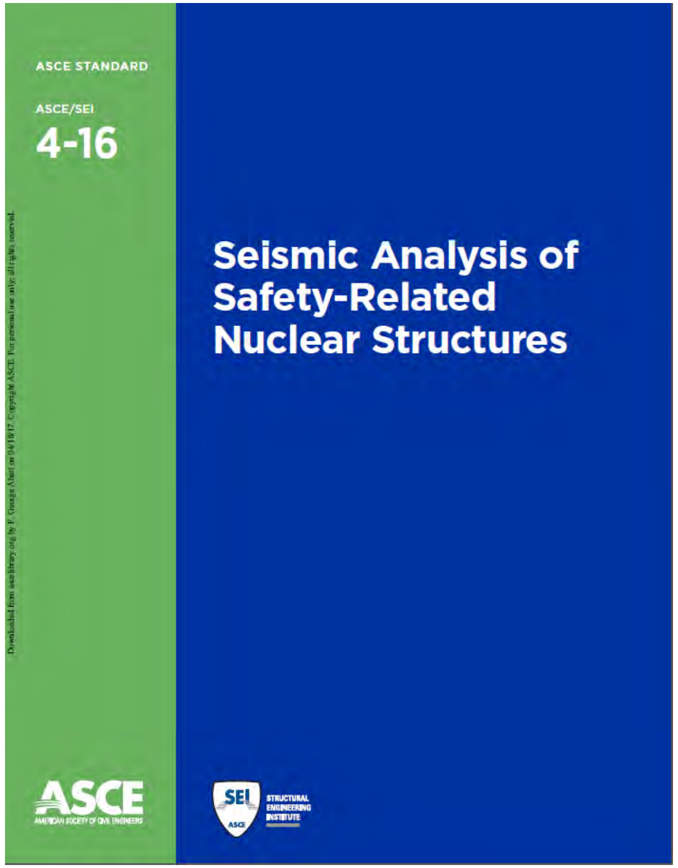
TODAY

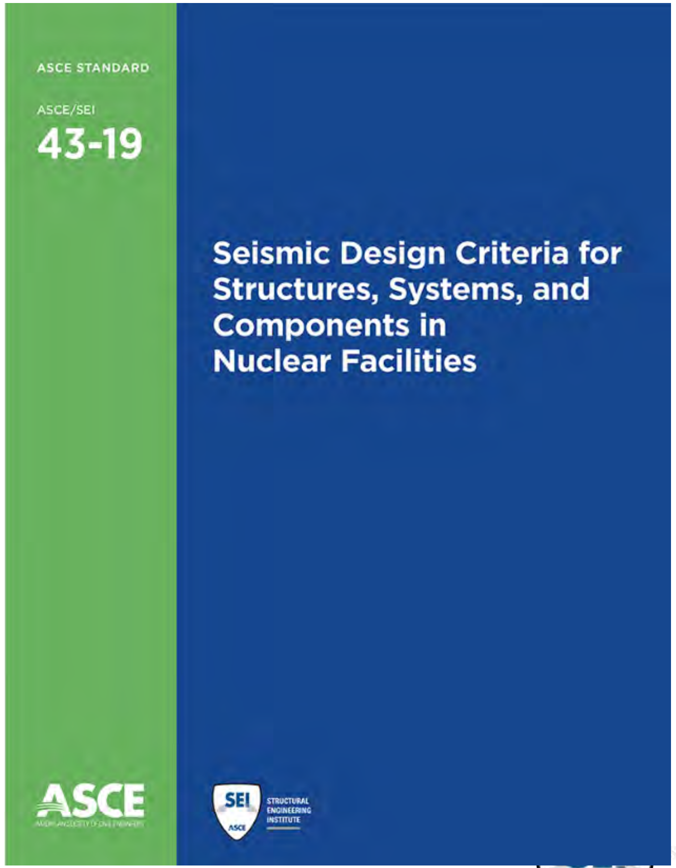
- ASCE nuclear standards
- Early days of RIPB design
- Related nuclear standards and opportunities
- ASCE 43 big ideas and added scope
- Seismic design categories, target performance goals, and limit states
- ASCE 43 and ANS 2.26 disconnects
- Design response spectrum
- Achieving limit states, inelastic action
- Seismic isolation
- Acknowledgments



ASCE STANDARDS







EARLY DAYS

A STATISTICAL ANALYSIS

OF THE

SHEAR STRENGTH OF REINFORCED CONCRETE BEAMS

A DISSERTATION
SUBMITTED TO THE DEPARTMENT OF CIVIL ENGINEERING
AND THE COMMITTEE ON THE GRADUATE DIVISION
OF STANFORD UNIVERSITY
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

By

Robert Phillip Kennedy

April 1967

Bulletin of the Seismological Society of America. Vol. 58, No. 5, pp. 1583–1606. October, 1968

ENGINEERING SEISMIC RISK ANALYSIS

By C. Allin Cornell

ABSTRACT

This paper introduces a method for the evaluation of the seismic risk at the site of an engineering project. The results are in terms of a ground motion parameter (such as peak acceleration) versus average return period. The method incorporates the influence of all potential sources of earthquakes and the average activity rates assigned to them. Arbitrary geographical relationships between the site and potential point, line, or areal sources can be modeled with computational ease. In the range of interest, the derived distributions of maximum annual ground motions are in the form of Type I or Type II extreme value distributions, if the more commonly assumed magnitude distribution and attenuation laws are used.

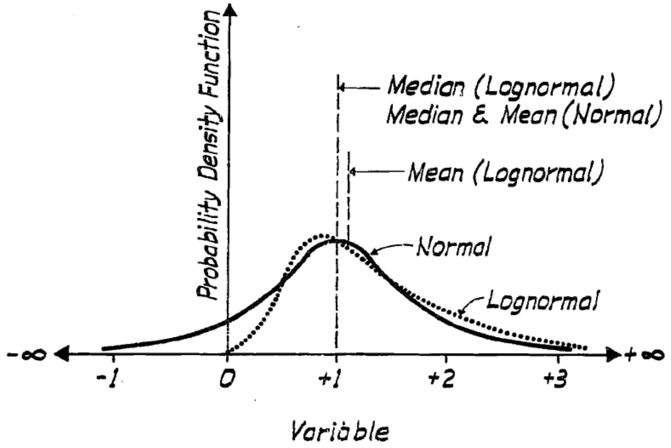
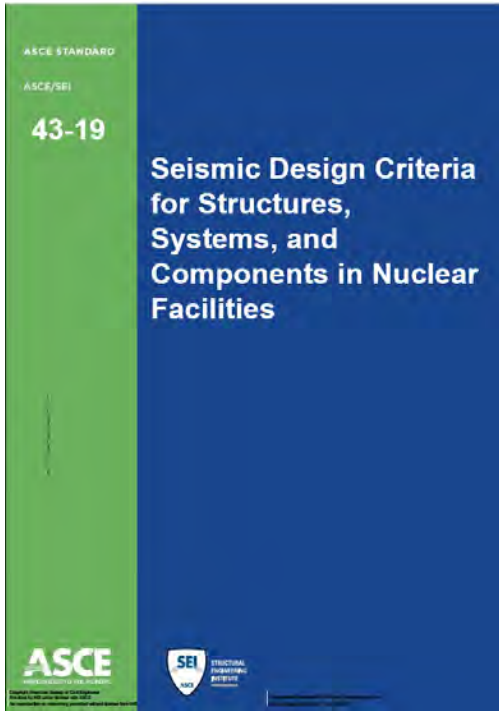
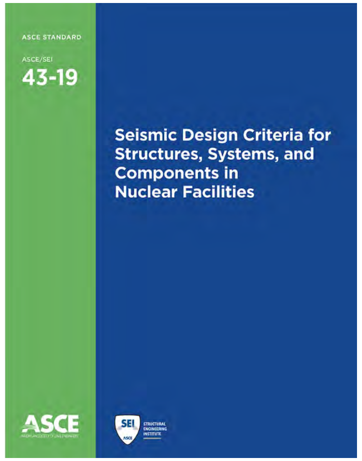
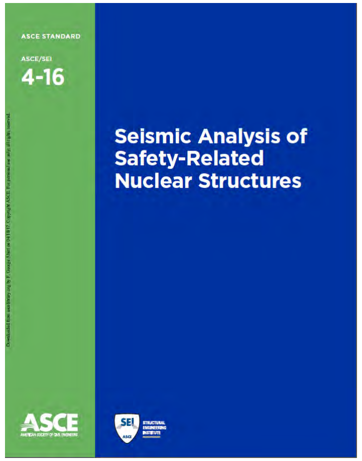


