# Prefabricated High-Strength Rebar Systems with High-Performance Concrete for Accelerated Construction of Nuclear Concrete Structures


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# Today's Objective

- Provide an overview of our newly started project
- Receive your feedback on proposed research

# Outline

A) Objectives and Vision

B) Scope

C) Background

D) Project Tasks

E) Questions and Commentary



# Outline

**A) Objectives and Vision**

**1. Project objectives**

**2. Project vision**

**3. Potential benefits**

B) Scope

C) Background

D) Project Tasks

E) Questions and Commentary

# A.1 Project Objectives

Reduce field construction times and fabrication costs of reinforced concrete nuclear structures through:

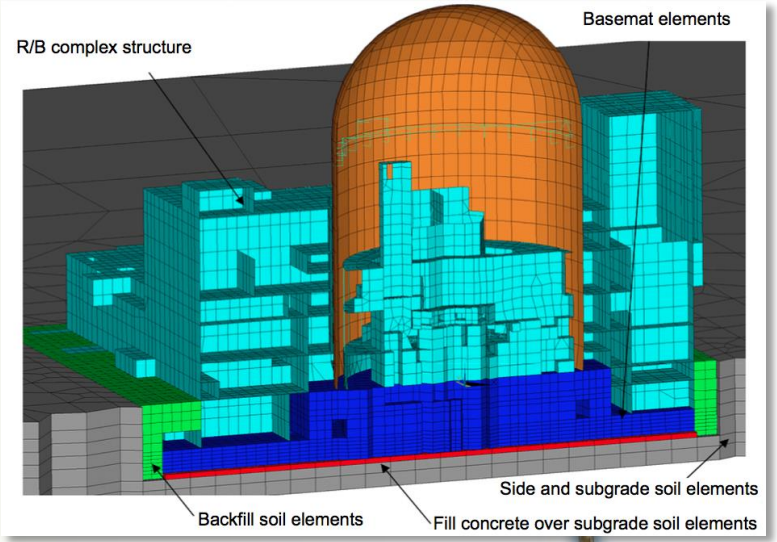
1) High-strength rebar

2) Prefabricated rebar assemblies, including headed anchorages

3) High-strength concrete

# A.2 Project Vision

- Explore effectiveness, code conformity, and viability of existing high-strength materials
- Focus on shear walls – most common lateral load resisting members in nuclear structures (pressure vessels not in scope)
- Aim to reduce complexities in rebar to improve construction quality and ease of inspection




US-APWR Design Control Doc.

