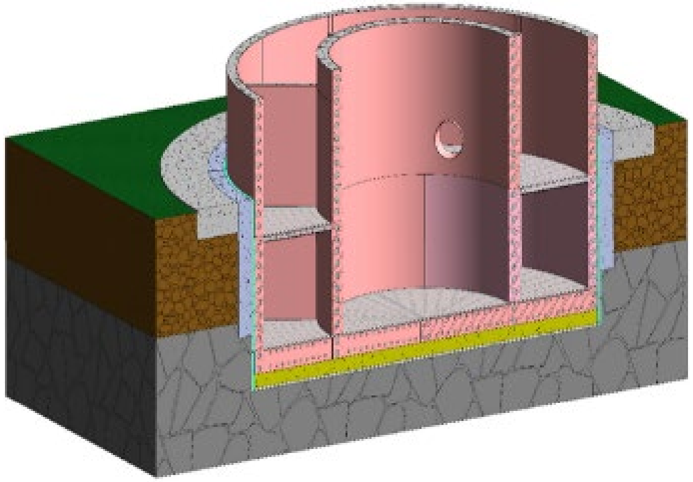
NRIC National Reactor Innovation Center

Advanced Construction Technology Initiative Program

Luke Voss, Program Manager

04/24/2024



ACTI Program Scope

- Demonstrate technologies to significantly reduce the cost and schedule for construction of advanced reactors.
- Demonstrate the technology by 2026/2027 to improve the economics of deploying advanced reactors.
- Selected technologies will not require major R&D efforts. With prototyping and testing, the technologies will be ready for deployment at scale.

Benefits of Demonstration and Testing

- Bridge the gap between development and commercialization
  - Mature technology readiness and reduce risks to participants for first of a kind build
  - Facilitate partnership between technology developers, end users, national labs, universities, regulators, industrial participants
- Learn by doing reduces risks associated with first commercial build
- Build confidence with regulators
- Develop supply chain

Recap - ACTI Project with GEH

- Team - General Electric Hitachi
  - EPRI, Black & Veatch, Purdue, UNCC, Aecon Wachs, and Tennessee Valley Authority
- Purpose - demonstrate technologies to:
  - Reduce the cost of new nuclear builds
  - Speed the pace of advanced nuclear deployment
- Phase 1
  - Build & test Steel Bricks™ specimens at Purdue
  - Design a reactor building demonstration
  - Develop advanced monitoring and digital twin technologies

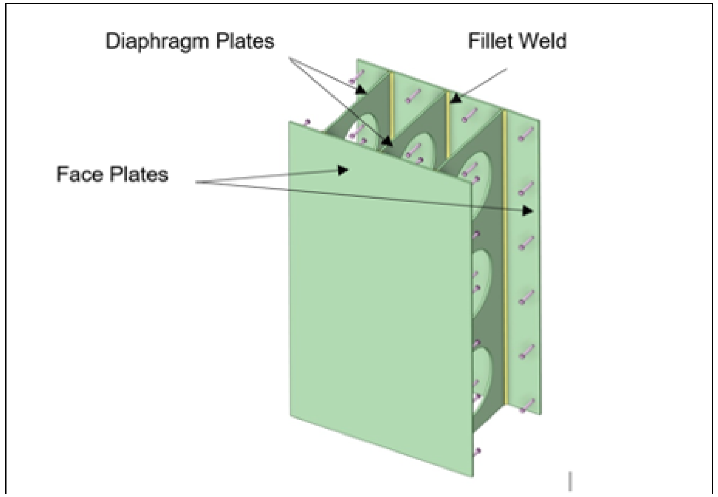
NRIC National Reactor Innovation Center

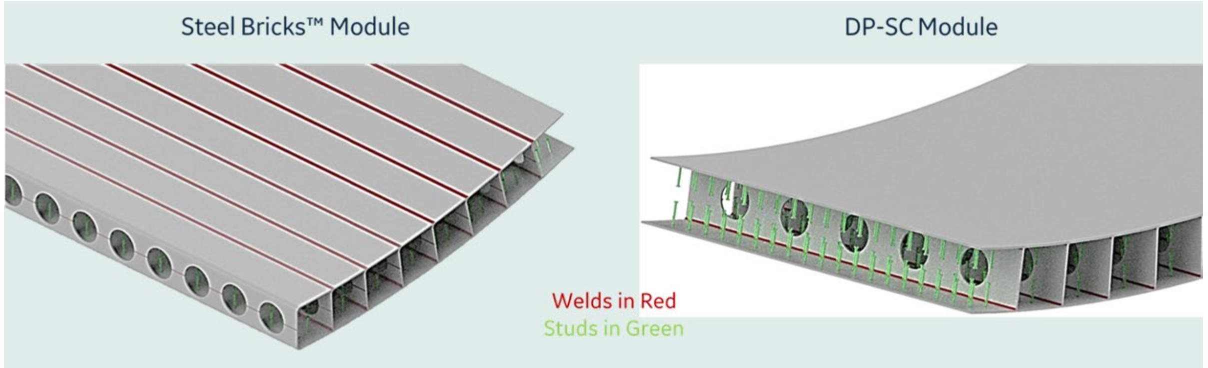
Recap - ACTI Project Accomplishments

- Demonstrated concept of fabricating Steel Bricks™ assemblies in a factory setting
- Successfully tested Steel Bricks™ specimens at Purdue
- Established digital twin and monitoring techniques
- Demonstrated NDE methods to inspect concrete inside Steel Bricks™

Design Pivot

- Design Pivot to Diaphragm Plate Steel Composite (DPSC):
  - From lessons learned in Phase I, GEH determined that DPSC are a better solution for the ACTI Project
  - Benefits over Steel Bricks™
    - Major reduction in weld volume and inspection
    - Faster to fabricate
    - Does not require post-forming heat treatment
    - Simplified fit-up
    - More cost effective





Current Project Status

- Extended Phase 1 to Q4 FY24
- Phase 1 Completion:
  - Fabricate and test DPSC specimens
  - Design Phase 2 demonstration using DPSC
  - Propose Phase 2 demonstration project with DPSC
- Potential Phase 2 scope may include:
  - Build and test structure using DPSC
  - Disassemble and decommission

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PHASE 1 COMPLETION PROJECT NRIC PROGRAM REVIEW

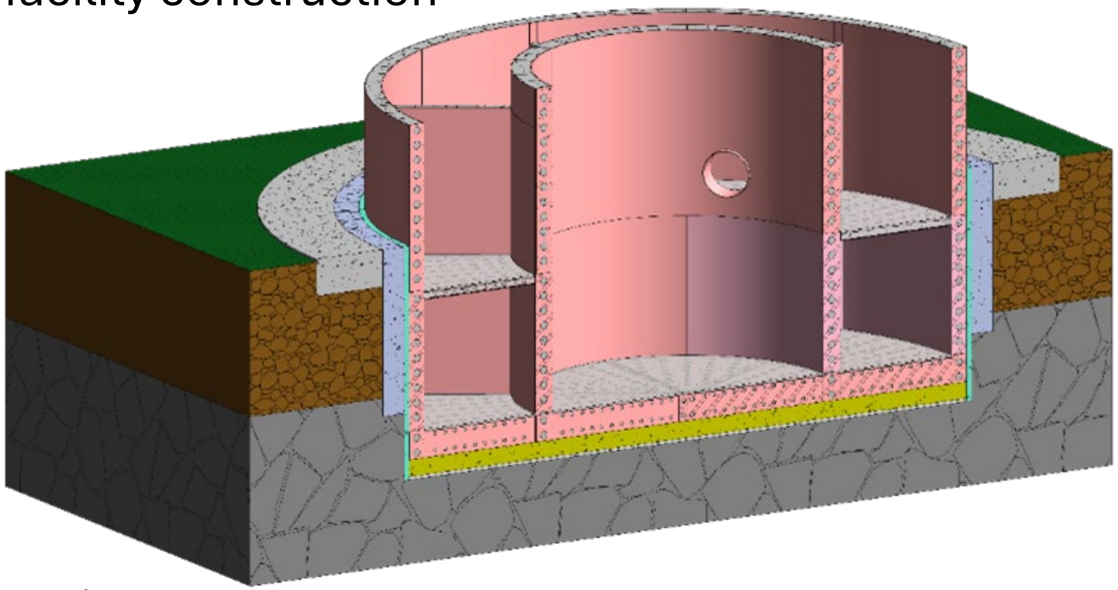
National Reactor Innovation Center (NRIC) Advanced Construction Technology (ACT)

April 24, 2024

Project Phase 1

- **Original Phase 1 Project**
  - Completed through 90% Design Review with SteelBricks™ (SB) Technology

- **Phase 1 Completion Project**
  - Consists of three major scopes
    1. DPSC Engineering to support demonstration facility construction
       - 90% design in progress
    2. DPSC Sample Fabrication and Testing
       - Material procurement in progress
       - 9 specimens and tests
    3. Phase 2 Proposal
       - Development in progress



Project Potential Phase 2

- **Potential Phase 2 Scope:**
  - Implementation of Phase 1 Deliverables
    - Design drawings, construction plan, test plan, decommissioning plan
  - Fabrication of DPSC Panels
  - Construction of Demonstration Facility
  - NDE Testing and Digital Twin
  - Decommissioning