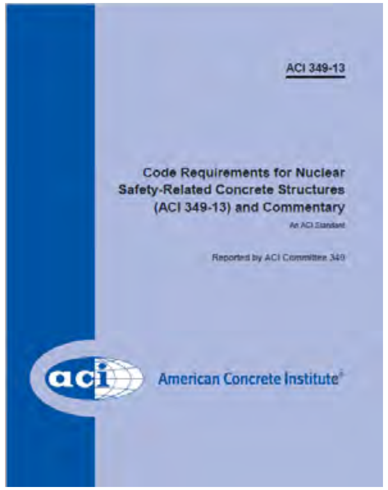
FIGURE 3.2: TYPICAL NORMAL AND LOGNORMAL PROBABILITY DENSITY FUNCTIONS

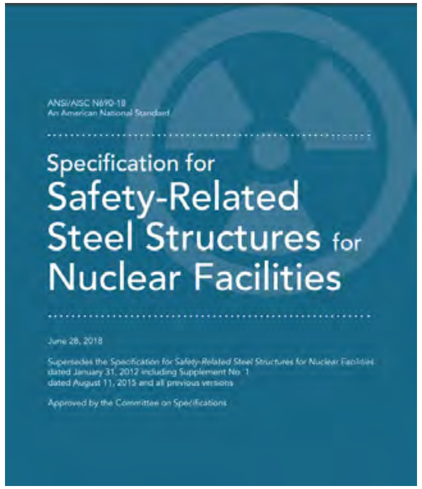


RELATED NUCLEAR STANDARDS



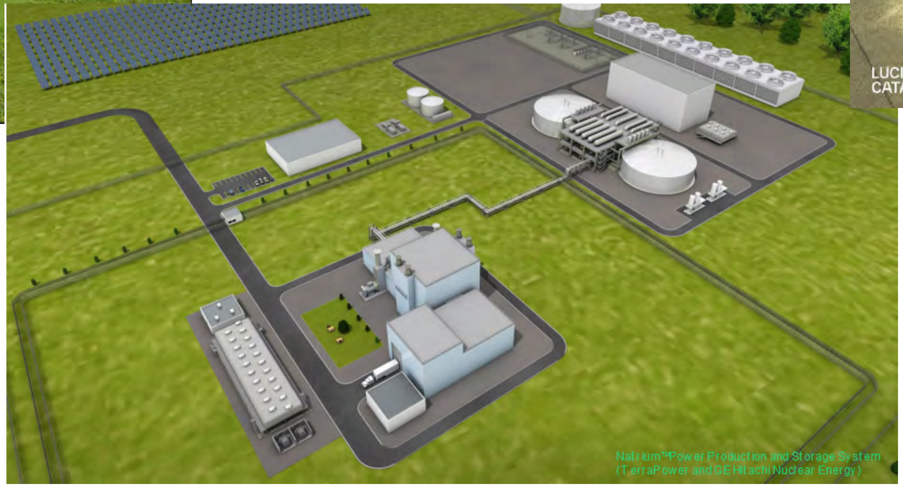






ORIGINAL TARGET– DOE FACILITIES

FUTURE APPLICATIONS



BIG IDEAS IN ASCE 43-19

- **Performance oriented**, graded according to tolerable risk
- **Seismic design category** (SDC) defines target performance goals
  - Function of material at risk
    - Gigawatt large light water reactor = SDC-5 (P_f = 1 x 10^{-5} AFE)
  - Defines starting point for establishing design basis shaking: the design response spectrum (DRS)
- **Limit state** (LS) defines system-level response
  - Gigawatt large light water reactor = LS-D (essentially elastic, limit state D)
- **Seismic design basis** (SDB) = SDC plus LS
  - Gigawatt large light water reactor = SDC-5D
- **Deterministic procedures** used to achieve probabilistic performance goals
  - Design seismic demand at 80%-ile, *design* strength at 98%-ile

ASCE 43 - ADDED SCOPE

American National Standard ANSI/ANS-2.26-2004

Table 1 – SDCs based on the unmitigated consequences of SSC failure

Category	Unmitigated Consequence of SSC Failure: Worker	Public	Environment
SDC-1[a]	No radiological/ toxicological release consequences but failure of SSCs may place facility workers at risk of physical injury.	No radiological/ toxicological release consequences.	No radiological/ toxicological release consequences.
SDC-2[a]	Radiological/ toxicological exposures to workers will have no permanent health effects, may place more facility workers at risk of physical injury, or may place emergency facility operations at risk.	Radiological/ toxicological exposures of public areas are small enough to require no public warnings concerning health effects.	No radiological or chemical environmental consequences.
SDC-3	Radiological/ toxicological exposures that may place facility workers' long-term health in question.	Radiological/ toxicological exposures of public areas would not be expected to cause health consequences but may require emergency plans to assure public protection.	No long-term environmental consequences are expected, but environmental monitoring may be required for a period of time.
SDC-4	Radiological/ toxicological exposures that may cause long-term health problems and possible loss of life for a worker in proximity of the source of hazardous material, or place workers in nearby on-site facilities at risk.	Radiological/ toxicological exposures that may cause long-term health problems to an individual at the exclusion area boundary for 2 hours.	Environmental monitoring required and potential temporary exclusion from selected areas for contamination removal.
SDC-5	Radiological/ toxicological exposures that may cause loss of life of workers in the facility.	Radiological/ toxicological exposures that may possibly cause loss of life to an individual at the exclusion area boundary for an exposure of 2 hours.	Environmental monitoring required and potentially permanent exclusion from selected areas of contamination.

[a] "No radiological/toxicological releases" or "no radiological/toxicological consequences" means that material releases that cause health or environment concerns are not expected to occur from failures of SSCs assigned to this category.

- SDC-1 per ASCE/SEI Standard 7
  - System-level response
- SDC-3, -4 and -5 included in ASCE/SEI Standard 43-05
- SDC-2 added to scope in ASCE 43-19

SDC-2[a]	Radiological/ toxicological exposures to workers will have no permanent health effects, may place more facility workers at risk of physical injury, or may place emergency facility operations at risk.	Radiological/ toxicological exposures of public areas are small enough to require no public warnings concerning health effects.	No radiological or chemical environmental consequences.

SDC, P_F, AND LS

Table 1-1. Summary of Earthquake Design Provisions.

	Seismic Design Category			
	2	**3**	**4**	**5**
Target performance goal, P_F	4×10^{-4}	1×10^{-4}	4×10^{-5}	1×10^{-5}
DBE response spectrum or acceleration time series	SF × UHRS; Chapter 2 in this standard			
Damping for structural evaluation	Section 3.3.3			
Analysis methods for structures	ASCE 4 and Chapter 3 in this standard			
Analysis methods for systems and components	In-structure response spectra; ASCE 4 and Chapter 8 in this standard			
Load factor	1.0			
Inelastic energy absorption factors	Table 5-1 and/or Table 8-1 in this standard			
Material strength	Minimum specified value			
Component design strength	Design strength according to materials standards unless exceptions are made in this standard			
QA program	Chapter 10 in this standard			
Independent peer review	Chapter 10 in this standard			

Table 1-2. Deformation and Damage by Limit State.

