SUMMARY REPORT

USNRC Public Meeting: Draft provisions AISC N690- Appendix N9
(Steel-plate composite (SC) Walls)
Friday, November 15, 2013: 8:00 AM – 4:00 PM
Bethesda, Maryland

Comments about summary:

1. Only the questions and important discussions have been mentioned.
2. Where ever possible, the person asking the question or replying has been mentioned.

Summary:

1) Jose Pires (NRC) presentation from 8:00 - 8:15 am covered the following
   a) Meeting Agenda
   b) Brief discussion on NRC review process
   c) Discussion on SC walls and related NRC research activities
   d) Expectations from review

2) Taha Al-Shawaf (AREVA) presentation from 8:15 - 8:45 am covered the following
   a) Introduction to SC walls
   b) History, benefits, limitations, current status
   c) Appendix N9 development effort
   d) TC12 subcommittee timeline

3) Charlie Carter (AISC) discussion from 8:45 - 9:00 am on schedule for publication
   a) Second COS ballot: May 2014 (will also be available for public review)
   b) Third COS ballot (expected to be final ballot): September 2014 (based on 2nd ballot comments
   c) Will be sent to ANSI for accreditation (December 2014)
   d) Final appendix: Expected to be available by February 2015.

4) Amit Varma (Purdue University) Modular presentation on the Appendix from 9:00 am to 4:00 pm covered the following:
   a) Organization of the Appendix
   b) Flow chart to facilitate the use of the appendix
   c) Break-up of the section of appendix into modules
   d) Presentations discussing the various sections of the appendix.
      (i) Module 1 - General Requirements
      (ii) Module 2 - Analysis Requirements

(iii) Module 3 - Design of Shear Connectors
(iv) Module 4 - Design of Ties
(v) Module 7 - Connections
(vi) Module 8 - Fabrication, Inspection and Construction
(vii) Modules 5, 6 - not covered due to shortage of time (Design of SC walls)

5) Questions & significant discussions:
While this summary describes the questions and answers during the presentations, any additional significant discussions/comments have also been mentioned in italics. Please see next few pages.

1) Is there any information regarding the performance of Japanese reactors constructed with SC modules, which were subjected to the 2011 Earthquake?

   Answer: No issues have been reported regarding the earthquake performance of Japanese reactors with SC modules.

2) Bret Tegeler (NRC): Under what circumstances can the Appendix be used?

   Answer (Amit): The applicability of the appendix is governed by General Provisions discussed in Module 1 (Appendix Section N9.1.1)

3) Bret Tegeler (NRC): Is the appendix applicable to floor slabs?

   Answer (Amit): Currently no discussion of slabs in the appendix. However, inclusion of slabs was considered during the formation of appendix (left out due to various combinations possible). Also there is an AISC-COS ballot comment on this issue. Hence the applicability to slabs may be addressed in the subsequent ballot.

   Sanj (Bechtel): If the SC slab is looked at as a SC wall flipped horizontally, the provisions to calculate the demands and capacities can be applied.

   Madhumita (NRC): Steel plates may need to be checkered, if they serve as walking platforms.

   Sanj: This depends on the application. In many cases the floor slabs may not be used for walking. If needed, topping plates can be used.

   Charlie (AISC): Just steel floors may suffice given the loading magnitudes and depth.

   Carlos (Westinghouse): In most cases concrete is required due to shielding requirements. SC slabs are important.

4) Perry: Why do we need to consider non-yielding ties?

   Answer (Amit): There are some non-yielding tie systems in market (e.g., bi-steel systems). Since these systems are prevalent, the option has been provided in the Appendix.

   Comment (Sanj):

   The tie spacing requirements are the minimum requirements. Depending on the out-of-plane shear requirements, ties may be spaced closer. Construction loads have not been addressed in the Appendix, because they act on the empty module.

However, tolerances are given to ensure that the empty modules are good for construction.

5) Is there any warning to designer about construction loads not being addressed?

   Answer (Saahas, Purdue Univ.): There is a user note which cautions the engineer about controlling the rate of pour, etc.

6) Bret Tegeler: Minimum SC wall thickness for SC walls: Does the requirement apply to below grade/foundation SC walls like the kind possible in SMRs?

   Answer (Amit): The requirement is based on missile impact. Additional requirements due to below grade (such as corrosion related) that may require sacrificial thickness of faceplate have not been considered.

   Sanj: The additional loads (due to soil and water pressures have been addressed by including F & H loads in load combinations).

   Comment (Sanj*): The maximum faceplate thickness (1.5-in.) also prevents the pre-heat and post-heat welding requirements for thicker plates*.

7) Sanj: The appendix talks about different faceplate thicknesses on the two faces. But that may lead to problems/confusion. How to address this?

   Answer (Amit): This will be clarified in Ballot 2. Different thickness and nominal yield strengths are not recommended for the steel faceplates

8) Patel (NRC): In over-strength connection regions, plates may be thicker than at the normal regions? Is that addressed in the Appendix?

   Answer (Amit): This is project specific. The appendix does not address connection detailing. It needs to be dealt with by the engineer.

9) Perry: Why such a stringent requirement for upper limit of steel strength?

   Answer (Amit): The reasoning has been provided in the commentary.

10) George (NRC): How was minimum steel faceplate strength (50 ksi) arrived at?

    Answer (Amit): Most of the tests have been done for this grade. Also, 36 ksi will yield under the thermal loading.

11) Is there a requirement for a particular number of studs between ribs?

Answer (Amit): There is no such requirement because of the presence of ties. The splitting failure is prevented by the ties.

12) Perry: Why is there a limit on the depth of ribs?

Answer (Sanj): Ribs may introduce orthotropic behavior, not enough tests have been done with ribs.

(Amit): The depth is limited to prevent ribs from changing the mechanics of SC walls (since they are not credited for any additional resistance). Also discussed in commentary.

13) George: While there is a limit for connection regions, no minimum limit has been mentioned for interior regions. How do we ensure that enough extent is there to develop desired behavior?

Answer (Amit): This will be looked into, but there is no specific ductility target for nuclear facilities since the expectation is essentially elastic behavior at SSE.

Can an analogy be provided with deep beam construction?

Answer (Amit): This will be looked into.

Comment (Sanj): *The reference to ASCE 4 needs to be updated to the latest version, which will be out in a few months.*

14) Carlos: What stiffness and damping ratio values need to be used for OBE and SSE level earthquakes?

Answer (Amit): For OBE uncracked stiffness may be used with lower value of damping.

Sanj: NRC permits not having to do OBE design.

Amit: Damping ratio may vary from 4% to 7%. 5% included some cracking at SSE level.

Sanj: In case of custom designs, when ISRS need to be generated, OBE damping ratio may be needed. In that case 5% is conservative. Koreans use 6%.

Some OBE damping ratio can be mentioned in the commentary in Ballot 2.

15) Perry: Stainless steels will have different modulus of elasticity and modular ratios. They need to be discussed in the appendix.

Answer (Amit): It needs to be reviewed and added in Ballot 2 is needed. Appendix will be reviewed for other locations where SS material properties were inadvertently omitted.

16) Praveen: During construction, do you consider the effect of heat of welding on joining a filled module (with concrete behind) with an empty module? Do you suggest reduction in stiffness, strength, etc. due to potential concrete cracking due to the thermal effects from heat of welding.

Answer (Sanj): We will typically be welding empty modules to each other, or at least the concrete infill will be stopped short of the location of welding. The standoff distance may be 1-2 feet but has not be specified. Heat of welding will not be significant if sufficient distance has been maintained.

John: The effect depends on materials involved, process of welding, etc. Hence it is suggested to mention a distance depending on the type of application.

Charlie: Similar provision of ¾-in embedment is provided for conventional steel construction. Larry Kloiber may be requested to provide some guidance language on this aspect.

Amit: The recommendation will talk about the minimum stand-off distance and if there will be any repercussions on stiffness.

17) Sanj: $M_{r\text{-}th}$ expression: should the *(EI)'* term be be $E_s\ I_s$?

Answer (Amit): Will be reviewed. (EI)' is equal to E_sI_s at that point, but will check equation.

Is the other face fully restrained in calculation of $M_{r\text{-}th}$?

Answer (Amit): The wall is considered free to expand, so this is away from the support / restraint regions.

18) How does one establish S_{rxy} to determine if cracked or un-cracked in-plane shear stiffness will be used?

Answer (Amit): More guidance on how to apply it has been provided in the commentary.

Sanj: General guidance is to consider possible zoning along the height of wall, like at bottom the cracking will be more.

19) Bryan: Has any consideration been made for possible dissimilar modules within a wall (different sizing, thickness, etc.)?

Answer (Amit): No explicit consideration of discontinuity of parameters (mainly faceplate thickness). Need to think about adding it as a general requirement.

Comment (Sanj): Aggregation of demands over a region of $2t_{sc}$, considers FOSID on a small expanse. When contrasted against RC walls, where whole wall is considered an element and demand and capacity are checked over the whole length, the design evaluation basis for SC walls is more conservative.

20) Perry: If studs are yielding type, why do we need to consider cracking in concrete?

Answer (Amit): Experiments and analytical models for accidental thermal loading show plane section remain plane. Hence, some level of strain compatibility exists, causing concrete to crack.

Charlie: Also the thermal strains will be felt across the concrete.

21) Taha: Why is the stress distribution for non-yielding shear connectors considered triangular?

Answer (Amit): The assumption is conservative.

22) Adam (Bechtel): Majority of SC wall requirements are local. Are there any global limitations/requirements that need to be considered (e.g. if curved SC walls)?

Answer (Amit): There was a similar comment in COS ballot. We may specify a curvature limit for the wall in Ballot 2.

Comment (Sanj): Even if faceplates are of same strength, there will differences in the actual material strengths. Tie bar tensile strength calculation, all bars have been conservatively been considered to be non-yielding.

23) Taha: What happens to conservatism of ACI Out of plane shear equation with respect to experimental data as the depth increase beyond 40 in?

Answer (Amit): As depth increases the governing failure mode can change from shear to flexural yielding.

Perry: In the plots for variation with depth, there is a considerable variation in data at 20-in depth, Is there any explanation? Also can this be suppressed in data set?

Answer (Amit): The data set can't be suppressed.

Comment (Sanj): The size effect apparent from the plots has been considered by reducing the concrete contribution to $1.5\sqrt{f'_c}$ instead of $2\sqrt{f'_c}$ in the Appendix.

24) Taha: In the out-of-plane shear interaction equations, if concrete contribution in more than required, the first term goes negative. How is it addressed?

Answer (Amit): The charging language to the equations addresses this.

25) Sanj: Q_{cv}^{avg} equation may just converge to Von-Mises yielding equation?

Answer (Amit): The interfacial shear and out-of-plane shear act at different locations on ties.

26) Praveen: Don't the tolerances mentioned need to be included in analysis?

Answer (Amit): If the tolerances are met, no additional considerations in analysis need to be made. Deviations in excess of specified tolerances are not acceptable, and need to be dealt with, either by re-evaluating the structure or by fixing the modules to meet the tolerances.

27) Taha: The tolerances are specified as + or -. If two modules have additive deviations on tolerances, then how will they be welded?

Answer (Amit): Engineer needs to see that the applicable welding tolerances from AWS D1.1 etc. need to be met. This is specified in the Appendix.

28) If qualified procedure gives higher tolerances than from AWS 1.1 or 1.6, how will it be addressed? (Dimensional tolerances before making connections, bullet a)

Answer (Amit): The intent was to qualify A1010. Additionally, if the project develops specific weld qualification procedure (WQP), then the associated tolerances will be applicable. The sentence will be reviewed in Ballot 2.

29) Praveen: Tolerance commentary (Table **C-NM2.1) -** add the word 'wall' to thickness tolerances in second and third columns.

Answer (Amit): will be done.

30) Praveen: fit-up tolerances (bullet a), AWS 1.4 needs to be added for rebar welding.

Answer (Amit): Will be included in Ballot 2.

31) Praveen: Use of normal concrete v/s SCC. Has the effect of additional flowability been considered?

Answer (Amit): The additional flowability will not affect the lateral pressure.

Sanj: For SCC the pour rate of concrete needs to be lower as it sets slowly.

32) Perry: Can the plates be shored and the pour rate be increased?

Answer (Sanj): Yeah that can be done, but there may not be much benefit from the exercise.

33) Praveen: Connection design- Why is there just a 100% factor for non-seismic loads?

Answer (Amit): The factor is 100% because the demands are already factored in the LRFD load combination

Praveen: Overstrength connections - specifically mention that thermal loads are included in non-seismic loads.

Answer (Amit): It will be updated.

34) George: Will any qualified engineer be able to do the connection design?

Answer (Amit): Yes. Designs are currently being done by qualified engineers. It is performance based, hence less prescriptive. Just needs to be reviewed and done under guidance.

COMMENTS:

Madhumita: Design examples will definitely be needed and very useful.

Jose: Recommend paper(s) with design examples for the appendix.

The format of the RG on Modular SC construction will be similar to RG 1.136 and 1.142. The RG number may be 1.304.

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

Public Meeting on

Draft Provisions on Modular Composite Construction under Consideration by the American Institute of Steel Construction (AISC) N690, Appendix N9

Richard A. Jervey and Jose A. Pires

NRC Office of Nuclear Regulatory Research
Division of Engineering
Regulatory Guide Development Branch

November 15, 2013

Introduction

- Public meeting to discuss
  - Draft Provisions on Modular Composite Construction under Consideration by the American Institute of Steel Construction (AISC) N690, Appendix N9
  - Draft provisions made available by the AISC for discussion and comment
- 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
- Introductions

ANSI/AISC N690, "Specification for Safety-Related Steel Structures for Nuclear Facilities"

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

Agenda

8:00 – 8:30	Introduction, agenda, and administrative items	NRC
	Standard review and possible endorsement	NRC
8:45 – 10:15*	Introduction to the standard (ANSI/AISC N690 Appendix N9)	AISC
	Development of Appendix N9 and history	AISC
	Status and schedule for publication	AISC
Break		
10:30 – noon*	Discussion topics (standard provisions / technical bases)	AISC
Break (lunch)	noon – 1:00 pm	
1:00 – 2:30*	Discussion topics (standard provisions / technical bases)	AISC
Break		
2:45 – 4:10*	Discussion topics (standard provisions / technical bases)	AISC
Break		
4:15 – 4:30	Questions and discussion	NRC

* Last 10 minutes of session reserved for questions

NRC Review

- NUREG-0800, the Standard Review Plan for Nuclear Power Plants, currently refers to N690-1994 and its Supplement 2 (2004),
  - AISC N690-2012 already published
  - Standard for Modular Composite Construction (SC) planned as Appendix N9 to N690
- NRC plans to review N690-2012 and Appendix N9 for possible endorsement in a Regulatory Guide (related Draft Guide is DG-1304) on
  - Safety-Related Steel and Steel-Concrete Modular Composite Structures (Other than reactor vessels and containments)

NRC Review

- Review and possible endorsement
  - NRC staff review (including NRC contractors/consultants)
  - NRC staff concurrence
  - Publish DG-1304 for a 30-60 day comment period
  - Incorporation of comments and ACRS review
  - Issue final Regulatory Guide

Modular Composite Construction (SC)

- Steel plate and concrete composite modular (SC) have been adopted for safety-related structures of new reactor designs
  - E.g., containment internal structures
- SC construction is still outside the scope of existing US standards for safety-related structures
- Case-by-case review is still done for current applications, license amendments and potential new applications
- Standard under development by Ad-hoc subcommittee to AISC’s Task Committee 12 (TC 12)
  - Planned as Appendix N9 to ANSI/AISC N690

NRC Research Activities

- Sponsored research at Brookhaven National Laboratory (1990s) to review technical bases for regulatory guidance (NUREG/CR-6486, 1997)
- Engaged outside experts (academia and industry) to inform confirmatory reviews of certain proposed designs
- Staff participates in the activities of TC 12's ad-hoc subcommittee
  - Outside experts informed staff review of technical bases (2011)
  - Held public meeting (August 2011)
- Sponsoring numerical modeling research for interpretation of testing, benchmarking and confirmatory analysis tools
- Reviewing international codes and guidance
  - JEAC-4618 (2009) – Japan – ASD approach
  - KEPIC (2010) – Korea – LRFD approach

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

Review Expectations

- Resulting designs must satisfy regulations
- Resulting designs would (as examples):
  - Provide adequate strength and stiffness
  - Prevent non-ductile failure modes
  - Provide durability through the use of adequate materials, control of concrete cracking, prevention of steel and rebar corrosion
  - Provide clear load paths avoiding load path discontinuities
- Other items of interest
  - Materials and material properties (steel plates, studs, tie bars, etc)
  - Type of concrete (e.g., conventional vs. self-consolidating)
  - Constructability, inspection, corrosion
  - Harmonization with international standards

Review Expectations

- Challenges (examples)
  - Design criteria for connections and connections to other construction types, e.g. reinforced concrete
  - Experimental database for combined load effects
  - Designs should be based on sound engineering principles and validated methods
- Staff continues the review of the technical bases for the provisions in the US standard under development as well as review of the scope of the provisions
  - Effort includes review of existing international standards (E.g., JEAC and KEPIC)

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

Acronyms

- AISC – American Institute of Steel Construction
- ANSI – American National Standards Institute
- JEAC – Japan Electric Association Code
- KEPIC – Korea Electric Power Industry Code
- LRFD – Load and Resistance Factor Design
- SC – Modular Composite Construction (Wall modules constructed from large prefabricated sections of steel plates spaced apart and joined with intermittent steel members or tie bars, joined with other modules at the site, and then filled with concrete)

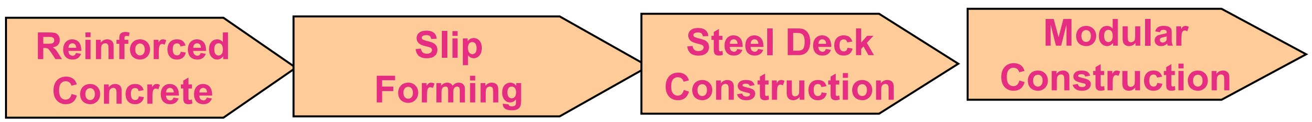
Steel-Plate Composite (SC) Modular Construction for Safety-Related Nuclear Facilities

Taha AL-Shawaf

Topics

- Purpose:
  - Exposure to SC Modular Construction
  - Benefits of SC Modular Construction
  - N690 Code Update
- Process:
  - What is Modular Construction
  - History
  - Benefits and Issues
  - State of the Industry
  - N690 Code Effort
- Payoff:
  - Awareness
  - Better informed

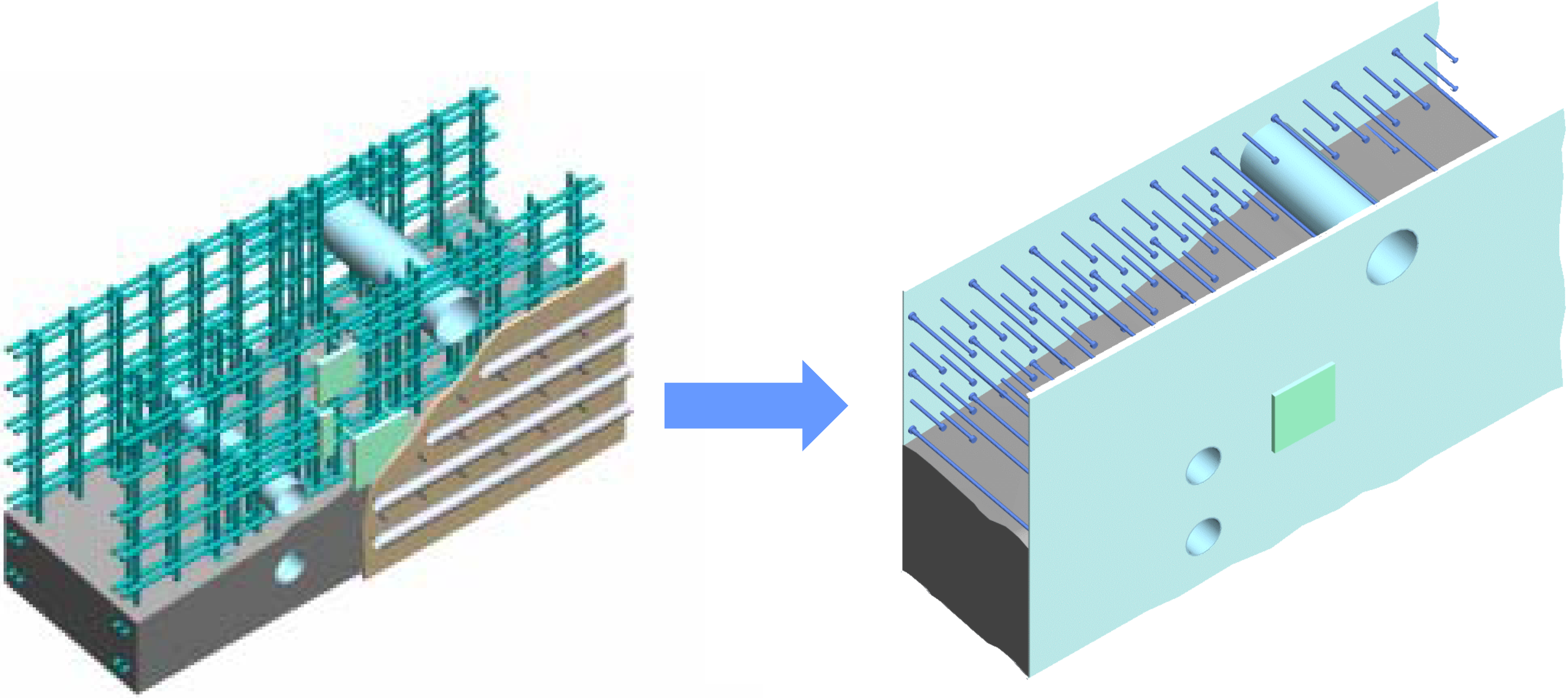
History of Construction Methods



Reinforcement Congestion

- Difficult
- Time-Consuming
- Virtually a wall
- Conc. flow-ability?