- **Potential Phase 2 Support:**
  - Estimated ~5 months of fabrication, ~7 months of construction
  - Reduced construction/material/duration
  - Provide ongoing lessons learned to industry as Phase 2 progresses

Project Objectives & Benefits

- The NRIC ACT Project will benefit the nuclear industry through the following:
- Demonstrate the ability to fabricate and lift a basemat constructed from DPSC and place it on a concrete mudmat with acceptable tolerances and adequate contact
- Demonstrate the fabrication of DPSC submodules and field erection of the critical joint and section types
- The workforce will be educated in building techniques using advance welding and assembly processes
- Module fit up techniques will be advanced with digital twin technology to better align sections
- Automated welding techniques will be employed to prove a reduction in construction time and improved quality
- Capture Lessons Learned in a robust program to share with future projects
- Develop construction and fabrication workforce capability for DPSC modules
- Reduce regulator risks for using SC for containment and basemat structures
- Demonstrate improvement of costs and schedule of new nuclear build projects as well as mitigation of construction risk during construction preventing cost overruns and schedule delays experienced by many new nuclear builds.
- Establish and improve supply chain capabilities for mass deployment to nuclear industry

Digital Representation of the Demonstration Structure

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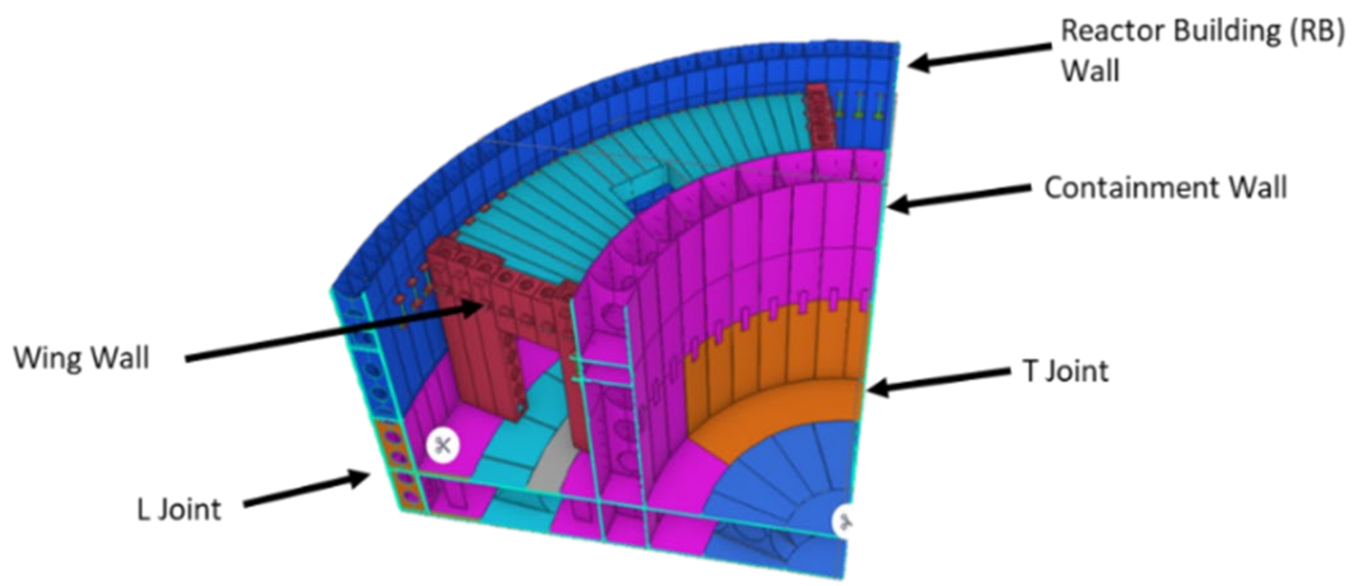


Tekla model of proposed demonstration section with steel brick components.

(DPSC Tekla model in development)

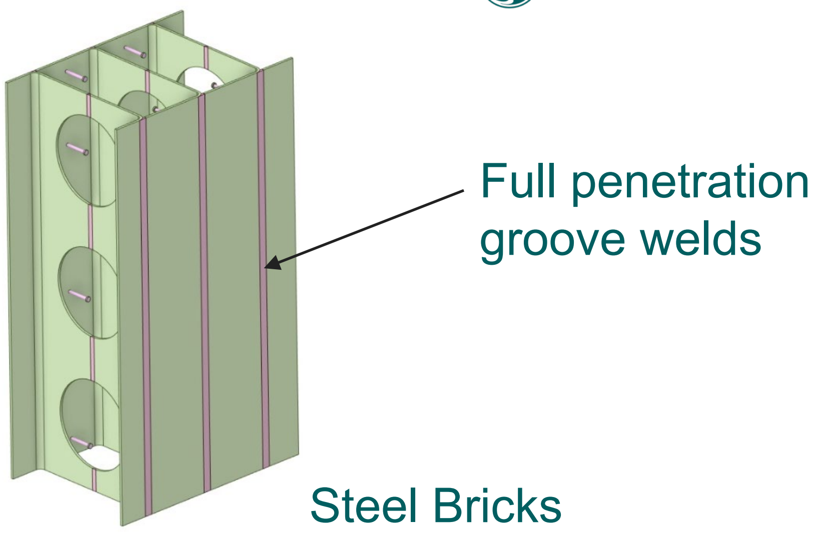
Steel Bricks™ vs DPSC Basic Design

Steel Bricks™ System

Full penetration welds are used throughout the fabrication of the Steel Bricks™ and the assembly of the structural components to increase strength. Full penetration welds are the only weld type for the faceplates permitted by AISC N690 Appendix N9.

Limitations using full penetration welds:

- High weld volume (20% of the demonstration structure/facility outer wall is weld filler metal)
- Extensive NDE program on full penetration welds
- Bending/forming requires heat treatment post-forming
- Fit-up and tolerance management is very challenging with radiused wall sections

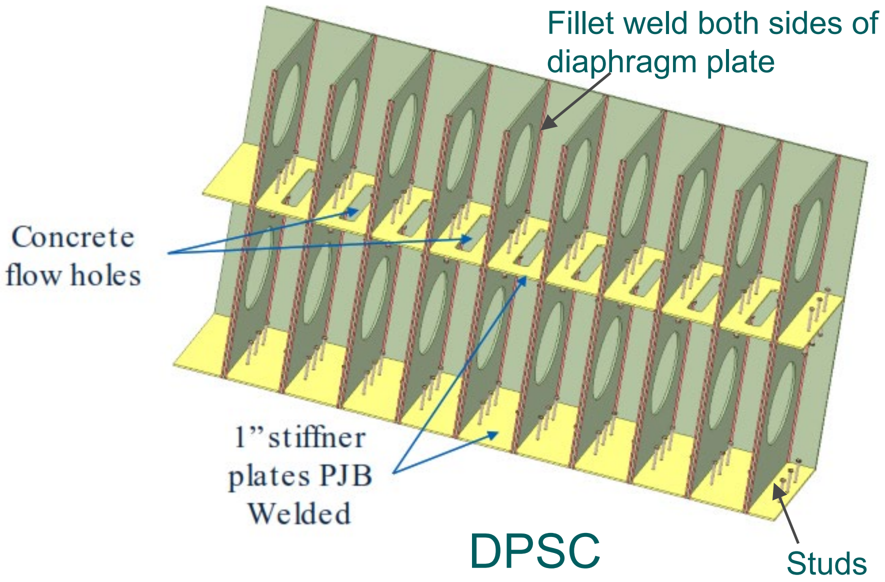


DPSC System

To address the construction limitations of the full penetration welds in Steel Bricks™ system, an alternative is to use a DPSC.

DPSC System Component

- Each DPSC component (or brick) is composed of two continuous plates connected using diaphragm plates
- A DPSC module is formed from multiple components (or bricks) arranged and welded together
- The DPSC modules are spliced together to form structural walls, floors, or mat foundation sections.



Q&A

Questions?

DOE Program Review

National Reactor Innovation Center (NRIC) Advanced Construction Technology (ACT)

Phase 1 – Prototype Test Plan

Purdue University

April 24, 2024

Agenda

- Executive Summary
- Mat Foundation Prototype Testing
- Containment Testing
- Containment-to-Mat Foundation Connection Testing

Executive Summary

- Goals of the prototype testing are to:
  - Assess and improve the constructability and feasibility of DPSC system and its connections used in SMR
  - Develop relevant experimental results for accelerating regulatory review of the SMR design using the DPSC system and its connections
  - A total of 9 DPSC scaled prototype specimens
  - These include scaled prototypes of:
    - Mat foundation
    - Containment
    - Containment-to-mat foundation connection