Limit State	Expected Deformation	Expected Damage
A	Large permanent distortion, short of collapse	Significant
B	Moderate permanent distortion	Generally repairable
C	Limited permanent distortion	Minimal
D	Essentially elastic behavior	Negligible

Source: Adapted from ANS 2.26 (ANS 2017).

Building Performance Levels and Ranges

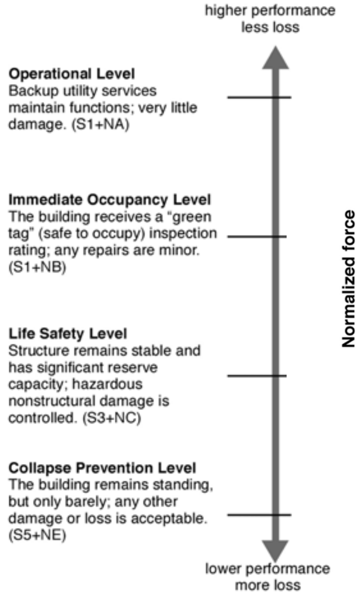
Performance Level: the intended post-earthquake condition of a building; a well-defined point on a scale measuring how much loss is caused by earthquake damage. In addition to casualties, loss may be in terms of property and operational capability.

Performance Range: a range or band of performance, rather than a discrete level.

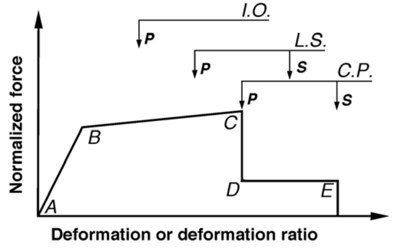
Designations of Performance Levels and Ranges: Performance is separated into descriptions of damage of structural and nonstructural systems; structural designations are S-1 through S-5 and nonstructural designations are N-A through N-D.

Building Performance Level: The combination of a Structural Performance Level and a Nonstructural Performance Level to form a complete description of an overall damage level.

Rehabilitation Objective: The combination of a Performance Level or Range with Seismic Demand Criteria.



FEMA 273, 1997



ASCE 43 AND ANS 2.26 DISCONNECTS

Table 1-1. Summary of Earthquake Design Provisions.

	Seismic Design Category			
	2	3	4	5
Target performance goal, P_F	4×10^{-4}	1×10^{-4}	4×10^{-5}	1×10^{-5}
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Material strength	Minimum specified value			
Component design strength	Design strength according to materials standards unless exceptions are made in this standard			
QA program	Chapter 10 in this standard			
Independent peer review	Chapter 10 in this standard			

Table A.3 – Guidance for SDC Based on Unmitigated Consequences of SSC Failures

	Unmitigated consequence of SSC failure	
Category	Worker	Public
SDC-1[a)]	No radiological or chemical release consequences but failure of SSCs may place facility workers at risk of physical injury.	No consequences
SDC-2	Lesser radiological or chemical exposures to workers than those in SDC-3 below in this column as well as placing more workers at risk. This corresponds to the criterion in Table 1 that workers will experience no permanent health effects.	Lesser radiological and chemical exposures to the public than those in SDC-3 below in this column, supporting that there are essentially no off-site consequences as stated in Table 1.
SDC-3	0.25 Sv (25 rem) < dose < 1 Sv (100 rem) AEGL2, ERPG2 < concentration < AEGL3, ERPG3. Concentrations may place emergency facility operations at risk, or place several hundred workers at risk.	0.05 Sv (5 rem) < dose < 0.25 Sv (25 rem) AEGL2, ERPG2 < concentration < AEGL3, ERPG 3
SDC-4	1 Sv (100 rem) < dose < 5 Sv (500 rem) concentration > AEGL3, ERPG3	0.25 Sv (25 rem) < dose < 1 Sv (100 rem), > 300 mg sol U intake, concentration > AEGL3, ERPG3
SDC-5	Radiological or toxicological effects may be likely to cause loss of facility worker life.	1 Sv (100 rem) < dose, concentration > AEGL3, ERPG3

DESIGN RESPONSE SPECTRUM

- Goal is to achieve target performance goal (probabilistic) but how?
  - Deterministic (traditional) design using ASCE/SEI 4 and demands at the 80%-ile
    - Conditioned on analysis using a derived seismic input
  - Materials standards, with *design* strengths at 98%-ile
  - Design response spectrum (DRS)
- Closed form solution
  - Hazard curve locally linearized in log-log space
  - Lognormal fragility function
  - Start with UHRS at the P_F
  - Back-calculate SF (<1 ≅ 0.5) to establish DRS
- Kennedy SMiRT paper (2011) and ASCE 43-19 provide details

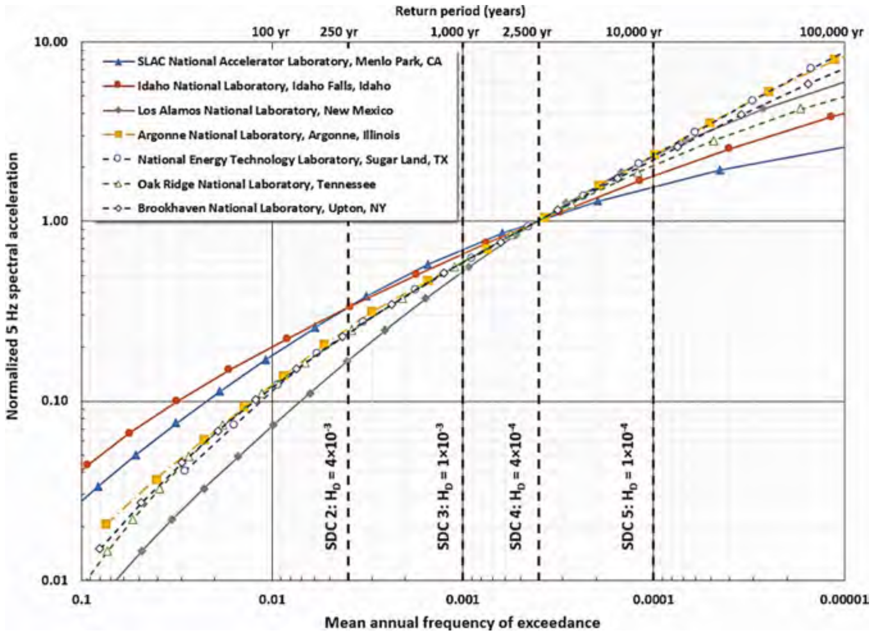


Figure C1-1. Normalized 5 Hz spectral acceleration at selected US DOE sites.

ACHIEVING LIMIT STATES A, B, AND C

5.1.2.1 Seismic Load Combinations for Strength-Based Acceptance Criteria. For elastic analyses, the total demand acting on an element shall be the sum of nonseismic demand, D_{NS}, and seismic demand, D_S, according to the following load combination as appropriate:

1. For bending moment, in-plane shear, and axial load in pairs of diagonal braces, use

$$D = D_{NS} + \frac{D_S}{F_\mu} \qquad \text{(5-1a)}$$

2. For other axial loads, other shear loads, and torsion, use

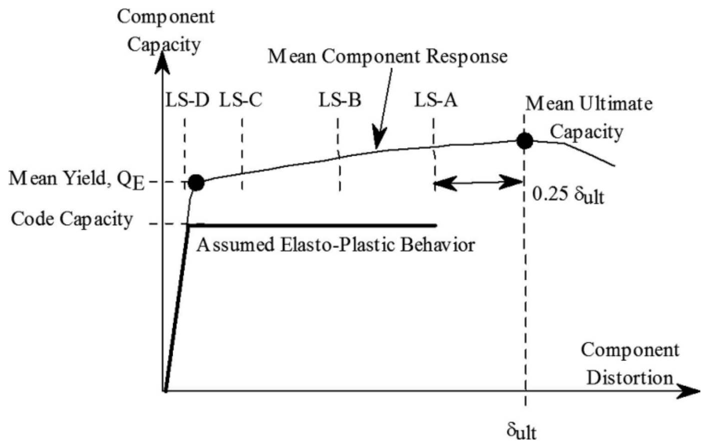
$$D = D_{NS} + \frac{D_S}{1.0} \qquad \text{(5-1b)}$$

