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

NEUP
Nuclear Energy University Programs

University of Notre Dame

High Strength Materials Prefabrication

Sandia National Laboratories

AECOM

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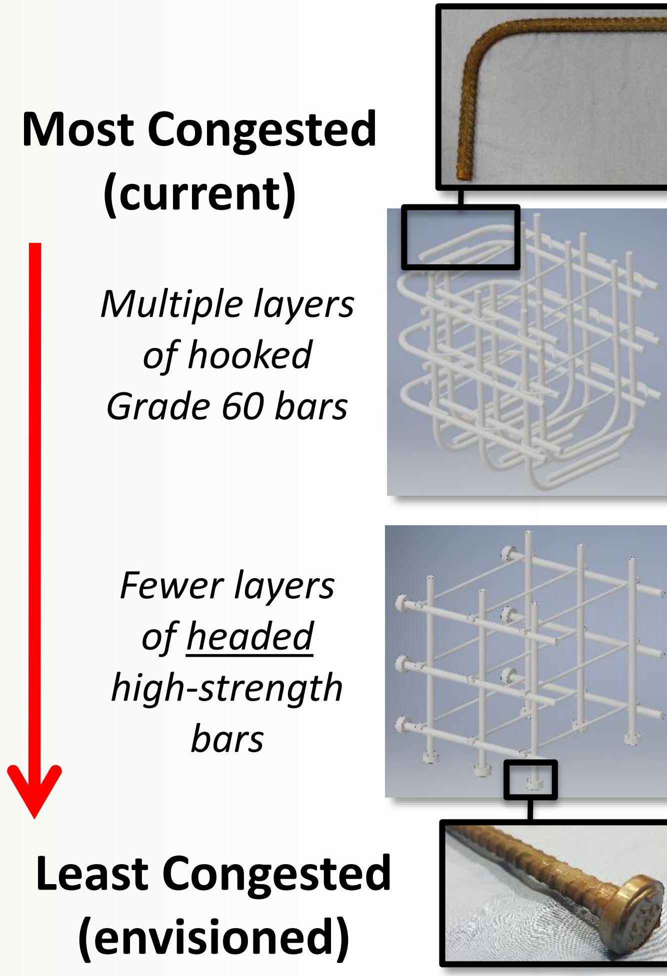
Primary Objective

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

1) High-strength reinforcing steel bars (rebar)
2) Prefabricated rebar assemblies, including headed anchorages
3) High-strength concrete



Primary Objective

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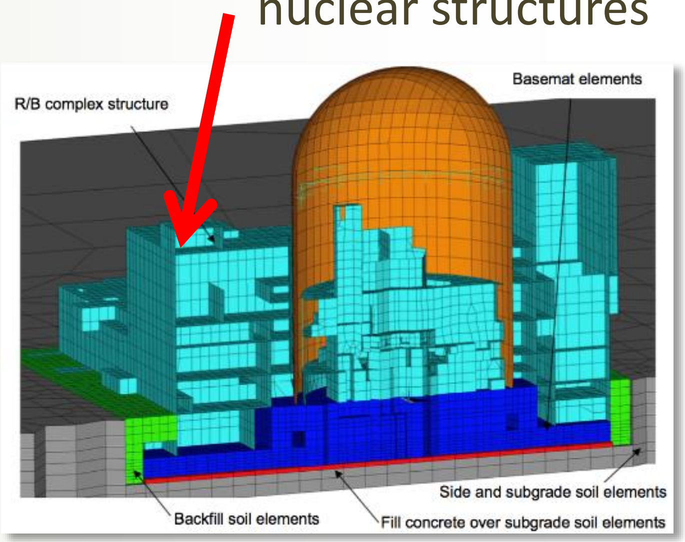
Focus on stocky shear walls
-most common lateral load resisting members in nuclear structures



US-APWR Design Control Doc.

Project Tasks

1. Evaluation of High-Strength Materials
2. Evaluation of Prefabricated Rebar
    - Industry Survey
    - Experimental Evaluation of Prefabricated Rebar
3. Optimization, Modeling, and Design
4. Experimental Testing of High Strength Materials
    - Deep Beam (Wall Slice) Specimens
    - Shear Wall Specimens
5. Design/Modeling/Construction Recommendations

Prefabricated Rebar Cages

- Evaluating prefab rebar cages for:
  - transportability
  - liftability
  - modularity

  through:
  - industry survey
  - full-scale experimentation

retrieved from http://www.siteright.net/prefabricated-reinforcement-p-38.html

retrieved from http://www.sellwoodbridge.org/?e=517

Industry Survey

- Developed under the guidance of an engineer with over 30 years of experience on heavy civil projects
- Divided into 2 primary sections:
  1. Labor and market pricing for prefabrication (quantitative)
  2. Logistics for prefabricated rebar assemblies (qualitative)
- Distributed to 236 manufacturers, engineers, and contractors
- Total of 19 respondents provided answers to all or part of survey

Section 3/5: Labor and Market Price

1) Please estimate the **total man-hours per ton of rebar** for the construction tasks below when assembling rebar systems in thick, long RC walls (e.g., greater than 20" and 50' respectively). Please provide estimates for the rebar densities indicated. List the predominant profession(s) for each construction task (e.g., laborers, ironworkers, operators) in the spaces proved in the far left column. If you define other tasks, please describe, including predominant profession(s), in the space provided.

1a) Tasks common to both erecting rebar systems in-place and erecting rebar systems that are preassembled on-site (i.e., rebar shipped to the site unassembled, tied out of the critical path in a designated area, and then hoisted, set, and secured in place).

	Normal rebar density (less than 200 lb/CY)	Significantly congested systems (200-400 lb/CY)	Extremely congested systems (greater than 400 lb/CY)
Cut, Bend, Bundle, Tag, Ship Profession:	0	0	0
Unload and Handle at Site Profession:	0	0	0
Other Task and Profession:	0	0	0
Other Task and Profession:	0	0	0
Total	0	0	0

Summary of Quantitative Responses

Reported Man-Hours for In-Place and Prefabricated Construction from Industry Survey

Construction Type	Construction Task	Man-Hours per Ton of Rebar		
		[1]< 200 lb/yd^3	[1]200-400 lb/yd^3	[1]> 400 lb/yd^3
Common to In-Place and Prefabricated	Cut, tag, bundle	1.98	2.20	3.42
	Unload and handle	3.26	4.97	9.08
	Other	0.05	0.07	0.09
	TOTAL	**5.29**	**7.24**	**12.59**
In-Place	Rebar tying	13.80	15.40	20.00
	Other	0.80	0.70	0.80
	[2]TOTAL	**19.89**	**23.34**	**33.39**
Prefabricated	Rebar tying	9.20	11.20	14.60
	Set and secure in-place	2.50	4.00	5.70
	Other	0.05	0.10	0.20
	[2]TOTAL	**17.04**	**22.54**	**33.09**

[1]rebar density in RC wall (i.e., degree of congestion), in pounds of rebar per cubic yard of concrete

[2]includes man-hours for tasks common to both in-place and prefabricated construction