What is SC Modular Construction?



Construction Sequence

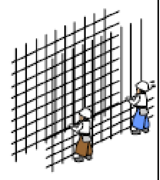
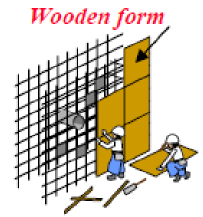
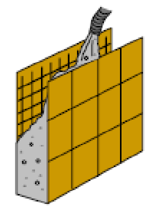
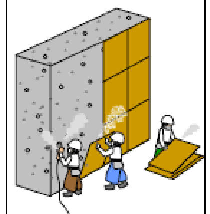
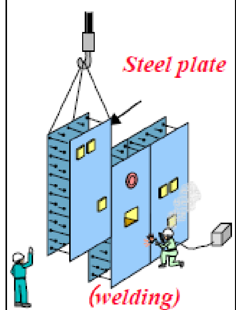
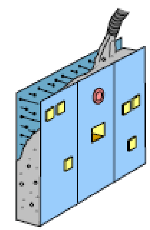
Work / Structure	Rebar arrangement	Form work (assembling	Placing concrete	Form work (removal)
RC				
28days	13days	7days	4days	4days
SC	—			—
14days	–	10days	4days	–

Figure A-2. Comparison of Construction Schedules for Reinforced Concrete

Lifting and Erection of Modules

Modular Construction

- An alternative to structural concrete reinforced with steel bars: parallel steel plates are tied together with steel rods, and are joined by headed studs to concrete poured between the plates
- Commonly referred to as SC

Previous Work

- Akiyama (Univ. of Tokyo), Sekimoto et al (MHI), "1/10th Scale Model Test of Inner Concrete Structure Composed of Concrete Filled Steel Bearing Wall," SMiRT Conference 1989
- Bi-Steel Design & Construction Guide, 2nd Edition, June 2003, Corus UK Ltd.
- "Technical Guidelines for Aseismic Design of Steel Plate Reinforced Concrete Structures – Buildings and Structures," Translation of JEAG 4618-2005
- "Specification for Safety-Related Steel Plate Concrete Structures for Nuclear Facilities" (June 2009), KSSC

Who Uses it?

- GE – Hitachi- Toshiba (ABWR) Kashiwazaki-Kariwa 6 and 7 (1996)
- TEPCO – (ABWR) Fukushima 7 and 8 (2007 and 2008)
- Westinghouse (AP600, AP1000)
  - One of the largest module is a four story, 700-metric-ton (772-ton) unit comes with rooms that are already piped, wired, and painted
- Mitsubishi Heavy Industries
- Small Modular Reactors – B&W, WEC

Advantages

- Reduce Schedule – Build Quicker with less field labor and coordination
  - Approximate reduction 2-5 months compared to the average construction time of 72-108 months.
- Early Delivery = $150M of potential electric generation
- Construction Cost potentially lower than conventional RC
- Mass Production (Economy of Scale). Think ship building.
- Reduction in project execution risk
  - Improve safety (work in the factory vs. on site)

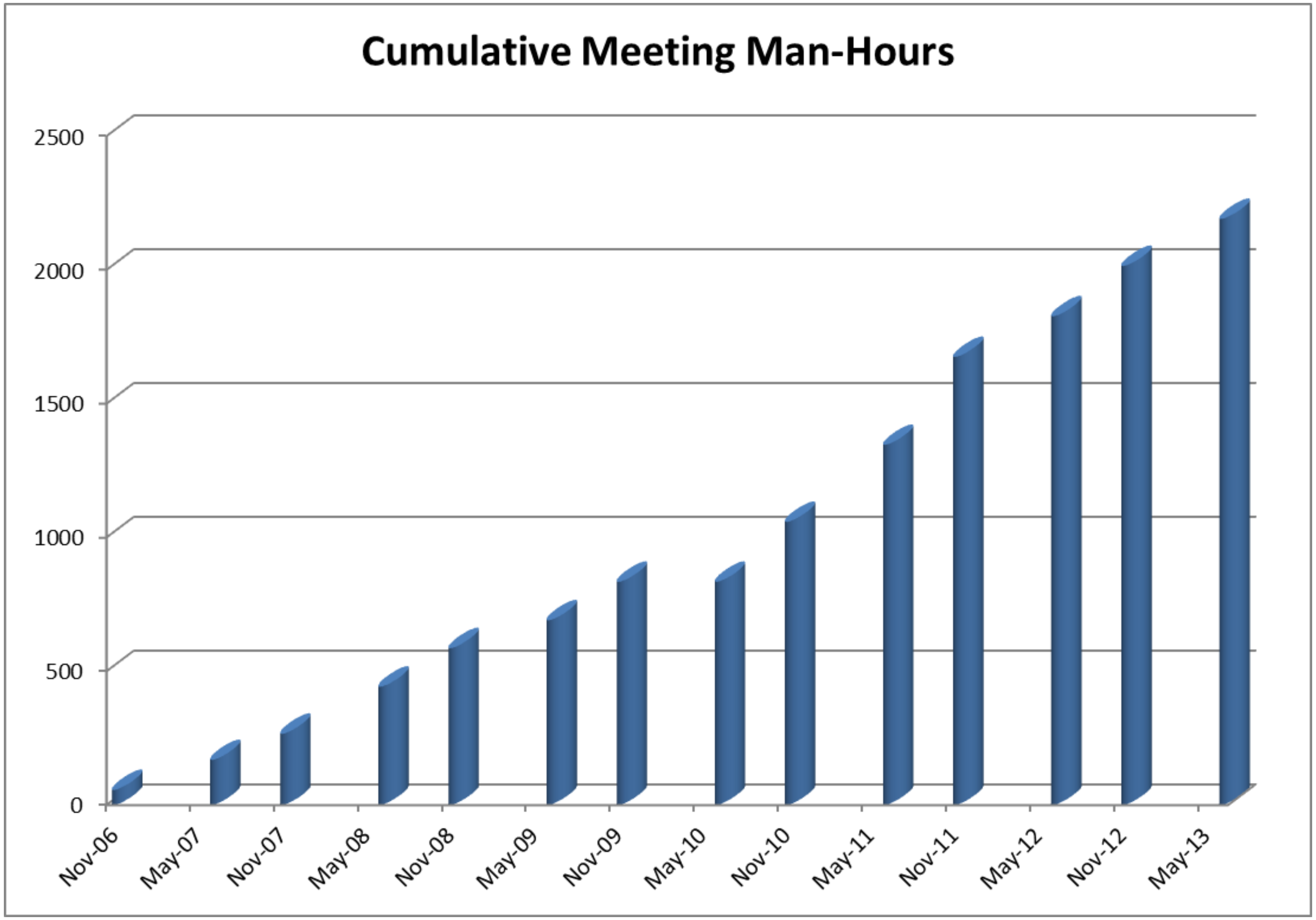
Some References on Modular Construction

- *‘Application of Advanced Construction Technologies to New Nuclear Power Plants’*, prepared for the Department of Energy, 2004
- *‘Assessment of Modular Construction for Safety Related Structures at Advanced Nuclear Power Plants’*, NRC NUREG / CR-6486, 1997
- Many papers in SMiRT and ICONE conferences
- New AISC N690 Code – Expected 2014

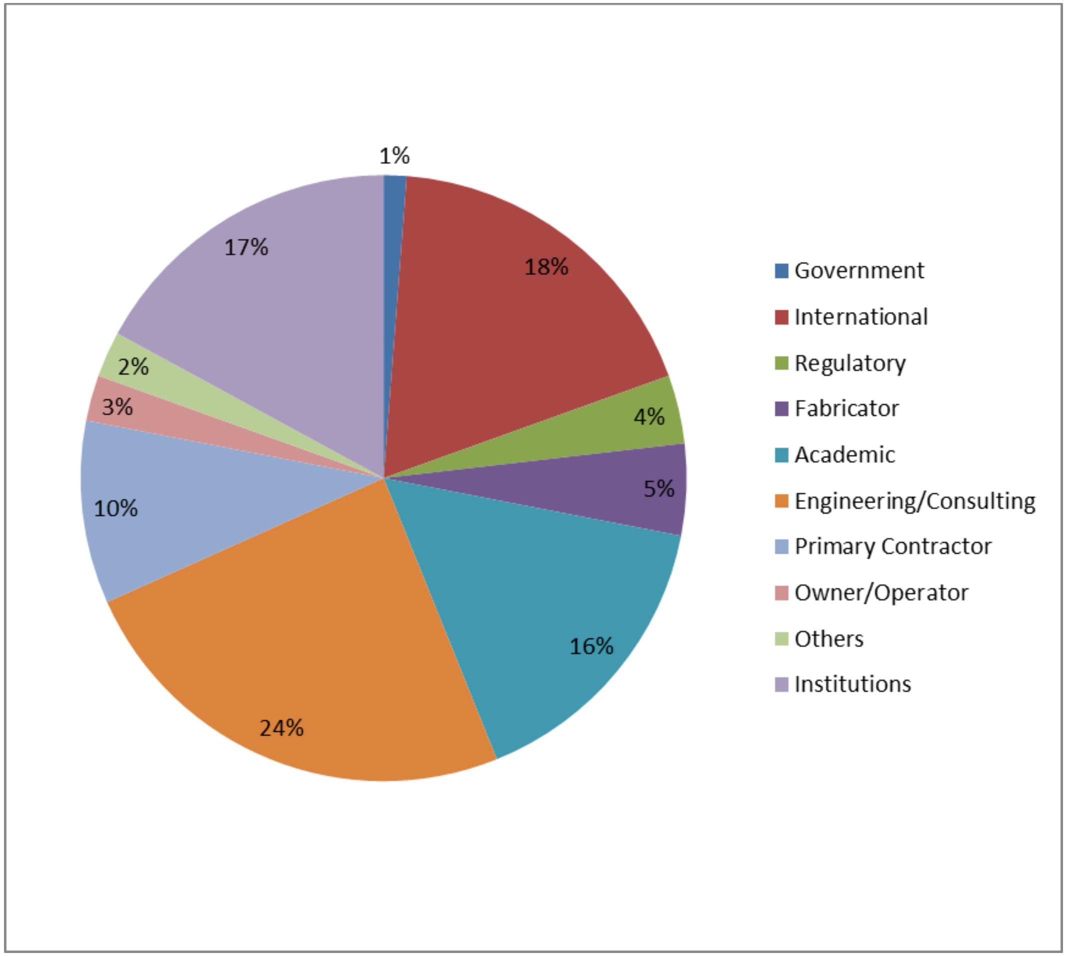
AISC TC-12 Ad Hoc Subcommittee

- First Meeting Nov. 2006
- Conducted a total of 14 meetings and many conference calls
- Has 20 active members
- Attendees include guests from a variety of institutions as well as international participation

TC-12 Ad-Hoc Sub-Committee on SC Structures



Sub-Committee Participants Affiliation



SC Ad-hoc Subcommittee Time Line

Nov.2006

- Introduction/Overview
- Preperatory/Organization

June2007

- Shear Connectors
- Flexural Behavior & Thermal
- Load Combination

Nov. 2007

- Draft Outline of Specification
- Actions to complete sections

SC Ad-hoc Subcommittee Time Line

June 2008

- Fabrication, Erection and QC
- Interaction of in-plane and out-of-plane loads
- Behavior of Combined Thermal & Mechanical Loads

Nov. 2008

- Construction Loads
- Shear Connector Design

June 2009

- Analysis Requirements
- Missile Impact
- Compactness Criteria

SC Ad-hoc Subcommittee Time Line

Nov. 2009

- Material Requirements
- Interaction Equation & local Effect
- Creep and Shrinkage Effect
- Connection Philosophy

Nov. 2010

- Design Requirements
- Min. and max. size/thickness
- Structural integrity
- Stability

June 2011

- Analysis Provisions
- Design for tension, compression, flexure and shear

SC Ad-hoc Subcommittee Time Line

Nov. 2011
- Vent Holes
- Impact Loads

June 2012
- Resolution of Ballot 1 comments

Nov. 2012
- Resolution of Ballot 2 Comments
- Tolerances

SC Ad-hoc Subcommittee Time Line

June 2013
- Discussion of Commentary
- Re-organizing format

Nov. 2013
- Discussion on COS Ballot results

June 2014
- ?

PURDUE
UNIVERSITY

AISC N690: Appendix N9

Design of Steel-Plate Composite (SC) Walls

By,

Amit H. Varma

University

Outline

- Layout and Organization of N690 Appendix N9
- Presentation Modules
- Plan For The Day

OBJECTIVE

- Specification for steel-plate composite SC walls in safety-related nuclear facilities
- Use with AISC N690 – LRFD code
- Instead of ACI 349 code for concrete structures for nuclear facilities → but all topics covered
- Specification for SC walls and associated connections

Layout and Organization of App N9

- N9.1 Design Requirements
  - N9.1.1 General Provisions
  - N9.1.2 Design Basis
    - N9.1.2a Required Strength
    - N9.1.2b Design for Stability
  - N9.1.3 Compactness Requirement
  - N9.1.4 Requirements for Composite Action
    - N9.1.4a Classification of Shear Connectors
    - N9.1.4b Spacing of Shear Connectors
  - N9.1.5 Tie Requirements
    - N9.1.5a Classification of Ties
    - N9.1.5b Required Tension Strength for Ties

Layout and Organization of App N9

- N9.1 Design Requirements (cont')
  - N9.1.6 Design for Impulsive and Impactive Loads
    - N9.1.6a Definition of Loads
    - N9.1.6b Dynamic Increase Factors
    - N9.1.6c Ductility Ratios
    - N9.1.6d Response Determination
  - N9.1.7 Design and Detailing Around Opening
    - N9.1.7a Design and Detailing Requirements Around Small Openings
    - N9.1.7b Design and Detailing Requirements Around Large Openings

LAYOUT AND ORGANIZATION OF APP N9

- N9.2 Analysis Requirements
  - N9.2.1 General Provisions
  - N9.2.2 Effective Stiffness for Analysis
  - N9.2.3 Geometric and Material Properties for Finite Element Analysis
  - N9.2.4 Analyses Involving Accidental Thermal Conditions
  - N9.2.5 Determination of Required Strengths

Layout and Organization of App N9

- N9.3 Design of SC Walls
  - N9.3.1 Uniaxial Tensile Strength
  - N9.3.2 Compressive Strength
  - N9.3.3 Out-of-Plane Flexural Strength
  - N9.3.4 In-Plane Shear Strength
  - N9.3.5 Out-of-Plane Shear Strength
  - N9.3.6 Strength Under Combined Forces
    - N9.3.6a Out-of-Plane Shear Forces
    - N9.3.6b In-Plane Membrane Forces and Out-of-Plane Moments

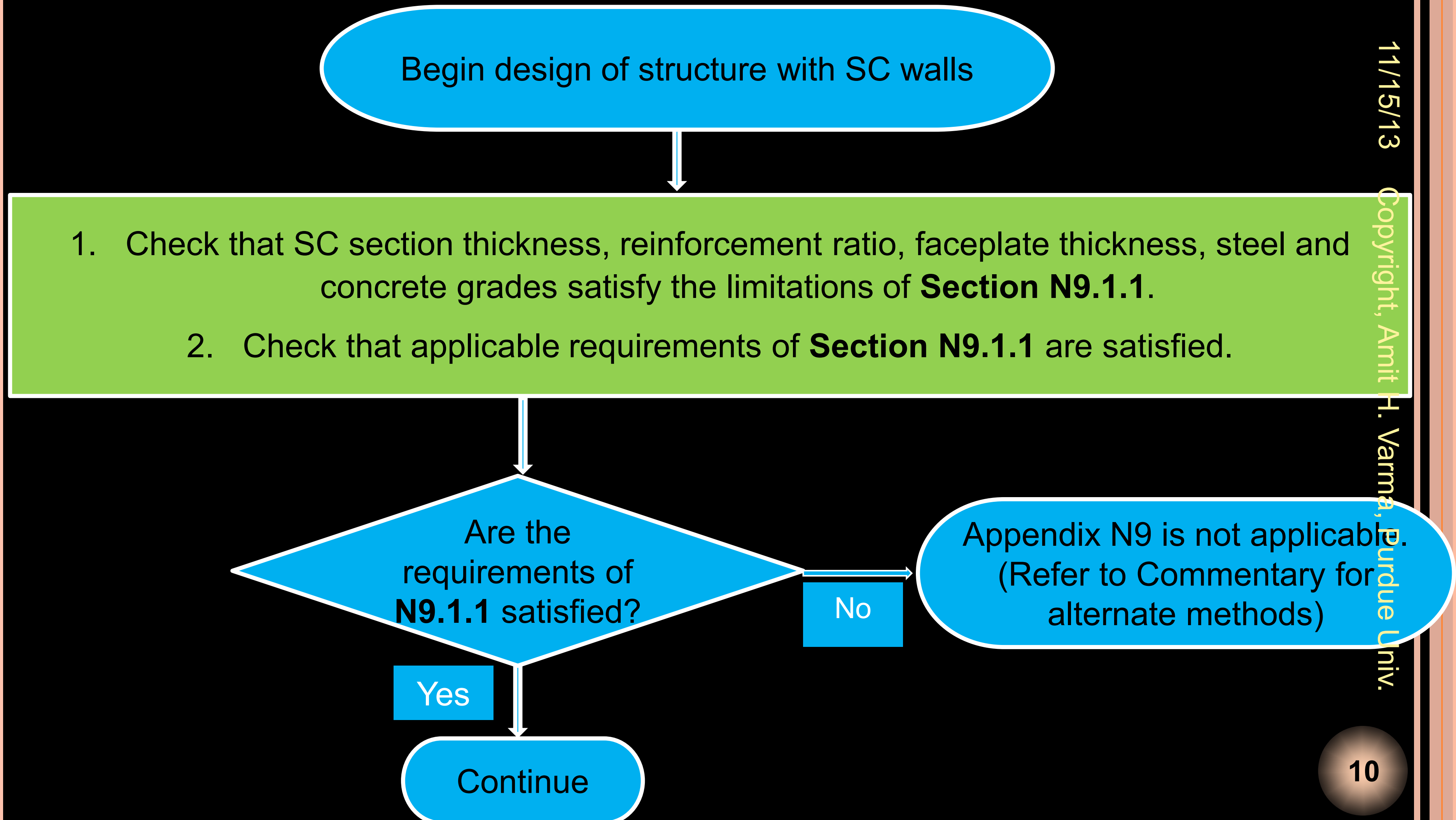
LAYOUT AND ORGANIZATION OF APP N9

- N9.4 Design of SC Wall Connections
  - N9.4.1 General Provisions
  - N9.4.2 Required Strength
  - N9.4.3 Available Strength

LAYOUT AND ORGANIZATION OF APP N9

- N690-12 Specification Additions
  - NA3 – Materials
  - NB2 – Loads and Load Combinations
    - Add F and H, and tread them like D and L (ACI 349)
  - NM2 – Fabrication, Erection, and Construction
    - Dimensional Tolerances
  - Minimum Requirements for Inspection of Composite Constructions

FLOWCHART: DESIGN AND SPECS



PURDUE UNIVERSITY

Flowchart: Design and Specs

Continue

Check that faceplate is compact (Section N9.1.3)

Provide composite action using shear connectors
Classify connectors as yielding or nonyielding type using **Section N9.1.4a**.
Check spacing of shear connectors using **Section N9.1.4b**

Provide structural integrity using ties
Check tie spacing using **Section N9.1.5**.
Check tie spacing in regions around openings using **Section N9.1.7**.
Classify ties as yielding or nonyielding using **Section N9.1.5a**.
Ties contribute to out-of-plane shear strength of SC walls according to **Section N9.3.5**
Calculate minimum required tension strength for ties using **Section N9.1.5b**.

