Composite Concrete Construction: Modularity, Innovation, Resilience and Sustainability through Design

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MODULARITY

- Structural & Construction
- Prefabrication, preassembly, and modularization are key elements to reduce construction time
- Steel-plate composite construction identified as part of modular solution
- Putting the M… in SMRs!

Lifting and Erection of Modules

AP1000, Sanmen, PRC

(c) WEC, LLC
(c) Sanmen Nuclear Power Co. Ltd.

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CA-20 module construction inside the Vogtle 3 and 4 module assembly building

January 2014

The 1,100-ton CA20 module is placed into Plant Vogtle Unit 3 nuclear island. The module, which is more than five stories tall, will house various plant components, including the used fuel storage area.

March 2014

The 1,100-ton CA20 module is placed into Plant Vogtle Unit 3 nuclear island. The module, which is more than five stories tall, will house various plant components, including the used fuel storage area.

March 2014

INNOVATION

- Use of context specific materials
- Steel, stainless steel, duplex steel
- High strength steel rebar, stainless steel rebar
- Concrete – conventional, self-consolidating, high strength, reduced cement, green concrete, engineered cementitious composites
- Recycled soil / rock as a structural material

Optimization

- Nuclear design can be hyper-conservative.
- Geometric dimensions governed by plant layout, little input from downstream engineers
- Prescriptive codes / standards do not foster optimization
- Intelligent optimization through advanced analysis, performance based design, and early engagement with plant layout process

RESILIENCE

- Multiple hazards have to be considered in design
- Design optimization to provide robustness, alternate load paths, and resilience for multiple hazards
- Seismic, Accident thermal, after-shock, fire, flood
- Probabilistic risk analysis – but for multiple hazards
- Benchmarked numerical tools

SUSTAINABILITY

- Cognizant approach from project initiation
- Sustainability is location specific, resource driven, and climate dependent
- Sustainable materials, fabrication techniques, construction approaches, maintenance schedules, and deconstruction aware

Steel-Plate Composite (SC)

- Potential for modularity, innovation, resilience, optimization, and sustainability
- Decades of research on SC structures. Japan, U.S. China, Europe…
- Lot of interest, intrigue, and investment
- AP1000 © containment internal structures (CIS) and shield building

Steel-Plate Composite (SC)

- APWR containment internal structures
- Portions of APR+, mPower, other SMR design
- Biggest hindrances were:
  - Lack of consensus standard or design code
  - Lack of connection details and design methodologies
  - Tolerances for fabrication, construction etc.

AISC N690-12s1 (2015)