# A.3 Potential Benefits

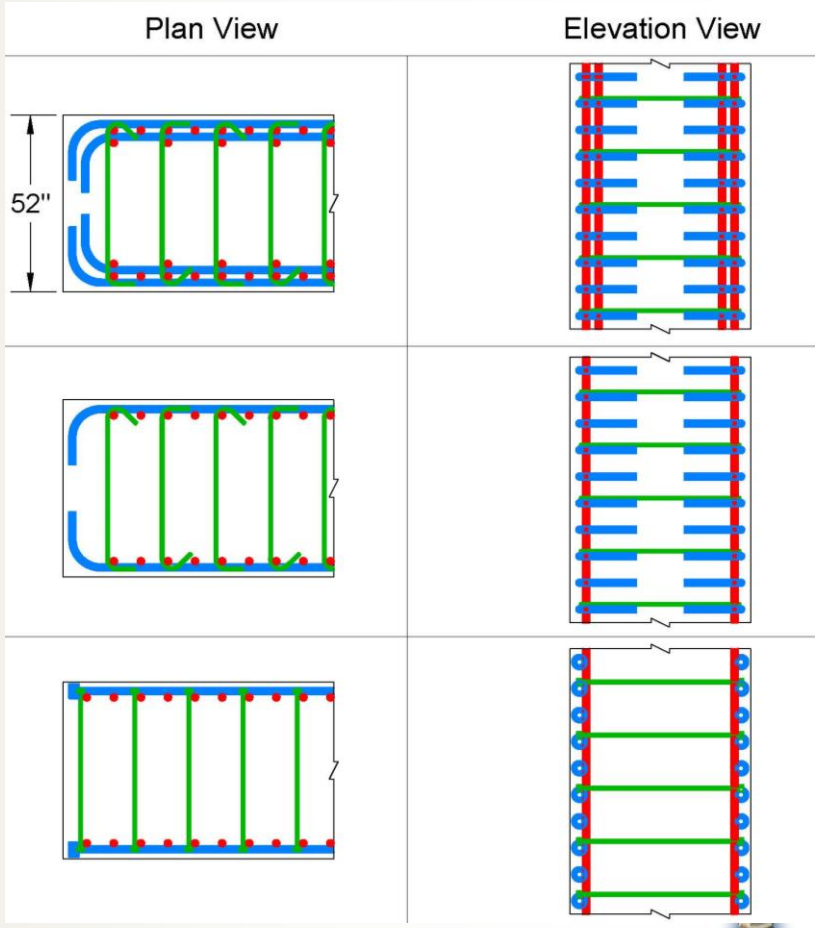
**Most Congested (current)**

***Multiple layers of hooked Grade 60 bars***

***Fewer layers of hooked high-strength bars***

**Least Congested (envisioned)**

***Fewer layers of headed high-strength bars***



# Outline

A) Objectives and Vision

**B) Scope**

**1. High strength materials**

**2. Prefabricated cages**

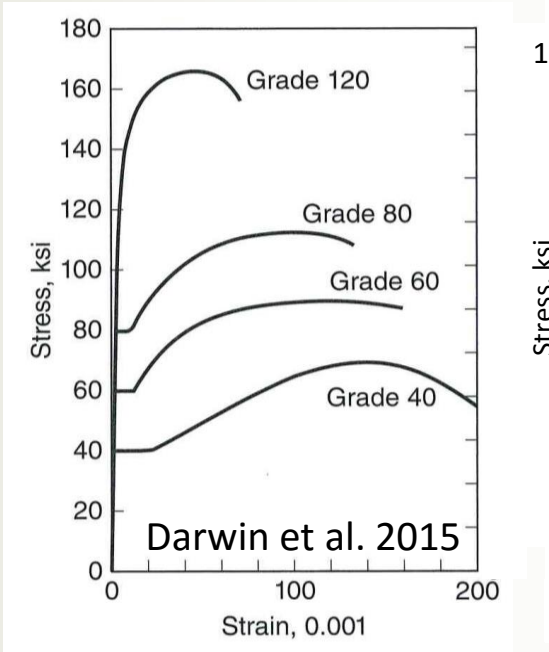
C) Background

D) Project Tasks

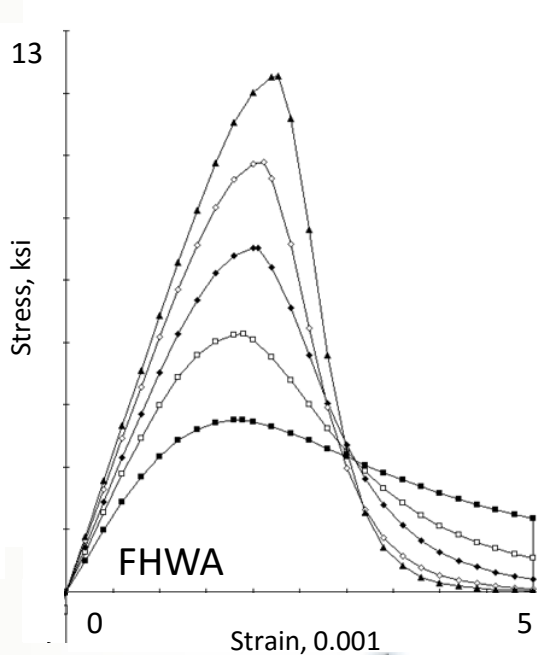
E) Questions and Commentary

# B.1 Scope: High Strength Materials

- High-strength rebar (up to grade 120) with high-strength, high durability concrete (around 15 ksi)
- Concrete strength of 5 ksi typical in current practice
- ACI 349 limits headed bars and shear reinforcement to grade 60



