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

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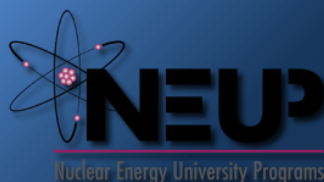Madalyn Sower[4]

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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

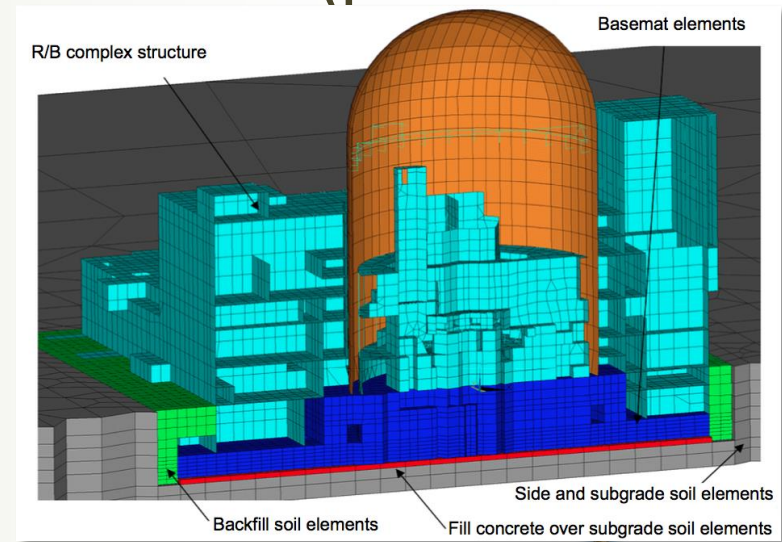C) Background

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 <u>existing</u> high-strength materials

- Focus on <u>shear walls</u> – most common lateral load resisting members in nuclear structures (pressure vessels not in scope)

- Aim to reduce <u>complexities in rebar</u> to improve construction quality and ease of inspection

US-APWR Design Control Doc.

A.3 Potential Benefits
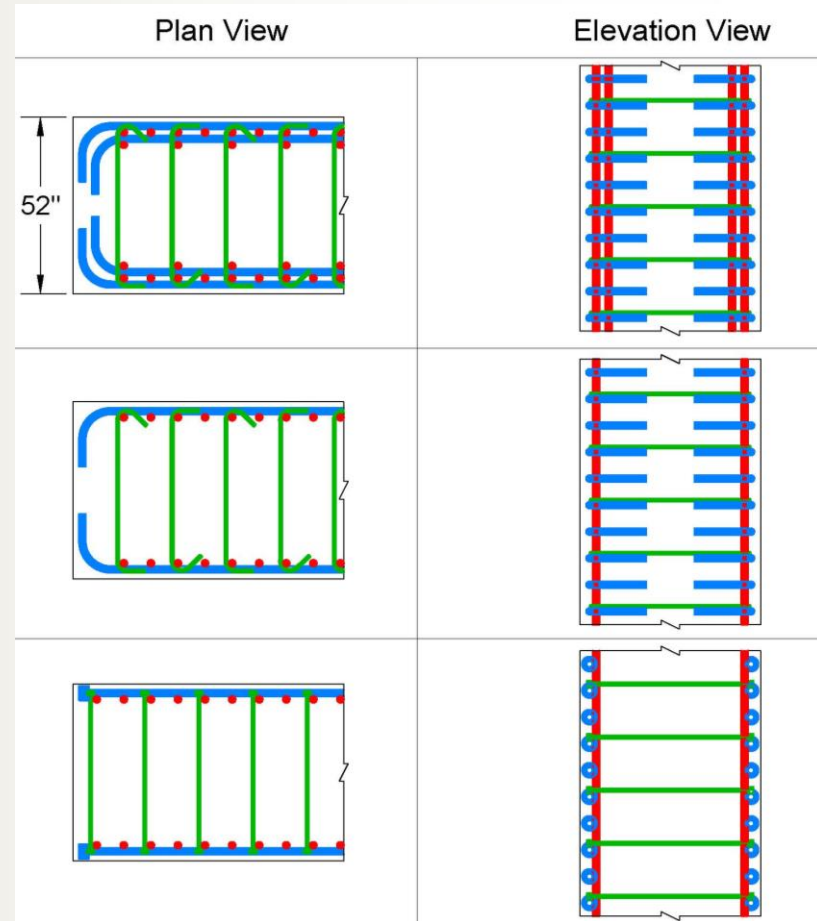
Most Congested (current)