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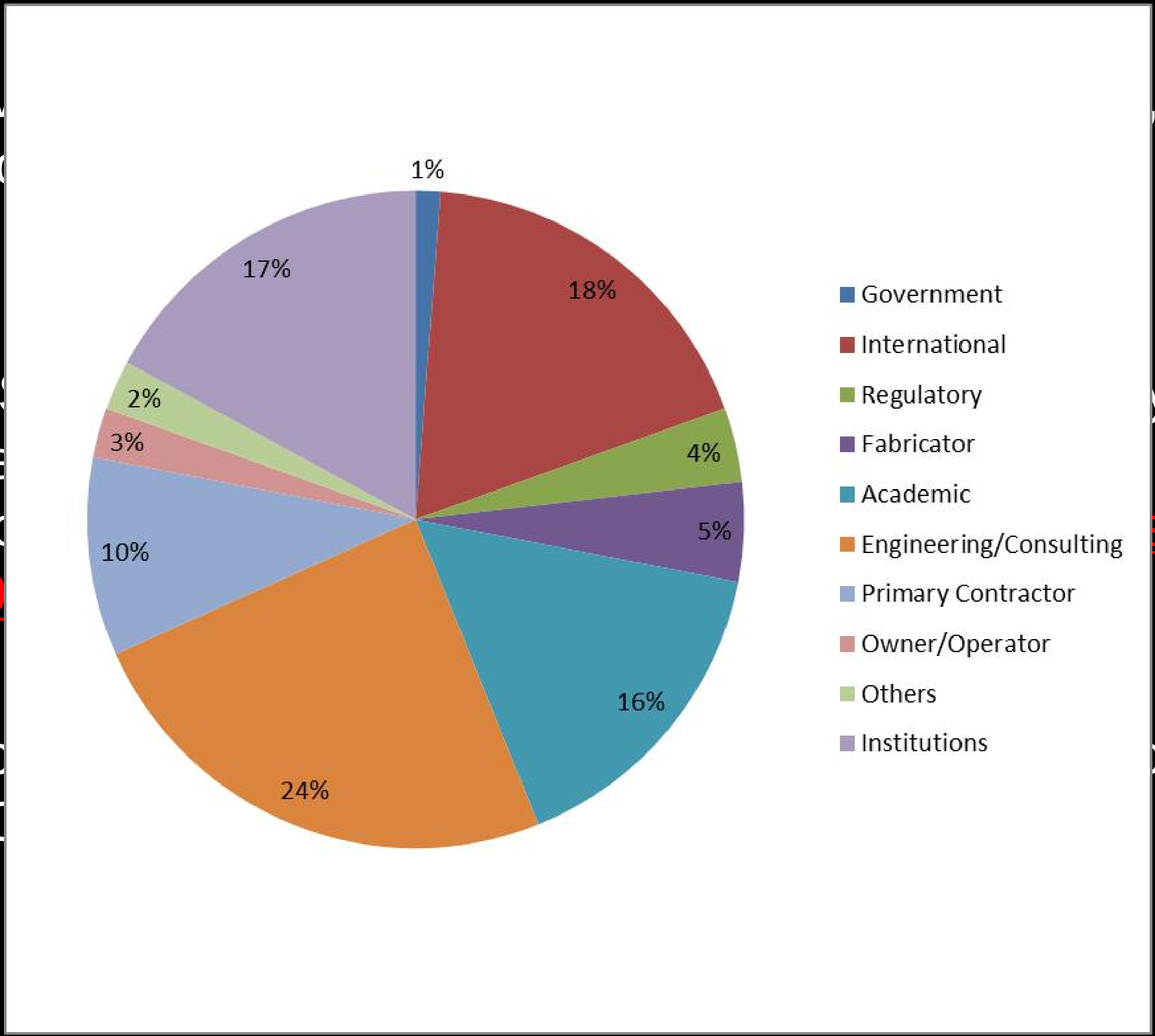

ANSI/AISC N690-12
ANSI/AISC N690s1-15
An American National Standard

Specification for Safety-Related Steel Structures for Nuclear Facilities

Including Supplement No. 1

January 31, 2012 (ANSI/AISC N690-12)
August 11, 2015 (ANSI/AISC N690s1-15)

Supersedes the *Specification for Safety-Related Steel Structures for Nuclear Facilities* dated September 20, 2006 and all previous versions of this specification

Approved by the AISC Committee on Specifications

AMERICAN INSTITUTE OF STEEL CONSTRUCTION
AISC
FOUNDED 1921

CONSENSUS STANDARD

APPENDIX N9

STEEL-PLATE COMPOSITE (SC) WALLS

This appendix addresses the requirements for steel-plate composite (SC) walls in safety-related structures for nuclear facilities. The provisions of this appendix are limited to SC walls consisting of two steel plates (faceplates) composite with structural concrete between them, where the faceplates are anchored to concrete using steel anchors and connected to each other using *ties*.

The appendix is organized as follows:

User Note: A fl wchart to facilitate the use of the appendix has been provided in the Commentary.