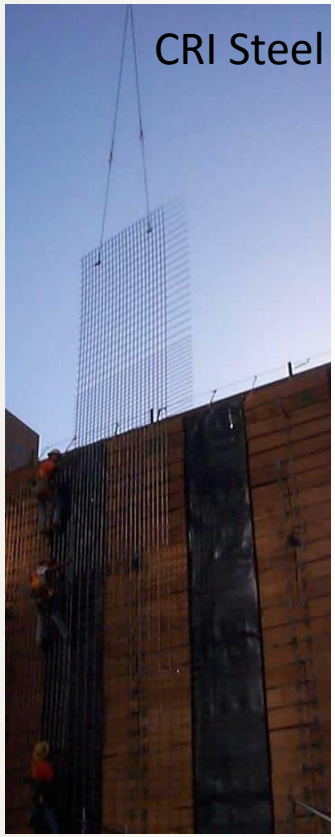

Steel

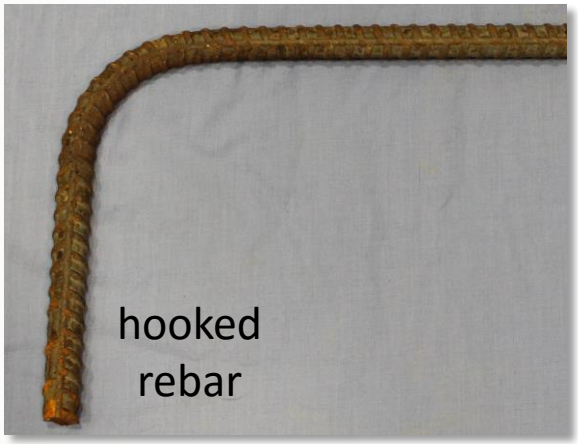



Concrete

# B.2 Scope: Prefabricated Rebar Assemblies

- Partially prefabricated cages for nuclear structural members (e.g., thick shear walls, slabs)
- Headed bars to reduce congestion (eliminates hooked bars)




# Outline

A) Objectives and Vision

B) Scope

**C) Background**

**1. High strength material advances**

**2. High strength material gaps**

**3. Nuclear shear wall advances & gaps**

D) Project Tasks

E) Questions and Commentary

# C.1 High Strength Material Advances

- Steel Advances
  - Material properties (NEHRP, 2014)
  - Analytical studies on buildings (Price et al., 2013)
  - Hooked anchorages (Darwin, 2015)
- Concrete Advances
  - Workable UHPC with $f'_c$ = 22 ksi (Mo et al., 2015)
  - Increased durability using substitute cementitious materials

# C.2 High Strength Material Gaps

- Interaction between high strength rebar and high strength concrete
- High strength rebar with heads
- Partially prefabricated rebar assemblies

# C.3 Nuclear Wall Advances & Gaps

- Advances
  - Nuclear shear walls with high strength materials (Ishimura et al., 1995)
  - Low- and mid-rise building walls with high strength materials (Kabeyasawa et al., 1998)
  - Low-rise shear walls (Gulec et al., 2011; Luna et al., 2015)
  - Nuclear walls with grade 80 rebar (Park et al., 2015)
- Gaps
  - Research on walls reinforced with grade 100 and 120 rebar with reinforcement ratios typical to nuclear structures

# Outline

A) Objectives and Vision

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**D) Project Tasks**

1. **Pre-test analytical study**
2. **Prefab rebar cages**
3. **Optimization, modeling, and design**
4. **Experimentation**
5. **Recommendations**