Multiple layers of hooked Grade 60 bars

Fewer layers of hooked high-strength bars

Least Congested (envisioned)

Fewer layers of headed high-strength bars

Plan View

Elevation View

52"

Outline

A) Objectives and Vision

B) Scope

    1. High strength materials

    2. Prefabricated cages
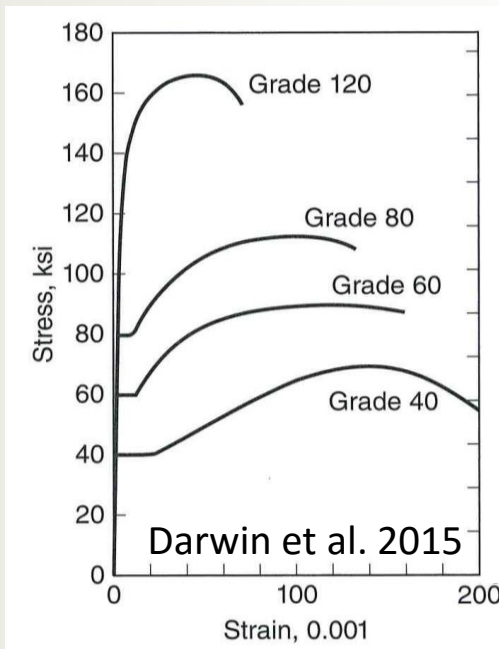
C) Background

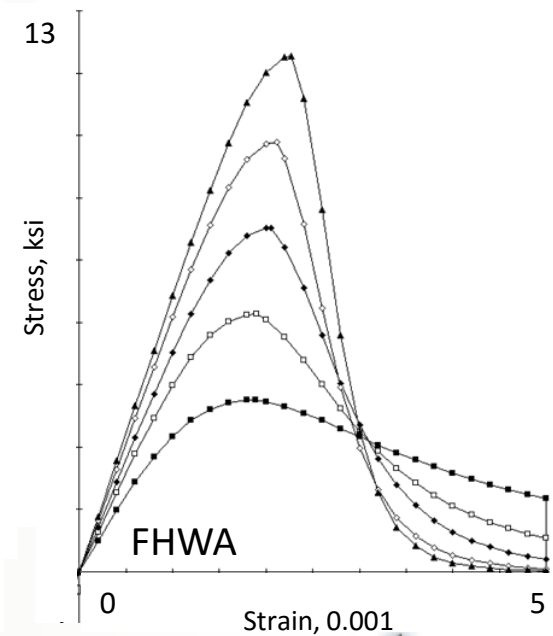D) Project Tasks

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

Darwin et al. 2015

FHWA

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)

CRI Steel

hooked rebar

headed rebar (HRC-USA)