Summary of Qualitative Responses

- Situations in which prefabricated rebar assemblies would likely be used in lieu of in-place construction:
  1. to save on construction schedule (primary project objective)
  2. to improve safety and/or quality control
  3. for areas with heavy rebar congestion
  4. for structures with significant repetition in rebar layout/configuration
- Most commonly reported disadvantages of prefabrication:
  1. more logistical planning
  2. increased capacity of lifting equipment
  3. more field adjustments
  4. difficulties interfacing prefabricated rebar assemblies with existing components

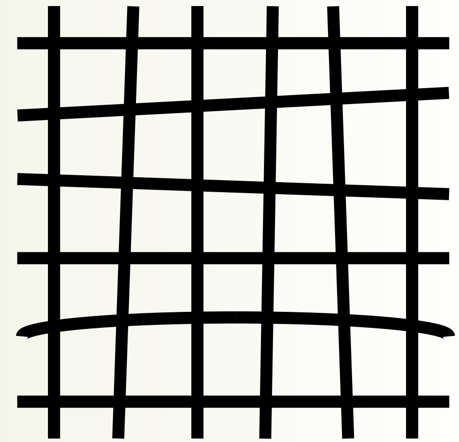
Summary of Qualitative Responses

- Two primary methods recommended for prefabricating RC walls:
  1. 2D mats that are set/braced in-place and connected by trans. bars
  2. Complete 3D cage that is transported and set in-place in the field

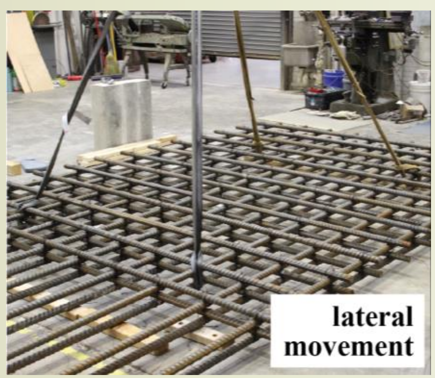
Prefabricated Rebar Assembly	Advantages	Disadvantages
2D Mat	• Lighter to lift • Easier to assemble • Easier to transport	• Less stable when erected • More picks to assemble full wall cage • Requires installation of transverse bars in place
3D Cage	• More stable when erected • Complete wall cage tied in advance • Ease of inspection of completed wall reinforcement	• More difficult to transport • Heavier to lift • More difficult to interface with completed construction and adjacent rebar assemblies

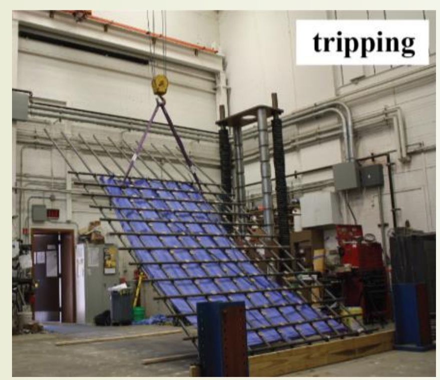
Experimental Evaluation of Prefab Rebar

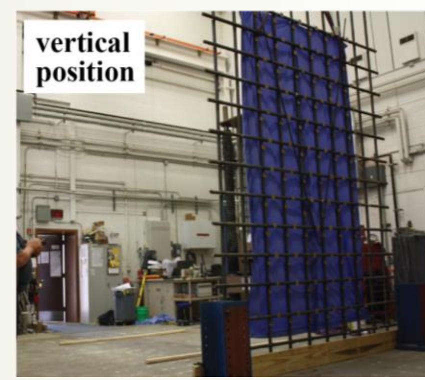
- Based on survey responses:
  - 2D mats or 3D cages are recommended prefabricated assemblies for walls
  - Assembling rebar horizontally at grade, laterally translating it to site, and tripping (or rotating) it into a vertical orientation reduces fabrication time and results in better work safety conditions
- Performed full-scale experimental evaluation to determine effect of tripping on bar spacing