5.1.2.2 Seismic Load Combinations for Deformation-Based Acceptance Criteria. The total demand acting on an element for use with displacement-based acceptance criteria shall be the sum of seismic demand, D_S, and nonseismic demand, D_{NS}, as combined with the following load combination:

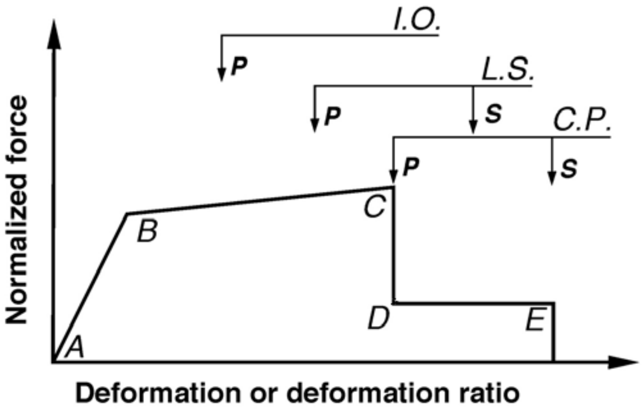
$$D = D_{NS} + D_S \qquad \text{(5-2)}$$

where D, D_{NS}, and D_S are as defined in Section 5.1.2.1.

This load combination is used for nonlinear seismic analyses. Equation (5-2) shall also be used to evaluate deformations in linear analyses.



pical load-deformation curve and limit states.



ACHIEVING LIMIT STATES A, B, AND C

- Elastic analysis, using component reduction factors, $F_{u,C}$
  - Based on 5% failure probability, values back-calculated from R_w per UBC
  - Additional adjustments for soft stories, high frequency response, ratcheting
  - Alternate approach to *m* factors in ASCE 41
- Nonlinear static analysis
- Nonlinear dynamic analysis
- Acceptance criteria, function of LS, for story drift, component rotation,

BASIS FOR SEISMIC PROVISIONS OF DOE-STD-1020

Prepared by:

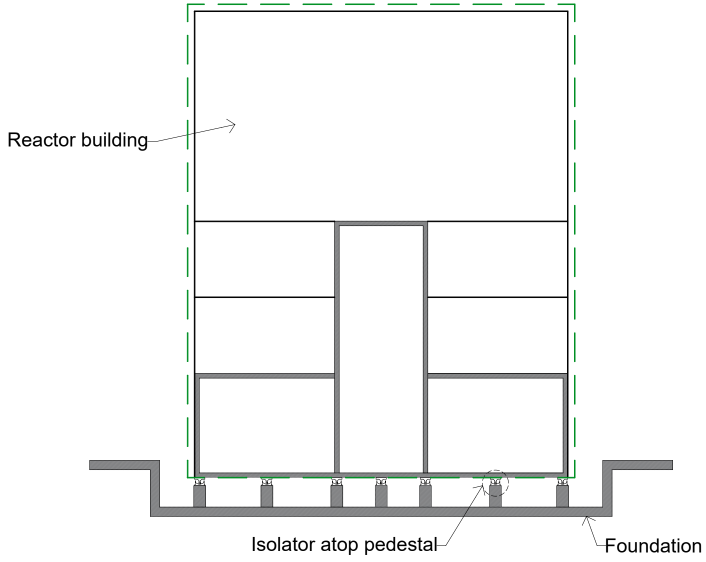
Robert C. Kennedy
RPK Structural Mechanics Consulting, Inc.
and
Stephen A. Short
EQE International, Inc.

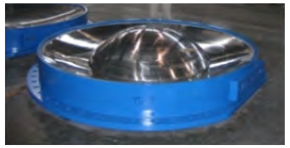
Table 5-1. Inelastic Energy Absorption Factor, $F_{\mu C}$.

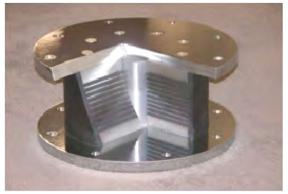
Limit State		Reduction Factor, F_μ[a] LS A	LS B	LS C
Special reinforced concrete moment frames:				
Beams	$15 \le \ell/h$	5.25	4.0	2.5
	$\ell/h \le 10$	3.25	3.0	2.5
Columns[b]		2.0	1.75	1.5
Reinforced concrete shear walls and steel-plate composite walls, in-plane:				
Flexure-critical walls, $\frac{h_w}{\ell_w} \ge 2.0$	$6\sqrt{f'_c} < f_v$	2.25	2.0	1.75
	$f_v < 3\sqrt{f'_c}$	2.5	2.25	1.75
Shear-critical walls, $\frac{h_w}{\ell_w} < 2.0$		2.0	1.75	1.5

SEISMIC ISOLATION

- Chapter 12 of ASCE 4-16
  - Being revised, expanded scope
- Chapter 9 of ASCE/SEI 43-19
  - Underpinned by USNRC research, NUREG/CRs 7253, 7254, 7255
- ARPA-E funded research
- DOE-funded topical report in production
- USNRC project underway to write a Reg Guide





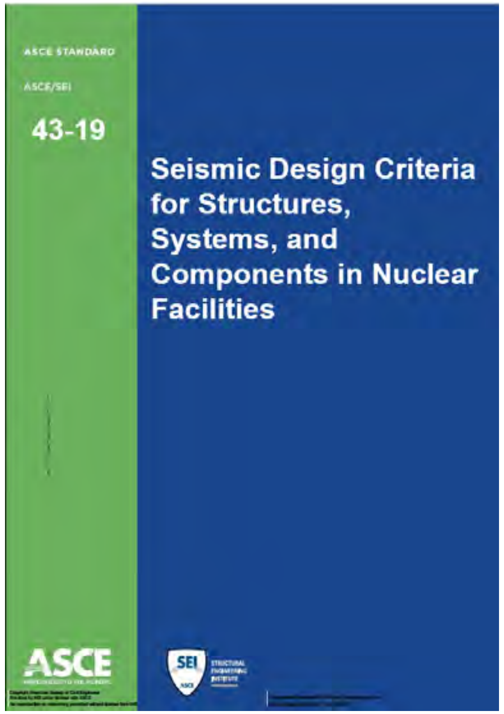


PLANNED (FUTURE) DEVELOPMENTS

- Integration of 4 and 43
- Incorporation of risk-informed methods
- Incorporation of performance-based earthquake engineering
  - Directly achieve target performance goals
  - Reference to ASCE 41 (*m* factors)
- Avoid prescriptiveness that stifles innovation
- Address emerging technical issues with advanced and micro-reactors
- Take advantage of opportunities enabled by high performance computing
- Keep pace with **or ahead of** current best practice
  - Across the DOE complex
  - Non-nuclear sectors, including buildings, bridges, oil and gas
- Support 10 CFR Part 53 licensing

ACKNOWLEDGMENTS

- ASCE Dynamic Analysis of Nuclear Structures (DANS) committee
  - Michael Salmon, P.E., F.ASCE, Chair
  - Brian McDonald, Ph.D., S.E., F.ASCE
- ASCE Nuclear Standards Committee
- Jim Xu, Ph.D., M.ASCE
- Robert Kennedy, Ph.D., P.E., M.ASCE, NAE
- C. Allin Cornell, Ph.D., NAE



FURTHER DISCUSSION

gabatt@becht.com

awhittak@buffalo.edu

Plan for Regulatory Guides on ASCE Standards 1, 4, and 43 for Risk-Informed Applications

Jim Xu, Ph.D.
Senior Level Advisor
NRC/RES
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U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Regulatory Guide for RIPB Seismic Safety