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

B) Scope

C) Background

D) Project Tasks

    1. Pre-test analytical study

    2. Prefab rebar cages

    3. Optimization, modeling, and design

    4. Experimentation

    5. Recommendations
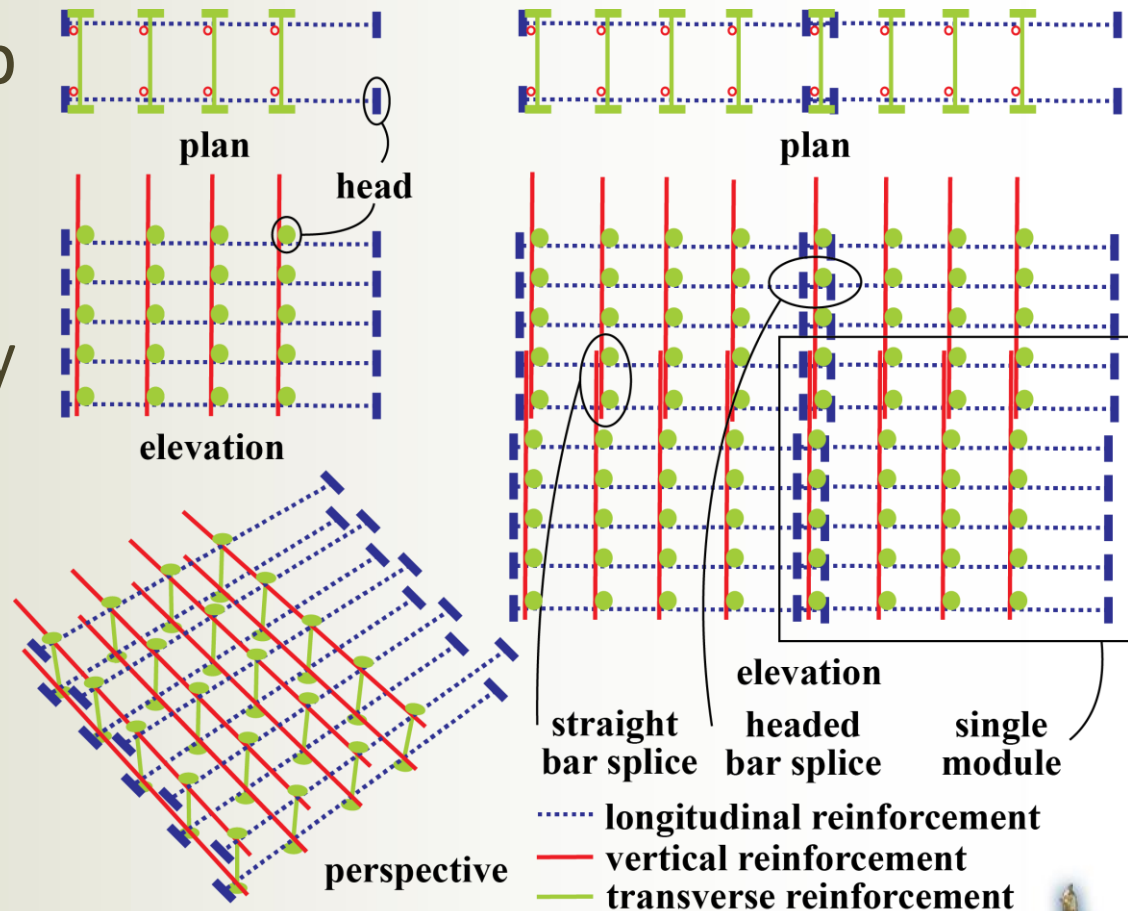
E) Questions and Commentary

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

plan

head

elevation

perspective

plan

elevation

straight bar splice

headed bar splice

single module

···· longitudinal reinforcement
— vertical reinforcement
— transverse reinforcement

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/yd³)	615	892	950
Fly Ash (lb/yd³)	-	82	50
Silica Fume (lb/yd³)	-	-	90
Coarse Aggregate Crushed Limestone (lb/yd³)	1610	1730	1830
Fine Aggregate (lb/yd³)	1510	927	1300
Water (lb/yd³)	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 <u>slice</u> to aid design of subsequent specimens