after cage/mat tripping

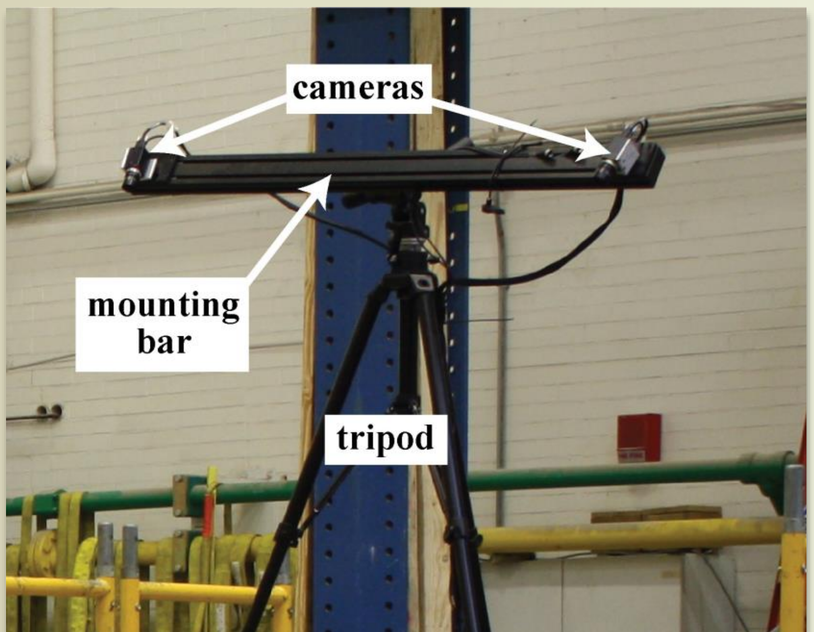


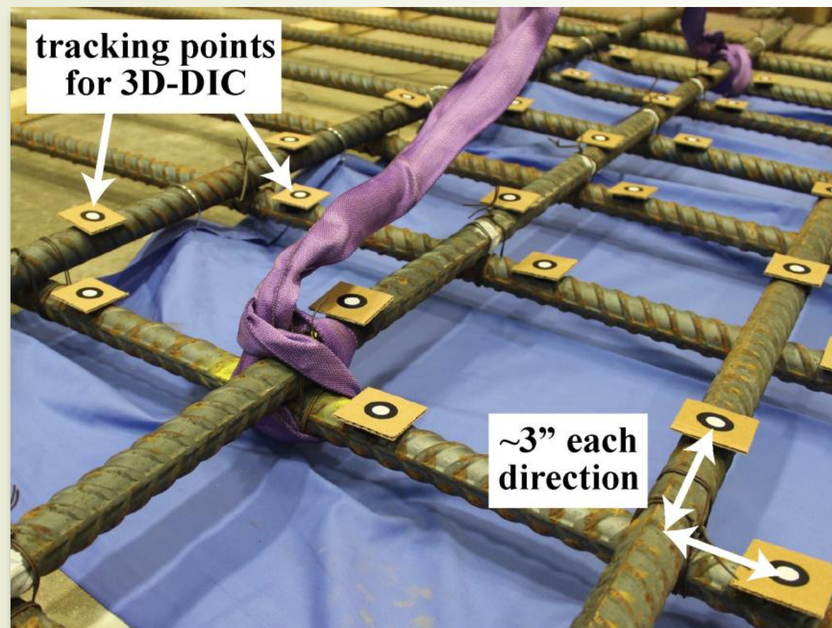




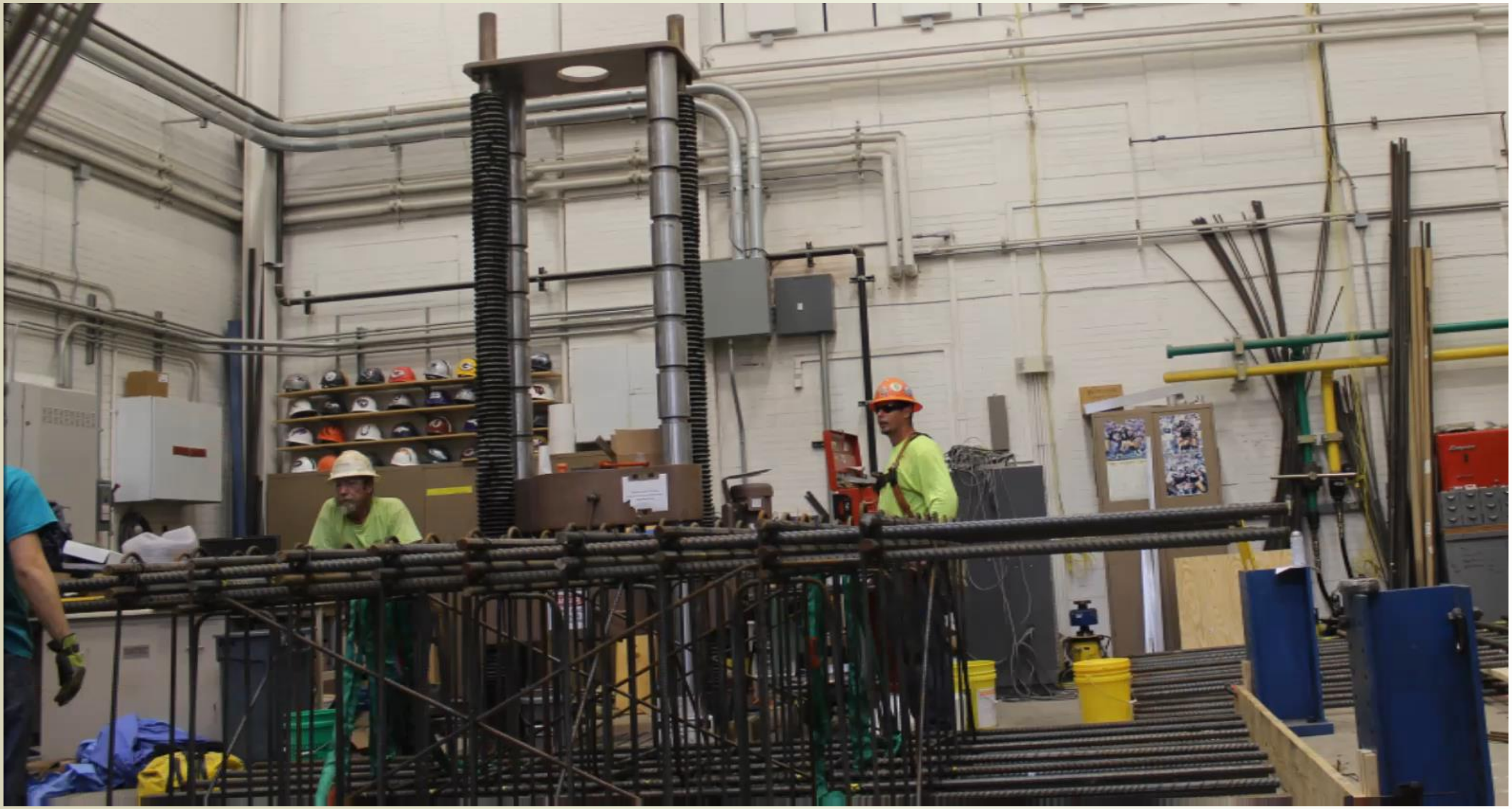
Experimental Evaluation of Prefab Rebar

- Measure relative bar movement during tripping using Digital Image Correlation (DIC)
- Compare relative movement to code-required tolerances for rebar placement