Continue

PURDUE UNIVERSITY

FLOWCHART: DESIGN AND SPECS

Continue

↓

<u>Develop linear elastic finite element (LEFE) model according to Sections N9.2.1 and N9.2.3</u>

Analyze LEFE model for load and load combinations from Section NB2.
Model openings using **Section N9.1.7**.
Model flexural and shear stiffness of SC walls using **Section N9.2.2**.
Loading due to accidental thermal conditions will be as per **Section N9.2.4**.
Model second-order effects using **Section N9.1.2b**

↓

Perform LEFE analysis to calculate design demands and required strengths.
Identify interior and connection regions using **Section N9.1.2**

Calculate required strengths for each demand type using **SectionN9.2.5**

↓

Continue

Flowchart: Design and Specs

Continue

Design Process for SC Walls: Required strengths ≤ Available strengths

Calculate available strengths for each demand type using **Section N9.3.**
The sub-sections are:

- Available uniaxial tensile strength using **Section N9.3.1**
- Available compressive strength using **Section N9.3.2**
- Available out-of-plane flexural strength using **Section N9.3.3**
- Available in-plane shear strength using **Section N9.3.4**
- Available out-of-plane shear strength using **Section N9.3.5**
- Check available strength for combined forces using **Section N9.3.6**
- Combined out-of-plane shear demands using **Section N9.3.6a**
- Combined in-plane membrane forces and out-of-plane moments using **Section N9.3.6b**

Continue

Flowchart: Design and Specs

Continue

Design Process for SC Wall Connections

Select full strength or overstrength connection design philosophy, and design force transfer mechanisms for connections as per **Section N9.4.1.**

Calculate connection required strength for each demand type in accordance with **Section N9.4.2**

Calculate connection available strength using **Section N9.4.3**

Check connection required strength ≤ connection available strength

Check SC wall design for impactive and impulsive loads in accordance with **Section N9.1.6**

Continue

PURDUE
UNIVERSITY

FLOWCHART: DESIGN AND SPECS

Continue

↓

Fabrication, Erection and Construction Requirements

1. Specify detailing for regions around openings using **Section N9.1.7**
2. Specify dimensional tolerances for fabrication of SC wall panels, sub-modules, and modules using **Section N9.5**

↓

Specify quality assurance/quality control requirements for SC walls in accordance with **Section N9.6**

↓

End design of structure with SC walls

Presentation Modules

Module 1:
General Provisions, Requirements, Limitations

Module 2:
Analysis Requirements and Recommendations

Module 3:
Shear Connectors, Local buckling Composite Action

Presentation Modules (Contd.)

Module 4:
Tie Bars
Design requirements
Out-of-Plane Shear

Module 5:
Available Strength
Tension, Compression
Flexure, In-Plane
Shear

Module 6:
Design Interaction
equations for
combined forces
and moments

Module 7:
Connection
Design

General Provisions

An SC section must satisfy these requirements in order for the Appendix provisions to be applicable.

THICKNESS

- SC Wall thickness (t_{sc}) shall be
  - ≤ 60-in.
  - ≥ 18-in. for exterior SC walls
  - ≥ 12-in. for interior SC walls
- Steel faceplate thickness (t_p) shall be
  - ≤ 1.5-in.
  - ≥ 0.25-in.

SC Wall Thickness (Reasoning)

- Minimum thickness for exterior SC walls based on Table 1 of Standard Review Plan (SRP), Section 3.5.3, Revision 3.
- Minimum thickness for exterior SC walls based on maximum reinforcement ratio and minimum faceplate thickness.
- Maximum SC thickness limit due to lack of test data and thus concerns about section behaving as a unit.

Purdue University

Steel Faceplate thickness (Reasoning)

- Minimum faceplate thickness required for:
  - Adequate stiffness and strength during concrete placement, rigging and handling.
  - Thinner faceplates may have sheet metal (and not structural plate) material properties and waviness.
- Maximum faceplate thickness limit corresponds to maximum reinforcement ratio for a 60-in. thick SC wall.

REINFORCEMENT RATIO

- Reinforcement Ratio (ρ) defined as:

$$\rho = \frac{2t_p}{t_{sc}}$$

- shall be:
  - ≤ 0.050
  - ≥ 0.015

REINFORCEMENT RATIO (REASONING)

- Lower reinforcement ratio (lower than 0.015) poses concerns regarding
  - handling strength and stiffness
  - residual stresses due to fabrication operations and concrete casting

SC Wall Thickness

- Mention the provisions and the corresponding explanations.
- Vent holes
- Alternate methods

Ties & Shear Connectors

While the shear connectors ensure composite behavior of SC walls, the ties primarily provide structural integrity.

SHEAR CONNECTORS

- Explain the purpose
- Classification: yielding and non-yielding
- Compactness requirement
- Spacing Requirements

TIES

- Explain the purpose
- Transfer length and development length concepts
- Tie Spacing requirements
- Tie Spacing requirements (region around openings)
- Classification of ties
- Contribution to out-of-plane strength
- Minimum required tensile strength of ties

Analysis Procedure

Linear Elastic Finite Element model is developed and design demands are calculated.

SC WALL REGIONS

- Identifying Interior and connection regions

Design for Stability

- Modeling of second order effects if needed.

MODELING PARAMETERS

- Discuss about how to model openings
- Flexural and shear stiffnesses
- Including accidental thermal loading
- Material properties for LEFE model

Required Strengths

- Averaging
- Demand types
- Dynamic SSI analyses, equivalent static analysis

SC Wall Design

Calculate the available strength for individual demand types and compare with corresponding required strengths.

GENERAL CONSIDERATION:

- Tensile contribution of concrete
- Contribution of steel ribs

AVAILABLE UNIAXIAL TENSION

- Specification Chapter D
- No permissible rupture failure

Available Compressive Strength

- Section I2.1b
- Modifications to the section

Available Out-of-Plane Flexural Strength

- Using Steel principles
- Using Reinforced Concrete principles

Available In-Plane Shear Strength

- Strength adjusted reinforcement ratio

AVAILABLE OUT-OF-PLANE SHEAR STRENGTH

- Need of project specific large scale tests
- Refer to Ties section for contribution of ties
- Concrete and steel contributions based on the spacing of shear reinforcement

COMBINED OUT-OF-PLANE SHEAR INTERACTION

- Equation derivation, explanation of different component terms
- Use for yielding and nonyielding reinforcement
- Q_{cv}^{avg} calculation
- Spacing of shear connectors
- Expanation for cases not considered

In-Plane Membrane force and Out-of-Plane Moment Interaction

- Concept of notional halves
- Interaction in Principal Plane
- Interaction in In-Plane Membrane Strengths

SC Wall Connection Design

Decide Connection design philosophy, calculate connection available strengths and check against required demands

CONNECTION DESIGN

- Select design philosophy, force transfer mechanisms.
- Calculate required strength for each demand type
- Calculate available strength
- Check

Impactive and Impulsive Loading

The SC wall designed needs to be checked for load combinations including the missile impact loading

IMPACTIVE AND IMPULSIVE LOADING

- Classification of loads
- DIF
- Ductility ratios
- Response determination
- Checking the design
- Method to determine thickness to prevent perforation

DETAILING AROUND OPENINGS

The region around the openings needs to be detailed based on the opening size and the edge development.

Module 1: General Provisions

An SC section must satisfy these requirements in order for the Appendix provisions to be applicable

By,

Amit H. Varma

University

Outline

- Thickness
- Reinforcement Ratio
- Material Strengths
- SC Behavior Requirements
- Steel Ribs & Splices
- Recommendations for SC walls not meeting these requirements

Thickness

- SC Wall thickness (t_{sc}) shall be
  - ≤ 60-in.
  - ≥ 18-in. for exterior SC walls
  - ≥ 12-in. for interior SC walls
- Steel faceplate thickness (t_p) shall be
  - ≤ 1.5-in.
  - ≥ 0.25-in.

SC Wall Thickness (Reasoning)

- Minimum thickness for exterior SC walls based on Table 1 of Standard Review Plan (SRP), Section 3.5.3, Revision 3.
- Minimum thickness for exterior SC walls based on maximum reinforcement ratio and minimum faceplate thickness.
- Maximum SC thickness limit due to lack of test data and thus concerns about section behaving as a unit.

Steel Faceplate thickness (Reasoning)

- Minimum faceplate thickness required for:
  - Adequate stiffness and strength during concrete placement, rigging and handling
  - Thinner faceplates may have sheet metal (and not structural plate) material properties and waviness
- Maximum faceplate thickness limit corresponds to maximum reinforcement ratio for a 60-in. thick SC wall

Reinforcement Ratio

- Reinforcement Ratio (ρ) defined as:

$$\rho = \frac{2t_p}{t_{sc}}$$

- shall be:
  - ≤ 0.050
  - ≥ 0.015

Reinforcement Ratio (Reasoning)

- Lower reinforcement ratio (lower than 0.015) poses concerns regarding
  - Handling strength and stiffness
  - Residual stresses due to fabrication operations and concrete casting
- High reinforcement ratios (above 0.050) can result in
  - Higher concrete stresses
  - Change of governing limit state from steel faceplate yielding to concrete inelasticity and failure in compression

Material Strengths

- Specified minimum yield stress of steel faceplates, F_y, shall be
  - ≥ 50 ksi
  - ≤ 65 ksi
- Concrete compressive strength, f'_c, shall be
  - Minimum: 4ksi
  - Maximum: established in accordance with ACI 349

Steel Strength (Reasoning)

- Minimum yield stress (50 ksi) specified to prevent premature yielding from limiting the strength or ductility due to
  - Residual (locked-in) stresses from concrete casting
  - Thermally induced stresses
- Steels with yield stress greater than 65 ksi
  - Typically less ductile
  - Not desirable for beyond SSE shaking
  - Require special weld electrodes

Concrete Strength (Reasoning)

- Minimum concrete strength of 4,000 psi specified so that:
  - Minimum principal (compressive) stress in concrete remains in the elastic range while steel faceplate yielding occurs under in-plane shear loading
- Also use of lower strength concrete is rare in safety-related nuclear facilities
- Requirements for concrete mix design as per ACI 349

SC Behavior Requirements

- Steel faceplates shall be non-slender
- Composite action shall be provided between steel faceplates and concrete using shear connectors
- System integrity to be ensured by tying opposite steel faceplates to each other
- Detailed discussion on how to achieve these in Module 2

PURDUE UNIVERSITY

SC Behavior Requirements (Reasoning)

- Non-slenderness requirement to prevent SC specific limit state of steel faceplate local buckling from occurring before yielding in compression
- Composite action requirement to:
  - Develop the yield strength of the steel faceplate in less than $3t_{sc}$
  - Prevent interfacial shear failure before out-of-plane shear failure
- System integrity requirement to prevent section delamination through plain concrete

SC Behavior Requirements (Contd.)

- For faceplates with holes, the effective rupture strength shall be greater than the yield strength
- In case of dissimilar faceplate thicknesses or yield stresses:

$$\frac{\text{larger yield strength}}{\text{smaller yield strength}} \leq 1.33$$

SC Behavior Requirements (reasoning)

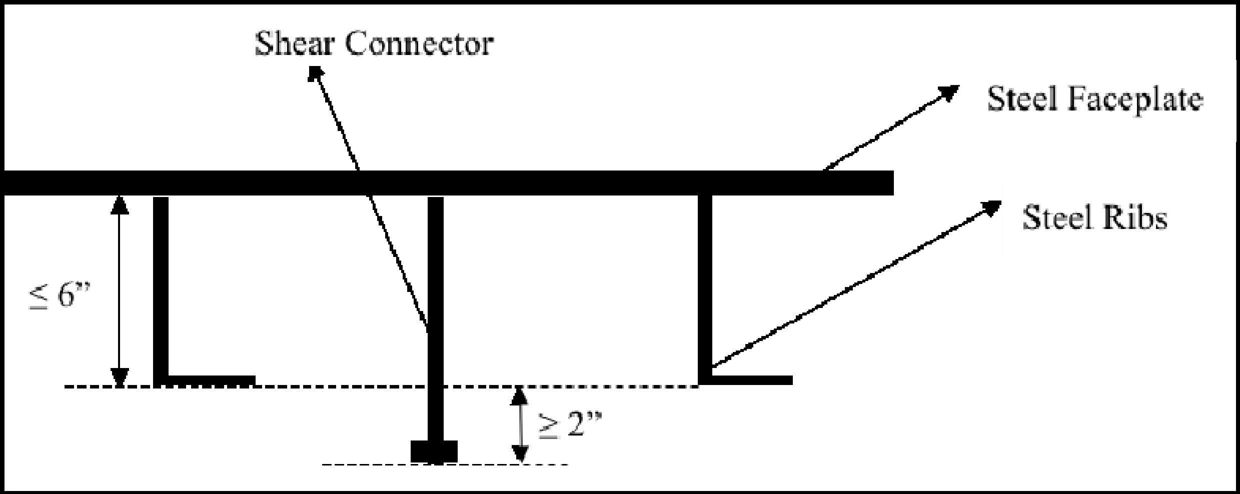
- Rupture strength greater than yield strength ensures gross yielding of faceplates governs over net section rupture

- Limiting value for ratio of yield strengths of faceplates placed as lack of uniformity exacerbates the potential for section delamination through the plain concrete.

CONTD.

STEEL RIBS

- When used, steel ribs shall be
  - Embedded into concrete as shown



  - Welded to the steel plates, and anchored in the concrete to develop 100% of their nominal yield strength.

Steel Ribs (Reasoning)

- Steel ribs may be used to:
  - Increase the stiffness and strength of the empty modules
  - Improve the resistance of the steel faceplates to hydrostatic pressure from concrete casting
  - Help prevent local buckling of steel faceplates after concrete hardening
- Embedment of steel ribs is limited to:
  - Prevent larger depth steel ribs from altering the mechanics of SC wall behavior
  - Minimize the interference of ribs on the performance of the other shear connectors

SPLICES

- Splices between faceplates shall be either
  - Welded using complete joint penetration groove welds

    Or

  - Bolted to develop the yield strength of the weaker of the two (spliced) faceplates

REASONING

- Detailing ensures that the gross section yielding limit state governs

SC Walls not meeting Requirements

- Design using alternate methods based on
  - Project-specific large-scale test data
  - Results of nonlinear inelastic analyses conducted using benchmarked and peer-reviewed modeling approaches

- Design in accordance with ACI 349, provided
  - Faceplate functions as formwork
  - Conventional rebar is provided to develop adequate section strength for demands
  - Faceplate design is similar to the design of liner plates in concrete containment structures according to ACI 359

Module 2: Analysis Requirements

Parameters for modeling, analysis and determining design demands

By,
Amit H. Varma

University

OUTLINE

Design Basis

- SC Wall Regions
- Required Strength
- Design for Stability

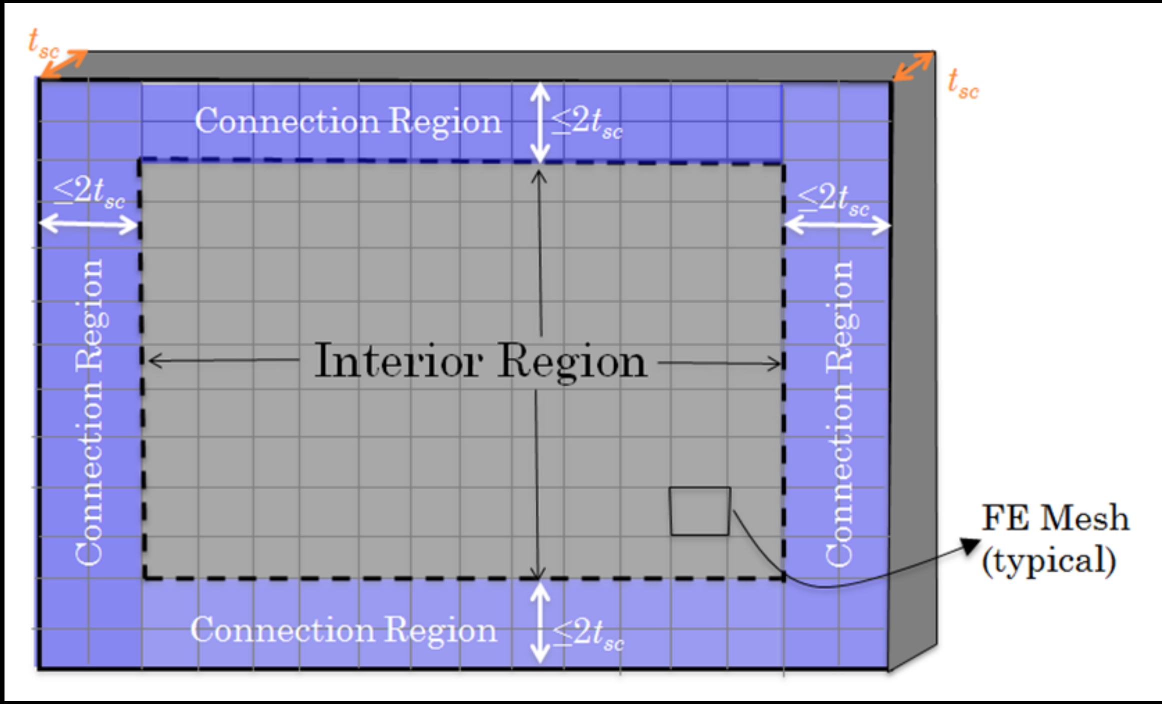
- Required Strengths
  - Aggregating
  - Design Demand Types

Modeling Parameters

- General Provisions
- Design Around Openings
- Effective stiffness
- Accidental thermal loading
- Material properties

N9.1.2. SC Wall Regions

- For Design purposes, division of SC walls into interior and connection regions



SC Wall Regions (Contd.)