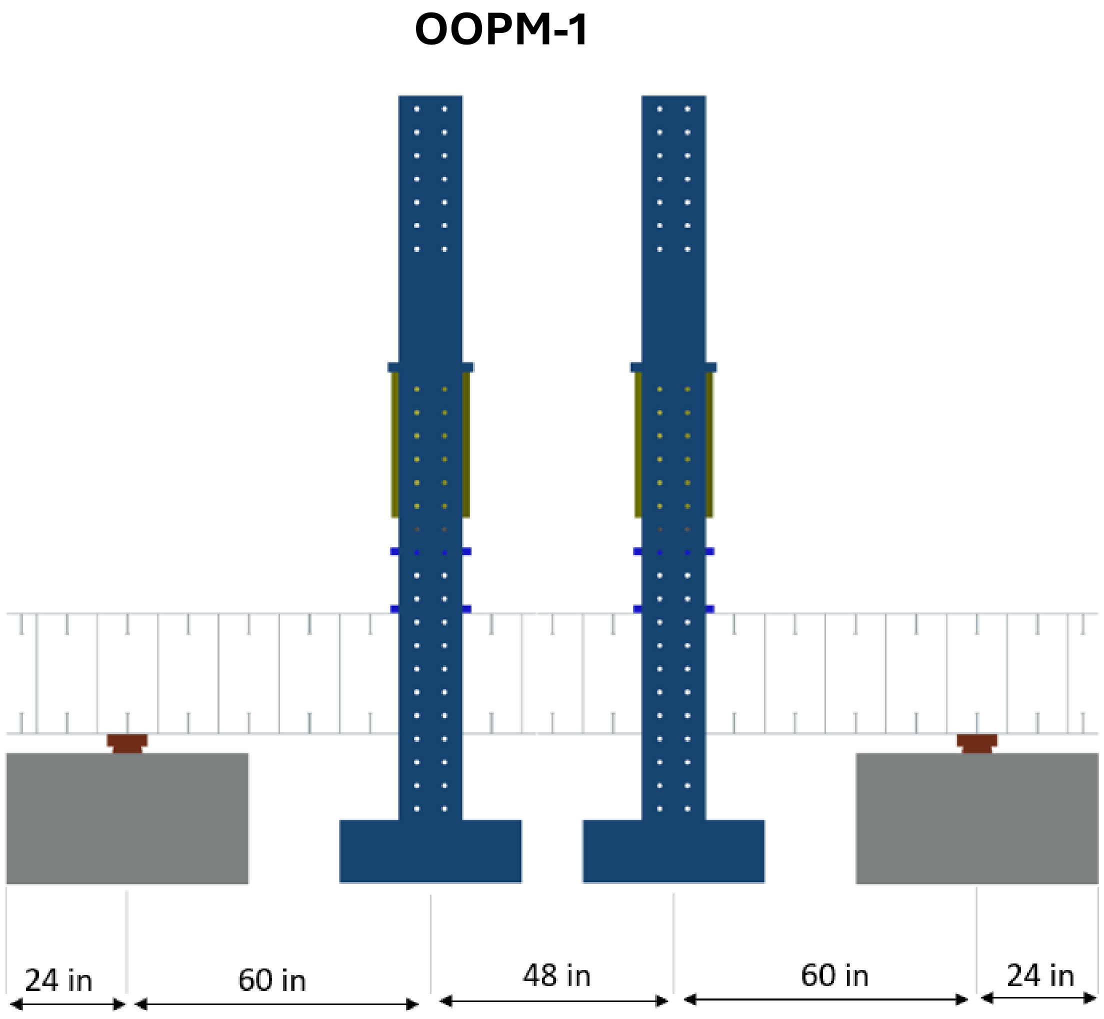
Mat Foundation Prototype Tests

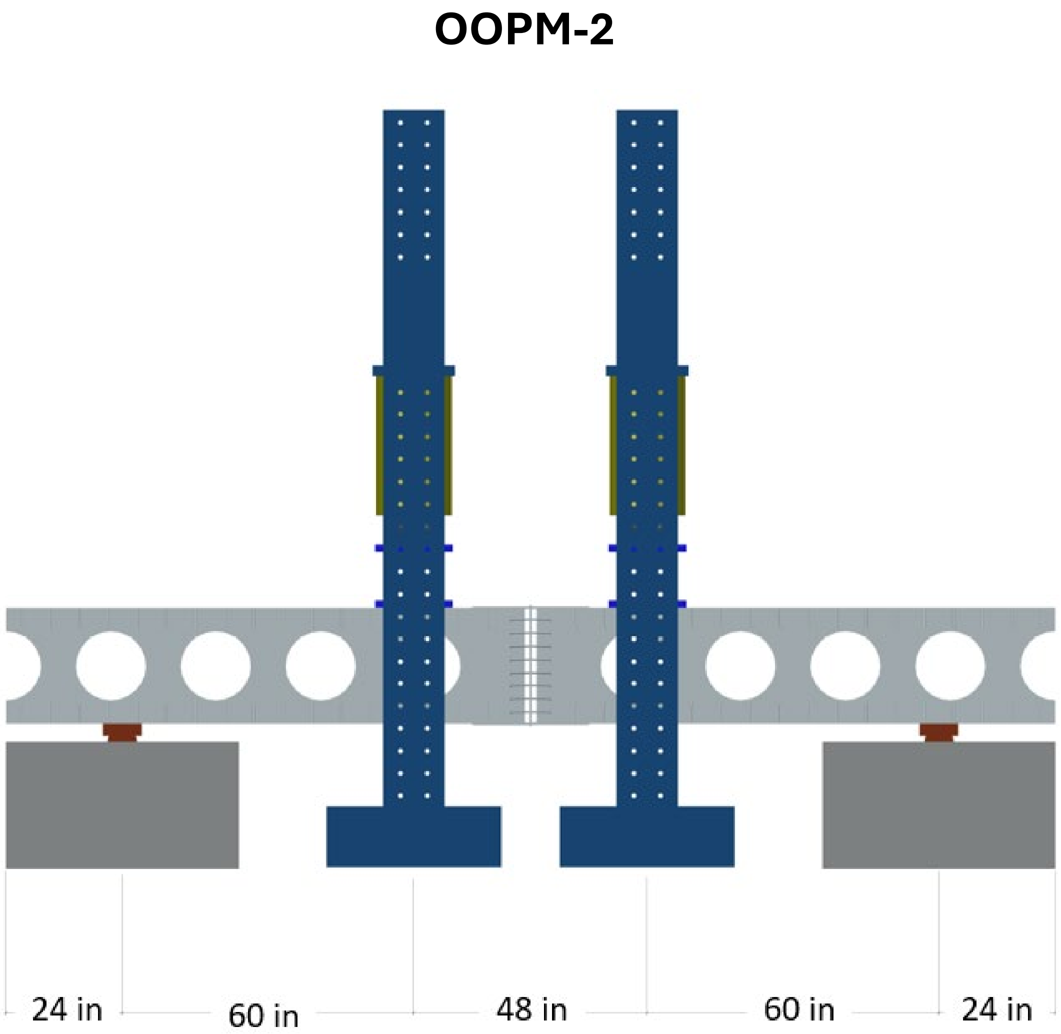
- Two out-of-plane flexure tests and two out-of-plane shear tests will be conducted on DPSC mat foundation prototype specimens with shear span (a/d) ratios of 2.5.
- These tests will verify the out-of-plane flexure and shear strength equations.
- The tests will be performed at ambient temperature.

Mat Foundation Prototype Tests

Brief Summary of OOPM and OOPV Tests							
Tests	Corresponding Prototype	Specimen Number	Scale	Section thickness, in	Plate thickness, in	Orientation	Note
Out-Of-Plane Flexure (OOPM)	Mat Foundation	1	1:2	24	¼	1	Splice in Flexure
		2	1:2	24	¼	2	
Out-Of-Plane Shear (OOPV)	Mat Foundation	1	1:2	24	¼	1	Splice in Shear
		2	1:2	24	¼	2	