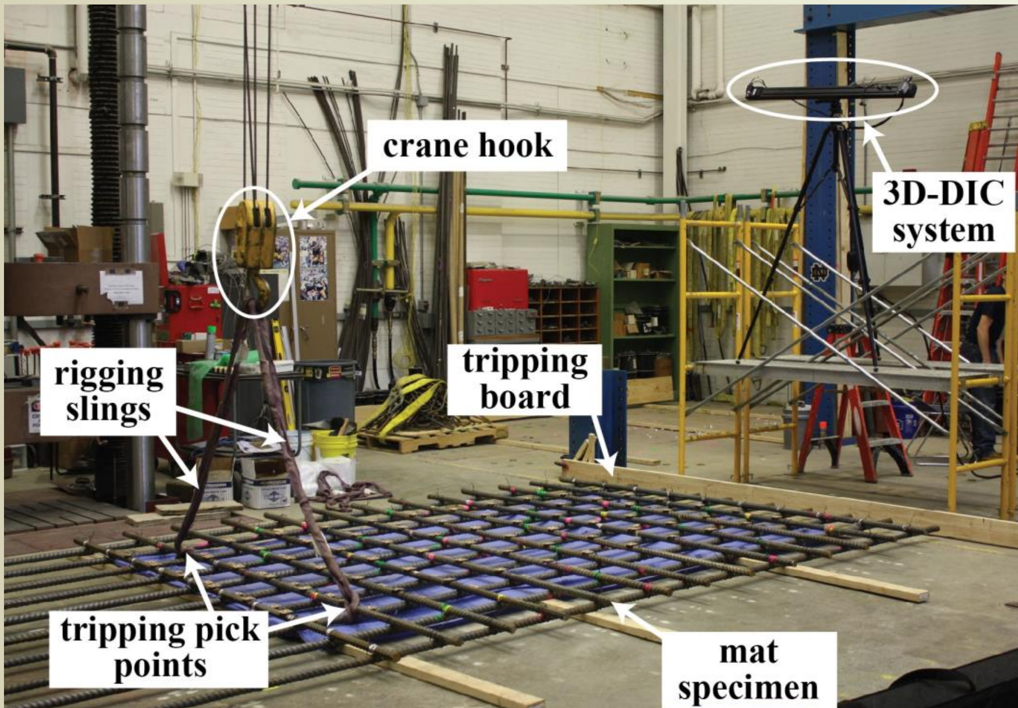


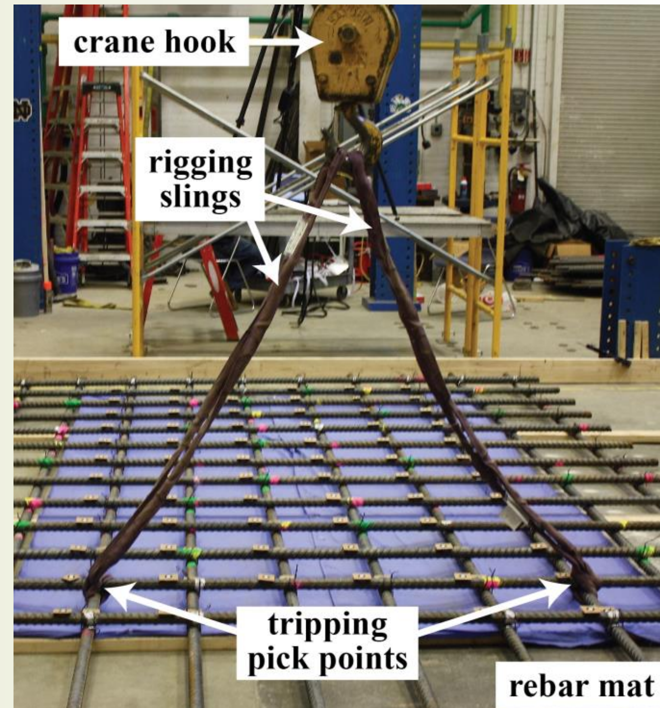


Assembly of Rebar Cage



Experimental Evaluation: 2D Mats





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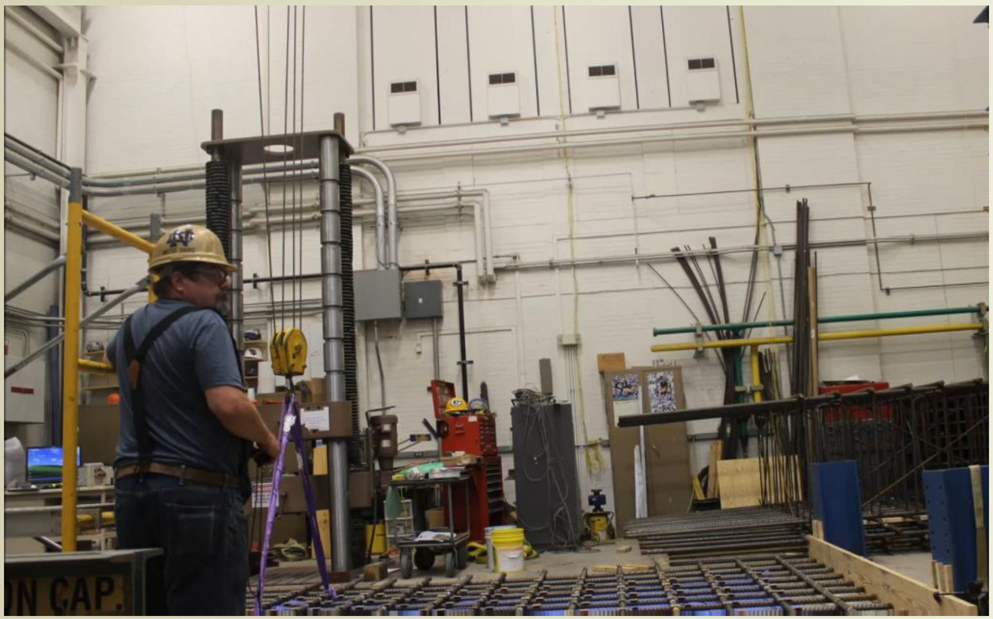
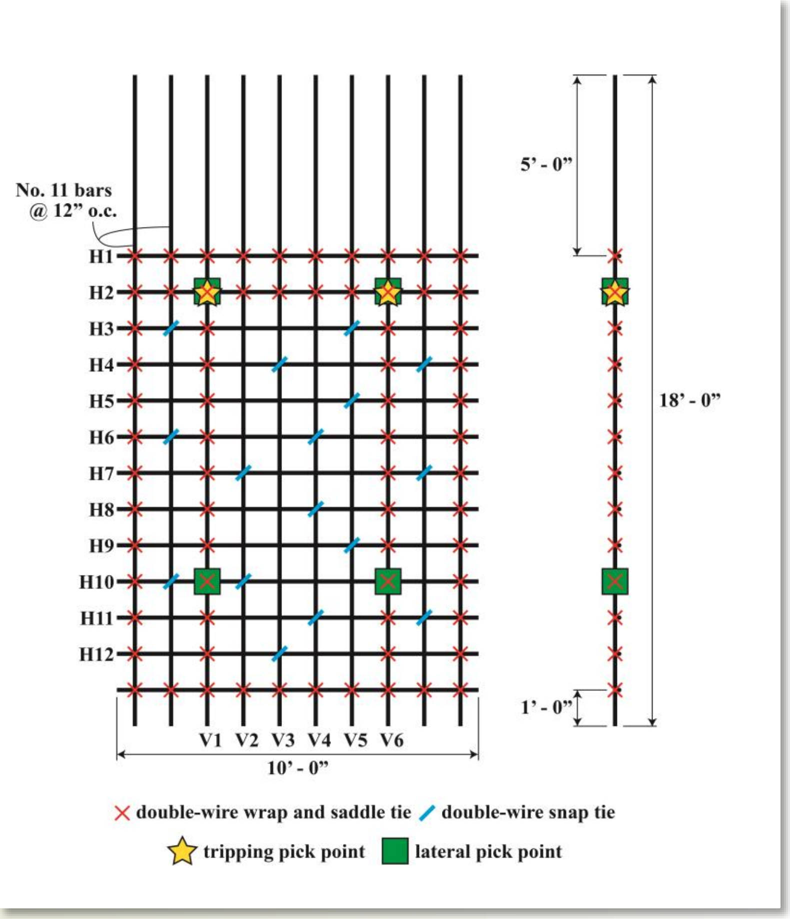
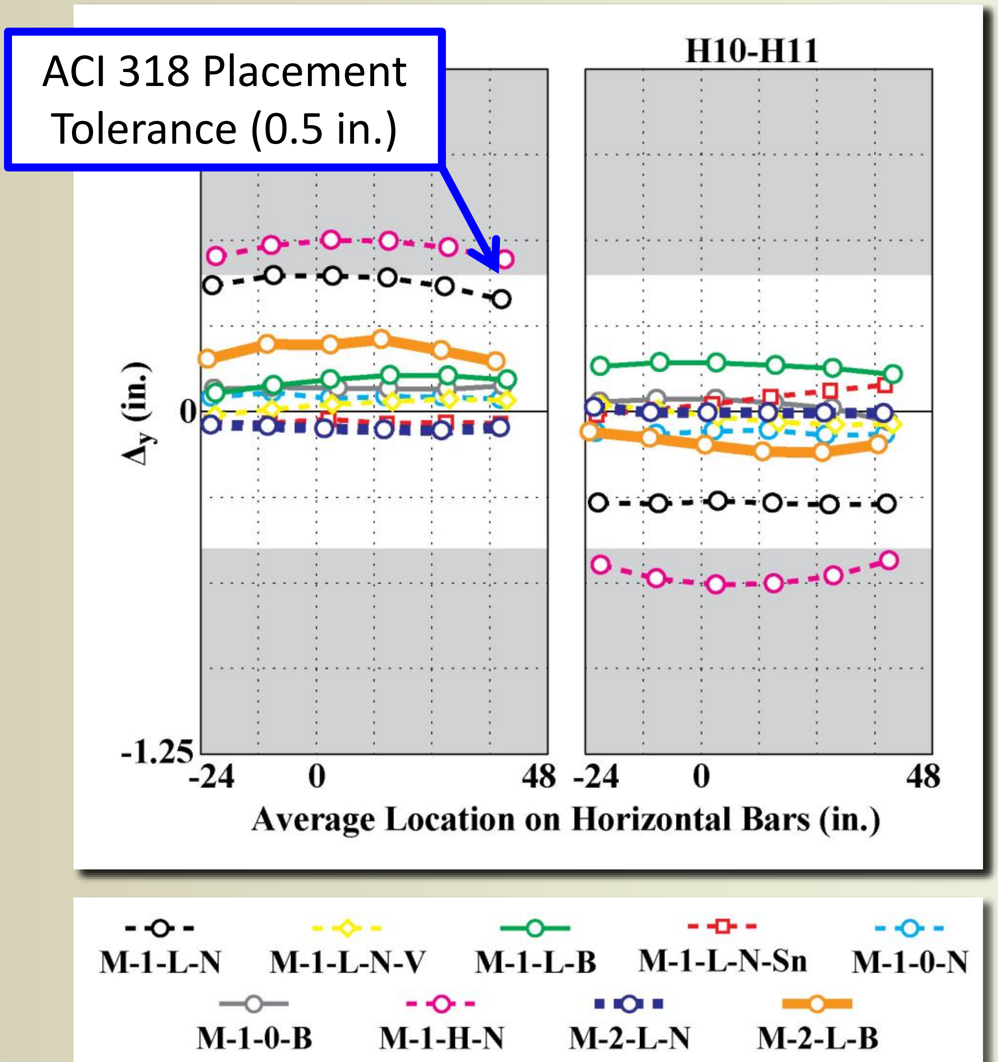