- Incorporate RIPB principles in graded seismic design using a combination of seismic design category (SDC) and design limit state (LS)
- Provide regulatory positions and process for how to determine alternate SDCs and LSs for SSCs considering LMP or other framework
- Use Performance standards such as ASCE 1, 4, and 43 to support SDC/LS seismic design
- Provide considerations for applications referencing the RIPB approach under various regulatory environments, e.g., Part 50/52, or Part 53

Timelines

- Preliminary draft guide to be completed by February 2022 which will include regulatory positions, technical bases, and implementation guidance
- RES will coordinate with NRR/DANU to engage with stakeholders, obtain public feedback, and brief ACRS in parallel with technical guidance development
- Issue draft guide for use by applicants by June 2022

Regulatory Guide for Applications of Seismic Isolation Technologies

- Provide high level framework for incorporating seismic isolation (SI) in reactor applications
- Align the safety aspects with RIPB and LMP
- Leverage ASCE 4 and 43 relevant provisions to the extent practicable
- Engage stakeholders, applicants, and practitioners to achieve technical alignment
- Timeline: Issue draft guide for use by applicants by June 2022

Updates on ACI 349 Development of Codes and Standards Part 2

By

Adeola K. Adediran (SRR/Bechtel)

Chair – ACI 349

OUTLINE

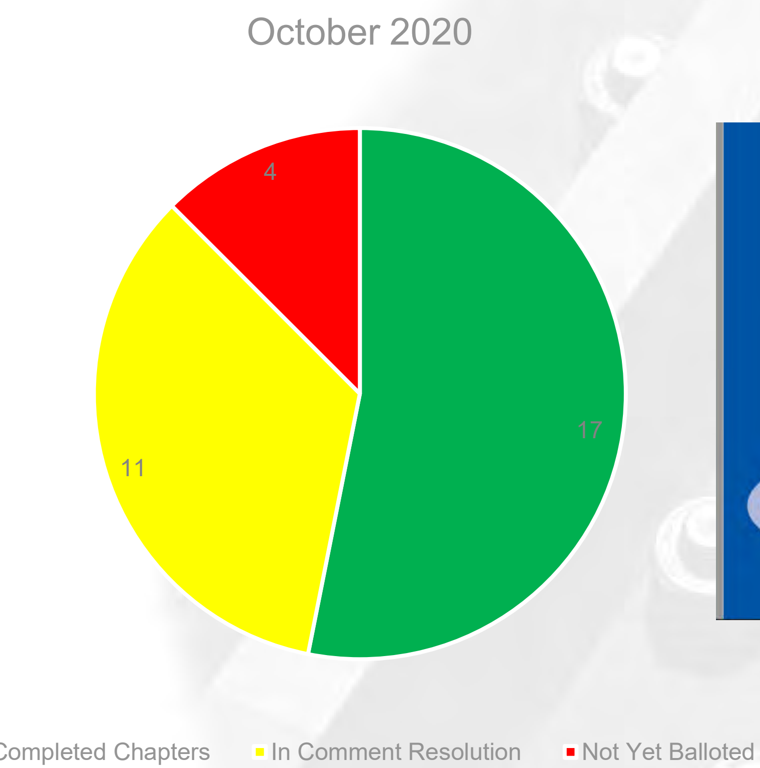
- ACI 349 Documents in the works and planned
- Update on ACI 349-XX code
- When codes conflict – Case Study
- Conclusion & Recommendations for Standards Development

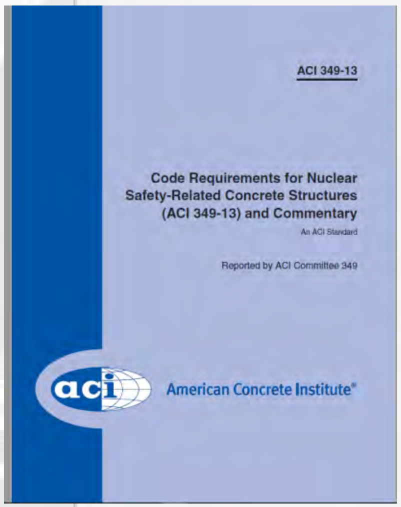
ACI 349 Documents in the works and planned

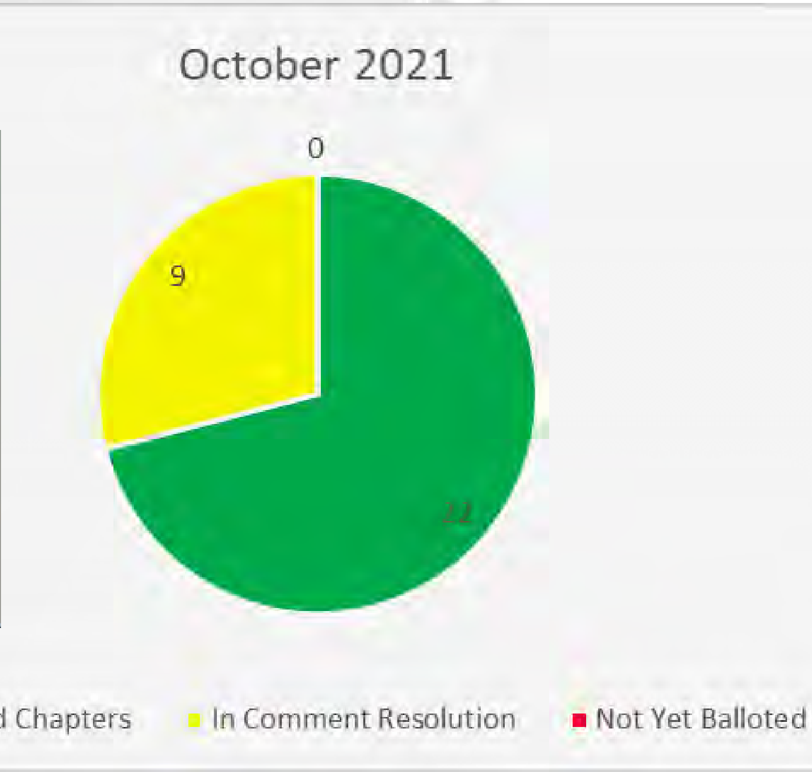
Technical Activities Committee Approved ACI 349 documents:

- *349: Code Requirements for Nuclear Safety-Related Concrete Structures (ACI 349-XX) and Commentary*
- *349.4R: (349-359-370)R: Report on the Design for Impactive and Impulsive Loads for Nuclear Safety Related Structures*
- *349.1R: Reinforced Concrete Design for Thermal Effects on Nuclear Power Plant Structures*
- *349.2R: Guide to the Concrete Capacity Design (CCD) Method--Embedment Design Examples*
- *349.3R: Report on Evaluation and Repair of Existing Nuclear Safety-Related Concrete Structures*
- *349.XR (New): Report on Blast Test Simulation Benchmark*
- *SP XX (New): Use of Advanced Finite Element Methods for Design of RC Nuclear Structures*