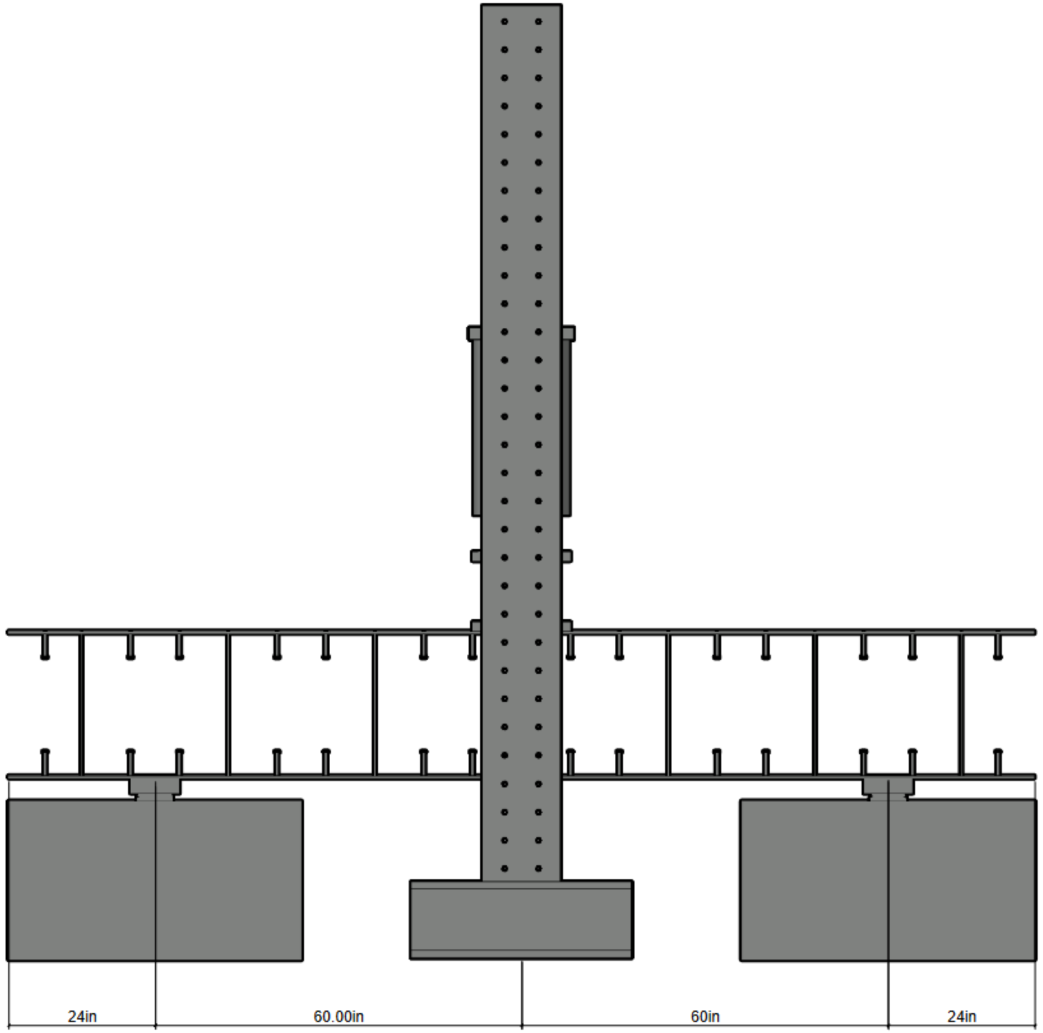
Test Setup and Specimen Drawings-OOPM



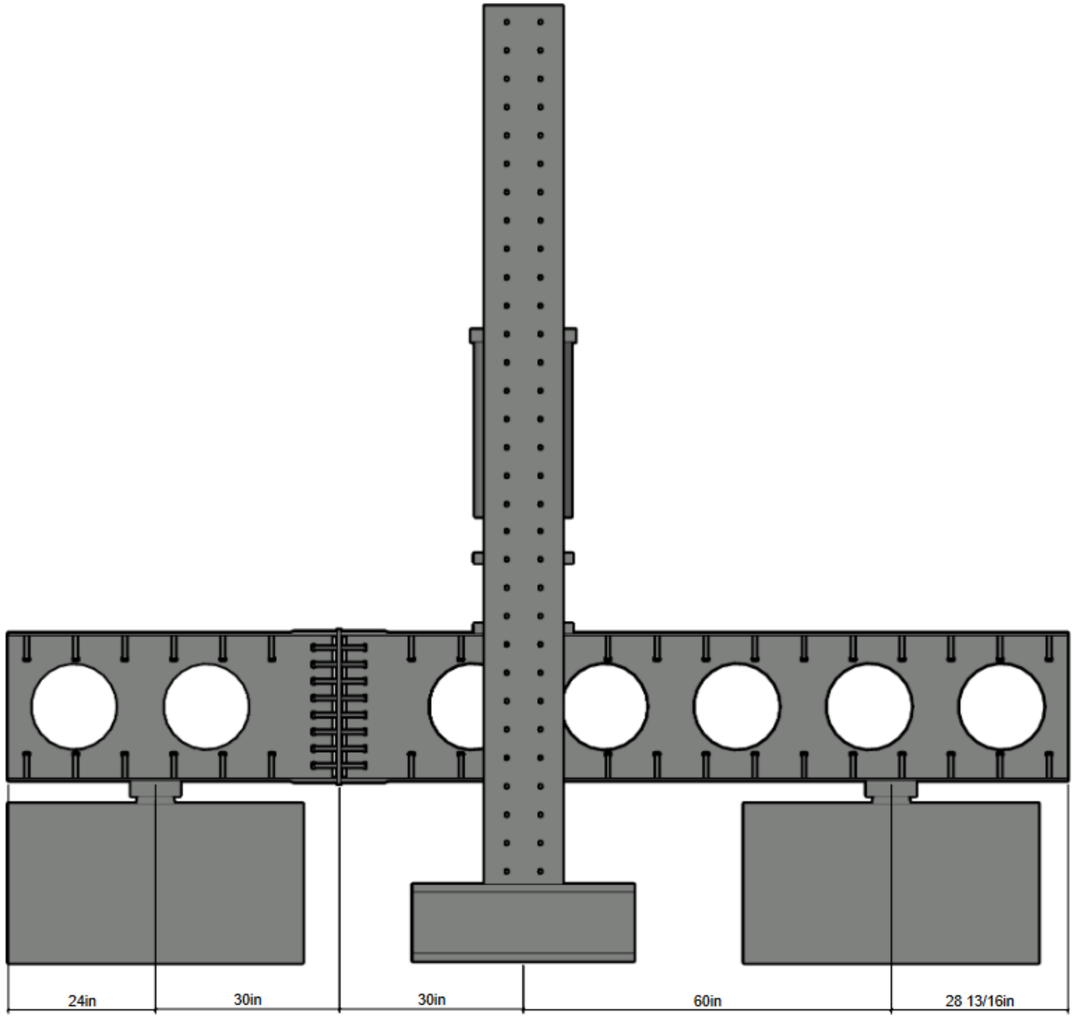


Test Setup and Specimen Drawings-OOPV

OOPV-1



OOPV-2

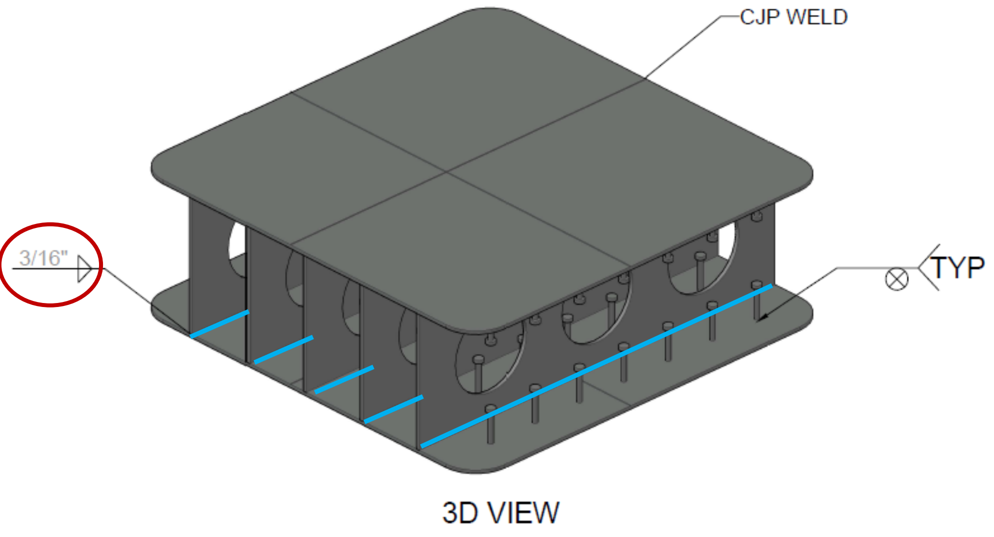


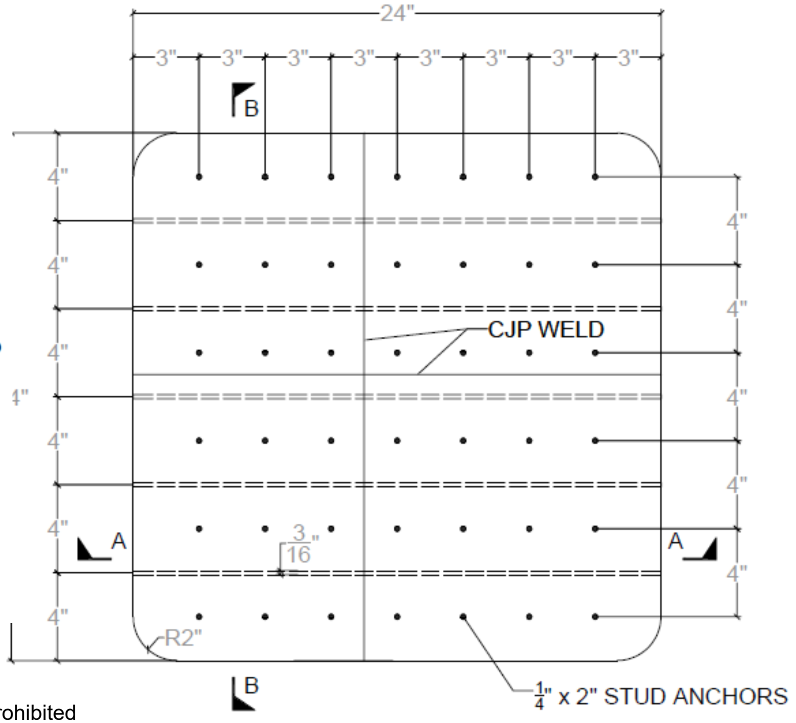
Containment Prototype: Bi-Axial Tension Test