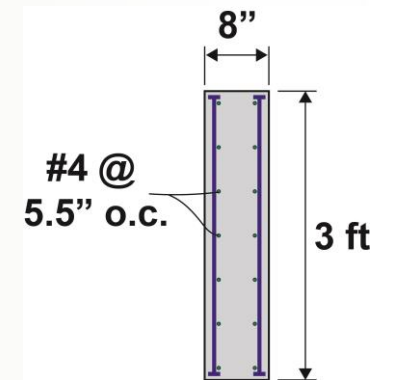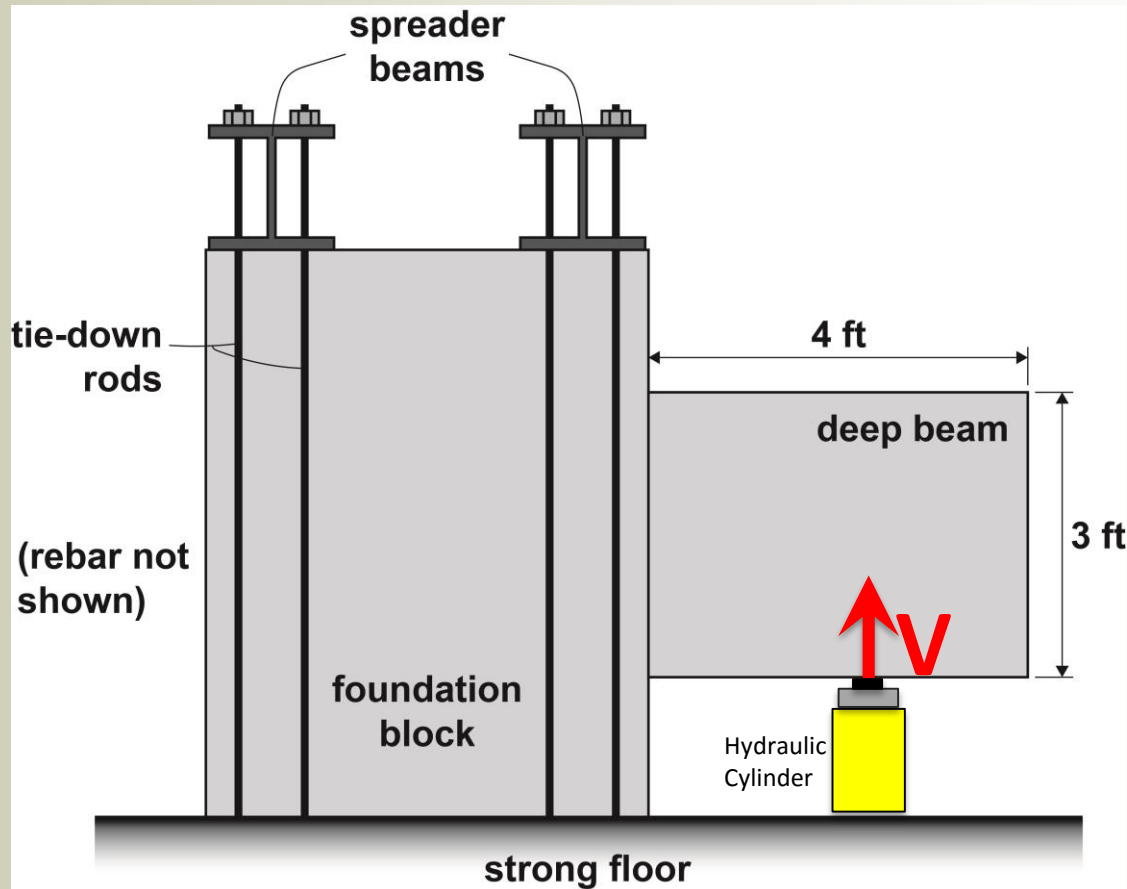| Variables	Proposed Values
f'_c (ksi)	5 (control), 10, 17
f_y (ksi)	60 (control), 100, 120
Reinforcement Ratio (%)	0.45 (TBD), 0.9, 1.3, 1.8
Moment to Shear Ratio (M/V*L)	0, 0.25, 0.5, 1, 1.25