E) Questions and Commentary

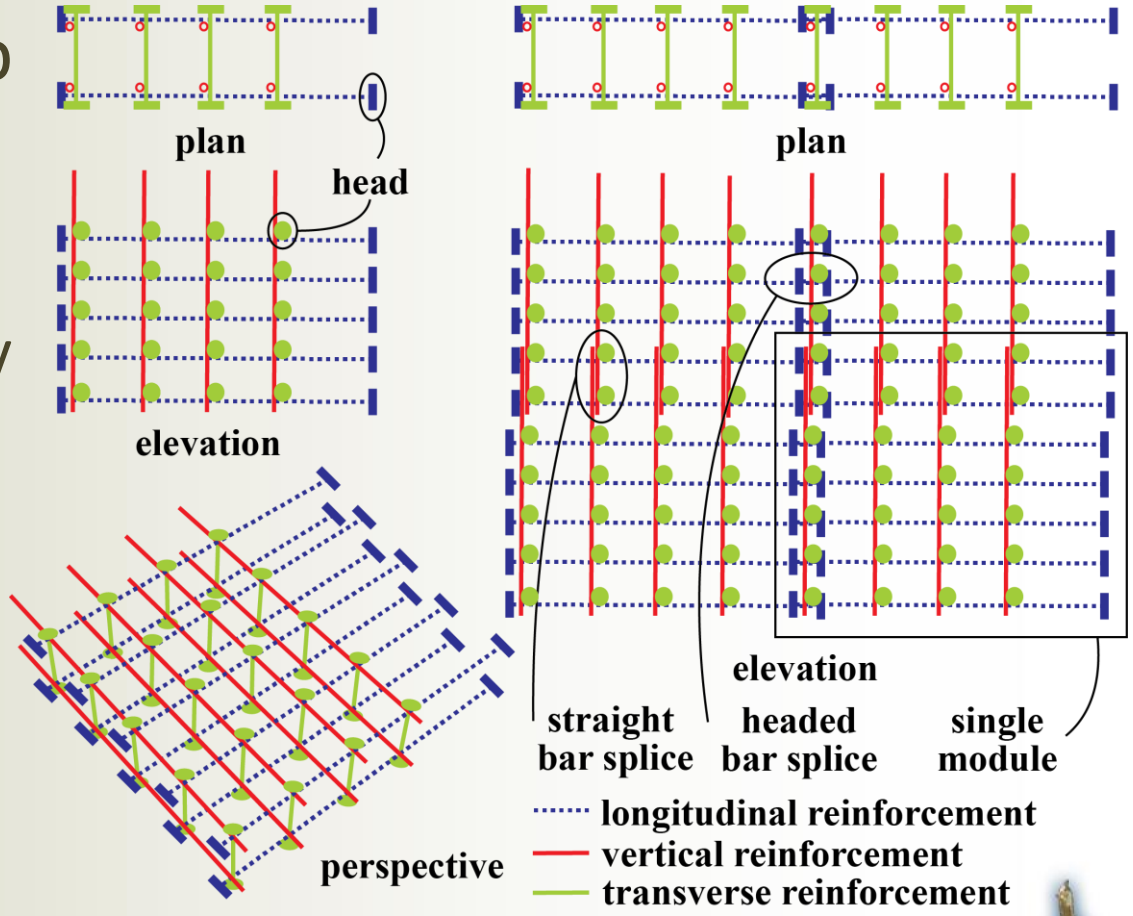
# D.1 Pre-test Analytical Study

Analytical study on limits/benefits, to:

- Establish effects of high-strength materials on structural deformation capacities
- Establish required concrete strengths so that use of high-strength rebar does not cause poor concrete performance
- Determine reduction in steel volumes
- Inform subsequent tasks of project

# D.2 Prefab Rebar Cages

- Evaluate prefab headed rebar cages for:
  - transportability
  - liftability
  - modularity
- Develop field procedures



# D.3 Optimization, Modeling, Design

- Develop optimization procedure to select materials and prefabrication solutions for:
  - minimum fabrication cost
  - minimum in-situ rebar cage assembly time
- Basic (design-level) and detailed (high-fidelity) numerical modeling
- Design of prototypes
- Pre-test design and analytical predictions

# D.4 Material Testing

- ASTM tests for concrete and rebar materials
- Rebar grades 100 & 120
- Preliminary mix designs 5 to 17 ksi