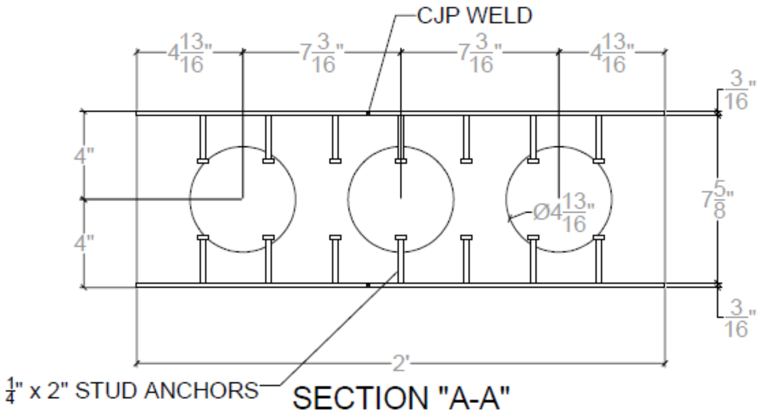
- Two bi-axial tension tests will be conducted on DPSC containment prototype specimens to verify that DPSC containment with unique splicing details can withstand accidental pressure and thermal loading conditions with acceptable steel strain limits
- These tests will simulate the bi-axial loading condition induced by accidental pressure and thermal loading conditions
- The specimen was designed as a 1/4 scaled prototype of the containment. All two specimens are 24 in by 24 in by 8 in with a plate thickness of 3/16 in

Containment Prototype: Bi-Axial Tension Test

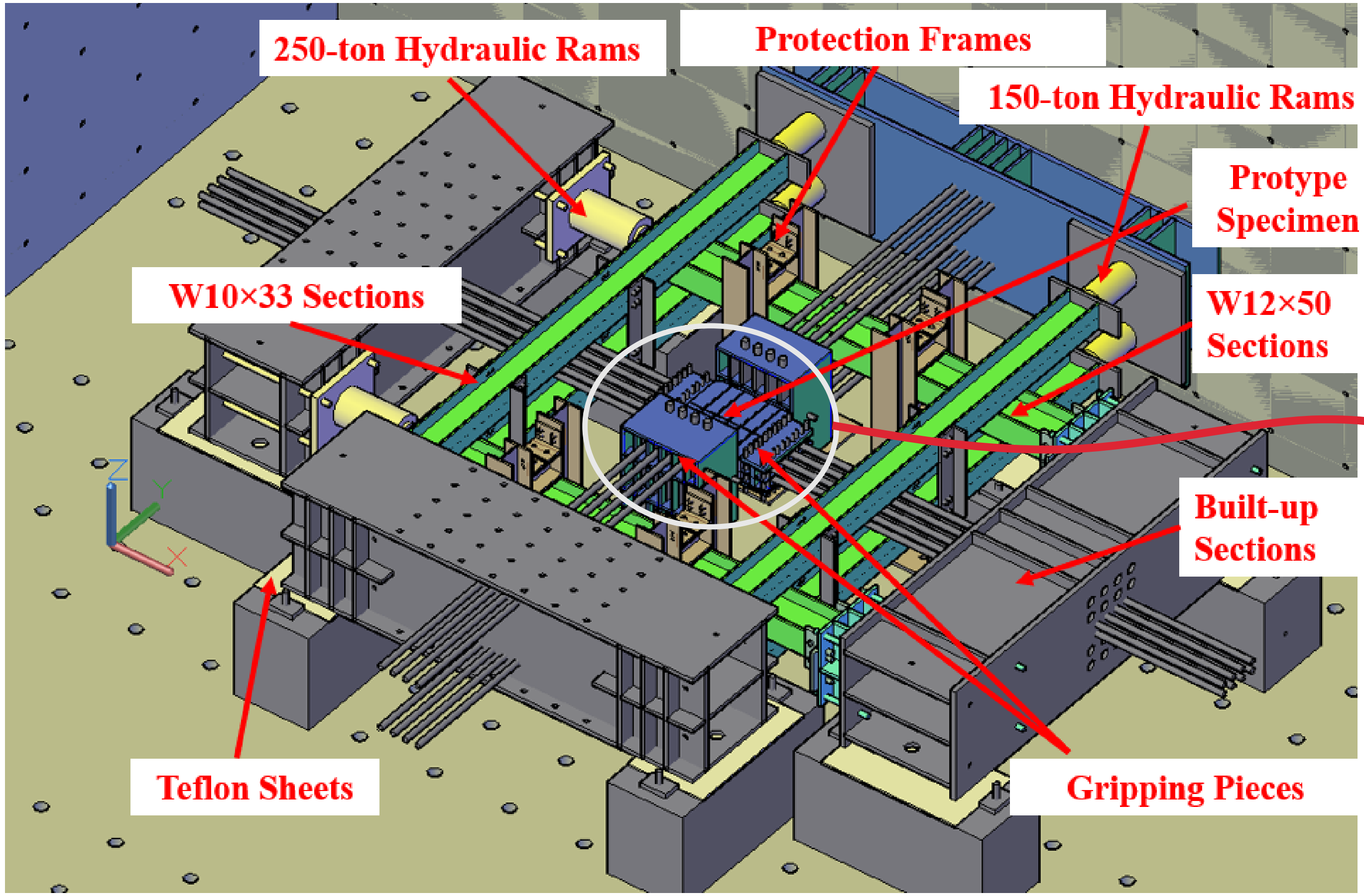
Specimen	Width (in)	Length (in)	T_s (in)	t (in)	Steel Grade (ksi	Loading **Orientation**	Thermal Effect
1	24	24	8	3/16	36	One	No
2	24	24	8	3/16	36	One	Yes