Update on ACI 349-XX







Update on ACI 349-XX October 2020

Chapter Full Title	Prepared by Lead	Checked by Chair	Out for Ballot	Negatives Resolved	Comments Incorporated	Ballot Summary Uploade
Chapter 1 - General	Complete	Complete	Complete	Complete	Complete	Complete
Chapter 2 - Notations and Terminology	Pending Anderson					
Chapter 3 - Referenced Standards	Pending Anderson					
Chapter 4 - Structural Systems Requirements	Complete	Complete	Complete	Complete	Complete	Complete
Chapter 5 - Loads	Complete	Complete	Complete	Pending 4 Negatives	Ballot Closes 10-12-20	
Chapter 6 - Structural Analysis	Complete	Complete	Complete	Pending 13 Negatives	Comment from Farhad; possibly discussing next week	
Chapter 7 - One-Way Slabs	Complete	Complete	Complete	Complete	Complete	Complete
Chapter 8 - Two-Way Slabs	Complete	Complete	Complete	Complete	Pending Galunic	
Chapter 9 - Beams	Complete	Complete	Complete	Complete	Complete	Complete
Chapter 10 - Columns	Complete	Complete	Complete	Complete	Complete	Complete
Chapter 11 - Walls	Complete	Complete	Complete	Complete	Complete	Complete
Chapter 12 - Diaphragms	Complete	Complete	Complete	Pending 8 Negatives		
Chapter 13 - Foundations	Complete	Complete	Complete	Complete	Complete	Complete
Chapter 14 - Plain Concrete	Complete	Complete	Complete	Complete	Complete	Complete
Chapter 15 - Beam-Column & Slab-Column Joints	Complete	Complete	Complete	Complete	Complete	Complete
Chapter 16 - Connections Between Members	Complete	Complete	Complete	Complete	Complete	Complete
Chapter 17 - Anchorage to Concrete	Complete	Complete	Complete	Pending 29 Negatives	scope language and grouted anchors; shear lugs	
Chapter 18 - Earthquake Resistant Structures	Complete	Complete	Complete	Pending 36 Negatives	Ready for Oct (under Sub B mtg); possiby post partial ballot	
Chapter 19 - Concrete Design and Durability	Complete	Complete	Complete	Complete	Complete	Complete
Chapter 20 - Steel Reinforcement Properties, Durabi	Complete	Complete	Complete	Pending 4 Negatives		
Chapter 21 - Strength Reduction Factors	Complete	Complete	Complete	Pending 7 Negatives	Pending phi 0.6 issue; ballot in Oct mtg	
Chapter 22 - Sectional Strength	Complete	Complete	Complete	Complete	Complete	Complete
Chapter 23 - Strut and Tie Models	Complete	Complete	Complete	Complete	Complete	Complete
Chapter 24 - Serviceability Requirements	Complete	Complete	Complete	Complete	Complete	Complete
Chapter 25 - Reinforcement Details	Complete	Complete	Complete	Complete	Ballot Closes 10-30-20	
Chapter 26 - Construction Documents and Inspectior	Complete	Complete	Complete	Complete	Complete	Complete
Chapter 27 - Strength Evaluation of Existing Structure	Complete	Complete	Complete	Complete	Complete	Complete
Chapter 28 - Shells	Complete	Complete	Complete	Complete	Pending Galunic	
Chapter 29 - Special Provisions for Impactive and Im	Pending Adediran					
Chapter 30 - Thermal Considerations	Complete	Complete	Complete	Complete	Complete	Complete
Chapter 31 - Alternative Load and Strength-Reductio	Complete	Complete	Complete	Pending 13 Negatives	Similar negatives to Ch21; phi 0.6; ballot in Oct mtg	
Commentary References	Pending Anderson					

Update on ACI 349-XX September 2021

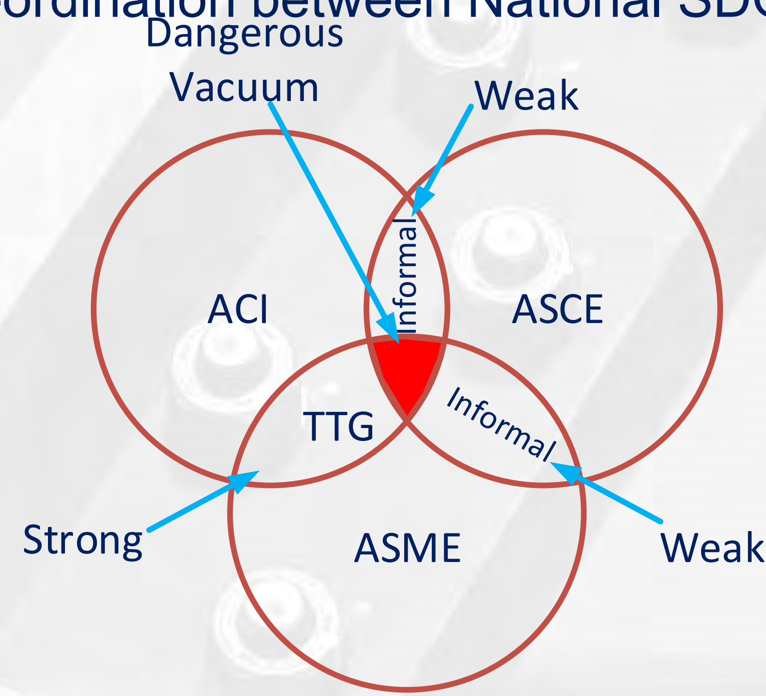
Chapter	Chapter Full Title	Prepared by Lead	Checked by Chair	Out for Ballot	Negatives Resolved	Comments Incorporated	Ballot Summary Uploaded
1	Chapter 1 - General	Complete	Complete	Complete	Complete	Complete	Complete
2	Chapter 2 - Notations and Terminology	Complete	Complete	Complete			
3	Chapter 3 - Referenced Standards	Complete	Complete	Complete			
4	Chapter 4 - Structural Systems Requirements	Complete	Complete	Complete	Complete	Complete	Complete
5	Chapter 5 - Loads	Complete	Complete	Complete	Complete	Complete	Complete
6	Chapter 6 - Structural Analysis	Complete	Complete	Complete	Complete	Complete	Complete
7	Chapter 7 - One-Way Slabs	Complete	Complete	Complete	Complete	Complete	Complete
8	Chapter 8 - Two-Way Slabs	Complete	Complete	Complete	Final Ballot pending		
9	Chapter 9 - Beams	Complete	Complete	Complete	Complete	Complete	Complete
10	Chapter 10 - Columns	Complete	Complete	Complete	Complete	Complete	Complete
11	Chapter 11 - Walls	Complete	Complete	Complete	Complete	Complete	Complete
12	Chapter 12 - Diaphragms	Complete	Complete	Complete	Complete	Complete	Complete
13	Chapter 13 - Foundations	Complete	Complete	Complete	Complete	Complete	Complete
14	Chapter 14 - Plain Concrete	Complete	Complete	Complete	Complete	Complete	Complete
15	Chapter 15 - Beam-Column & Slab-Column Joints	Complete	Complete	Complete	Complete	Complete	Complete
16	Chapter 16 - Connections Between Members	Complete	Complete	Complete	Complete	Complete	Complete
17	Chapter 17 - Anchorage to Concrete	Complete	Complete	Complete	Complete	Pending Silva's final incorporation of comments	
18	Chapter 18 - Earthquake Resistant Structures	Complete	Complete	Complete	Complete	No Negatives pending but pending Cantarero incorporation	
19	Chapter 19 - Concrete Design and Durability	Complete	Complete	Complete	Complete	Complete	Complete
20	Chapter 20 - Steel Reinforcement Properties, Durabi	Complete	Complete	Complete	Complete	Complete	Complete
21	Chapter 21 - Strength Reduction Factors	Complete	Complete	Complete	Complete	Complete	
22	Chapter 22 - Sectional Strength	Complete	Complete	Complete	Complete	Complete	Complete
23	Chapter 23 - Strut and Tie Models	Complete	Complete	Complete	Complete	Complete	Complete
24	Chapter 24 - Serviceability Requirements	Complete	Complete	Complete	Complete	Complete	Complete
25	Chapter 25 - Reinforcement Details	Complete	Complete	Complete	Complete	Pending Silva's final incorporation of comments	
26	Chapter 26 - Construction Documents and Inspection	Complete	Complete	Complete	Complete	Complete	Complete
27	Chapter 27 - Strength Evaluation of Existing Structure	Complete	Complete	Complete	Complete	Complete	Complete
28	Chapter 28 - Shells	Complete	Complete	Complete	Complete	Complete	Complete
29	Chapter 29 - Special Provisions for Impactive and Im	Complete	Complete	Complete	Final Ballot pending		
30	Chapter 30 - Thermal Considerations	Complete	Complete	Complete	Complete	Complete	Complete
31	Chapter 31 - Alternative Load and Strength-Reductio	Complete	Complete	Complete	Final Ballot pending		
	Commentary References	Complete	Complete	Complete			

Codes & Standards Gaps

- New Construction processes – e.g. Modularization
- Advanced computational tools – Element based designs
- Benchmarking Lower Limits that still do not precipitate radiation release.
- Conformity across Standards with Load factors and Load combinations when Hybrid Structures are modeled.
- Jurisdictional conflicts between Standards, lags in coordination between Standards and structures that fall in the cracks between Standards.
- New and Advanced Reactors and their unique set of building constraints. For example SMR are most often buried structures, mega concrete tanks for nuclear waste disposal etc.