- Force transfer between SC walls, and composite action between steel faceplates and concrete develops over connection regions
- The requirement for connection region expanse based on l_d of #11- #18 bars
- Shorter connection regions can be impractical and lead to detrimental congestion of shear connectors and tie bars

N9.1.2a: Required Strength

- Determined by conducting linear-elastic finite element (LEFE) analyses for the applicable load combinations.

- Recommendations for developing LEFE models given in Sections N9.2.1 to N9.2.4 (discussed later)

- Seismic analysis conducted in two steps:
  - dynamic soil structure interaction (SSI) analyses
  - subsequent equivalent static or dynamic analyses of the structure only

N9.1.2b: Design for Stability

- If Section 10.10.1 (ACI 349) applies, second-order analysis not required
- Else use first-order analysis method of AISC 360 Appendix 7.3
- If limitations for App. 7.3 not met, use AISC 360 Appendix 8

- Second-order analysis generally not required for SC walls in safety-related nuclear facilities

MODELING PARAMETERS

General Provisions, Design Around Openings, Effective stiffness, Accidental thermal loading, Material properties

N9.2.1 General Provisions

- Elastic, three-dimensional, thick-shell or solid finite elements shall be used
- Regions around section penetrations larger than half the section thicknesses shall be modeled with appropriately refined mesh
- Viscous damping ratio for SSE analysis ≤ 5% for analysis

GENERAL PROVISIONS (REASONING)

- Viscous damping ratios are based on 1/10th scale tests of the entire containment internal structure (CIS) (Akiyama et al., 1989).

- Recommendations for finite elements:
  - Based on ASCE 4-98
  - Element size,
    - ≤ $2t_{sc}$ in interior region
    - ≤ t_{sc} for connection regions and around section penetrations
  - Because design capacity equations do not apply to whole walls

N9.1.7 Requirements around Openings

- N9.1.7a. Small Opening: openings with largest dimension not greater than half the section thickness. Need not be modeled.

- For large opening detailed as:
  - Free edge: as-modeled opening shall be larger than physical opening, extending to where the faceplates are fully developed

  - Fully developed edge: openings shall be modeled and designed considering the physical boundary

N9.2.2A Effective Flexural Stiffness

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

where

c_2	=	0.48 ρ'+ 0.10
ρ'	=	ρn
	=	stiffness adjusted reinforcement ratio
E_s	=	elastic modulus of the steel faceplates
	=	29,000 ksi (200,000 MPa)
I_s	=	moment of inertia of the fully cracked section
	=	$12[t_p(t_{sc}-t_p)^2/2]$, in^4/ft $[1000(t_p(t_{sc}-t_p)^2/2)$, $mm^4/m]$
t_{sc}	=	section thickness of SC wall, in. (mm)
ρ	=	reinforcement ratio
	=	$2t_p/t_{sc}$

Effective Flexural Stiffness (Contd.)

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

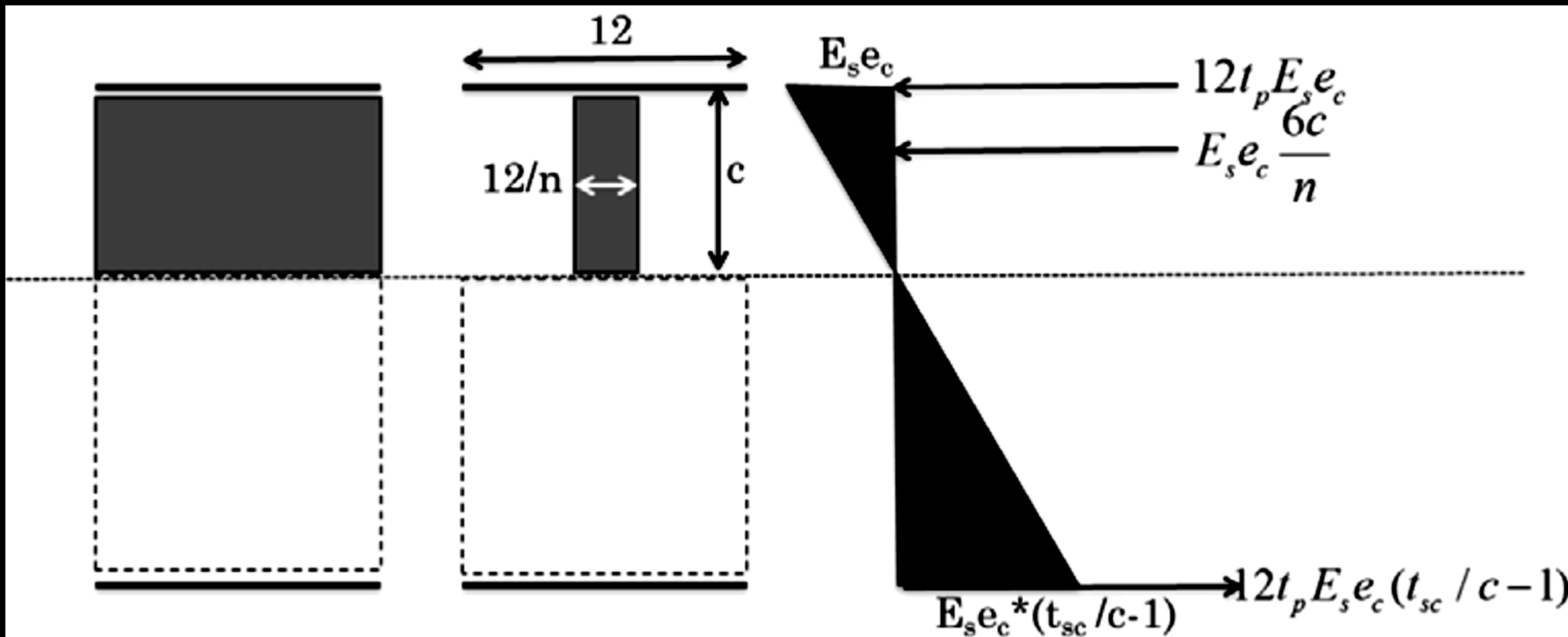
n	=	modular ratio of steel and concrete
	=	E_s/E_c
E_c	=	elastic modulus of concrete, ACI 349 Section 8.5.1, ksi (MPa)
I_c	=	moment of inertia of concrete
	=	$12\,(t_c^3/12)$, in.^{4}/ft ($1000t_c^3/12$, mm^4/m)
ΔT_{savg}	=	average maximum temperature increase for steel faceplates due to accidental thermal conditions, °F (°C)

Effective Flexural Stiffness (Reasoning)

- Uncracked composite flexural stiffness generally not manifest due to:
  - Locked-in shrinkage strains in the concrete core
  - Partial composite action of the section
  - Reduced bond parameter due to discrete stud locations.

Effective Flexural Stiffness (Reasoning)

- Cracked-transformed flexural section stiffness ($EI_{cr\text{-}tr}$):



Resulting equation is:

$$(EI)_{cr\text{-}tr} = E_s \left\{ 12 t_p t_{sc}^{2} \left[1 + 2\left(\frac{c}{t_{sc}}\right)^2 - 2\frac{c}{t_{sc}} - \frac{t_p}{t_{sc}} \right] + \frac{4 t_{sc}^{3}}{n} \left(\frac{c - t_p}{t_{sc}} \right)^3 \right\}$$

With: $\frac{c}{T} = \sqrt{\rho'^2 + \rho'} - \rho'$ and $\rho' = \frac{2t_p}{t_{sc}} \frac{E_s}{E_c}$

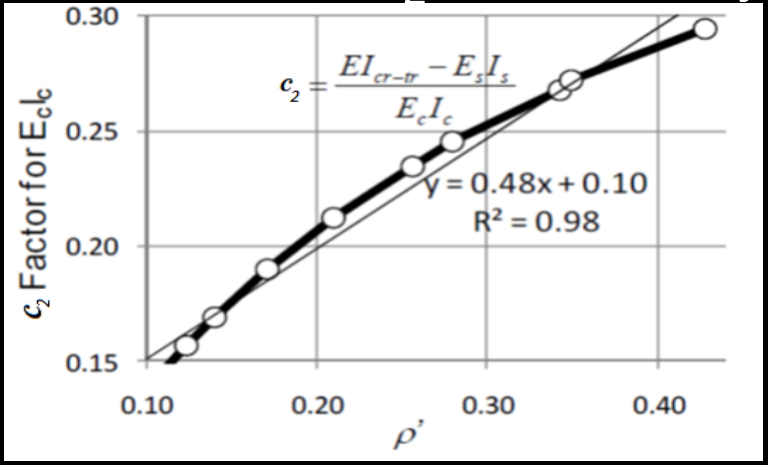
EFFECTIVE FLEXURAL STIFFNESS (REASONING)

- Simplified version of $EI_{cr\text{-}tr}$:

$$EI_{cr\text{-}tr} = E_sI_s + c_2\, E_cI_c$$

Where, $c_2 = 0.48\,\rho' + 0.10$

- Stiffness reduction factor, c_2 numerically calibrated:



- Effective flexural stiffness is proposed for combined concrete cracking and thermal effects:

$$EI_{eff} = E_sI_s + \left(\alpha E_cI_c\right)\left(1 - \frac{\Delta T_s}{150F}\right) \geq E_sI_s$$

EFFECTIVE FLEXURAL STIFFNESS (REASONING)

- Recommendation accounts for the potential cracking of the concrete due to the accidental thermal gradient through the composite section

- ΔT≥ 150° F on the steel faceplates will result in through section concrete cracking, i.e., the flexural stiffness will be equal to that of the steel, E_sI_s, alone

- For 0° F ≤ ΔT ≤ 150 ° F, the cracked-transformed flexural stiffness is linearly reduced till it equals the steel section stiffness, E_sI_s

N9.2.2B EFFECTIVE IN-PLANE SHEAR STIFFNESS

- Effective in-plane shear stiffness, GA_{eff}, for all load combinations that do not involve accidental thermal loading shall be based on the required membrane in-plane shear strength per unit width, S_{rxy}, in the panel sections

N9.2.2b Effective In-Plane Shear Stiffness (Contd.)

- (1) If S_{rxy} does not exceed the concrete cracking threshold, S_{cr}, GA_{eff} shall be equal to the shear stiffness of the uncracked transformed composite section GA_{uncr}.

N9.2.2b Effective In-Plane Shear Stiffness (Contd.)

where

$$S_{cr} = \frac{0.002\sqrt{f'_c}}{G_c} GA_{uncr} \qquad \text{(A-N9-6)}$$

$$S_{cr} = \frac{0.166\sqrt{f'_c}}{G_c} GA_{uncr} \qquad \text{(S.I.)} \qquad \text{(A-N9-6M)}$$

and

$$GA_{eff} = GA_{uncr}$$
$$= GA_s + G_cA_c \qquad \text{(A-N9-7)}$$

A_s = gross area of steel faceplates
= $12(2t_p)$, in.^{2}/ft [$1000(2t_p)$, mm^2/m]

G = shear modulus of steel plates
= 11,200 ksi (77 200 MPa)

G_c = shear modulus of concrete
= $24.4\sqrt{f'_c}$, ksi ($2023\sqrt{f'_c}$, MPa)

A_c = area of concrete
= $12t_c$, in.^{2}/ft ($1000t_c$, mm^2/m)

N9.2.2B Effective In-Plane Shear Stiffness (Contd.)

- If S_{rxy} exceeds the cracking threshold S_{cr}, but is not greater than two times S_{cr}, then GA_{eff} shall account for the effects of concrete shear cracking as follows

.

$$GA_{eff} = GA_{uncr} - \frac{GA_{uncr} - GA_{cr}}{S_{cr}}\left(S_{rxy} - S_{cr}\right) \quad \text{(A-N9-8)}$$

where

$$GA_{cr} = 0.5\overline{\rho}^{-0.42} GA_s \quad \text{(A-N9-9)}$$

$\overline{\rho}$ = strength-adjusted reinforcement ratio

$$\overline{\rho} = \frac{A_s F_y}{A_c\sqrt{f'_c}} \quad \text{(A-N9-10)}$$

- (3) If S_{rxy} exceeds two times S_{cr}, then the effective in-plane shear stiffness, GA_{eff}, of SC walls shall be equal to GA_{cr} calculated using Equation A-N9-9.

N9.2.2b Effective In-Plane Shear Stiffness (Contd.)

- The in-plane shear stiffness, GA_{eff}, for all loading combinations involving accident thermal conditions shall account for the effects of concrete cracking using Equation A-N9-9

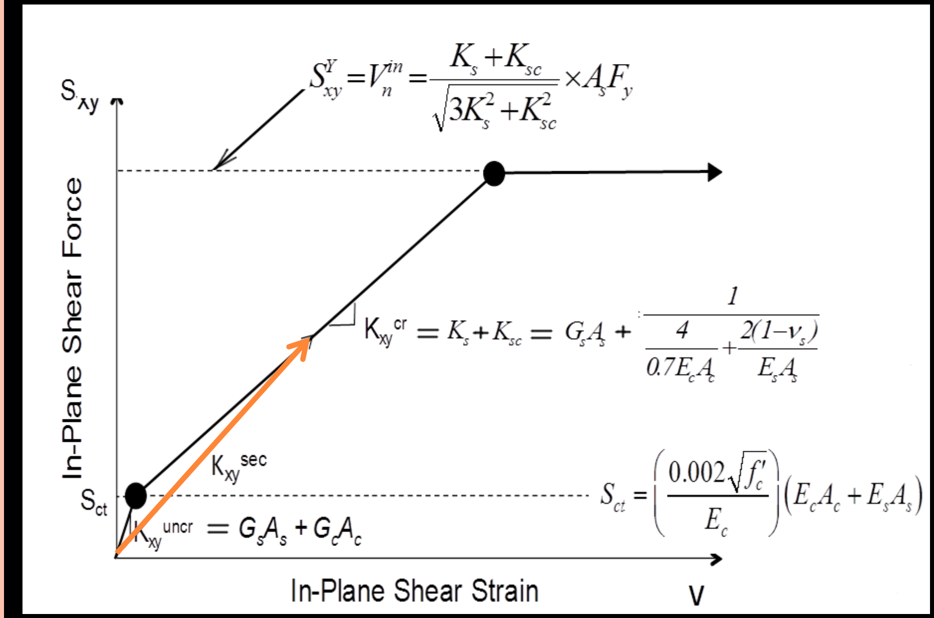
- i.e., $GA_{eff} = GA_{cr}$, irrespective of the corresponding required membrane in-plane shear strength per unit width (S_{rxy} in Section N9.2.5).

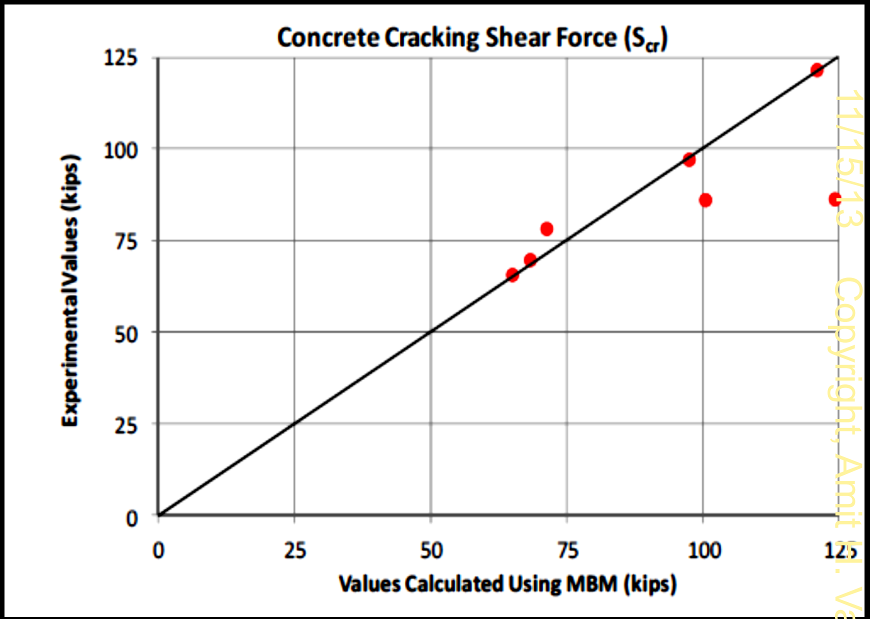
Effective In-Plane Shear Stiffness (Reasoning)

- In-plane shear behavior of SC walls is governed by:
  - plane-stress behavior of the steel faceplates
  - orthotropic cracked behavior of the concrete infill

- Ozaki et al. (2004) and Varma et al. (2011) developed a tri-linear mechanics based model (MBM)
- Tri-linear model:
  1. Uncracked composite stiffness (K_{xy}^{uncr})
  2. Tangent stiffness, composite, cracked concrete (K_{xy}^{cr})
  3. Von Mises yielding of steel plates (S_{xy}^{Y})

Effective In-Plane Shear Stiffness (Reasoning)

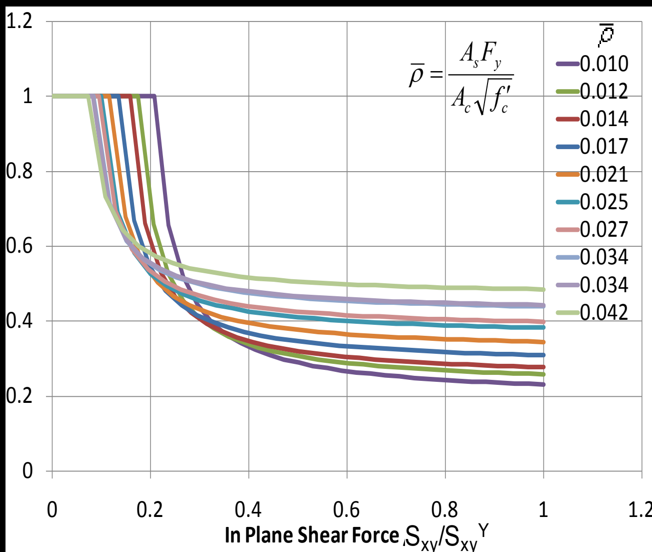




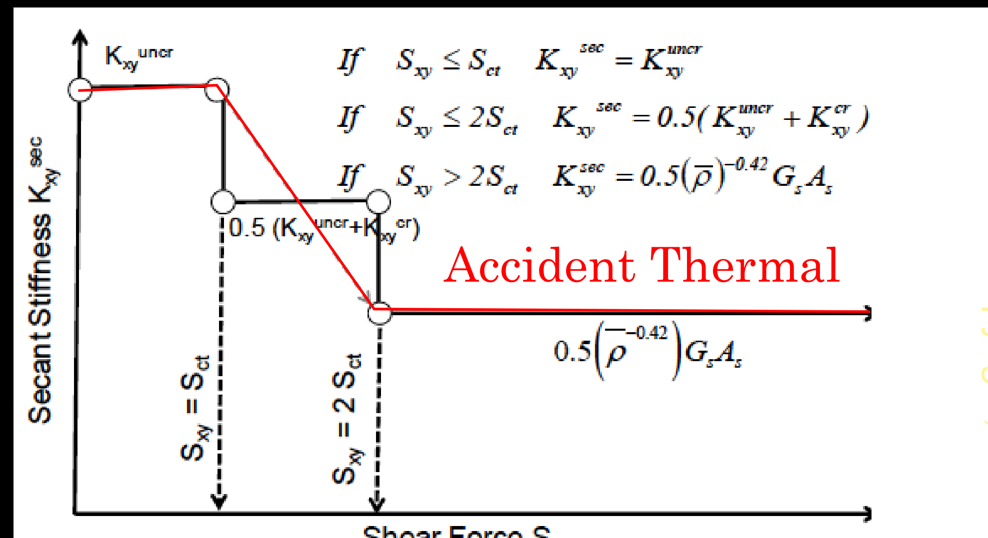
However, under seismic loading the cyclic behavior of SC walls is governed by secant stiffness, and not tangent stiffness.