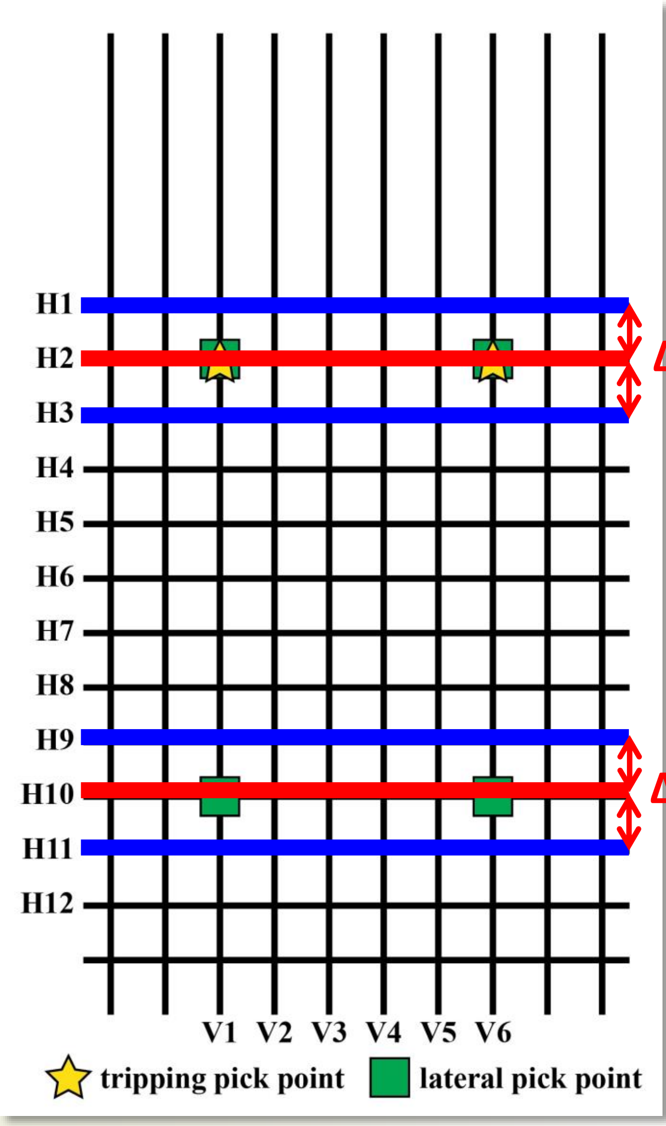
2D Mat Test Parameters

Specimen ID	Rebar Layers	% of Snap Tied Intersections	Diagonal Bracing
M-1-L-N	**1**	**25 to 30**	**No**
M-1-L-N-V	1	25 to 30	No
M-1-L-B	1	25 to 30	Yes
M-1-L-N-Sn	1	25 to 30	No
M-1-0-N	1	0	No
M-1-0-B	1	0	Yes
M-1-H-N	1	45 to 50	No
M-2-L-N	2	25 to 30	No
M-2-L-B	2	25 to 30	Yes