N9.1. DESIGN REQUIREMENTS

1. General Provisions

The following provisions apply to SC walls:

Organization of Appendix N9

- N9.3 Design of SC Walls
  - N9.3.1 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

N9.4 Design of SC Wall Connections

- N9.4.1 General Provisions
- N9.4.2 Required Strength
- N9.4.3 Available Strength

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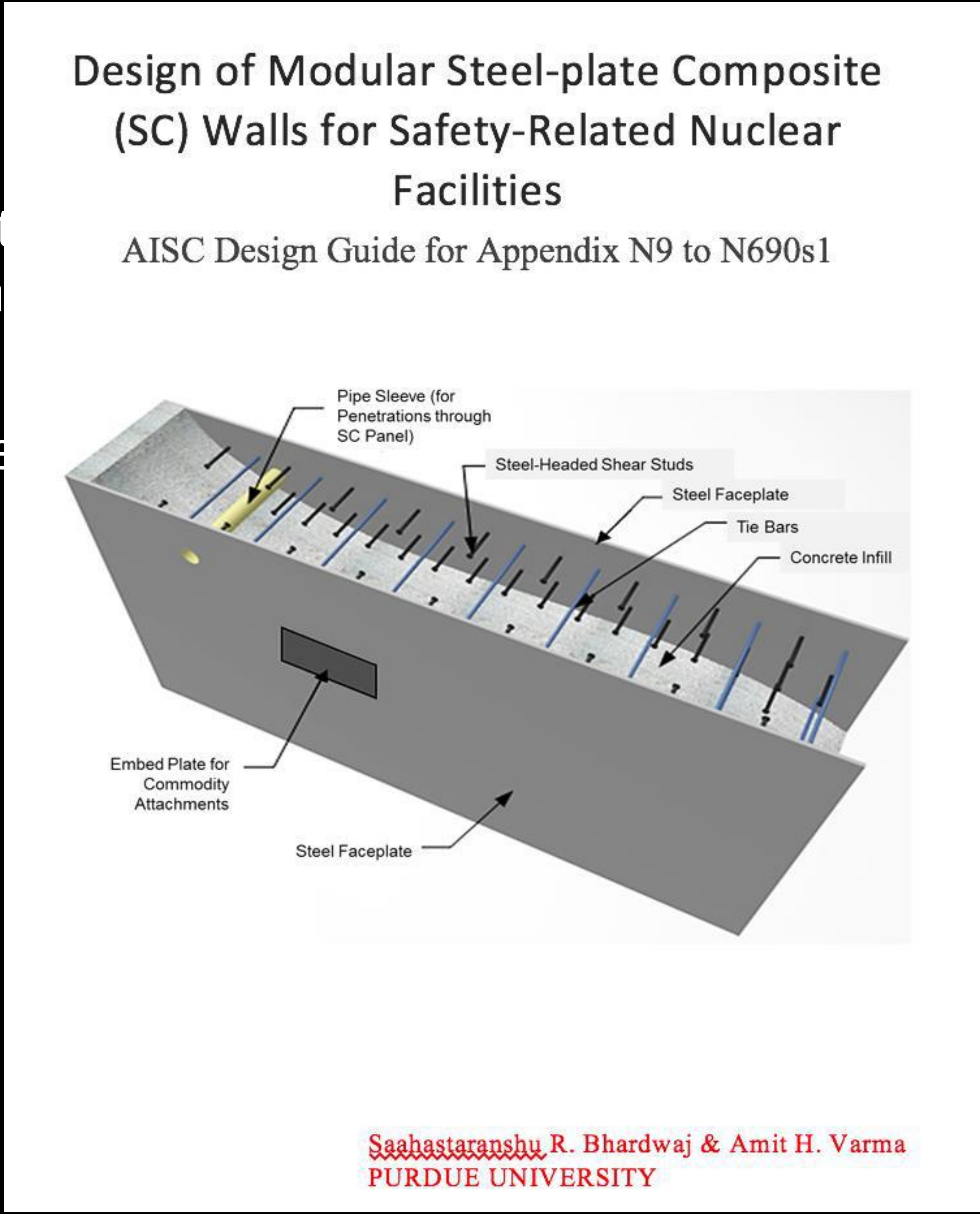