# D.4 Material Testing

| Constituents | 5 ksi | 10 ksi | 17 ksi |
|---|---|---|---|
| PC Type II (lb/yd$^3$) | 615 | 892 | 950 |
| Fly Ash (lb/yd$^3$) | - | 82 | 50 |
| Silica Fume (lb/yd$^3$) | - | - | 90 |
| Coarse Aggregate Crushed Limestone (lb/yd$^3$) | 1610 | 1730 | 1830 |
| Fine Aggregate (lb/yd$^3$) | 1510 | 927 | 1300 |
| Water (lb/yd$^3$) | 323 | 369 | 255 |
| Water/Binder Ratio | 0.53 | 0.38 | 0.23 |
| Superplasticizer (fl. oz./cwt) | 4.91 | - | 36 |
| Slump (in.) | - | - | 8+ |
| Actual 28 Day Strength (ksi) | 5.20 | 10.2 | 17.3 |

# D.4 Deep Beam Tests (Scale 1:6.5)

- Vary multiple characteristics on a representative wall slice to aid design of subsequent specimens

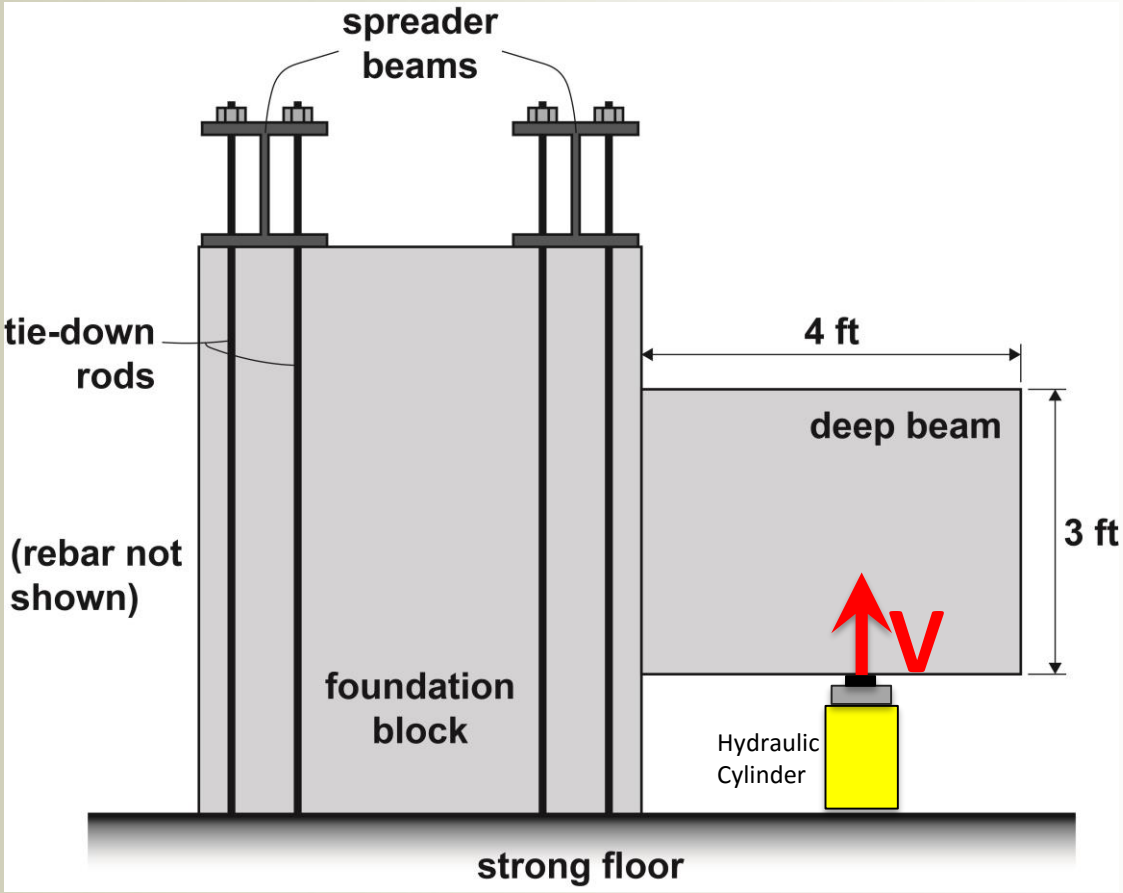
| Variables | Proposed Values |
|---|---|
| $f'_c$ (ksi) | 5 (control), 10, 17 |
| $f_y$ (ksi) | 60 (control), 100, 120 |
| Reinforcement Ratio (%) | 0.45 (TBD), 0.9, 1.3, 1.8 |
| Moment to Shear Ratio (M/V*L) | 0, 0.25, 0.5, 1, 1.25 |