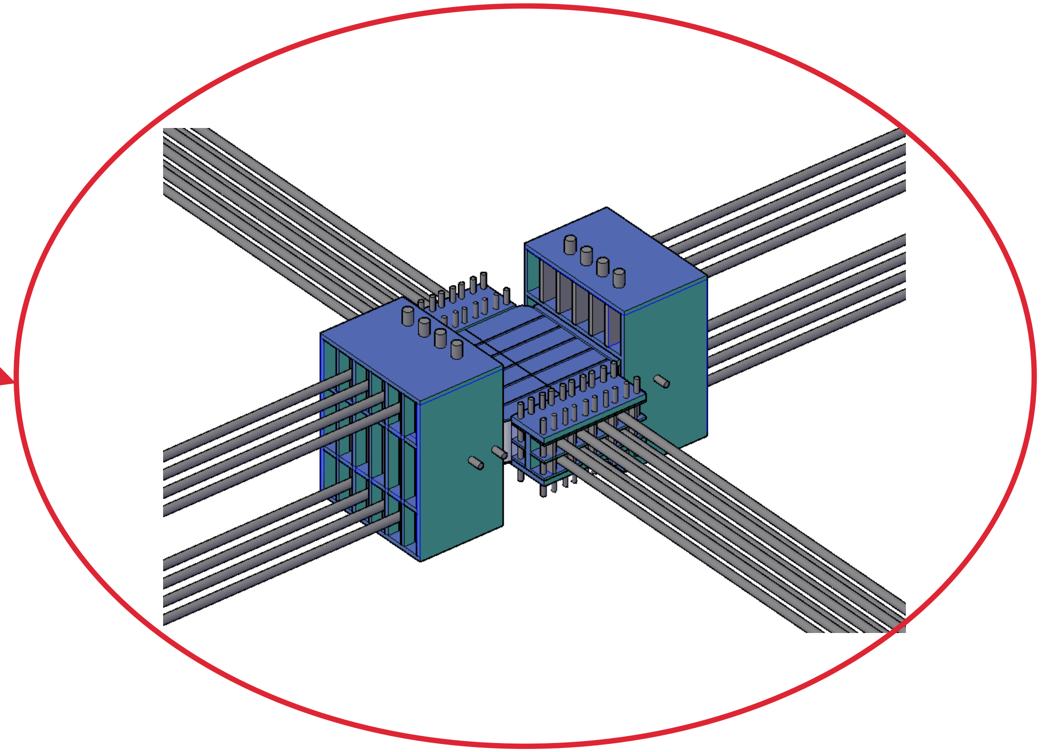






Containment Prototype: Bi-Axial Tension Test





Containment-to-Mat Foundation Connection: In-Plane Shear Tests

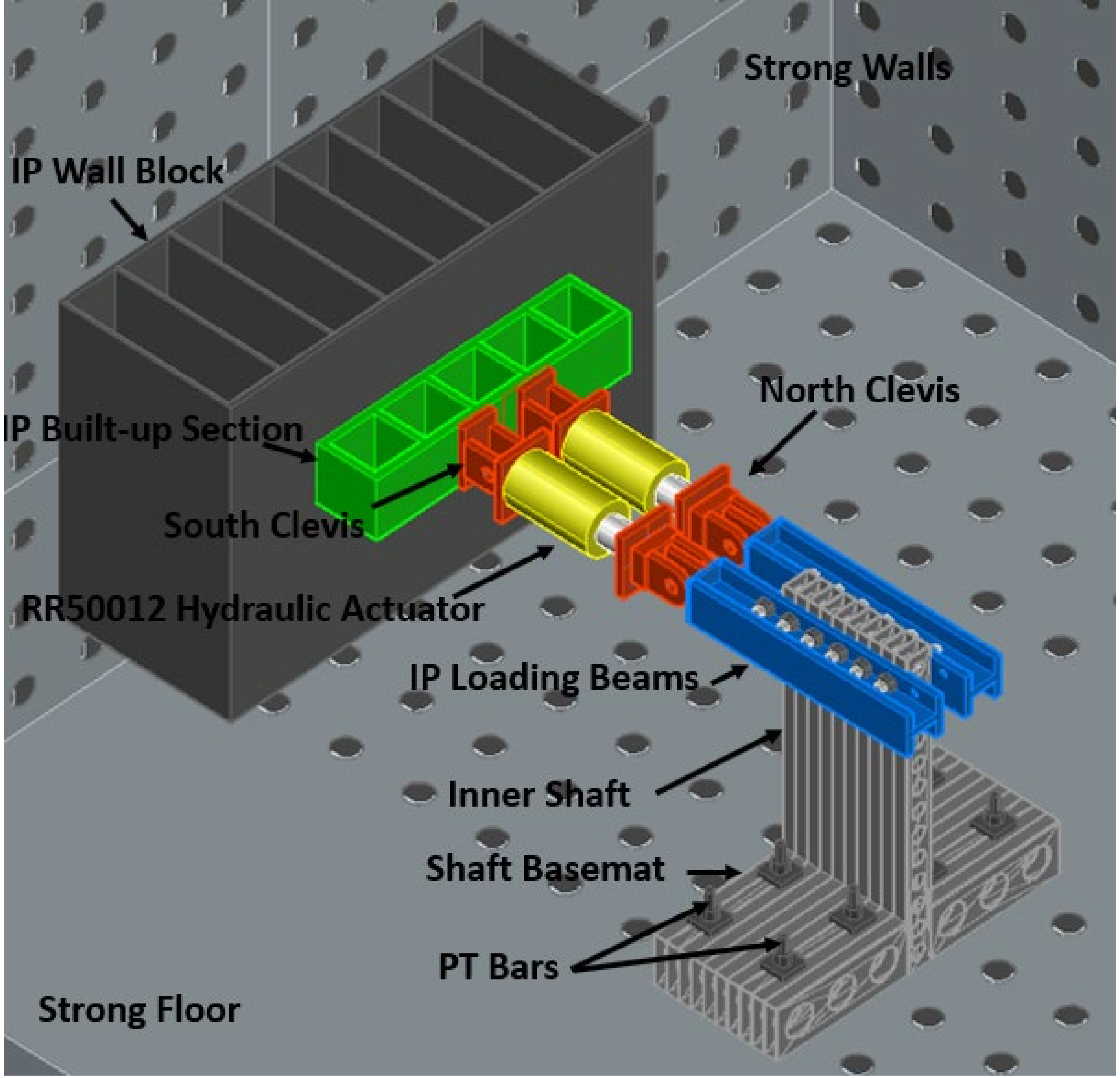
- Three containment-to-mat foundation connection DPSC prototype specimens will be tested by subjecting them to cyclic in-plane shear loading and cyclic out-of-plane shear loading.
- The test results will verify that the connection details as well as splicing details are strong enough such that they can withstand design demands without any failure occurring in the connections.
- One of the three tests will be performed at ambient temperature and the other test will be performed at elevated temperature simulating accident thermal conditions.

Containment-to-Mat Foundation Connection: In-Plane Shear Tests

The specimens represent a 1:3 scale model of the full-scale structure connection.

Tests	Corresponding Prototype	Specimen Number	Scale	Section Thickness, in	Steel Plate thickness, in	Note
In-plane Shear	Inner Shaft-Mat Foundation Connection (IPV)	1	1:3	12 (IS) 16 (SB)	3/16 (IS) 3/16 (SB)	Ambient IPV
		2	1:3	12 (IS) 16 (SB)	3/16 (IS) 3/16 (SB)	Thermal IPV
		3	1:3	12 (IS) 16 (SB)	3/16 (IS) 3/16 (SB)	Thermal OOPV

Test Setup



Strong Walls
IP Wall Block
IP Built-up Section
North Clevis
South Clevis
RR50012 Hydraulic Actuator
IP Loading Beams
Inner Shaft
Shaft Basemat
PT Bars
Strong Floor

Future Work

- Fabrication
- Shipping being arranged

NRIC Advanced Construction Activities

- Demonstration of Nondestructive Evaluation of Concrete in Mockup and Prototypes
- Demonstration of Digital Twins for Advanced Construction

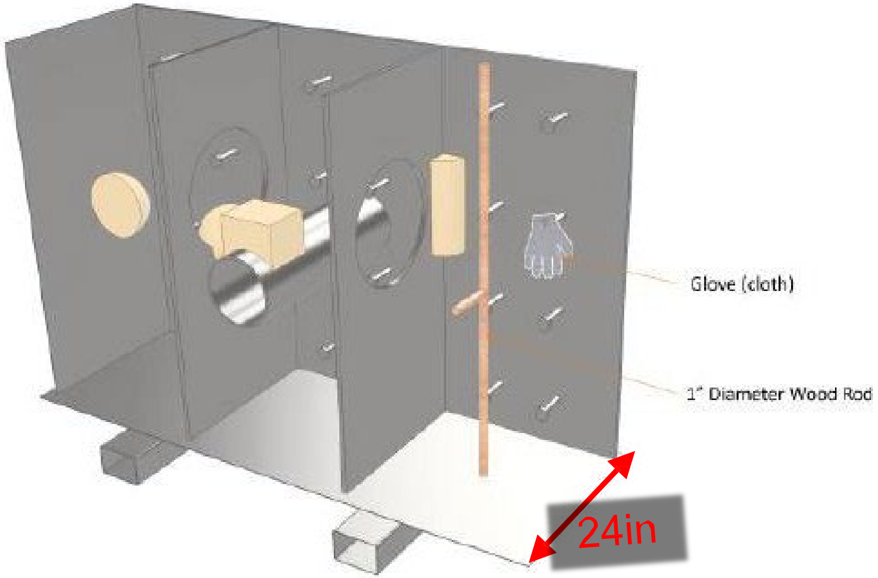
Bruce Greer
Principal Technical Leader – Advanced Reactor Engineering
EPRI Advanced Nuclear Technology Program

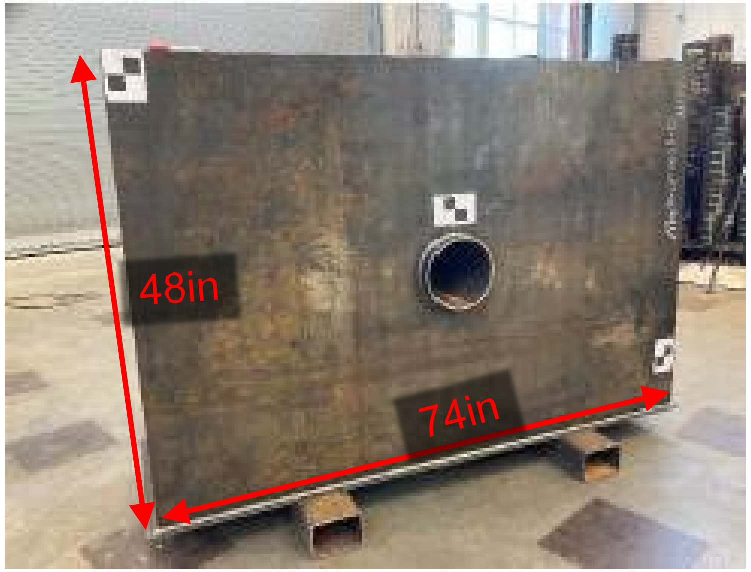
April 24, 2024

Non-destructive (NDE) Evaluation

NDE Goals and Approach

- Goals
  - Identify and test methods that can be deployed on a steel-plate composite (SC) structure during construction
  - Ensure the quality of the concrete through nondestructive examination
- Approach
  - Build a mockup of SC construction and test NDE methods
- NDE Methods
  - Maturity Method
    - Provides an estimation of compressive strength based on temperature history
  - Guided Wave Phased-Array
    - Long range ultrasonic examination technique for screening for defects in the steel plates
  - High Energy X-Ray
    - Detection of voids and foreign material contained within the concrete
  - Low-Frequency Ultrasound
    - Evaluation on of steel plate contact with concrete
    - Detection of defects with concrete





Results

- Maturity Method
  - The method can be deployed in the field following the guidance of ASTM C1074-17 “Standard Practice for Estimating Concrete Strength By the Maturity Method” as demonstrated in this study.
    - Perform a temperature history and compressive strength correlation in the laboratory for the concrete mix to be used for the project
- Guided wave phased array
  - The effects of attenuation, due to concrete placement on the interior walls of the mockup were negligible. The technique can be deployed via an access port for screening the condition of an outer steel plate.
    - The transducer needs to be in contact with the plate being inspected. Therefore, for screening the wall in contact with the soil an access port to the plate is necessary
- High Energy X-rays:
  - The technique can be used for detecting defects in concrete lined by steel plates.
    - The technique <u>requires access to both sides</u> of the structure being inspected.
- Low frequency ultrasound:
  - When tested on a concrete surface, the technique was demonstrated to be able to detect reflections up to a depth of 48-in. (1.22-cm). When testing on a surface of a 5/8-in. (16-mm) thick plate, the waves did not penetrate into the concrete and testing was not successful. The technique was capable of providing data from the full thickness of the steel-lined structures when the steel liner was at or below 0.31 in. (8mm).
    - Additional research ongoing at EPRI to investigate capability on thicker plate

Discussion

- General Comments
  - Access ports to allow for NDE of the back plate should be considered. The access ports are important because there are no NDE techniques that can bypass a steel plate and concrete to measure the thickness of a back plate.
    - This comment is relevant for a deeply embedded structure that has potential for corrosion when in contact with earth.
  - To monitor concrete placement in highly congested areas cameras can be installed inside the steel walls to monitor the concrete flow during placement. The cameras will remain embedded in the concrete after concrete hardening.
  - Mockups of highly congested areas should be fabricated to demonstrate the ability of the concrete to fill all the cavities within the area of interest.
  - Results from NDE report are still valid with change from Steel Bricks to DPSC
    - EPRI mockup was DPSC not Steel Brick