Design of Modular Steel-plate Composite (SC) Walls for Safety-Related Nuclear Facilities

AISC Design Guide for Appendix N9 to N690s1

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DOE NEUP Project 2012 - 16

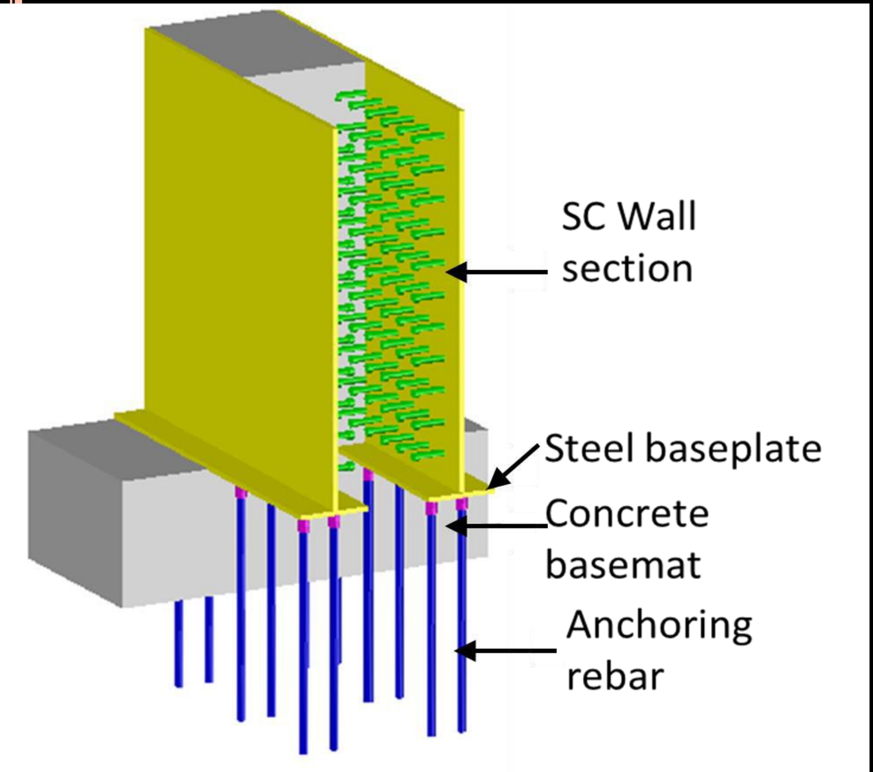
- Modular Connection Technologies for Composite Walls in SMRs: Development and Experimental Verification
- Goal: The goal of the project was to develop and verify connection technologies for steel-plate composite (SC) walls.
- Specifics:
  1. The verified connection technologies and data etc. should be available in the public domain for easy access by industry, regulators, DOE
  2. Include SC wall-to-basemat anchorage, SC wall-to-wall joints, and SC wall-to-slab connections
  3. Consider different connection design and performance philosophies