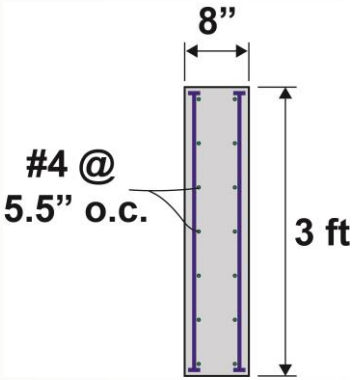
# D.4 Deep Beam Tests (Scale 1:6.5)

## Initial Proposed Specimens

| $f'_c$ (ksi) | $f_y$ (ksi) | Reinforcement Ratio (%) | M/V*L |
|---|---|---|---|
| 5 | 60 | 0.9 | 0.5 |
| 5 | 60 | 1.8 | 0.5 |
| 5 | 120 | 0.9 | 0.5 |
| 5 | 120 | 0.45 (TBD) | 0.5 |

# D.4 Deep Beam Tests (Scale 1:6.5)




Cross-Section (transverse bars not shown)

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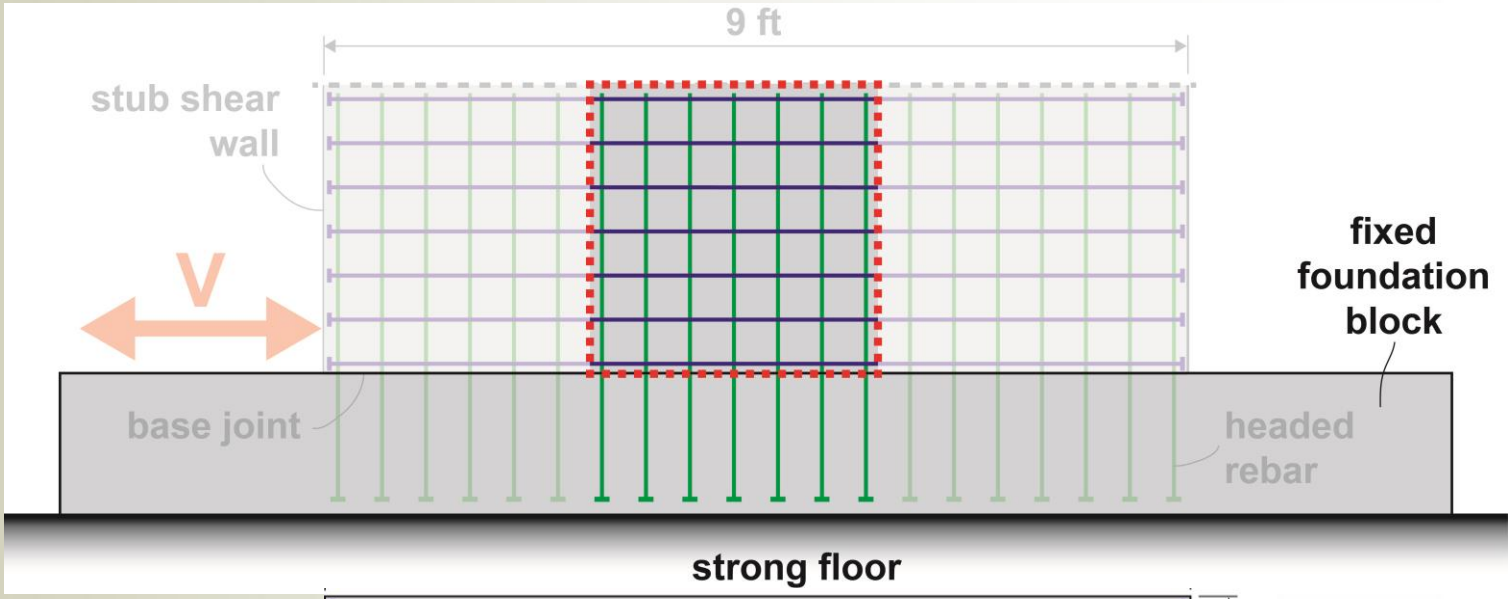
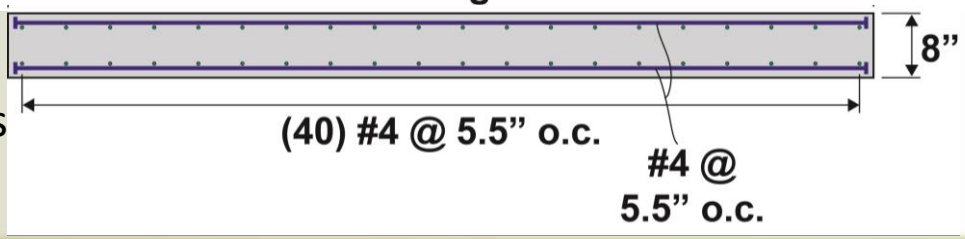
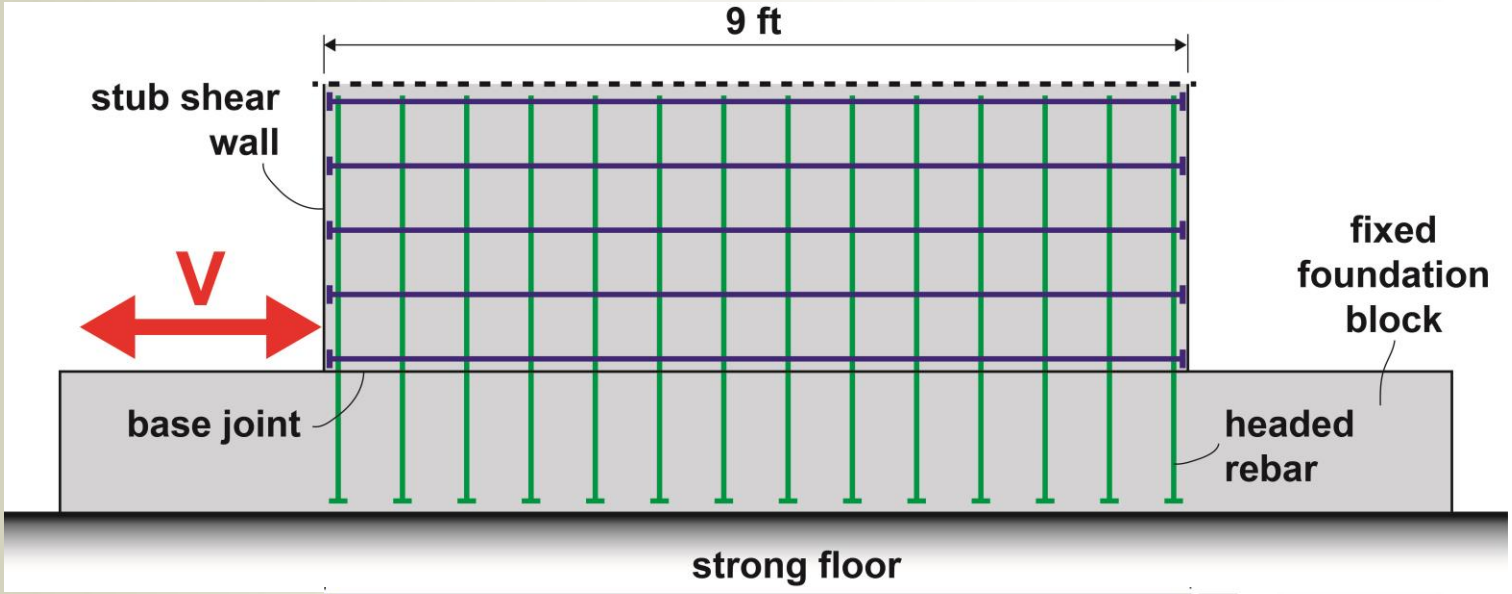



Cross-Section (transverse bars not shown)