Effective In-Plane Shear Stiffness (Reasoning)

Secant stiffness for cyclic loading:



Secant stiffness of SC walls



3 Step Secant Stiffness Model

$\overline{\rho}$ is strength normalized reinforcement ratio calculated as $A_s F_y / A_c (f'_c)^{0.5}$

- Good prediction for:
  - Reinforcement ratios of 1.5% - 5%,
  - Concrete f'_c from 4000 psi - 6000 psi
  - Steel F_y from 50 ksi to 65 ksi

Effective In-Plane Shear Stiffness (Reasoning)

- Nonlinear thermal gradients develop through the concrete section due to the accidental thermal loading.

- This gradient induces concrete cracking in two orthogonal directions due to the expansion of steel faceplates and the low cracking threshold of the concrete.

- These orthogonal cracks due to thermal loading do not reduce the in-plane shear strength of SC wall panels significantly.

N9.2.4. Accident Thermal Loading

PURDUE UNIVERSITY

- Analyses for load combinations involving accidental thermal conditions shall include heat transfer analyses.
- Heat transfer analysis will yield:
  - Temperature histories
  - Through-thickness temperature profiles
- Results of heat transfer analyses used to define thermal loading for structural analyses
- Required out-of-plane flexural strength due to thermal gradients need not exceed $M_{r\text{-}th}$

N9.2.4. Accident Thermal Loading (Contd.)

$$M_{r\text{-}th} = (EI)'\left(\frac{\alpha_s \Delta T_{sg}}{t_{sc}}\right) \quad \text{(A-N9-11)}$$

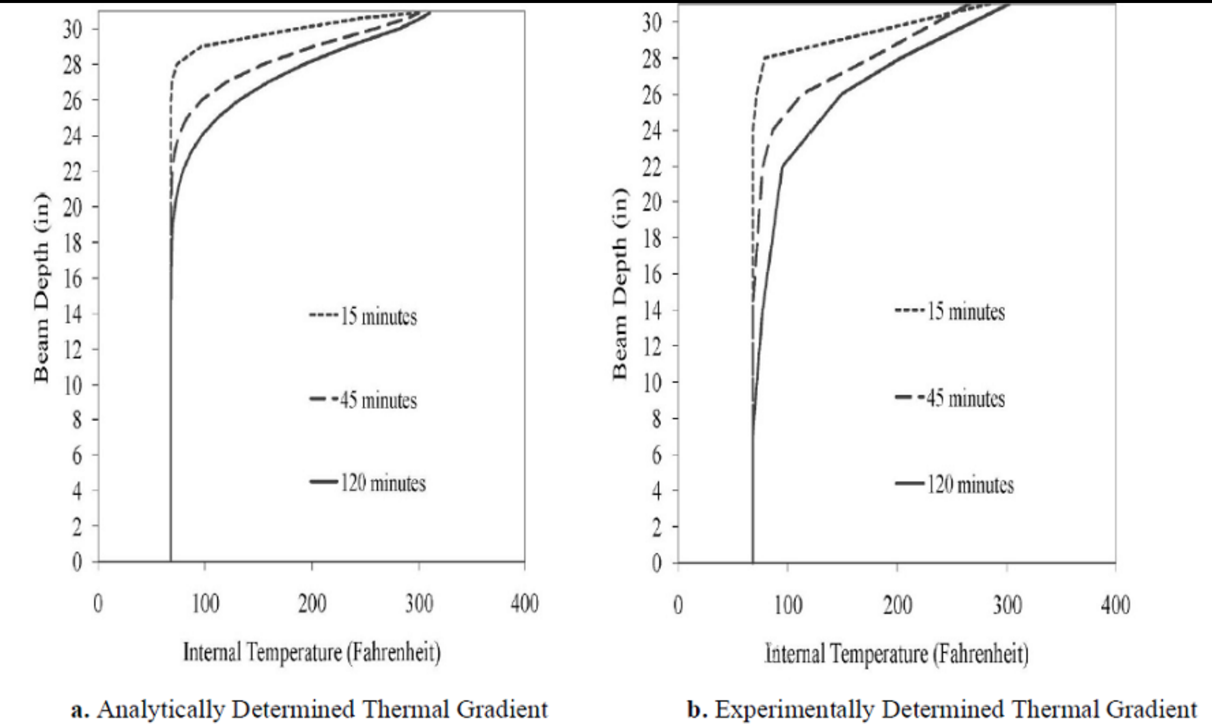
where

α_s = thermal expansion coefficient of steel faceplate in °F^{-1} (°C^{-1})

ΔT_{sg} = maximum temperature difference in °F (°C) between steel faceplates due to accidental thermal conditions

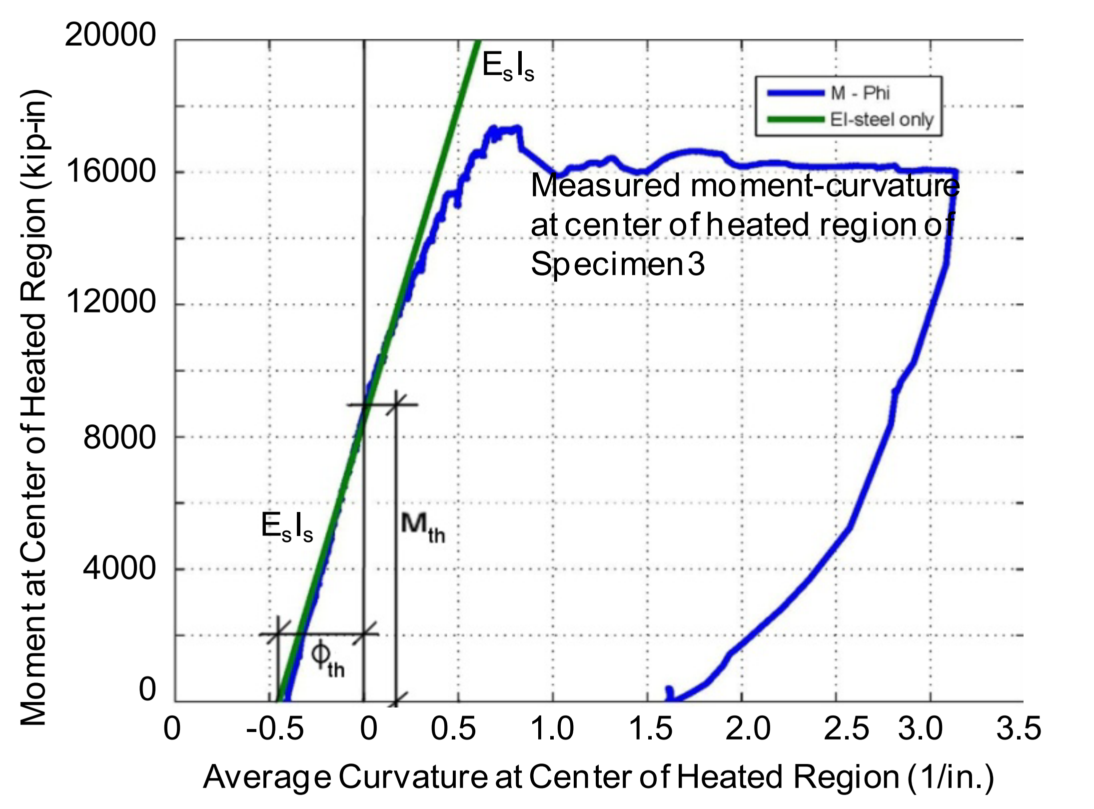
ACCIDENTAL THERMAL LOADING (REASONING)

- Booth et al. (2007) and Varma et al.(2009) observed that on applying accidental thermal loads, a nonlinear thermal gradient develops across the concrete cross section, causing the concrete to crack in tension



ACCIDENTAL THERMAL LOADING (REASONING)

- This gradient shifts the *M*- ϕ response to left with nonzero thermal curvature, ϕ_{th}, at zero moment and nonzero thermal moment, M_{th}, at zero curvature.



Accidental Thermal Loading (Reasoning)

- The stiffness of the SC wall subjected to heating (to 300 ° F) can thus be predicted using fully cracked (steel only) section properties.
- The equations in the specification are based on the above observations.
- These equations do not apply at supports that may be fully restrained from expansion.

N9.2.3. Material Properties

- (a) Poisson ratio, ν_m, thermal expansion coefficient, α_m, and thermal conductivity, k_m, shall be taken as that for the concrete.
- (b) Section thickness, t_m, and the material elastic modulus, E_m, shall be established through calibration to match the effective stiffness values, $(EI)'$ and GA_{eff} defined in Section N9.2.2.
- (c) Density, γ_m, shall be established through calibration after establishing the model section thickness, t_m, to match the mass of the SC section.
- (d) Specific heat, c_m, shall be established through calibration after establishing density so that the model specific heat equals the specific heat of the concrete infill.

N9.2.3. Material Properties (Reasoning)

- ν_m, α_m and k_m of the material are matched to concrete because these will govern the thermally induced displacements of the structure.
- Calibration of thickness and elastic modulus to match model stiffness to those of physical SC wall section
- Calibration of material density to match the mass of the model with that of the physical section.
- Calibration of specific heats to allow transient heat transfer analysis to be accurately conducted using single material LEFE model.

N9.2.5. Required Strength Determination

In-plane membrane forces, out-of-plane moments, and out-of-plane shear forces shall be determined by the LEFE analysis

PURDUE UNIVERSITY

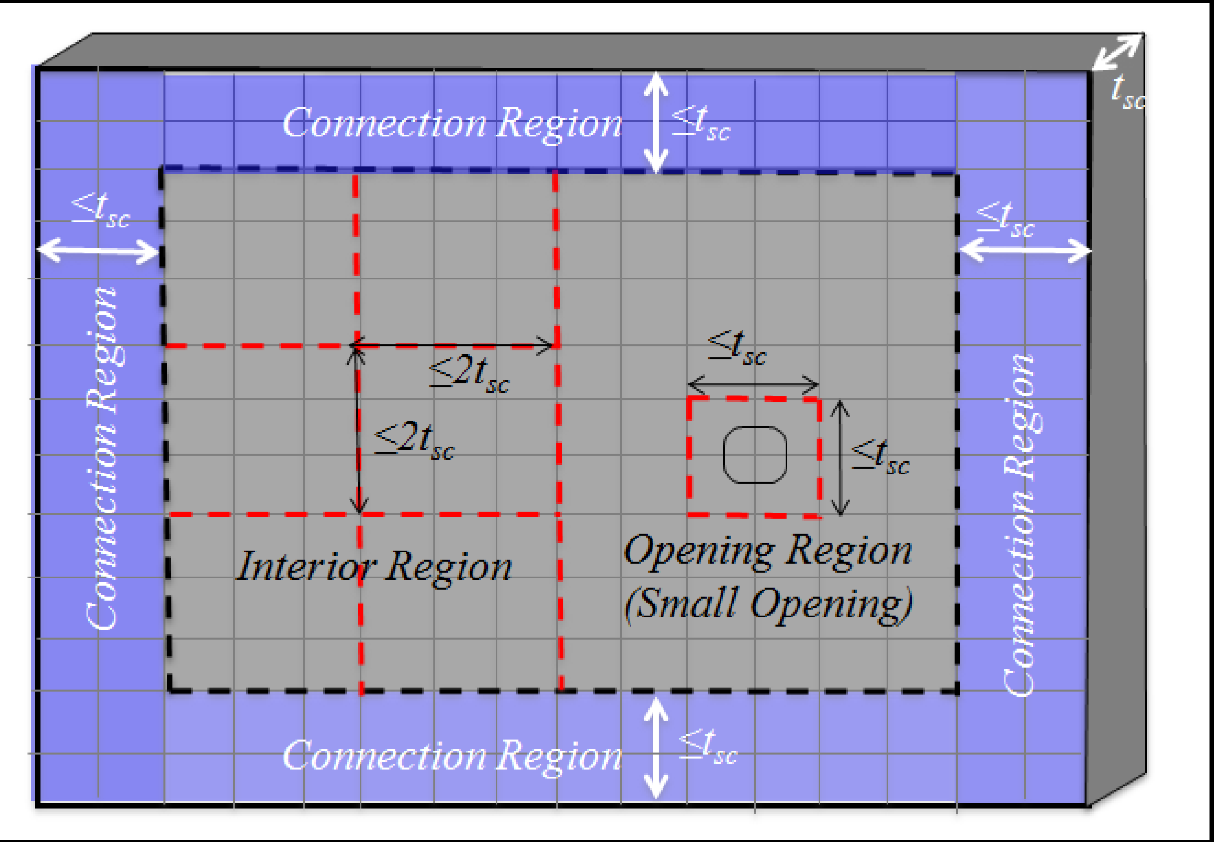
AGGREGATING OF DEMANDS

- Required strength for each design type shall be aggregated over panel sections ≤ $2t_{sc}$ each dimension
- For connection regions and regions around openings, the strength aggregate shall be calculated over panel sections ≤ t_{sc} each dimension

REASONING

- The aggregation of required strengths is done over the chosen panel section sizes because they represent reasonable but not extensive yielding (first onset of significant inelastic deformation at SSE).

AGGREGATING OF DEMANDS (CONTD.)



Required Strength for Each Demand Type

S_{rx} = required membrane axial strength per unit width in direction x, kip/ft (N/m)

S_{ry} = required membrane axial strength per unit width in direction y, kip/ft (N/m)

S_{rxy} = required membrane in-plane shear strength per unit width, kip/ft (N/m)

M_{rx} = required out-of-plane flexural strength in direction x, kip-in./ft (N-mm/m)

M_{ry} = required out-of-plane flexural strength in direction y, kip-in./ft (N-mm/m)

M_{rxy} = required twisting moment strength per unit width, kip-in./ft (N-mm/m)

V_{rx} = required out-of-plane shear strength per unit width along edge parallel to direction y, kip/ft (N/m)

V_{ry} = required out-of-plane shear strength per unit width along edge parallel to direction x, kip/ft (N/m)

x, y = local coordinate axes associated with the finite element model

Module 3

Shear Connectors

Local buckling and composite action

By,

Amit H. Varma

Purdue University

OUTLINE

- Purpose
- Classification
- Compactness
- Spacing Design

SHEAR CONNECTORS:PURPOSE

- Composite action shall be provided between steel faceplates and concrete using shear connectors.
- Shear connectors are used to transfer the shear at the steel-concrete interface. They are designed to:
  - develop yield strength of the steel faceplates
  - prevent interfacial shear failure
- Design according to N9.1.3 and N9.1.4

SHEAR CONNECTORS: CLASSIFICATION

- ***Yielding* shear** connectors
  - Sh…
    in. …
    the…
  - Q_{cv}…
- ***Non-y***…
  - Sh…
  - Q_{c}…

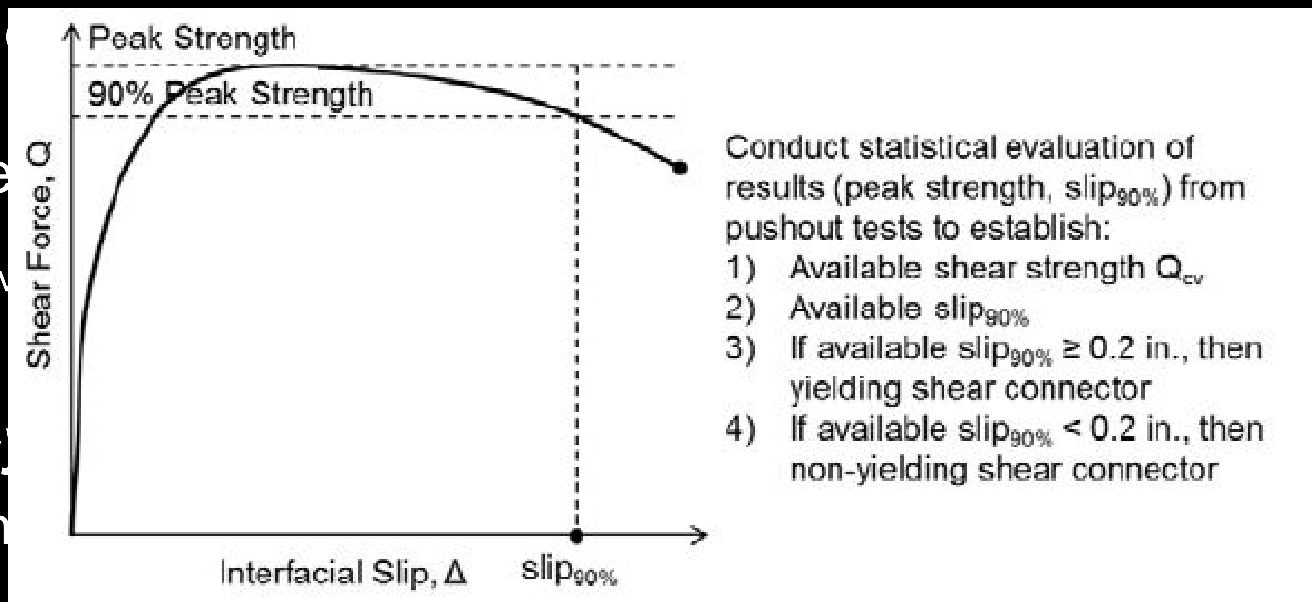


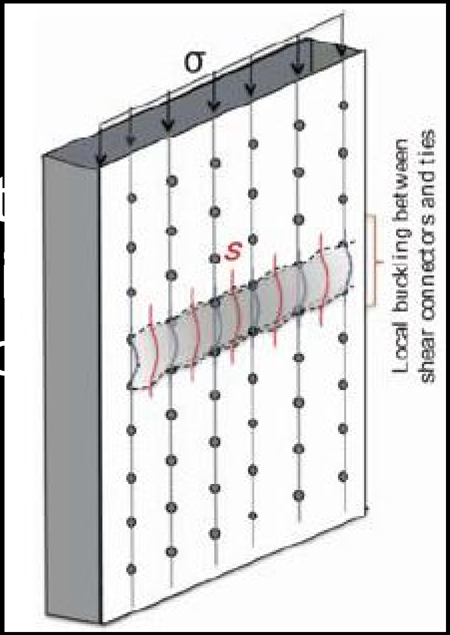
Fig. C-A-N9.1.6. Typical shear connector force-slip behavior from pushout test.