Research Products

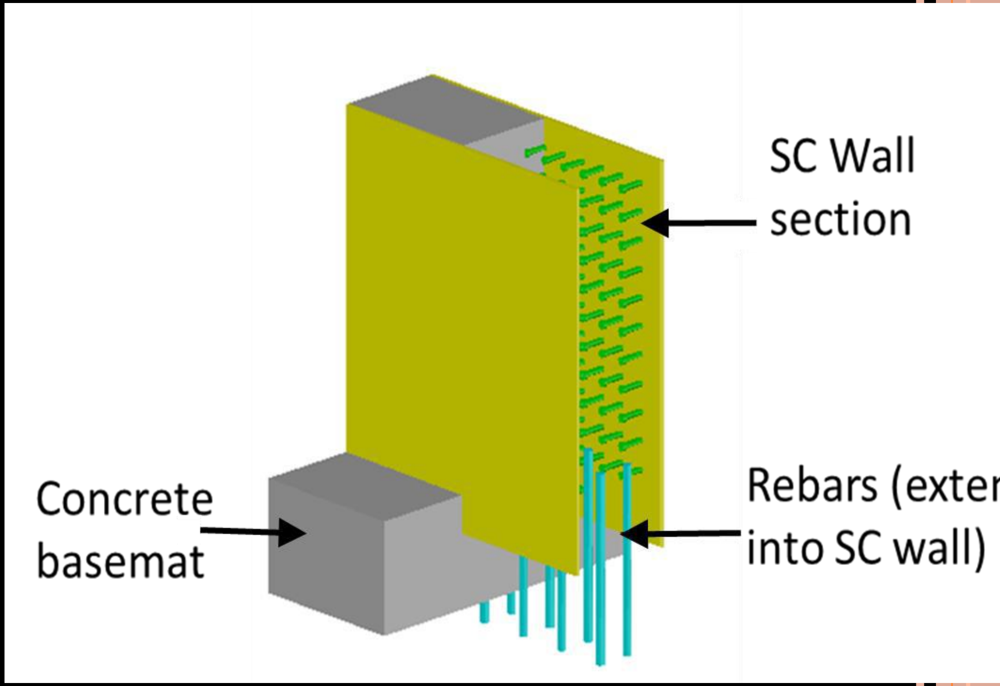
- Design philosophy and recommendations for SC wall connections included in AISC N690-12s1 (2015)
- Examples included in AISC Design guide. Several journal articles and conference proceedings
- Include SC wall-to-basemat connection, SC wall-to-wall connections
- Full-strength connections, and overstrength connections

Example:
SC Wall-to-Basemat Anchorage Connection

Can be designed either as full-strength or over-strength anchorage. Full-strength design is preferred and convenient



Split-baseplate SC Wall-to-Basemat Connection



SC Wall-to-Basemat Anchorage using non-contact spliced rebars

DOE NEUP PROJECT 2014 - 17

- Improvement of Design Codes to Account for Accident Thermal Effects on Seismic Performance
- Goal: Design of SC Walls and RC Walls for multiple hazards, namely, seismic and accident thermal loading
- Experimental evaluation, numerical simulations, and design code development ongoing
- ACI 349.1R (Design for accident thermal conditions) being edited …