D.4 Deep Beam Tests (Scale 1:6.5)
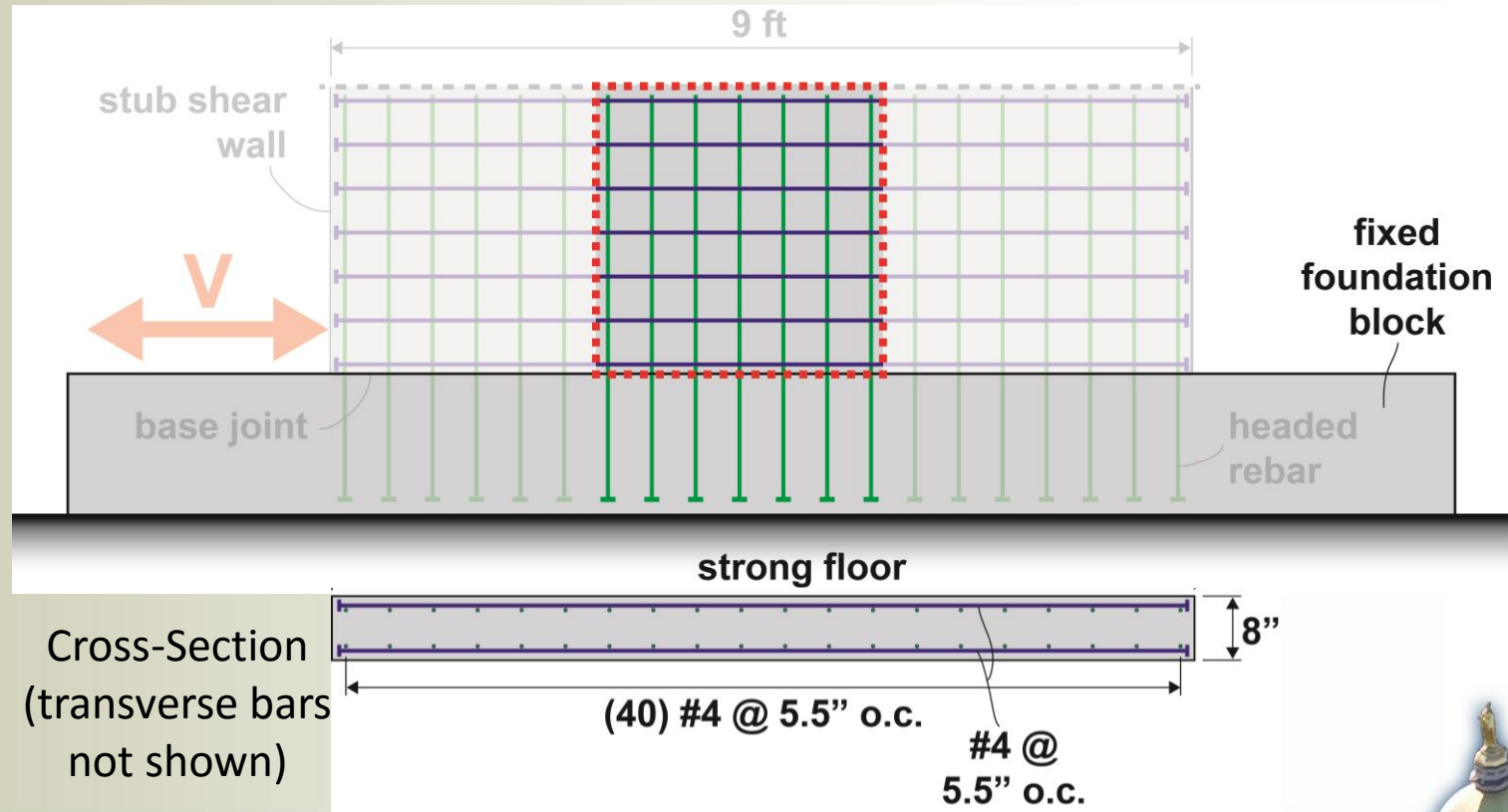
Initial Proposed Specimens