SHEAR CONNECTORS: COMPACTNESS

- N9.1.3: The width-to-thickness ratio of the steel faceplates shall not exceed:

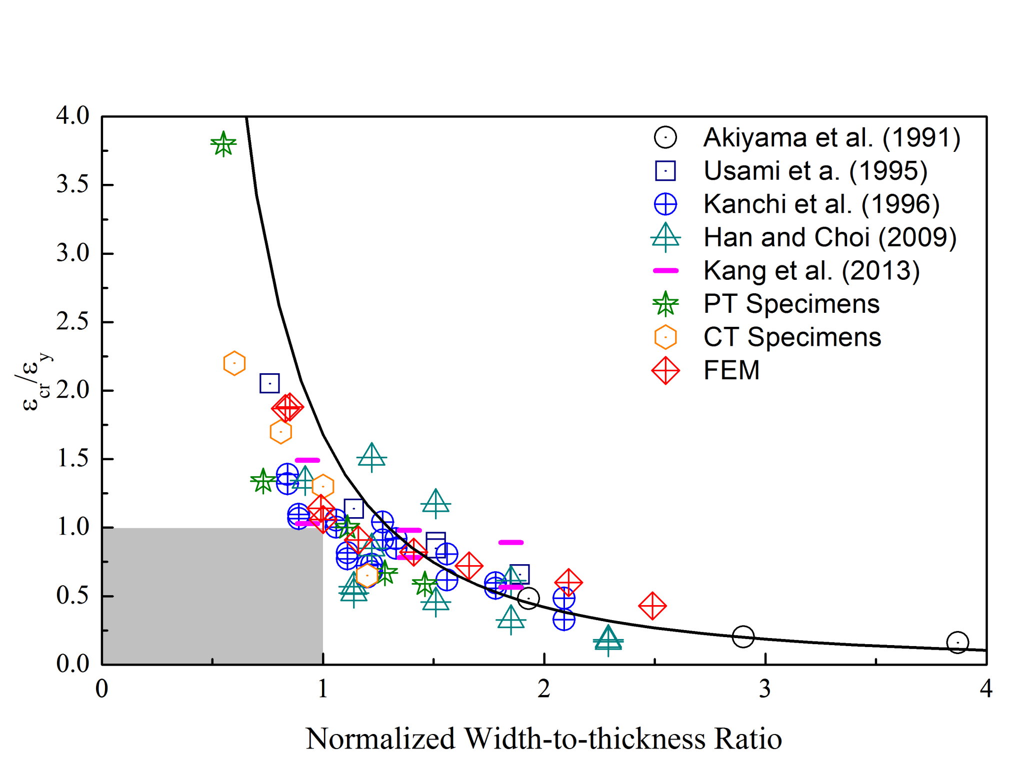
$$\lambda_p = 1.0\sqrt{\frac{E_s}{F_y}}$$

- This detailing requirement prevent buckling, which is a SC specific limi occurring before yielding in compressio



SHEAR CONNECTORS: COMPACTNESS

- Experimental and analytical investigations show no data point in the shadowed region, implying yielding occurs before local buckling for a normalized width-to-thickness ratio less than 1.0



SHEAR CONNECTORS: SPACING DESIGN

- N9.1.4: Shear connectors shall be spaced not to exceed the spacing required to develop the yield strength of the steel faceplates over development length.

$$s \le c_1 \sqrt{\frac{Q_{cv} L_d}{T_p}}$$

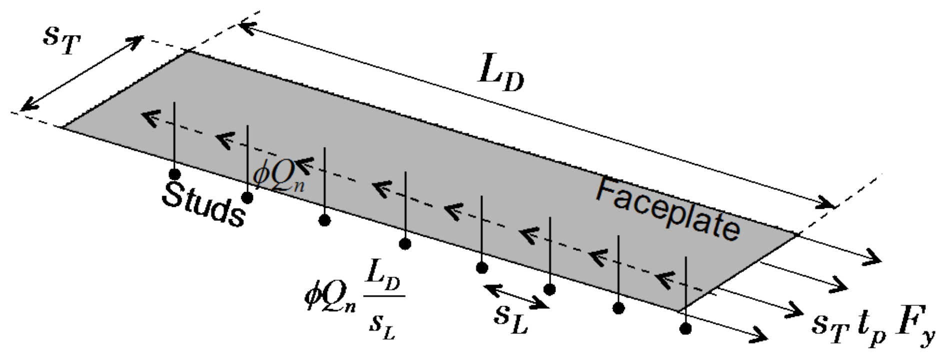
- N9.1.4: Shear connectors shall be spaced not to exceed the spacing required to prevent interfacial shear failure before out-of-plane shear failure of the SC section.

$$s \le c_1 \sqrt{\frac{12 Q_{cv}}{V_c / (0.9 t_{sc})}}$$

SHEAR CONNECTORS: SPACING DESIGN

- Development length (L_d) is the length over which the steel faceplate can develop its yield strength in axial tension. It is similar to rebar development length in RC structures.

- The development length (L_d) should be designed to be approximately two to three times the wall thickness (t_{sc}).



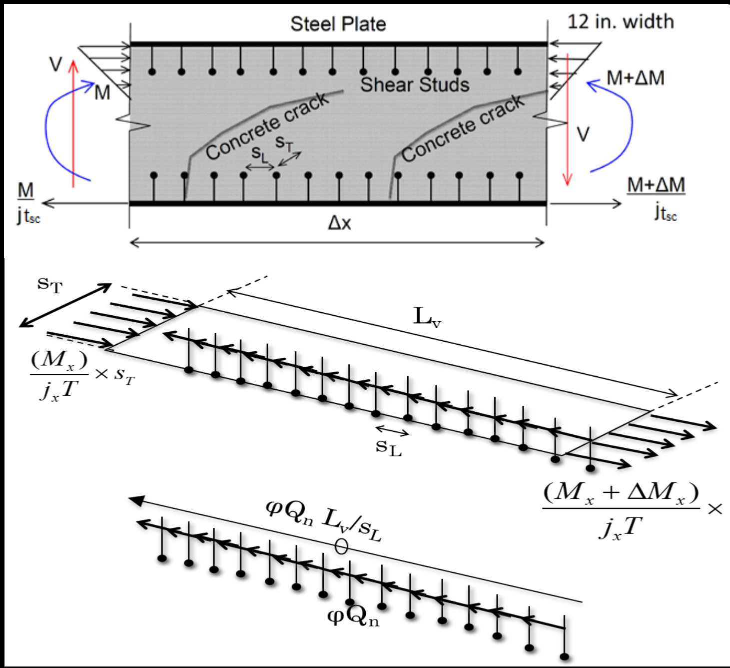
$$\phi Q_n \frac{L_d}{s_L} \geq s_T t_p F_y$$

$$\therefore \frac{\phi Q_n L_d}{t_p F_y} \geq s_T s_L$$

$$\therefore s \leq \sqrt{\frac{\phi Q_n L_d}{t_p F_y}}$$

Shear Connectors: Spacing Design

- The interfacial shear strength of SC walls is specified to be greater than the corresponding out-of-plane shear strength of SC walls. This prevents interfacial shear failure from governing the behavior and failure mode.



$$\phi Q_n \frac{L_v}{s_L} \geq \frac{\Delta M_x}{j_x t_{sc}} s_T$$

$$\therefore s_T s_L \leq \phi Q_n \left(\frac{L_v}{\Delta M_x} \right) j_x t_{sc}$$

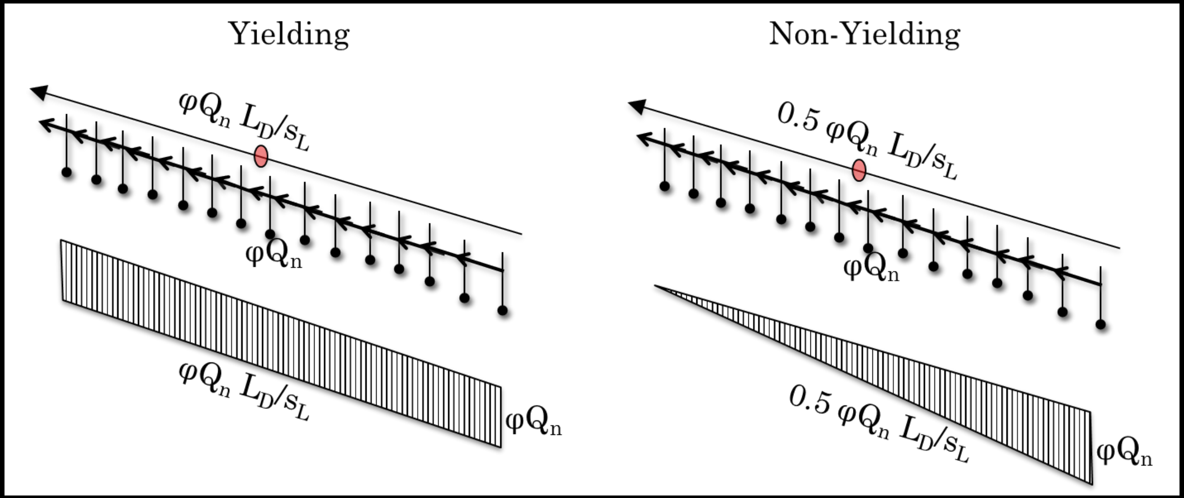
$$\therefore s \leq \sqrt{\frac{\phi Q_n (j_x t_{sc})}{V_{no}}}$$

Substituting;

$$\frac{\Delta M_x}{L_v} = V \leq V_{no}$$

Shear Connectors: Spacing Design

- For non-yielding shear connectors, the resistance is not divided equally to all connectors. Instead, a triangular distribution is assumed with the maximum value for the first (or last) connector. It results in the changes in the spacing requirements for non-yielding shear connectors, i.e. the c_1 value.



Module 4:

Design of Ties

Out-of-Plane Shear Design

Interaction

By,

Amit H. Varma

University

OUTLINE

- Purpose and Classification
- Development Length and Transfer Length
- Tie Spacing requirements
- Contribution to out-of-plane strength
- Minimum required tensile strength of ties
- Out-of-Plane Shear Strength
- Interaction of out-of-plane and interfacial shear

Ties: Purpose

- N9.1.5: The opposite steel faceplates of SC walls shall be connected to each other using ties.
- While the shear connectors ensure composite behavior of SC walls, the ties primarily provide structural integrity.
- Tie serve a dual purpose: provide structural integrity by preventing section splitting and delamination; serve as out-of-plane shear reinforcement.

TIES: PURPOSE

PURDUE UNIVERSITY

- Ties may participate in force transfer in connection region of SC walls.
- Ties provide sufficient capacity and redundancy within the structure to allow for redistribution of forces due to internal steam pressure.
- In extreme localized cases (such as fire), the presence of ties prevents the spread of steel faceplate damage to unaffected regions of the wall.

Ties: Classification

- Yielding shear reinforcement: ties governed by the limit state of tension yielding.

- Non-yielding shear reinforcement: ties governed by the limit state of tensile rupture or available strength of associated connections.

Ties: Spacing Requirements

- Tie spacing shall not be greater than section thickness, t_{sc}
- Tie spacing design shall satisfy the compactness requirement, achieve development length (L_d) less than or equal to three times the wall thickness, and have transfer length (L_{TR}) less than or equal to three times the wall thickness (t_{sc}).
- The transfer length (L_{TR}) used in the spacing requirement is limited to three times the section thickness in interior regions and two times the section thickness in connection regions.

Ties: Transfer Length

- The transfer length (L_{TR}) is defined as the length required to develop 100% strain compatibility between the steel and the concrete if only one of the portions is loaded at the end.

- The transfer length (L_{TR}) is associated with the stiffness of shear connectors and their ability to develop strain compatibility between steel faceplates and concrete infill, i.e. stiffness-based.

- The development length (L_d) is associated with the shear strength of shear connectors and their ability to develop the yield strength of the steel faceplates, i.e. strength-based.

Ties: Transfer Length

- The transfer length (L_{TR}) are longer than the development length (L_d) for typical SC wall designs.

- However, the effects of having longer transfer lengths are inconsequential because the available strength of SC walls depend on developing the yield strength of the steel faceplates, not strain compatibility.

- The effective stiffness of the composite section depends on strain compatibility. However, the effects of having longer L_{TR} on effective stiffness are marginal (Zhang et al., 2013)

TIES: SPACING REQUIREMENT (AROUND OPENING)

- N9.1.7: The first row of ties around the opening shall be located at distance no greater than one quarter of the SC section thickness (t_{sc}).

- This detailing requirement is provided to help maintain structural integrity against any potential for splitting.

Ties: Required Tension Strength

- N9.1.5b: The minimum required tensile strength for ties is:

$$F_{req} = \left(\frac{t_p F_y t_{sc}}{4}\right)\left(\frac{S_T}{S_L}\right)\left(\frac{6}{2\left(\frac{L_{TR}}{S_L}\right)^2 + 1}\right)$$

where

t_p	=	thickness of steel faceplate, in. (mm)
F_y	=	specified minimum yield stress of steel faceplate, ksi (MPa)
t_{sc}	=	SC wall section thickness, in. (mm)
S_L, S_T	=	spacing of ties in orthogonal directions, in. (mm)
L_{TR}	=	transfer length, the length required to develop 100% strain compatibility between the steel and concrete portions of the composite section if only one of the portions (e.g., concrete or steel) is loaded at the end, in. (mm)

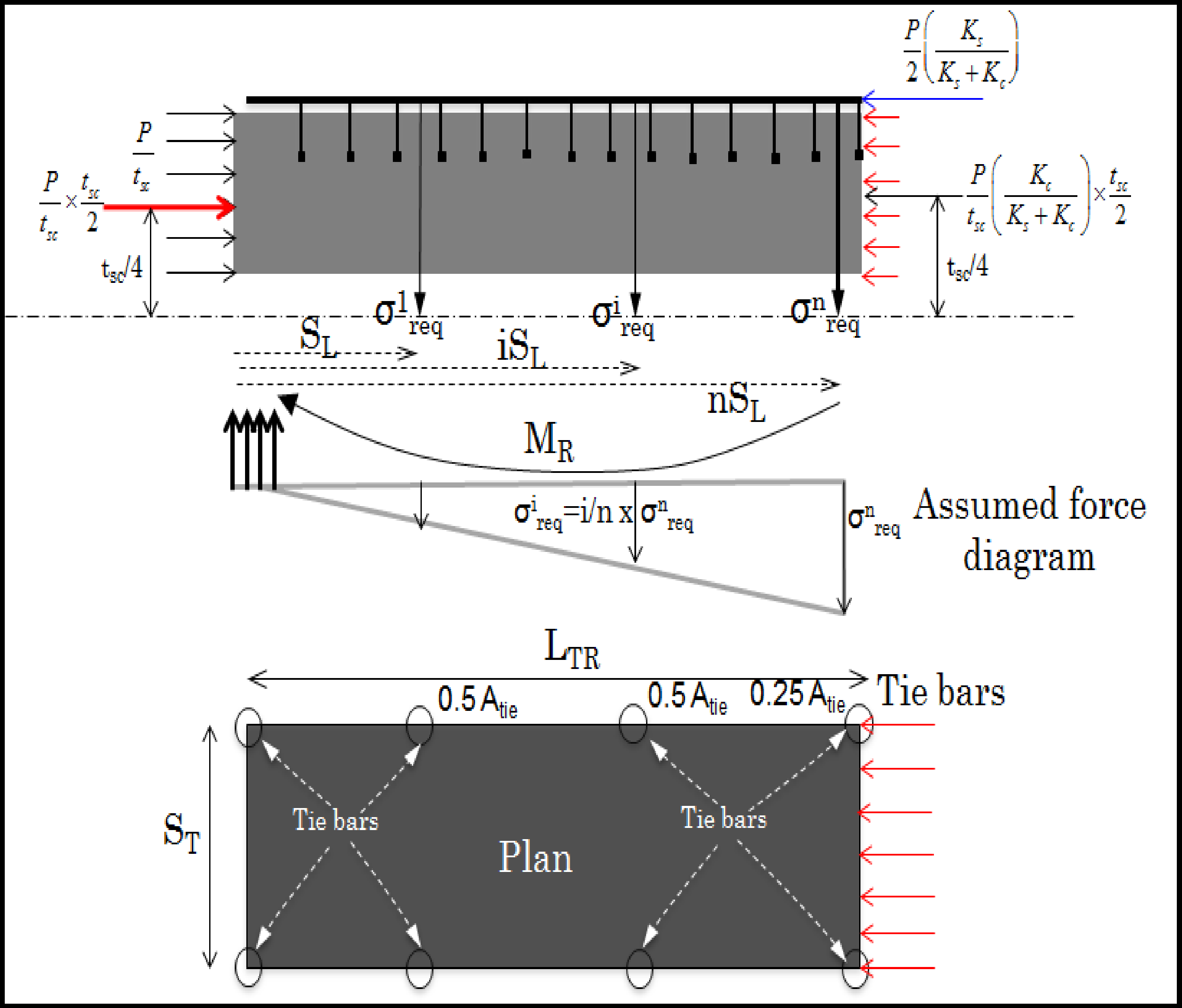
Ties: Required Tension Strength

- Eccentric moment on SC walls may cause splitting failure, which will be resisted by ties.

- Two cases that introduce eccentric moment: when the load is applied to concrete only and the moment is resisted by the composite section; an unbalanced force in the composite section due to different areas and yield strengths of the steel faceplates.

- The required tie strength (F_{req}) is estimated by setting the resisting moment (M_R) greater than or equal to the eccentric moment (M_o). The largest value for the eccentric moment, M_o, is equal to the steel faceplate force.

Ties: Required Tension Strength



Ties: Required Tension Strength

- The required force, F_{req}, is a hypothetical demand that has been posited to evaluate the structural integrity and splitting failure of the section. It is not a real force demand that needs to be deducted from the available capacity of the tie.

- When there is an imbalance in the forces in the thick composite cross section due to different areas and yield strengths of the steel faceplates, the ties have to provide structural integrity and prevent splitting failure.

OUT-OF-PLANE SHEAR STRENGTH

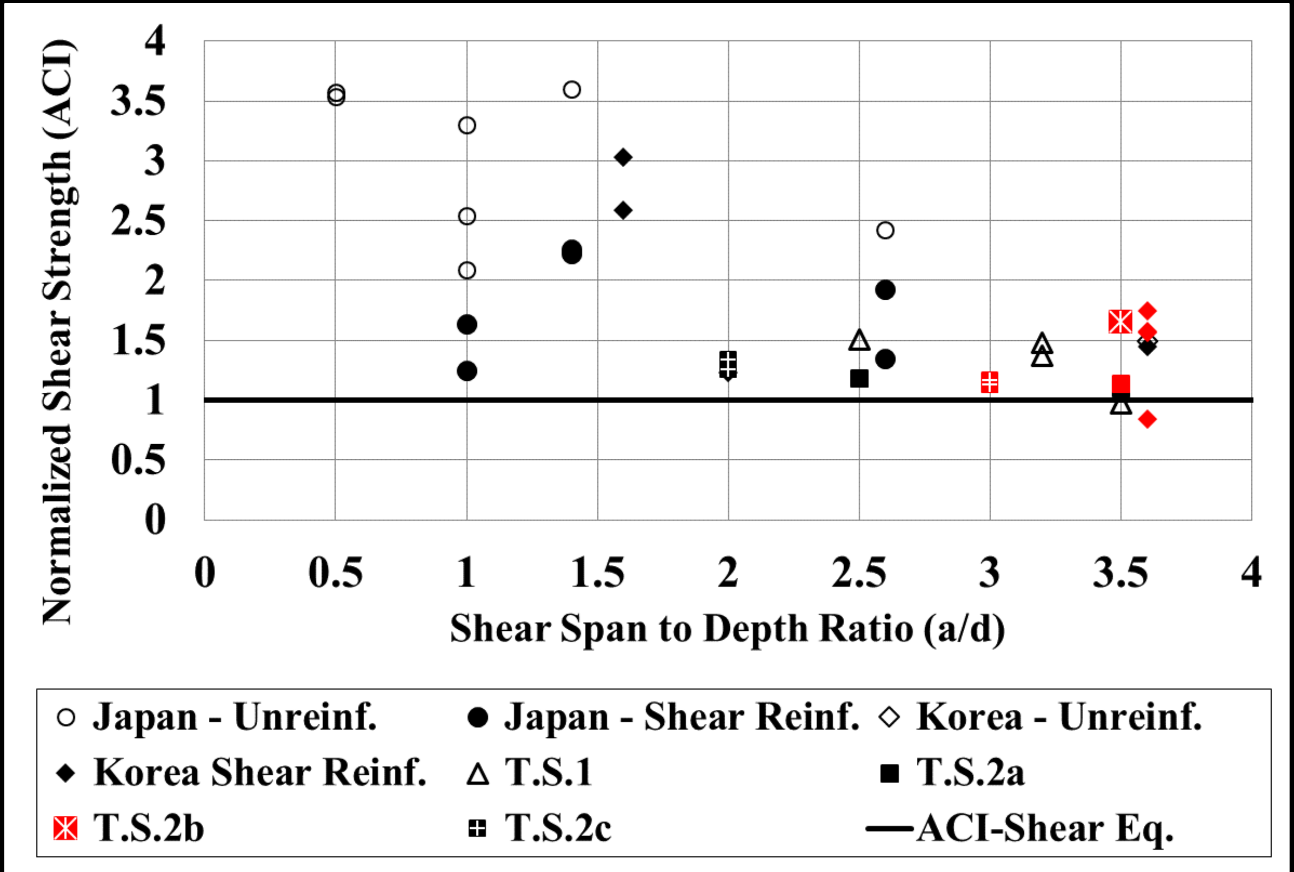
- The out-of-plane shear behavior of SC walls is similar to that of RC walls with some differences associated with crack spacing, width etc. due to the more discrete nature of the bond.