Codes & Standards Co-ordinations

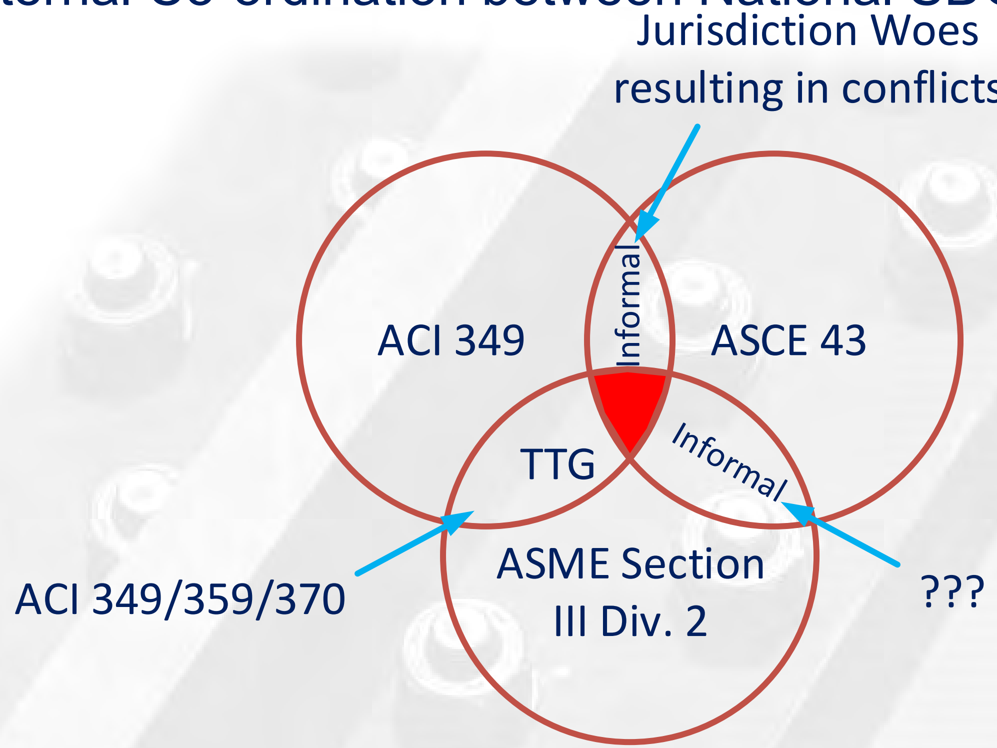
- ACI internal coordination is done two ways
  - First at the Technical Activities Committee level with committees with overlay sharing the same TAC rep and TAC forcing reviews by affected committees.
  - Second by task groups set up to facilitate discussions with groups with overlaying areas of jurisdictions.
- External Co-ordination between National SDO in Nuclear & Concrete



- No Formal External Co-ordination between International SDOs

Codes & Standards Co-ordinations

- External Co-ordination between National SDO in Nuclear contd.



- Three areas of conflicts:
  - invoking ACI 349 for limit states B and C
  - Contradicting provisions for size effects for concrete shear strength for slabs and walls
  - Disagreement between ASCE and ACI on bi-strength interactions between in-plane and out-of-plane shear

CONFLICT 3

ASCE 43 has introduced a bi-directional shear interaction for walls and slabs that does not exist in ACI and is very difficult to defend

ACI considers bi-directional shear only for beams and columns

Even in the case of beams and columns, ACI states that bi-directional shear may be ignored in 22.5.1.10, as shown below

22.5.1.10 The interaction of shear forces acting along orthogonal axes shall be permitted to be neglected if (a) or (b) is satisfied.

(a) $$\frac{V_{u,x}}{\phi V_{n,x}} \leq 0.5 \qquad (22.5.1.10a)$$

(b) $$\frac{V_{u,y}}{\phi V_{n,y}} \leq 0.5 \qquad (22.5.1.10b)$$

However, ASCE 43 has a bi-directional shear ratio with 100% applicability for walls and diaphragm, shown on the next slide

Unlike ACI, ASCE 43 does not cite research in their commentary for this.

CONFLICT 3: ASCE 43 SOLUTION

The shear failure recognized in ACI is actually diagonal tension failure, which results in a

The crack c ... russ analogy mc

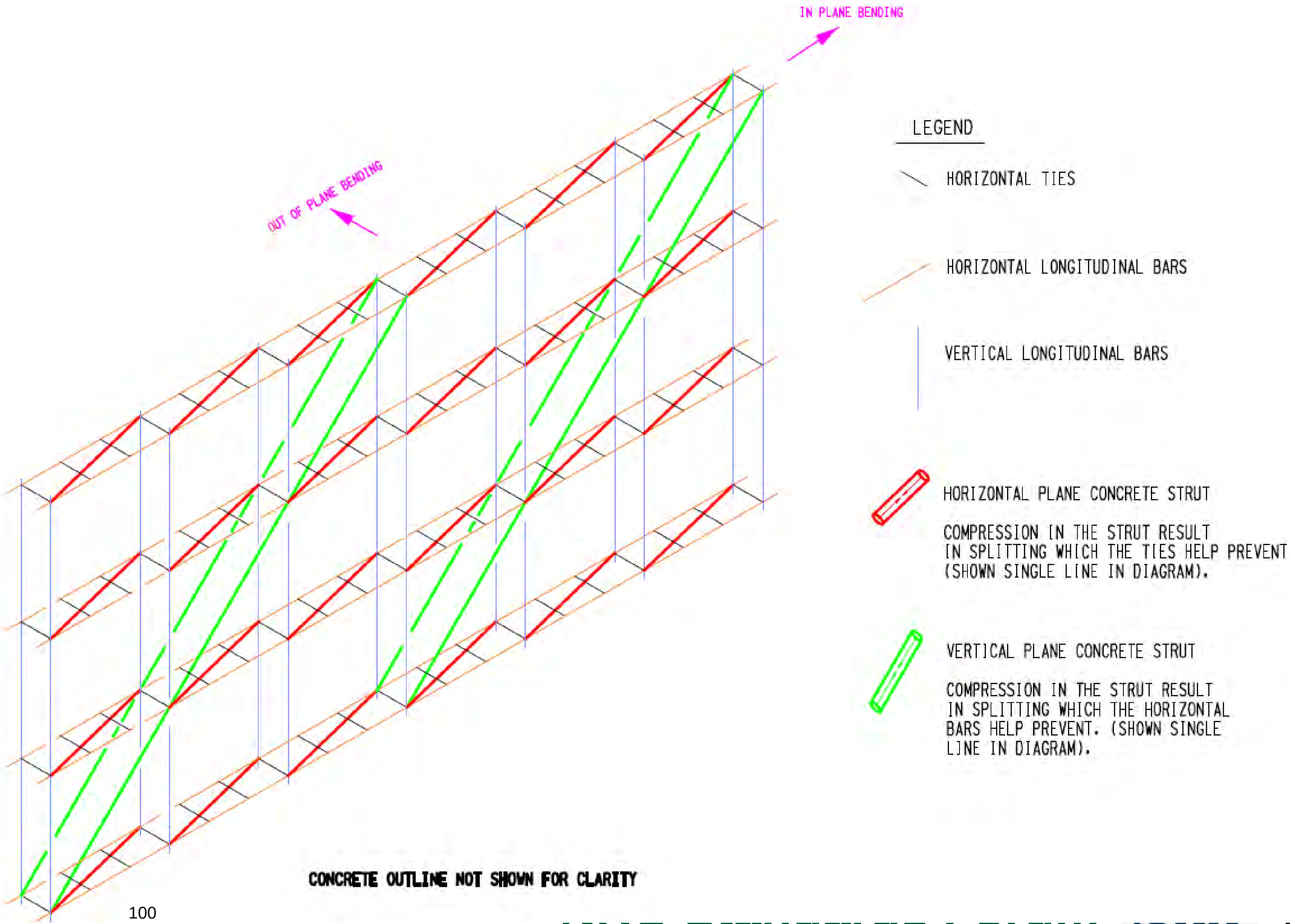
The concre ... r the out-of-plane

The trusses ... odes are the strongest part of the truss analogy model

4.2.2.2 Combined In-Plane and Out-of-Plane Shear in Slabs, Diaphragms, and Walls. The in-plane and out-of-plane shear forces in slabs, diaphragms, and walls shall be combined as follows:

$$\left(\frac{V_u}{\phi V_n}\right)^2_{\text{In-plane}} + \left(\frac{V_u}{\phi V_n}\right)^2_{\text{Out-of-plane}} \le 1.0 \qquad (4\text{-}2)$$