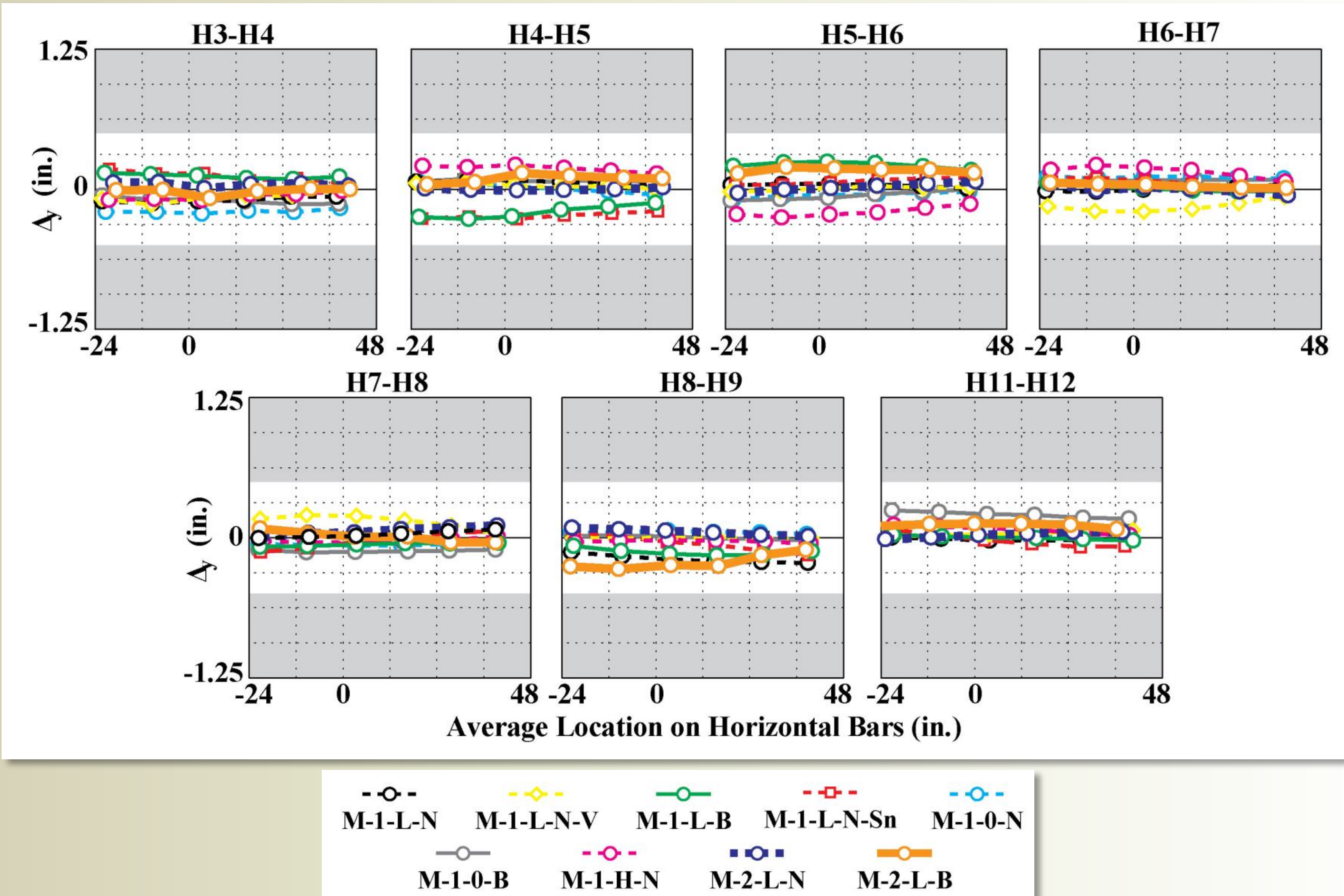


Experimental Evaluation: 2D Mats

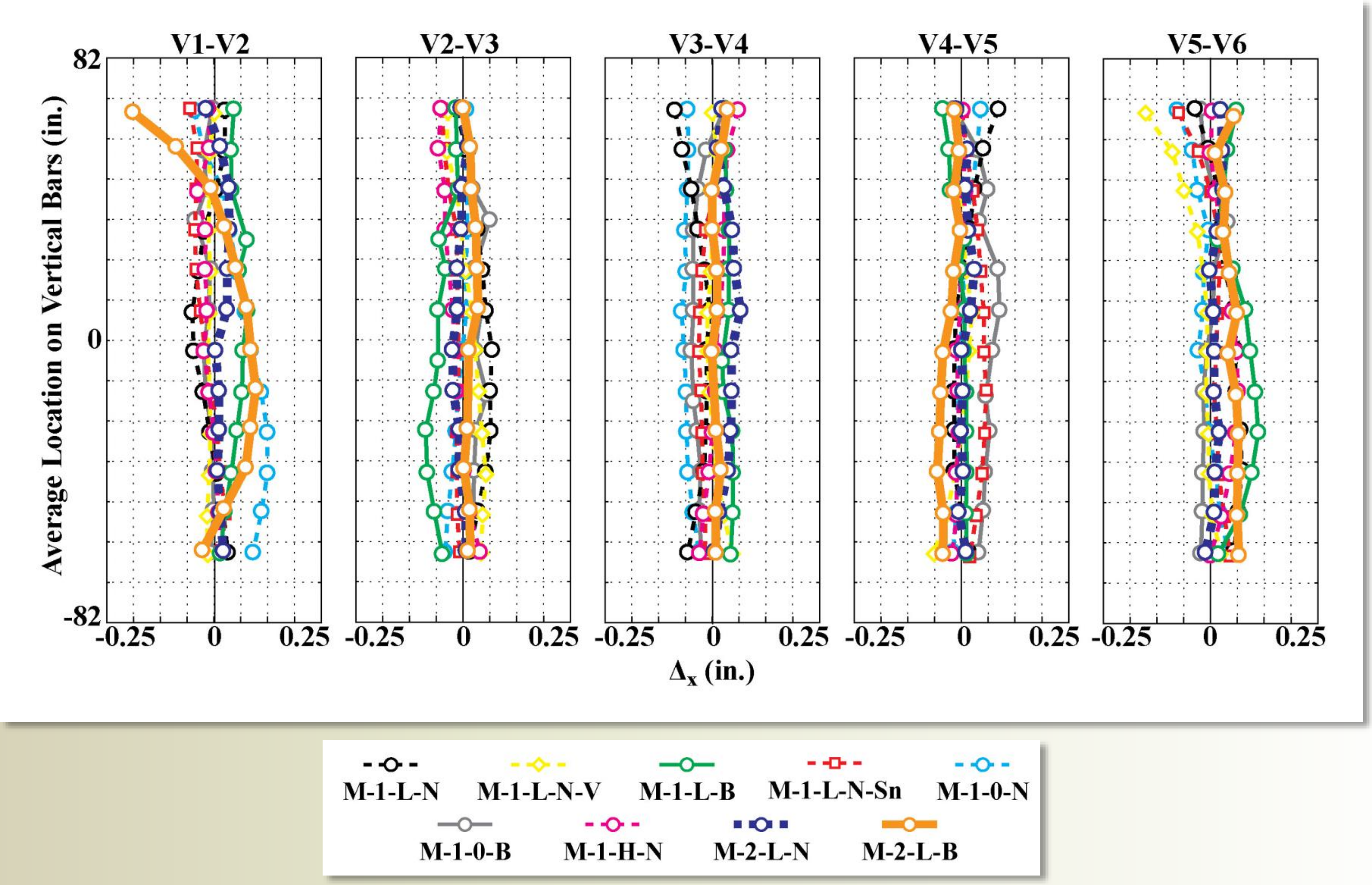




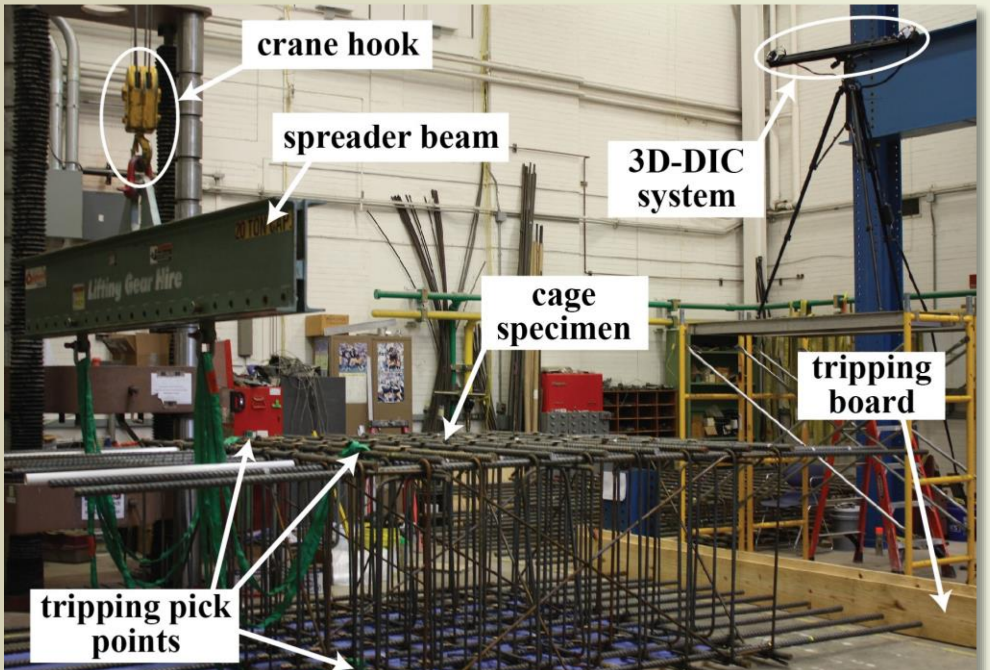
Experimental Evaluation: 2D Mats

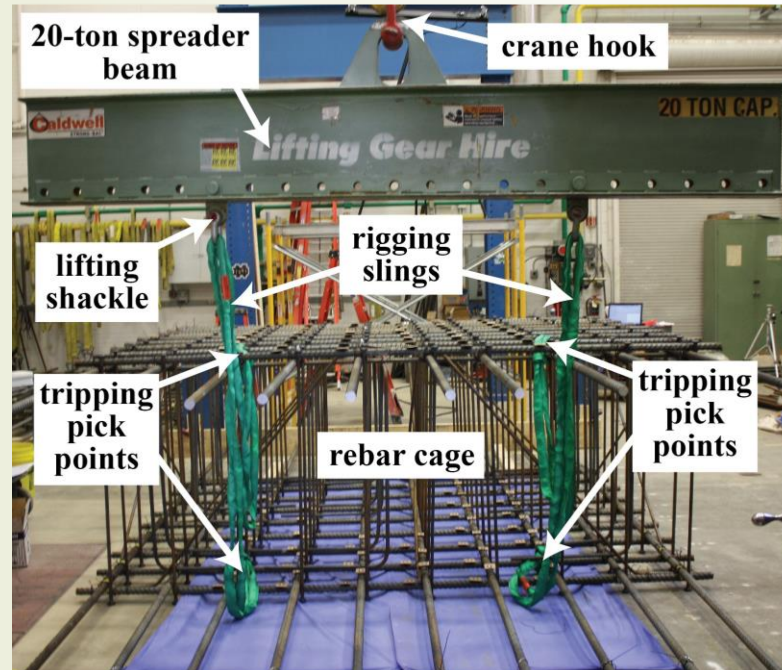


Experimental Evaluation: 2D Mats

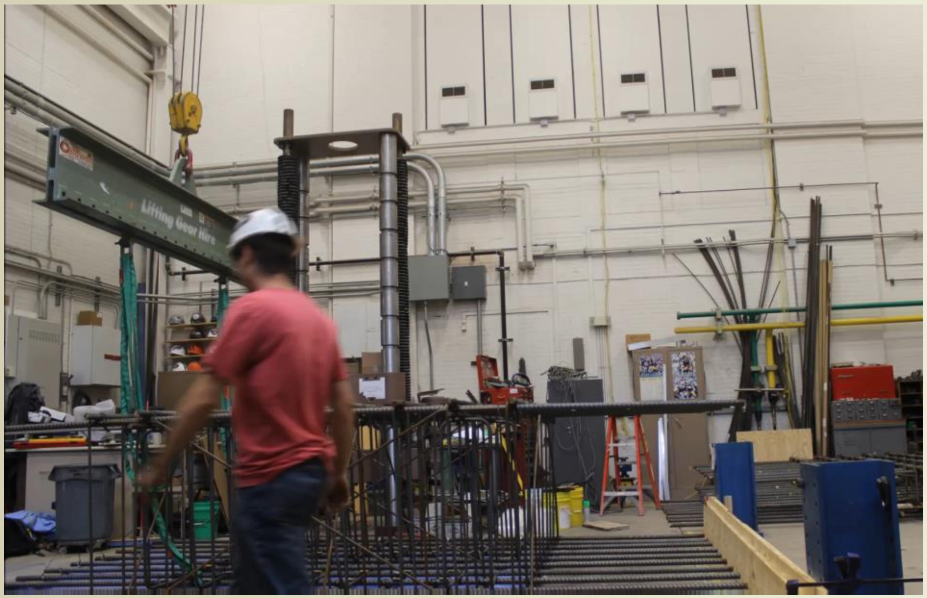


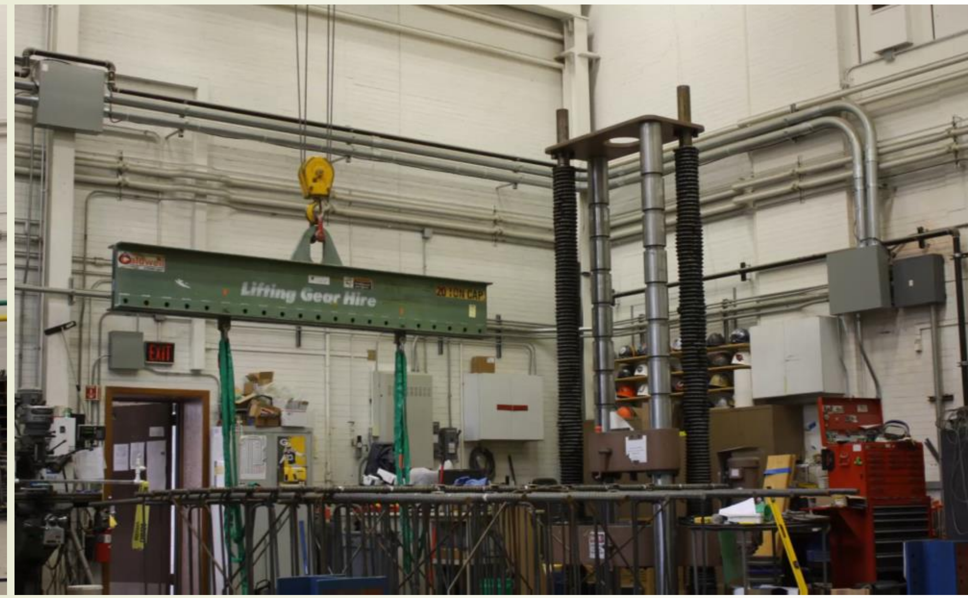
Experimental Evaluation: 3D Cages





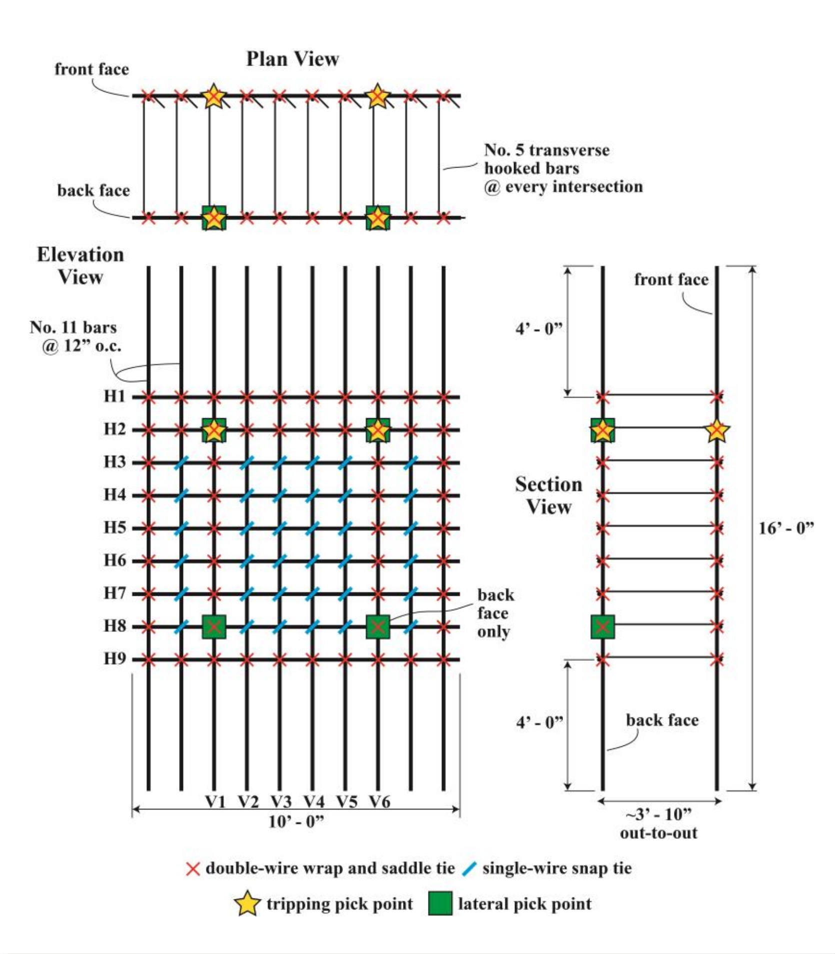
Experimental Evaluation: 3D Cages



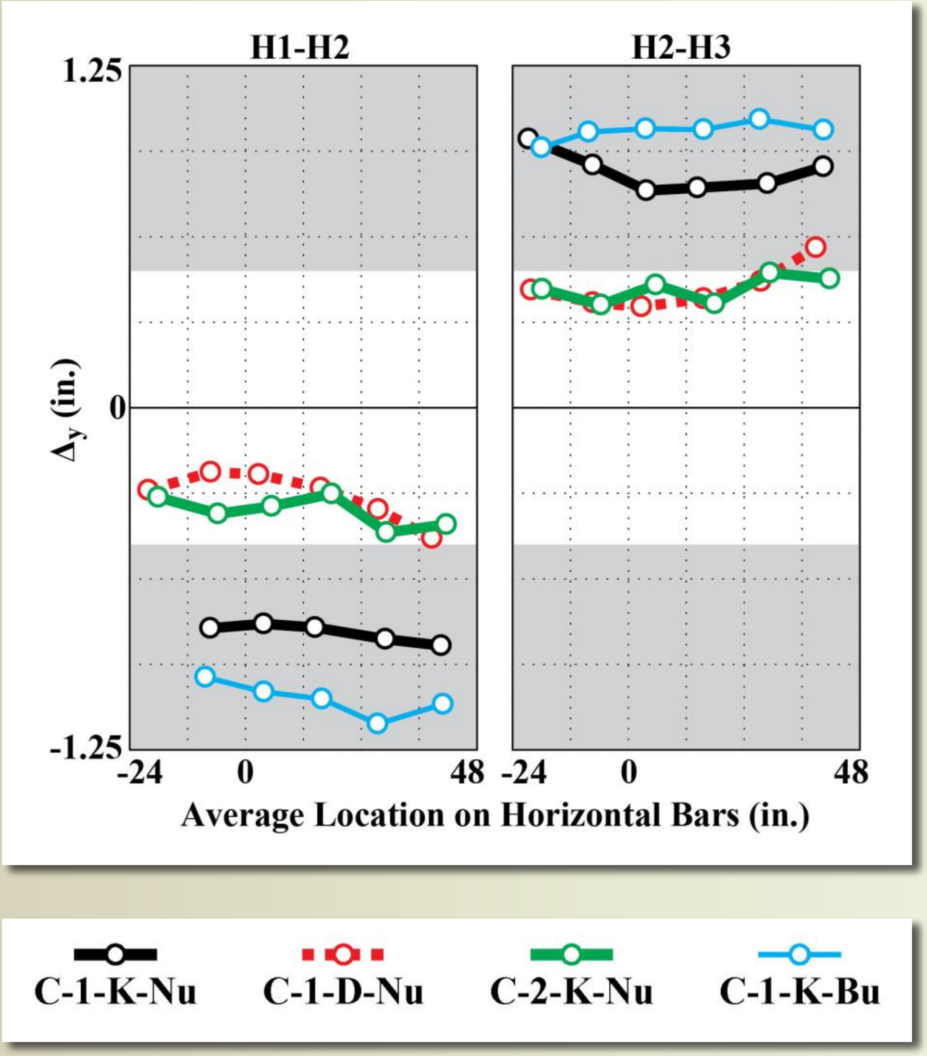