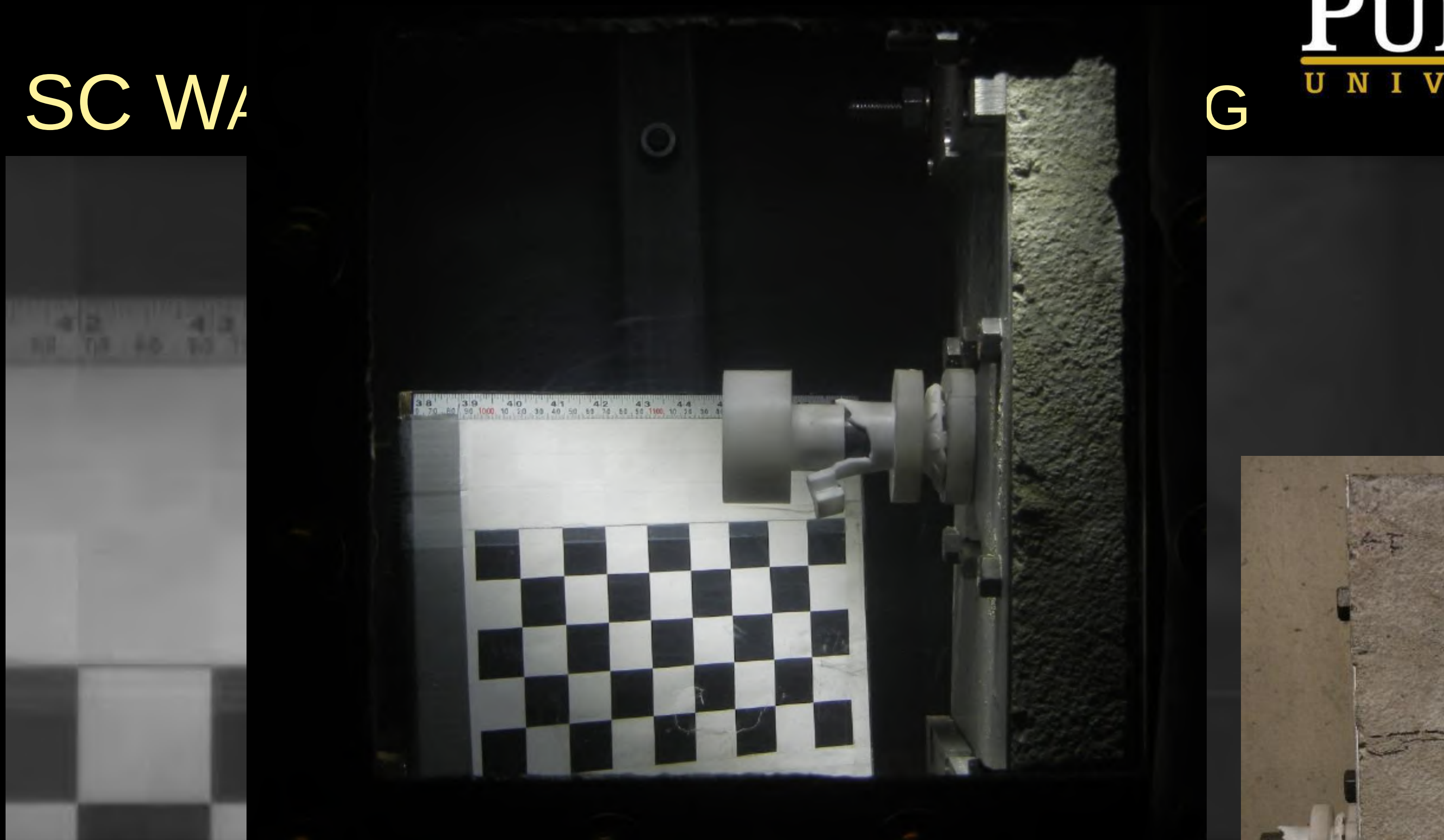
DOE NEUP PROJECT 2014 - 17

- Effects of accident temperature and duration of heating on the cyclic response of composite walls
- Reduction in stiffness as function of temperature, heating duration, reinforcement ratio etc.
- Reduction in strength as function of temperature …
- Research ongoing

USNRC Grant – Missile impact

- Design of composite walls for impactive and impulsive loading including beyond design-basis aircraft impact scenario
- Testing in the laboratory, and at USACoE, Vicksburg
- Missile impact testing and blast testing
- Data, numerical models and design equations

SC WA… G



OTHER RESEARCH PROJECTS

- NEUP project on the use of high strength steel and concrete in RC design. Modularity using pre-fabricated cages
- Project and testing ongoing at UND
- ACI 349 committee deliberating the use of high strength materials in nuclear…
- ACI Strategic Development Council (SDC) looking for options to innovate and optimize concrete in nuclear…

REGULATORY APPROVAL

- Sharing / dissemination of research results into the public domain through journal articles, conference proceedings etc. is very important
- Deliberations by code committees / standard committee of research results is extremely important
- Education of the professional community about research findings, solutions, and consequences …

REGULATORY APPROVAL

- Changes in the expectations / requirements of the regulator can be extremely expensive and time consuming
- Understanding the expectation of the the regulator, and communicating own position is extremely important
- Developing consensus between regulator and applicant can be the most expensive and time consuming part of the licensing process.