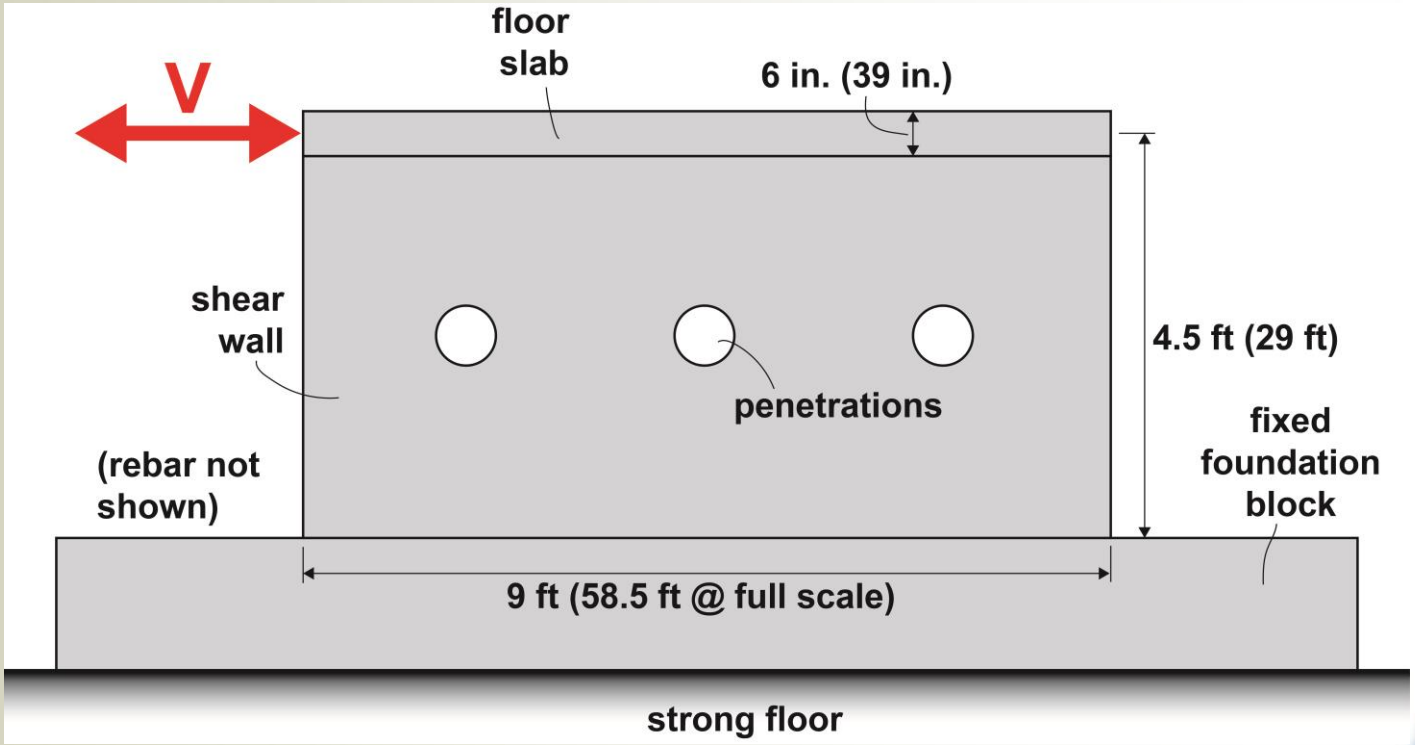
# D.4 Stub Wall Tests (Scale 1:6.5)

- Shear-wall-to-foundation joints under pure shear to establish shear friction strength



# D.4 Wall Panel Tests (Scale 1:6.5)

- Representative wall panels under moment+shear
- Includes thermal loads to explore thermal cracking



# D.5 Recommendations

- Design, modeling, and construction recommendations on:
  - Appropriate high-strength materials
  - Prefabricated headed rebar assemblies
  - Basic (design-level) and detailed (high-fidelity) models
  - Optimization for minimum cost/construction time
  - Assumptions/approximations for design and analysis
  - Effective field methods for concrete/rebar placement
- Design Procedure Document

# Feedback

*http://phsrc-nuclearwalls.nd.edu*