Digital Twins for Advanced Construction

Digital Twin Team

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

PURDUE UNIVERSITY

Amit Varma

Jungil Seo

UNIVERSITY OF NORTH CAROLINA CHARLOTTE

Robert Cox

Malind Khire

Matt Whelan

Younjin Park

Tim Kernicky

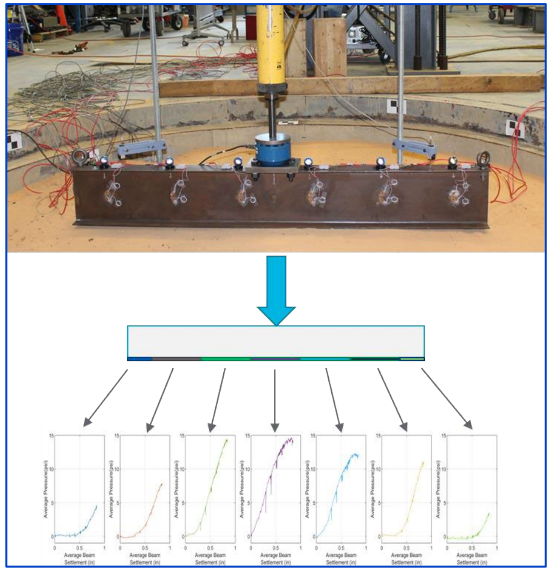
Jeff Hawkins

NUCLEAR AMRC

David Malley

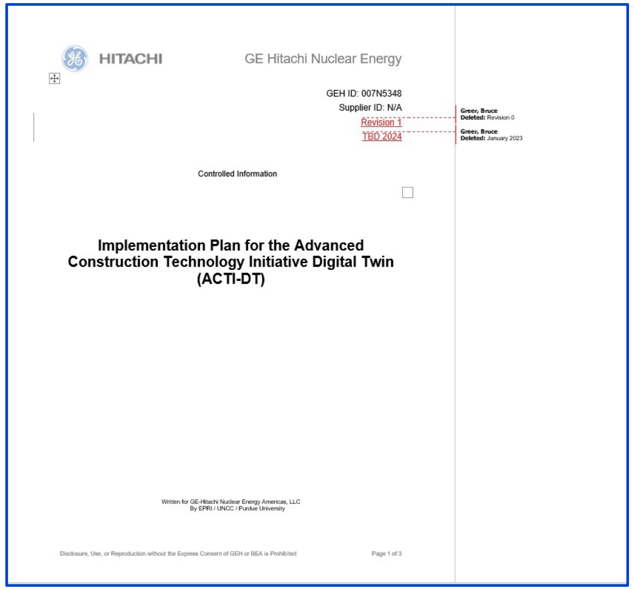
David Anson

Two Key Digital Twin Deliverables for Phase 1



- NRIC Mini Digital Twin Report
  - GEH ID: 007N5347
  - Describes work completed in Phase 1
  - Does not need revised

- Implementation Plan for the Advanced Construction Technology Initiative Digital Twin (ACTI-DT)
  - GEH ID: 007N5348
  - Describes planned implementation in Phase 2
  - Needs revised to address proposed design changes



HITACHI GE Hitachi Nuclear Energy

GEH ID: 007N5348
Supplier ID: N/A
Revision 1
TBD 2024

Greer, Bruce
Deleted: Revision 0
Greer, Bruce
Deleted: January 2023

Controlled Information

Implementation Plan for the Advanced Construction Technology Initiative Digital Twin (ACTI-DT)

Written for GE-Hitachi Nuclear Energy Americas, LLC
By EPRI / UNCC / Purdue University

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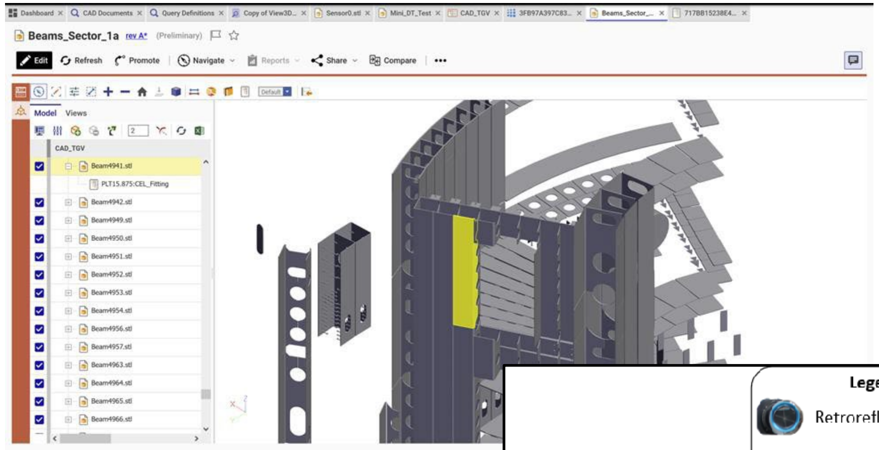
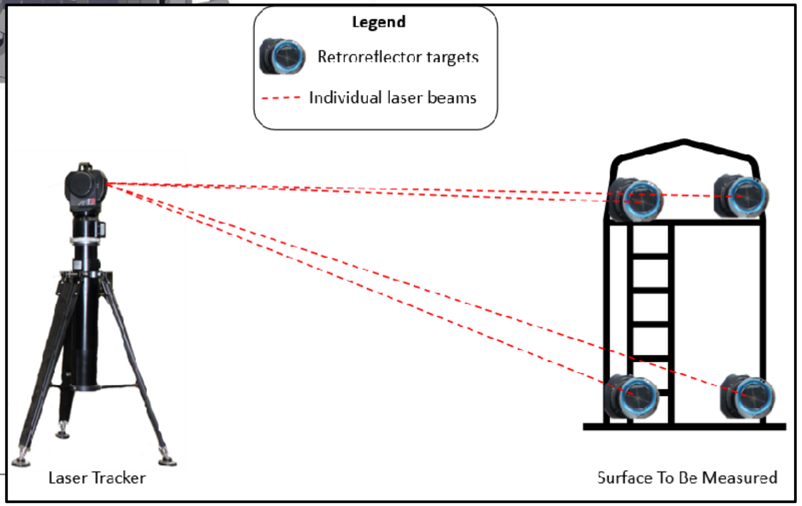
Page 1 of 3

Key Items Proposed for Included in Phase 2 Plan (1 of 2)

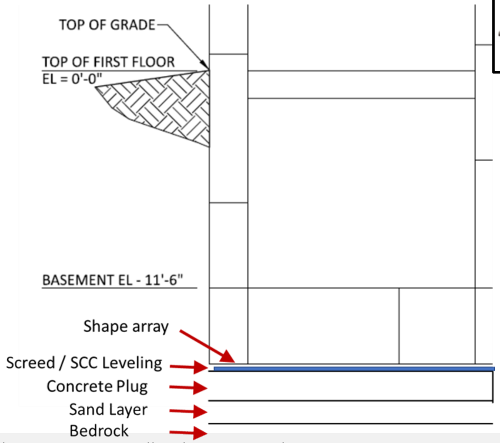
- Creation of data-sharing platform known as Digital-Twin Environment (Section 3 & Section 5.3.1 of 007N5348)



- “Scans” of modules and global structure throughout Phase 2 (Section 5.3.3 007N5348)
  - Semi-automated updates of BIM & FEA models