- Researchers in Japan (Ozaki et al., 2001), South Korea (Hong et al., 2009) and the US (Varma et al., 2011) have done extensive experiments to study the out-of-plane shear behavior of SC walls.

- Sener et al. (2013) compared the experimental database with the ACI 349 shear strength equations.

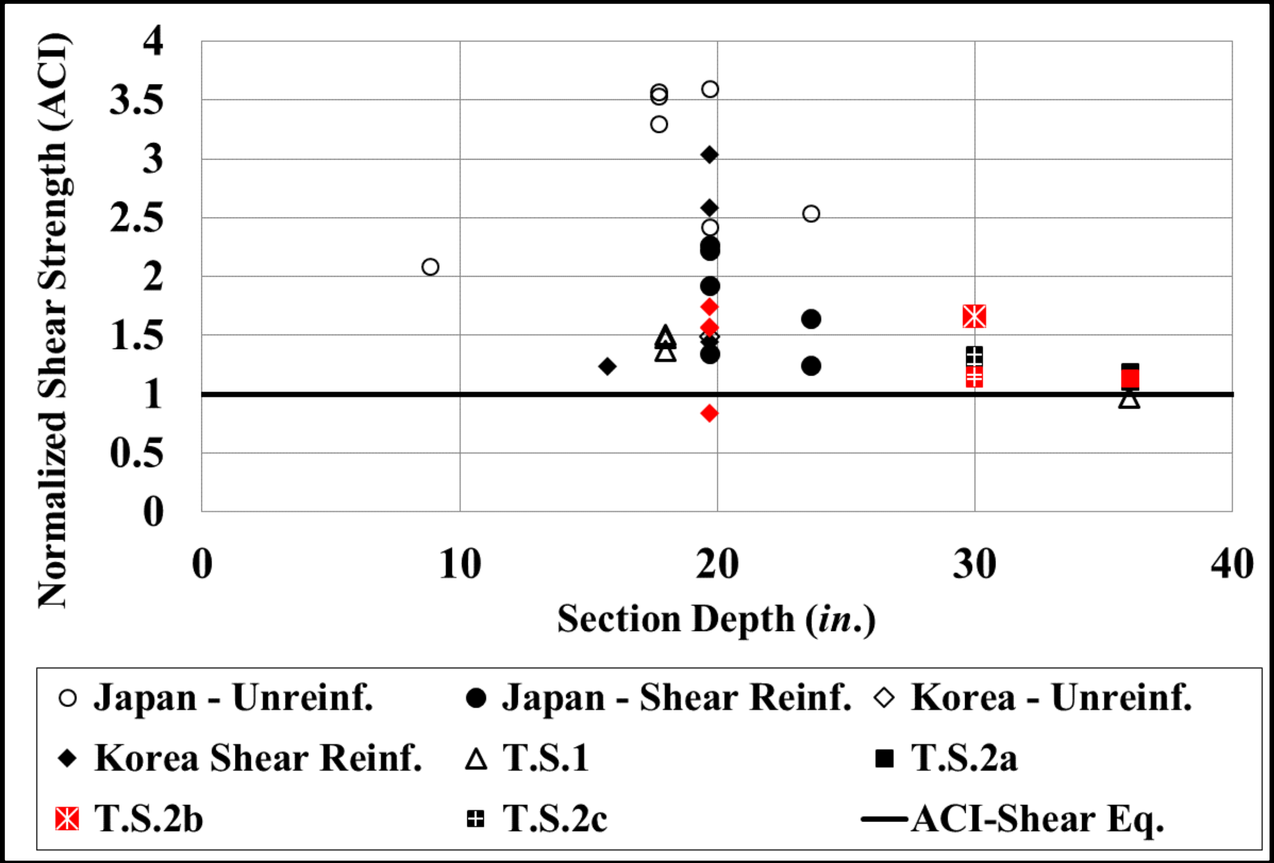
OUT-OF-PLANE SHEAR STRENGTH

- Comparison with the ACI 349 approach.
  - In the figure the filled marks indicate specimens with shear reinforcement, and the red ones are specimens failed in flexural shear



OUT-OF-PLANE SHEAR STRENGTH

- Comparison with the ACI 349 approach.
  - The x-axis is the section thickness.



Out-of-Plane Shear Strength

- N9.3.5: The nominal out-of-plane shear strength per unit width shall be established by:
  - conducting project specific large-scale out-of-plane shear tests, or
  - using applicable test results available in published literature.
- In the absence of such data, the out-of-plane shear strength per unit width of panel sections shall be calculated as follows.

Out-of-Plane Shear Strength
Tie Spacing: wall thickness / 2 or less

- When the shear reinforcement spacing is no greater than half of the section thickness, the nominal out-of-plane shear strength can be calculated as: $V_{no} = V_{conc} + V_s$

$$V_{conc} = 0.0015(f'_c)^{0.5} t_c(12)$$

$$V_s = \xi p_s F_t(12 / S_T) \leq 0.008(f'_c)^{0.5} t_c(12)$$

- When the shear reinforcement spacing is greater than half the section thickness, the nominal out-of-plane shear strength shall be the greater of V_{conc} and V_s (with ξ and p_s both equal to 1.0)

Out-of-Plane Shear Strength

- The resistance factor ($\phi = 0.75$ and safety factor ($\Omega = 2.00$) reflect the non-ductile nature of shear failure.
- The shear reinforcement contribution is based on the mechanism of a shear or flexure-shear crack passing through several yielding-type shear reinforcement ties, and engaging them in axial tension.
- The determination of ties' available axial tensile strength is important. The concrete contribution has been conservatively taken as $1.5\sqrt{f'_c}$ in psi.

Out-of-Plane Shear Strength
Tie Spacing: less than wall thickness

- For yielding type shear reinforcement (ties) spaced greater than half of the section thickness, the shear strength being limited to the larger of V_{conc} and V_s is based on the fact that SC beams develop an internal truss mechanism for equilibrium. The strength of this truss mechanism is limited to that of the shear reinforcement.

- The concrete and steel contributions cannot be added for shear reinforcement spacing greater than the wall thickness divided by two because the shear or flexural-shear crack may not pass through more than one shear reinforcement tie.

Out-of-Plane Shear Strength

- For nonyielding shear reinforcement (ties) spaced no greater than half the wall thickness, the shear reinforcement contribution has been reduced by half.

- For nonyielding shear reinforcement with spacing greater than half the wall thickness, the out-of-plane shear strength is the same as those for yielding shear reinforcement spaced at more than half the wall thickness, with the reasoning being the same.

Ties: Interaction Out-of-Plane Shear + Interfacial Shear

- N9.3.6(a): If the required strength for both x (V_{rx}) and y (V_{ry}) axes is greater than the available strength contributed by the concrete ($V_{c,conc}$), and the shear reinforcement (i.e. ties) is spaced no greater than half the section thickness:

$$[(\frac{V_r - V_{c,conc}}{V_c - V_{c,conc}})_x + (\frac{V_r - V_{c,conc}}{V_c - V_{c,conc}})_y]^{5/3} + [\frac{\sqrt{V_{rx}^2 + V_{ry}^2} / \{12(0.9t_{sc})\}}{\psi(Q_{cv}^{avg} / s^2)}] \leq 1.0$$

- N9.3.6(b): If the available strength (V_c) is governed by the steel contribution alone and the shear reinforcement (i.e. ties) is spaced greater than half the section thickness, $V_{c,conc}$ shall be taken as zero in the equation above.

Ties: Interaction Out-of-Plane Shear + Interfacial Shear

- In the first part of linear interaction equations, the numerators are the portion of the demands greater than the corresponding concrete contributions (V_{conc}). The denominators are the contributions of the steel shear reinforcements (V_s). The second term in the interaction equation is due to the participation of *ties* in resisting interfacial shear force.

$$[(\frac{V_r - V_{c,conc}}{V_c - V_{c,conc}})_x + (\frac{V_r - V_{c,conc}}{V_c - V_{c,conc}})_y]^{5/3} + [\frac{\sqrt{V_{rx}^2 + V_{ry}^2} / \{12(0.9t_{sc})\}}{\psi(Q_{cv}^{avg} / s^2)}] \le 1.0$$

Ties: Interaction
Out-of-Plane Shear + Interfacial Shear

- The out-of-plane shear demands (V_{rx} and V_{ry}) both rely on using the same steel shear reinforcement for their steel contributions (V_s). Both V_{rx} and V_{ry} subject the steel shear reinforcement to axial tension demand after concrete cracks and its contribution (V_{conc}) in respective directions is exceeded.

- When one of the shear demands is less than the concrete contribution, ties are not subjected to that demand. Hence, there will be no interaction of out-of-plane shear demands in that case.

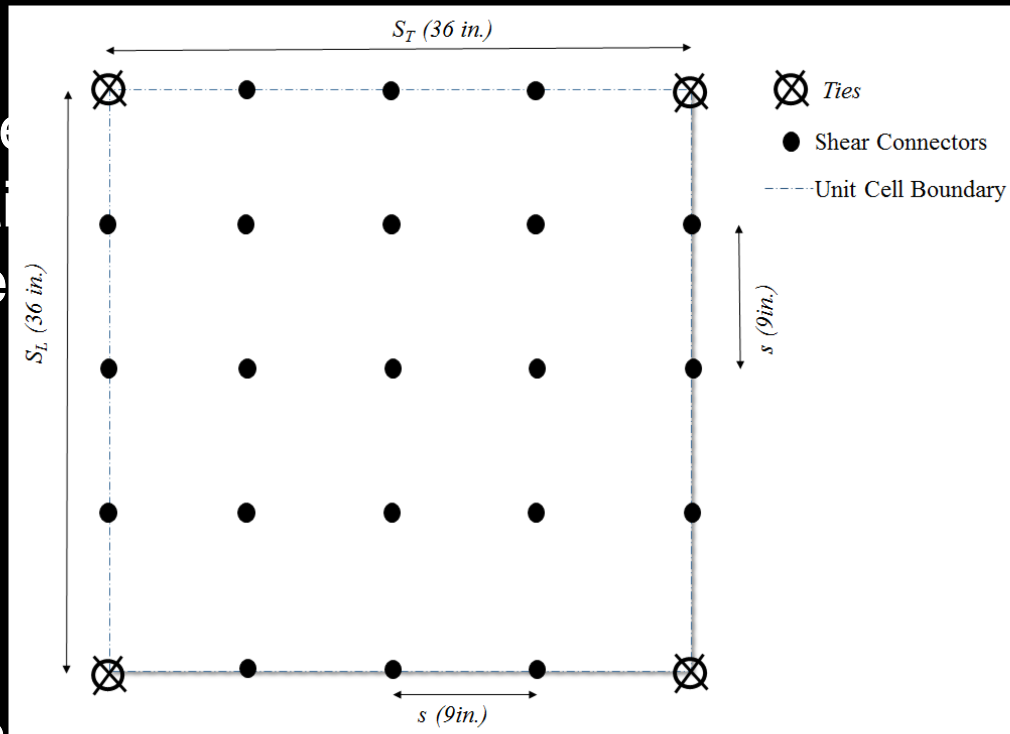
Ties: Interaction Out-of-Plane Shear + Interfacial Shear

- For shear reinforcement spaced greater than half the section thickness, the available strength will be equal to the greater of the ties and the concrete contributions.
- In the case of the steel contribution being more, the concrete contribution term in the equation will go to zero.
- If the concrete contribution is more, then the concrete infill will be subject to two-way shear (punching shear), which will be resisted by unit perimeter of the panel section.

PURDUE UNIVERSITY

Ties: Interaction
Out-of-Plane Shear + Interfacial Shear

- The we strength contributi can be calculate



- For an SC wall of thickness 36 in., with ties spaced at 36 in. and shear connectors spaced at 9 in., n_{et} for the case will be 1. The effective number of shear connectors contributing to the unit cell, n_{es}, will be 15[(1)(9)+(0.5)(12)].

Module 7:

SC Wall Connection Design

By,

Amit H. Varma

University

OUTLINE

- General Provisions
- Required Strength
- Available Strength

General Provisions

- This section addresses design requirements for:
  - splices between SC wall sections
  - splices between SC wall and RC wall sections
  - connections at the intersection of SC walls
  - connections at the intersection of SC with RC walls
  - anchorage of SC walls to RC basemats
  - Connections of SC walls to RC slabs
- Wall-to-wall, wall anchorage and wall splice connections shall be rigid for out-of-plane moment transfer.
- Wall-to-slab connections shall be consistent with the analysis model used.

General Provisions

- *Full strength connections*: develop the full strength of the weaker of the connected parts
- *Overstrength connections*: develop overstrength with respect to the connection design demands while ensuring that ductile failure modes govern the connection strength
- Full strength connections are preferred

GENERAL PROVISIONS

- For steel-to-steel connections:
  - Bolts and welds can be easily sized and installed to provide adequate strength and ductility,
  - For gusseted connections or extended plate connections, simple (empirical) methods (e.g., the uniform force method) exist that are adequate for design instead of having to perform design using complex finite element analyses

General Provisions

- For anchorage of linear steel components:
  - Linear steel members can be anchored into concrete (e.g., basemat) using anchor rods and lugs. Anchor rods are typically used to resist pullout forces and bending moments, while lugs are used to resist shear forces.
  - Demands on connecting elements due to simultaneous forces and moments acting on the anchored member can be easily determined for their adequate sizing.

GENERAL PROVISIONS

- For connections to RC elements:

  - Linear or continuum RC elements are often connected with other RC elements, usually across construction joints.

  - Typical connecting elements are dowels. Dowels act as splices for transfer of tension and bending moments; they act as shear-friction reinforcement for transfer of shear forces.

  - Closely spaced ties are used to achieve high strain capacity and high shear strength within the beam-column joints. A lot of test data and prescriptive design rules exist to adequately size RC connections.

General Provisions

- Generally, no prescriptive rules exist for designing connections between linear composite members and RC elements.

- However, various types of connection elements can be used to connect composite members and RC members including the following: PT bars or strands, steel-headed stud anchors, dowels, lugs, anchor rods, etc.

- SC connections are more complicated than connections involving linear composite members as multiple types of demands exist on plate/shell type SC elements.

General Provisions

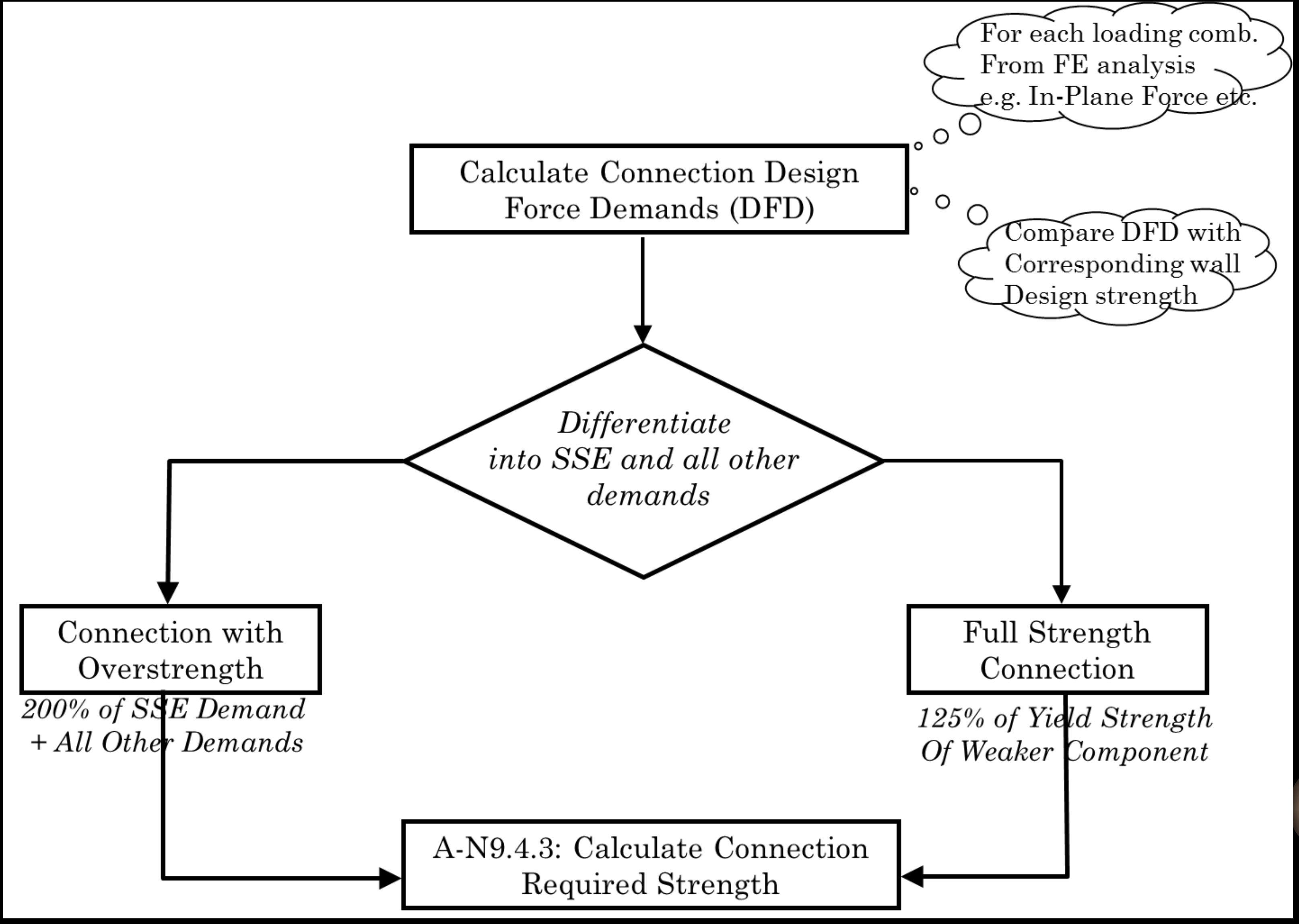
- Behavior beyond SSE performance needs to be considered, especially if the connection involves brittle failure mode, or if design needs to satisfy a "Review Level Earthquake".
- It is possible that the connection will need to be designed to be weaker than the connected elements (particularly for in-plane shear).

Required Strength

- For full strength connections: the required strength for each demand type shall be 125% of the smaller of the corresponding nominal strengths of the connected parts.

- For overstrength connections: the required strength for each demand type shall be 200% of the required strength due to seismic loads plus 100% of the connection strength due to nonseismic loads.

Required Strength



AVAILABLE STRENGTH

- The available strength for each demand type shall be calculated using the applicable force transfer mechanism and the available strength of its contributing connectors.

- The available strength for each demand type and for combinations of various types of demand types shall be peer-reviewed.