CONCRETE TRUSS ANALOGY



OBJECTIVE: ASCE 43-19

Objective: To review combined in-plane and out-of-plane shear in walls (Section 4.2.2.2)

However, current design codes and standard do not consider the interaction of in-plane and out-of-plane forces on the design and seismic performance of walls, and to-date have considered the separate effects of those two actions

$$\left(\frac{V_u}{\phi V_n}\right)^2_{\text{In-plane}} + \left(\frac{V_u}{\phi V_n}\right)^2_{\text{Out-of-plane}} \leq 1.0 \qquad \text{(4-2)}$$

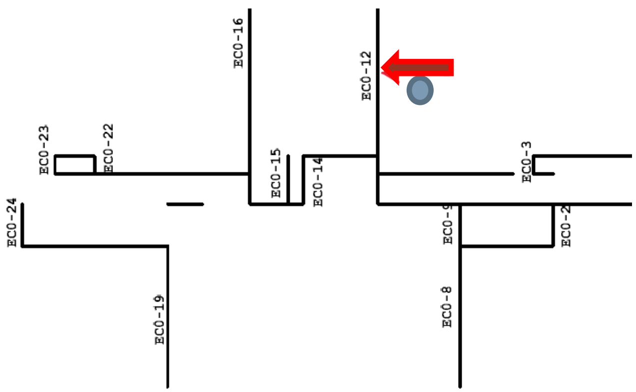
SRS BUILDING

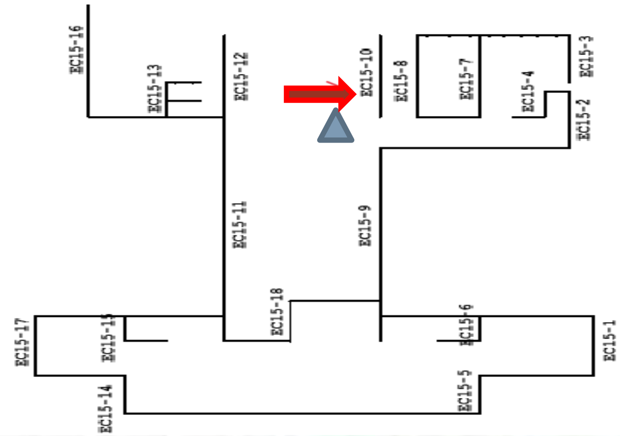
The Building walls range from 7 feet thick at the basemat and grade levels and it reduces to 2.5 feet thick at the upper levels of the tower. The demand loads were taken from Soil-Structure-Interaction (SSI) analysis and capacity D/C ratios were calculated.

The capacity of each structural element is evaluated using ACI 349-06

Then, applied the bi-directional shear from ASCE 43-19 to observe the impact of that new requirement.

SRS BUILDING





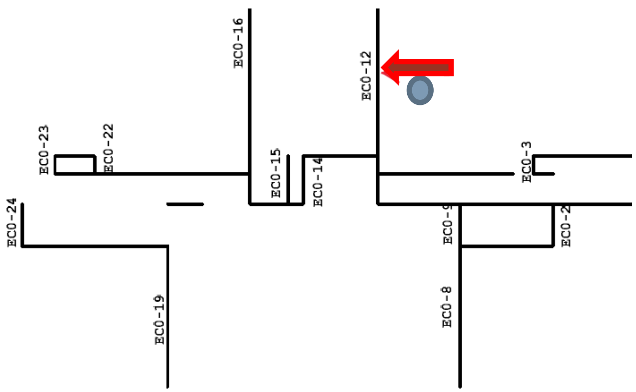
	EC0-8	EC0-12
Shear on Gross Section:	0.47	0.18
In-Plane Shear:	0.79	0.42
Shear Friction:	0.72	0.80
Bending + Axial Loads:	0.12	0.21
Torsional Moment:	0.09	0.12
Out-of-Plane Shear:	0.02	1.00

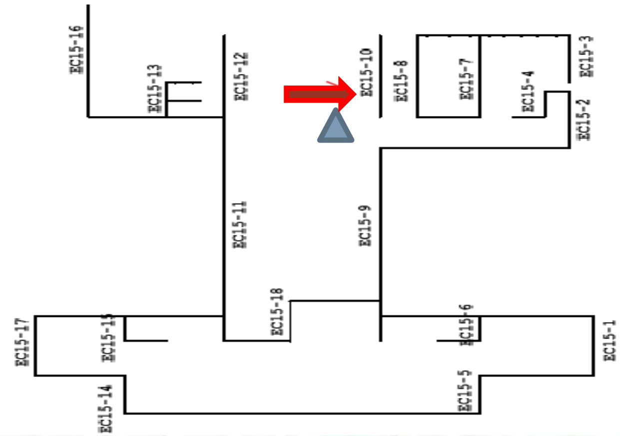
	EC15-1	EC15-9	EC15-10
Shear on Gross Section:	0.22	0.16	0.16
In-Plane Shear:	0.43	0.45	0.38
Shear Friction:	0.63	0.44	0.70
Bending + Axial Loads:	0.25	0.10	0.09
Torsional Moment:	0.15	0.26	0.11
Out-of-Plane Shear:	0.05	0.05	0.92

	Final Demands						
	P	P-	V	Fz	MB	MT	MZ
Wall ID	Axial Compression	Axial Tension	In-Plane Shear	Out-of-Plane Shear	Out-of-Plane Moment	Torsional Moment	In-Plane Moment
EC0-12	17728 k	7754 k	6709 k	11156 k	64430 k-ft	5667 k-ft	265764 k-ft

ECO-12 is 7 ft thick & *EC15-10 is 7ft thick*

SRS BUILDING





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$$(\mathbf{0.42})^2 + (\mathbf{1.0})^2 = \mathbf{1.18} > \mathbf{1.0}$$

Wall EC0-12 Fails ASCE 43-19

$$(\mathbf{0.38})^2 + (\mathbf{0.92})^2 = \mathbf{0.99} < \mathbf{1.0}$$

Wall EC15-10 Barely Passes ASCE 43-19

ECO-12 is 7 ft thick ***&*** ***EC15-10 is 7ft thick***

CONCLUSION & RECOMMENDATION

- Work is ongoing to resolve conflicts between US Codes and Standards.
- Future work being planned for ACI 349 not yet approved by TAC includes:
  - Revised Shell provisions with ACI 318.2
  - Moving some of the Element Based Design recommendations documented in the new SP to be created by ACI 349 to the Chapter 6 of the next code
  - Include the use of precast concrete for Nuclear applications when more damage levels are recognized.
- Recommendations:
  - A task group should be stood up between ACI and ASCE on Nuclear.
  - A task group should be stood up between ASME and ASCE on Nuclear.
  - Or one task group should be stood up between the oversight levels of ACI, ASCE and ASME.

QUESTIONS