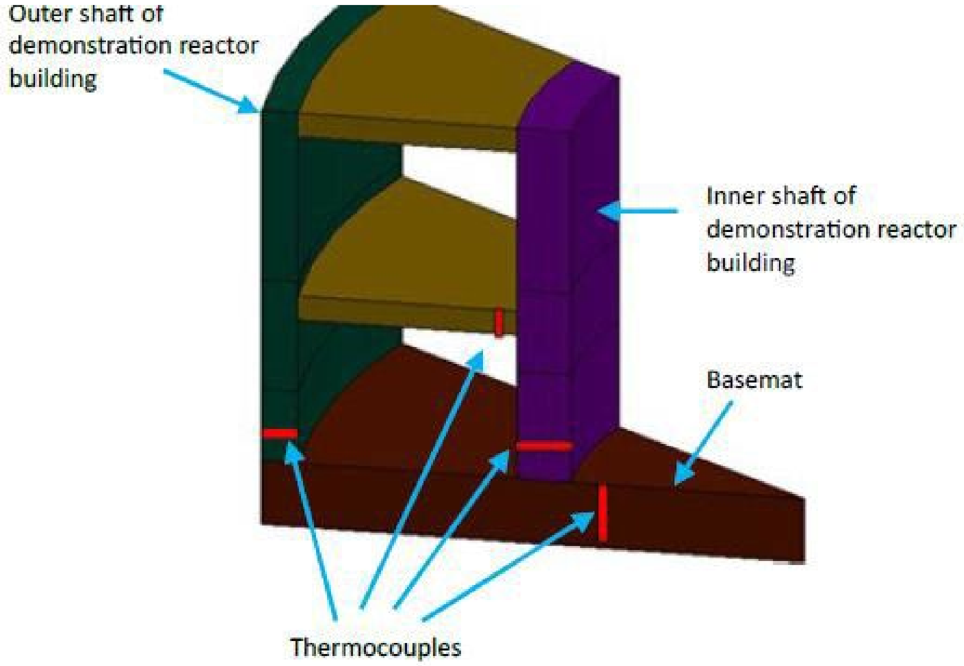


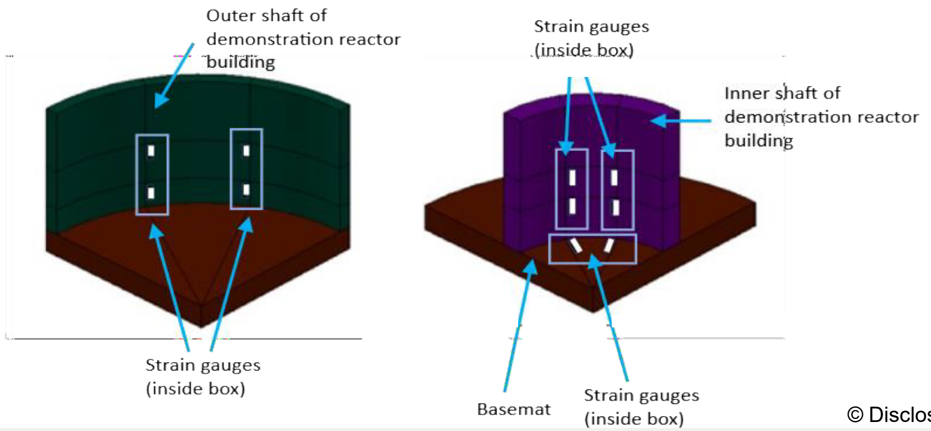
- Permanent logging of critical subsurface information (Section 4.2 007N5348)
  - Real-time monitoring of conditions behind secant-pile walls
  - Real-time monitoring of conditions under basemat



Key Items Proposed Included in Phase 2 Plan (2 of 2)

- Logging of critical structural sensors
  - Monitoring of strain on steel surfaces
    - This will feed into the structural model to complete the loop of data
  - Monitoring of temperature on steel surfaces
    - This information will be used to feed the analysis of the concrete strength
- Developing and testing DT use cases





Note: Strain gauge locations shown for illustration purposes only. Actual locations will be determined using modeling analysis.

Digital Twin Use Case Development

- Use Case Example 1: Module Fit-up
  - Laser tracker measurement performed in the field
  - Data uploaded to DT Environment
  - BIM model updates
- Use Case Example 2: Field Inspection Reporting and Records Repository
  - Inspector provided with tablet
  - PDF or similar files can be completed in the field
  - Data uploaded to DT environment
  - In addition to field inspections, should also be tested as repository for a percentage of quality records
- Use Case Example 3: Geotechnical Risk Reduction
  - Action based on differences between numeric models and sensor readings

Revisions to Phase 2 Plan Report due to Design Change

- Data backhaul plans will be modified to reduce number of backhaul locations
- Most Illustrations need updated for new building and sensor configurations
- Sensor installation sequencing will need to updated based on build
- Stain gauge sensing plan will need reviewed and updated
- Thermocouple placement will need updated for new concrete placement plan

Revisions to Phase 2 Plan Report due to Design Change

- Need to update guidance on scanning volume to be collected
  - Prior recommendation was 25% of full-scale structure
- Scanning and data collection milestones need updated for new construction sequence
- Geotechnical Model update use-case need to be evaluated to determine if it is still applicable
- Structural and Soil/Structure Model updates needs review to determine if recommendations are still applicable

TOGETHER...SHAPING THE FUTURE OF ENERGY®

2024 National Reactor Innovation Center (NRIC) Program Review

NRC Collaboration with (NRIC) under the Nuclear Energy Innovation Capabilities Act (NEICA)

Frederick Sock
Structural Engineer

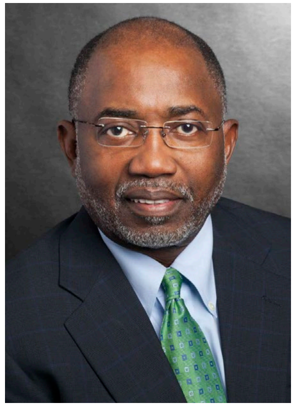
Allen Fetter
Senior Project Manager

Improving NRC's Technical Readiness for Regulation of Advanced Nuclear Reactor Technologies

- A February 2021 DOE-NRC MOU on Nuclear Energy Innovation includes the option for two NRC staff members to be on assignment with NRIC under the Intergovernmental Personnel Act

- This collaboration is intended to improve NRC's Technical Readiness for Regulation of Advanced Nuclear Reactor Applications

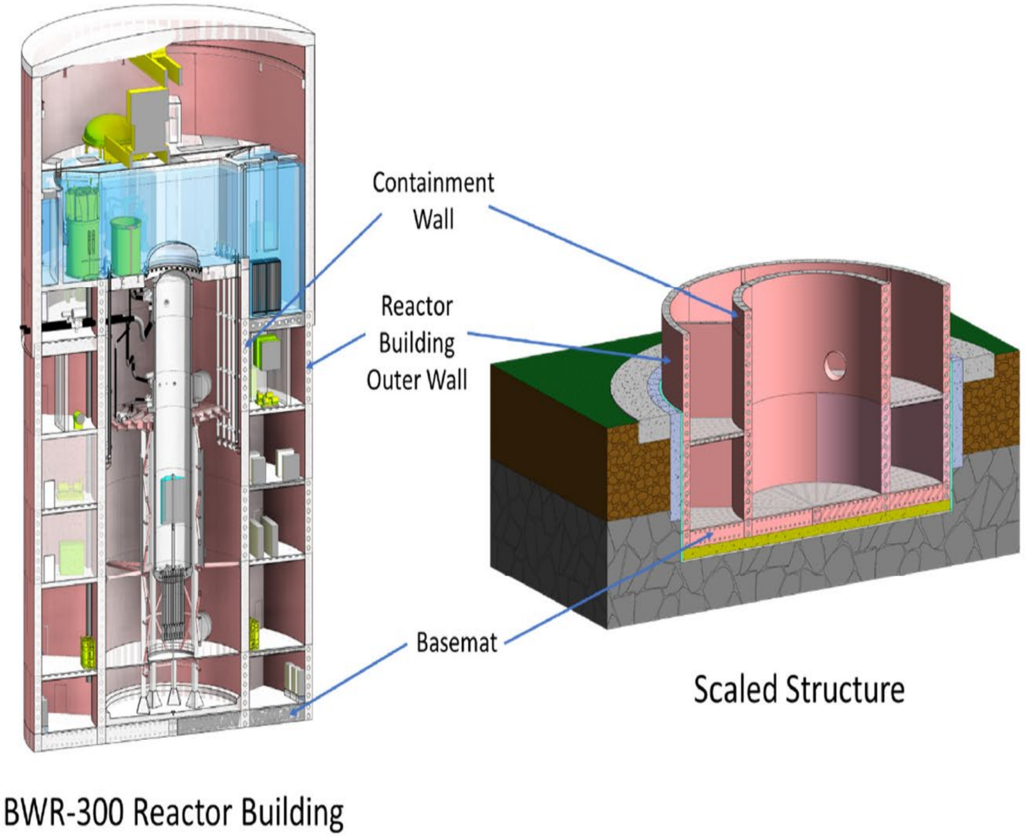
Allen Fetter- Office of Nuclear Reactor Regulation



Fred Sock - Office of Nuclear Regulatory Research

Improving NRC's Technical and Regulatory Readiness: Advanced Construction Technology (ACT) Initiative

- One of the programs within NRIC, the Advanced Construction Technology (ACT) Initiative, was launched to design and build a representative scaled down version of a portion of the reactor building of a Small Modular Reactor (SMR).



Improving NRC's Technical and Regulatory Readiness: Advanced Construction Technology (ACT) Initiative

- Construction of representative scaled down version of a portion of the reactor building of a Small Modular Reactor (SMR) would give NRC construction inspectors the opportunity to observe a demonstration project in advance of new reactor licensing and licensed construction

- NRC would be in a position to share observations during the demonstration project, as well as impart lessons learned from other recent reactor construction experience, to help optimize future NRC licensed construction

Other NRC-INL/NRIC Engagement Supporting Technical and Regulatory Readiness

- NRC-INL/NRIC staff have coordinated on a microreactor siting exercise at the INL complex to identify potential differences in DOE and NRC siting criteria and requirements

- Regarding any data collected during INL/NRIC demonstration projects, tests and experiments that NRC would review in the future, the NRC has stressed the importance of following Appendix B to 10 CFR Part 50, “Quality Assurance Criteria for Nuclear Power Plants and Reprocessing Plants” to ensure that the quality and pedigree of the data collected can be relied on for making necessary regulatory findings.

Benefits of the NRC-INL/NRIC Collaboration

Benefits to NRC

- Access and the opportunity to monitor and learn about the various NRIC tests, experiments and new construction technologies that can be leveraged to support staff readiness for NRC future licensing.
- The opportunity to evaluate the inspection and acceptance criteria the staff are currently using, and if needed, update the current NRC Inspection Manuals and Procedures as part of the Advanced Reactor Construction Oversight Program

Benefits to INL/NRIC

- The collaboration should help support a smoother transition from testing to commercialization, for a connection of NRIC team members to other expertise at the NRC and for the sharing of expertise, technical and regulatory knowledge