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)

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

9 ft

stub shear wall

V

base joint

fixed foundation block
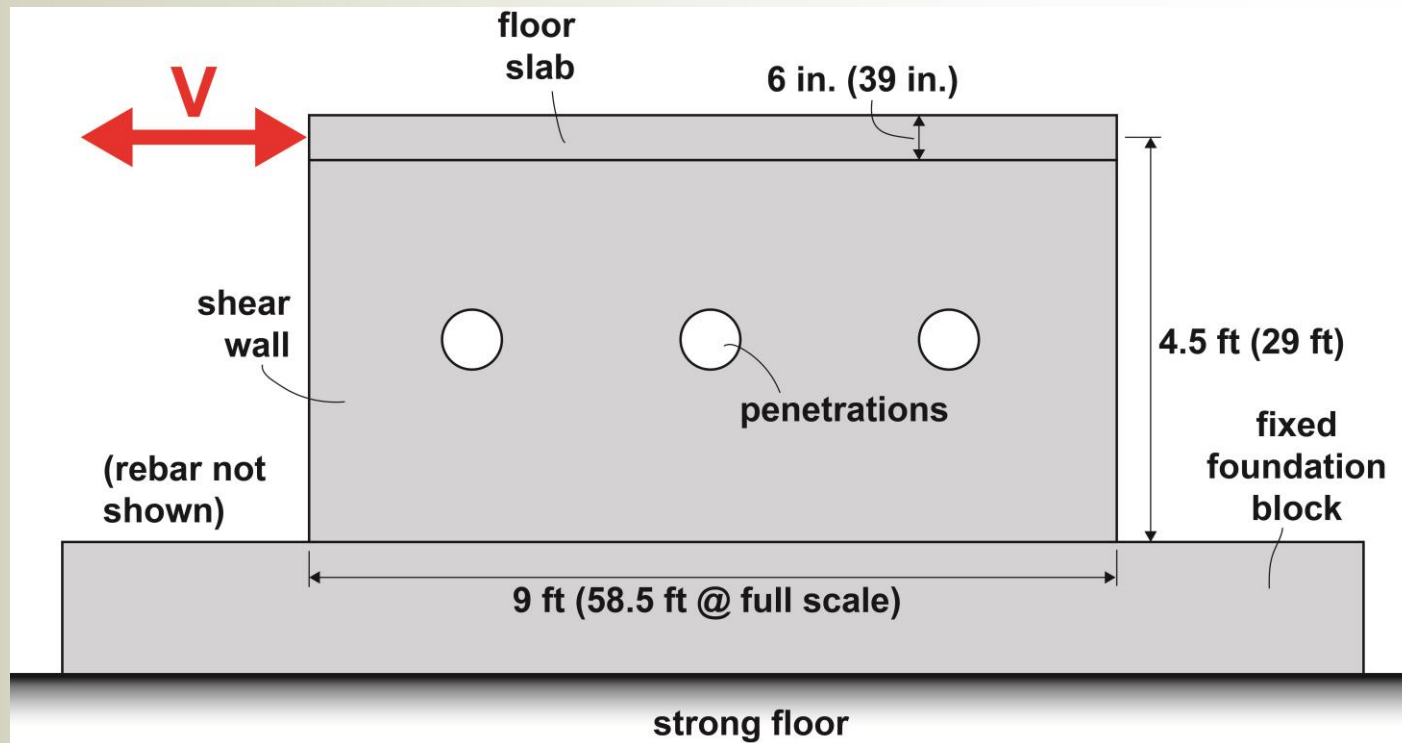
headed rebar

strong floor

Cross-Section (transverse bars not shown)

8"

(40) #4 @ 5.5" o.c.

#4 @ 5.5" o.c.

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

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

Cross-Section (transverse bars not shown)

24

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