- The available strength for connectors shall be determined as follows.

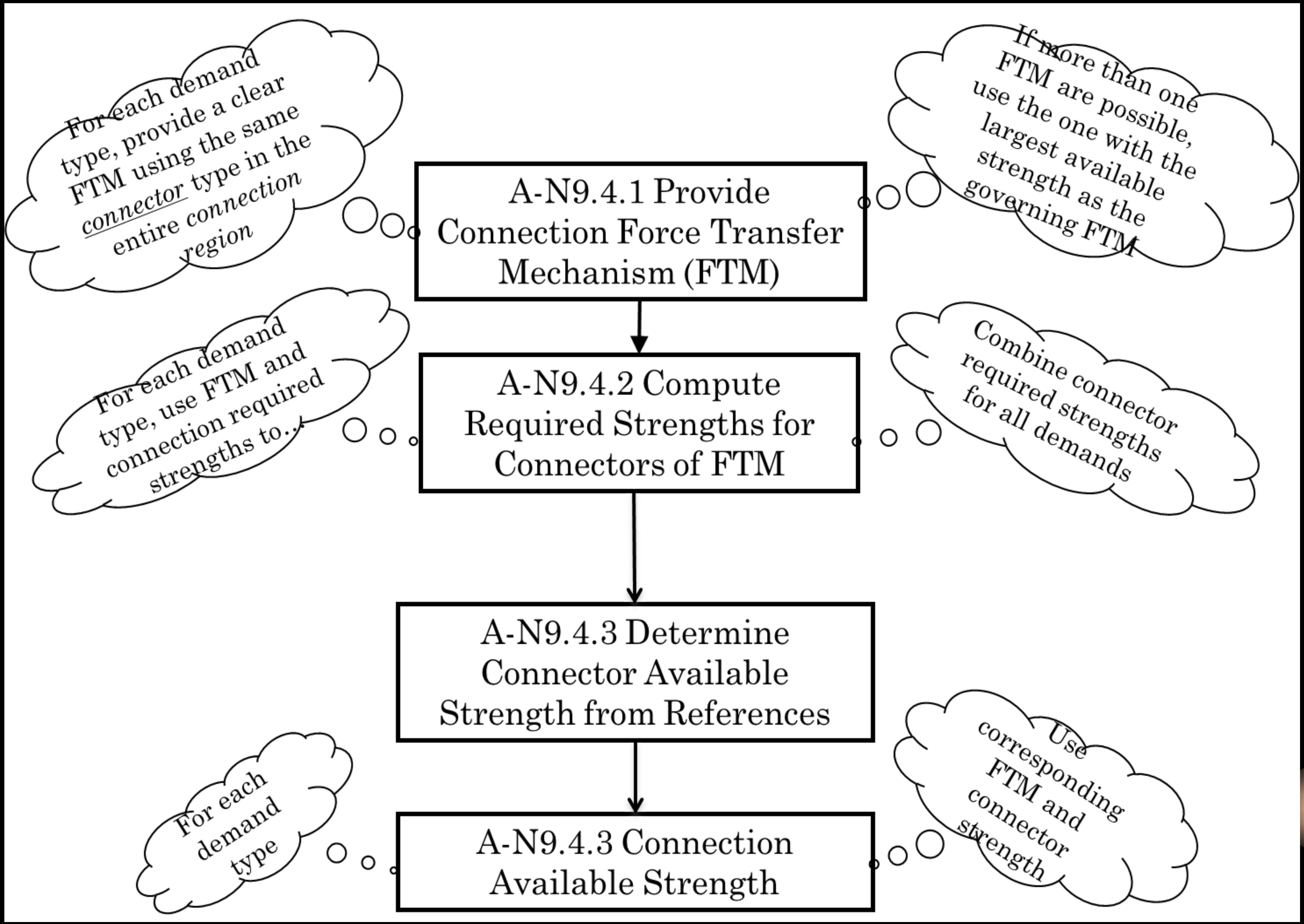
AVAILABLE STRENGTH

- For steel headed stud anchors, the available strength shall be determined in accordance with *Specification* Section I8.3a.
- For welds and bolts, the available strength shall be determined in accordance with *Specification* Chapter J.
- For compression transfer via direct bearing on concrete, the available strength shall be determined in accordance with *Specification* Section I6.3a.

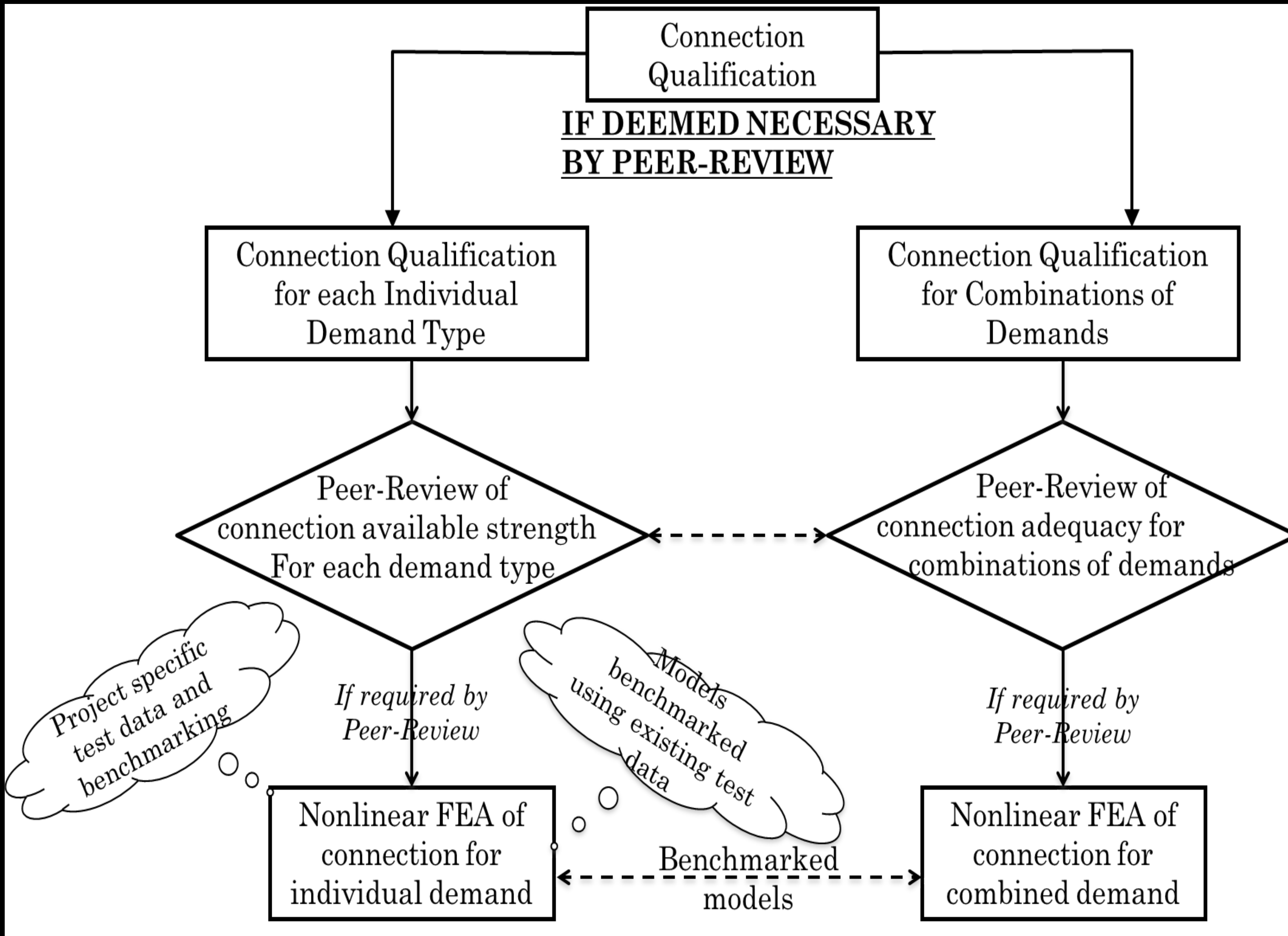
Available Strength

- For shear friction load transfer mechanism, the available strength shall be determined in accordance with ACI 349 Section 11.7.
- For embedded shear lugs and shapes, the available strength shall be determined in accordance with ACI 349 Appendix D.
- For anchor rods, the available strength shall be determined from ACI 349 Appendix D.

AVAILABLE STRENGTH



Connection Qualification



MODULE 8

Fabrication, Erection, Construction, and Inspection

By,

Amit H. Varma

University

Dimensional Tolerances

- Dimensional tolerances shall be in accordance with *Code of Standard Practice*, Section 6, and as listed

- If acceptable tolerances are not found in the *Code of Standard Practice* and are not listed below, the *engineer of record* shall provide the necessary tolerances.

FABRICATION

- SC construction consists of different phases. Dimensional tolerances are applicable to:
  (i) SC wall panels and *sub-modules* fabricated in the shop and inspected before release
  (ii) Adjacent SC walls panels, *sub-modules*, and *modules* just before connecting them
  (iii) Erected SC wall *modules* before concrete casting, and
  (iv) Constructed SC structures after concrete casting.

FABRICATION

- SC wall *panels* are typically fabricated in the shop, and then shipped to the field.
- The overall dimensions of the fabricated SC wall *panels* are limited by the applicable shipping restrictions.
- SC wall *panels* that are shipped by road are limited to 8-10 ft. in width and 40-50 ft. length maximum.
- Additionally, SC wall *sub-modules* that may consist of corner, joint, or splicing *modules* may also be fabricated in the shop and then shipped to the field. They are subjected to the same size restrictions as the wall *panels*.

Dimensional Tolerances

- Dimensional tolerances of SC wall panels as measured in the fabrication shop shall be as follows:
  - At *tie* locations, the perpendicular distance between the opposite faceplates shall be within plus or minus t_{sc}/200, rounded upward to the nearest 1/16 in.
  - This tolerance check shall be performed for the row of tie-bars located closest to the free edges of SC panels.

DIMENSIONAL TOLERANCES

- In between *tie* locations, the perpendicular distance between the opposite faceplates shall be within plus or minus t_{sc}/100, rounded upward to the nearest 1/16 in. This tolerance check shall be performed along the free edges of the SC wall panels.

- The *tie* locations (*tie* spacing) shall conform to the shear stud (connector) provisions of AWS D1.1 or AWS D1.6 as applicable.

- The squareness and the skewed alignment of opposite steel faceplates shall be such that the applicable dimensional tolerances for making the connections between adjacent *panels*, *sub-modules* or *modules* shall be met. No additional squareness or skewed alignment tolerances are required.

Dimensional Tolerances

- The dimensional tolerances for SC wall *panels* and *sub-modules* fabricated in the shop have to be inspected before release for shipping to the side.
- The dimensional tolerances are primarily for the fabricated panel thickness (t_{sc}), where
  - Tolerance at *tie* locations is equal to t_{sc}/200 rounded up to the nearest 1/16 in. and the
  - Tolerance in between *tie* locations is equal to t_{sc}/100 rounded up to the nearest 1/16 in.

DIMENSIONAL TOLERANCES

Table C-A-N9.5.1
Thickness Tolerances for Fabricated SC Wall Panels and *Sub-modules*

Wall Thickness (t_{sc}) in.	Thickness Tolerance (in.) at *Tie* Locations	Thickness Tolerance (in.) Between *Tie* Locations
24	±1/8	±1/4
30	±3/16	±5/16
36	±3/16	±3/8
42	±1/4	±7/16
48	±1/4	±1/2
54	±5/16	±9/16
60	±5/16	±5/8

DIMENSIONAL TOLERANCES

- Dimensional tolerances as measured before making connections between steel faceplates of adjoining *panels*, *sub-modules*, or *modules* shall be as follows:

  - The fit-up tolerance of steel faceplates of adjoining SC wall *panels*, *sub-modules* or *modules* joined together by welding shall be governed by the applicable tolerances in AWS D1.1 and AWS D1.6, or as specified in applicable qualified weld procedure for the project.

  - The fit-up tolerance of steel faceplates of adjoining *panels*, *sub-modules* or *modules* joined together by bolting shall be governed by the applicable requirements of the *Code of Standard Practice*.

DIMENSIONAL TOLERANCES

- Dimensional tolerances for erected *modules* before concrete placement shall be governed by the erection tolerances defined in the *Code of Standard Practice,* section 7.13, with the exception that the working lines will be located at one steel faceplate of the SC wall.

- Dimensional tolerances for SC *modules* after concrete curing shall be governed by the concrete construction tolerances defined in ACI 349 and ACI 117.

DIMENSIONAL TOLERANCES

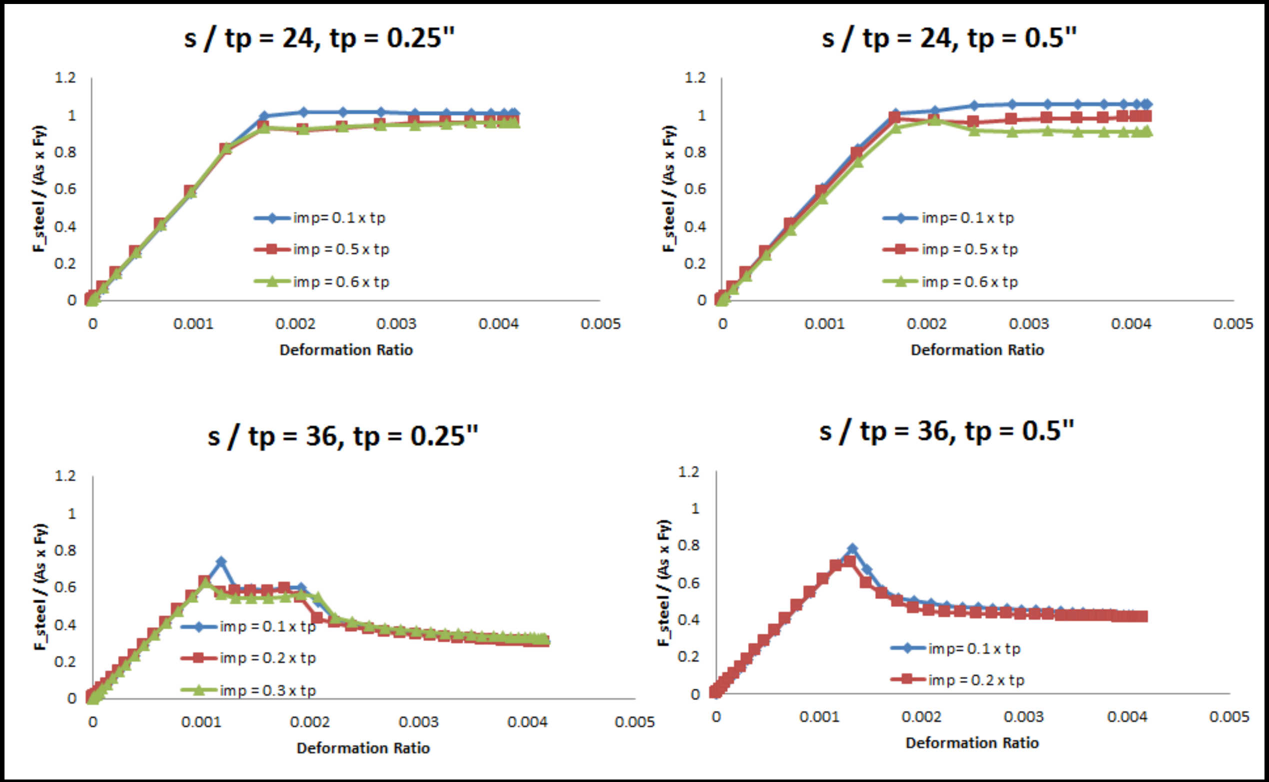
- The waviness of SC module faceplates after the concrete has cured shall be measured as the distance of the lowest point (trough) from the straight line joining two adjacent high points (crests).

- After concrete curing, the steel faceplate waviness shall not exceed half the steel faceplate thickness multiplied by the *tie* spacing divided by the shear connector spacing.

Dimensional Tolerances

- The waviness requirement following concrete placement is specified to limit excessive steel faceplate displacement due to concrete placement. The Engineer of record can specify the concrete pour rate and height to meet the waviness requirements.
- Benchmarked finite element models (Zhang et. al., 2013) were used to study the effect of steel faceplate waviness on the compressive strength of SC walls with non-slender and slender faceplates.

Dimensional Tolerances



Non-slender finite element models with imperfections up to $0.65t_p$ developed more than 95% of the faceplate strength (i.e., $0.95A_sF_y$).

PURDUE
UNIVERSITY

Erection

- Stability and Connections
- Composite SC structures shall be carried up true and plumb within the limits defined in the *Code of Standard Practice* and Contract Documents.
- The need for temporary bracing shall be evaluated in accordance with the requirements of the *Code of Standard Practice* and Contract Documents.
- Temporary bracing shall be provided wherever necessary to support the loads that the structure may be subjected to, including equipment loads and equipment operating loads.

Erection

- For composite SC structures, the required bracing shall resist impact and hydrostatic loads of fluid concrete during concrete placement. When bracing is required it shall be left in place as long as required for safety.

QUALITY CONTROL AND ASSURANCE

- Inspection
- For welding of steel faceplate, observation of welding operations and visual inspection of in-process and completed welds shall be the primary method to confirm that the materials, procedures and workmanship are in conformance with the construction documents.

- SC wall welding inspection of the *module* shall include verification of the welding consumables, welding procedure specifications, welding procedure qualification for non-prequalified joints, and qualifications of welding personnel prior to the start of the work, observations of the work in progress, and a visual inspection of all completed welds.

QUALITY CONTROL AND ASSURANCE

- Tests, Materials and construction requirements for concrete shall comply with the applicable provisions of ACI 349 "Code Requirements for Nuclear Safety Related Concrete Structures & Commentary."

TABLE A-N9.6.1
Inspection of Steel Plate Shear Wall Prior to Concrete Placement

Inspection of Steel Elements of Composite Construction Prior to Concrete Placement	QC	QA
Inspection of steel face plates	P	P
Placement and installation of tie connectors	P	P
Placement and installation of steel headed stud anchors	P	P
Document acceptance or rejection of steel elements	P	P

Quality Control and Assurance

TABLE A-N9.6.2
Inspection of Steel Plate Shear Wall
After Placement of Concrete

Inspection of Steel Elements of Composite Construction Prior to Concrete Placement	QC	QA
Inspection of steel face plates	P	P
Document acceptance or rejection of steel elements	P	P

Summary of Questions and Discussion Points from the 11-15-13 Meeting on N690 Appendix N9

Key comments and questions received at the meeting from stakeholders are summarized below.

1. The guidance is not clear if it can be applied to slabs. It is not currently written for slabs, but may be added later.

2. Why consider non-yielding ties? Because it is a technology which is available, and used.

3. What about the consideration of loads concurrent with construction? There is a note to the user to consider these factors.

4. Does the guidance allow for exterior walls below grade (consideration of soil load and corrosion)? Not explicitly addressed, but soil loads could be determined. Sacrificial corrosion plate thickness is not included currently.

5. Is there any intermediate plate thickness consideration. No.

6. How about plate thickness around penetrations or connection points? That is a project specific consideration.

7. How was the value of 50 Ksi arrived at? This was the testing point, and it was found that 36 Ksi would be insufficient.

8. What is there a limit on the embedment of ribs? They are used for stiffness and not as structural elements.

9. Connection region is where full composite strength is developed. Equilibrium of forces between steel and concrete happens there.

10. Modeling parameters discussed such as damping rations of <= 5%. Large openings = > ½ wall thickness.

11. Any consideration for the use of Stainless steel plates? Not currently. Will be considered.

Additional notes and discussion points are found in the NRC-AISC meeting summary notes elsewhere in this meeting package.