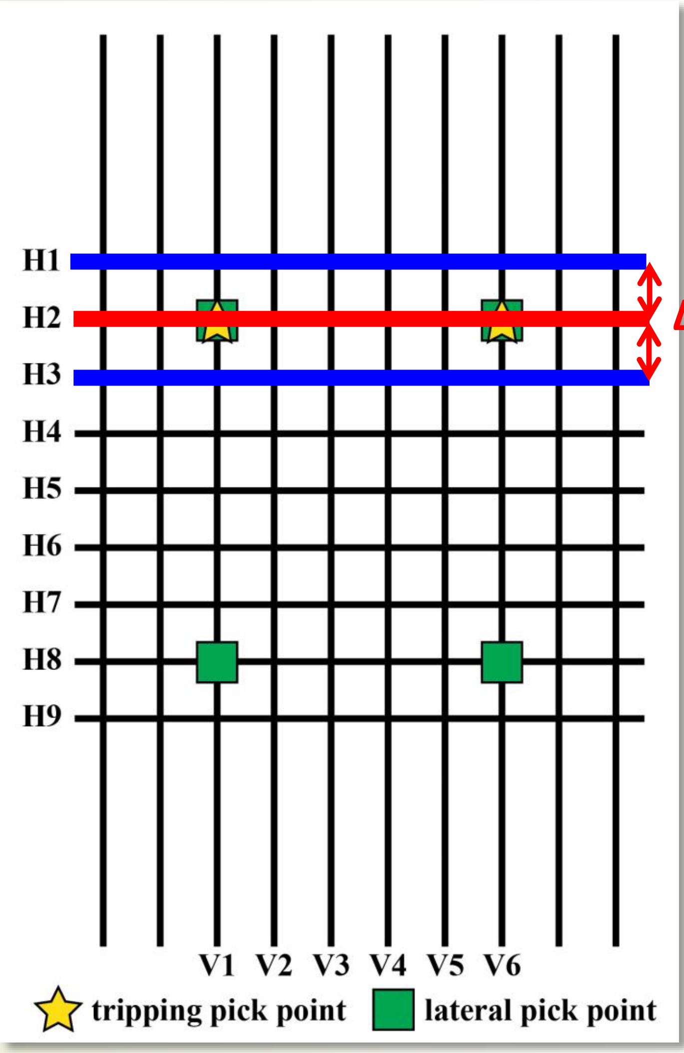
3D Cage Test Parameters

Specimen ID	Rebar Layers on Each Face	Transverse Reinforcement Type	Wall Thickness
C-1-K-Nu	**1**	**Hooked**	**Nuclear**
C-1-D-Nu	1	Headed	Nuclear
C-2-K-Nu	2	Hooked	Nuclear
C-1-K-Bu	1	Hooked	Building



Experimental Evaluation: 3D Cages





Summary of Prefab Rebar Tests

- Largest changes in spacing between bars in prefabricated assemblies were for horizontal bars involved in tripping/movement
- Spacing changes between all bars not directly involved in the tripping/moving of the specimens were typically small
- The following parameters did not have a significant effect on bar spacing changes:
  - Number of rebar layers in mats or cages
  - Type of transverse reinforcement (headed vs hooked) in cages
  - Thickness of cage (nuclear vs building thickness)

Devine, RD, Barbachyn, SM, Thrall, AP, and Kurama, YC “Effect of Tripping Prefabricated Rebar Assemblies on Bar Spacing,” *ASCE Journal of Construction Engineering and Management*, In Review.

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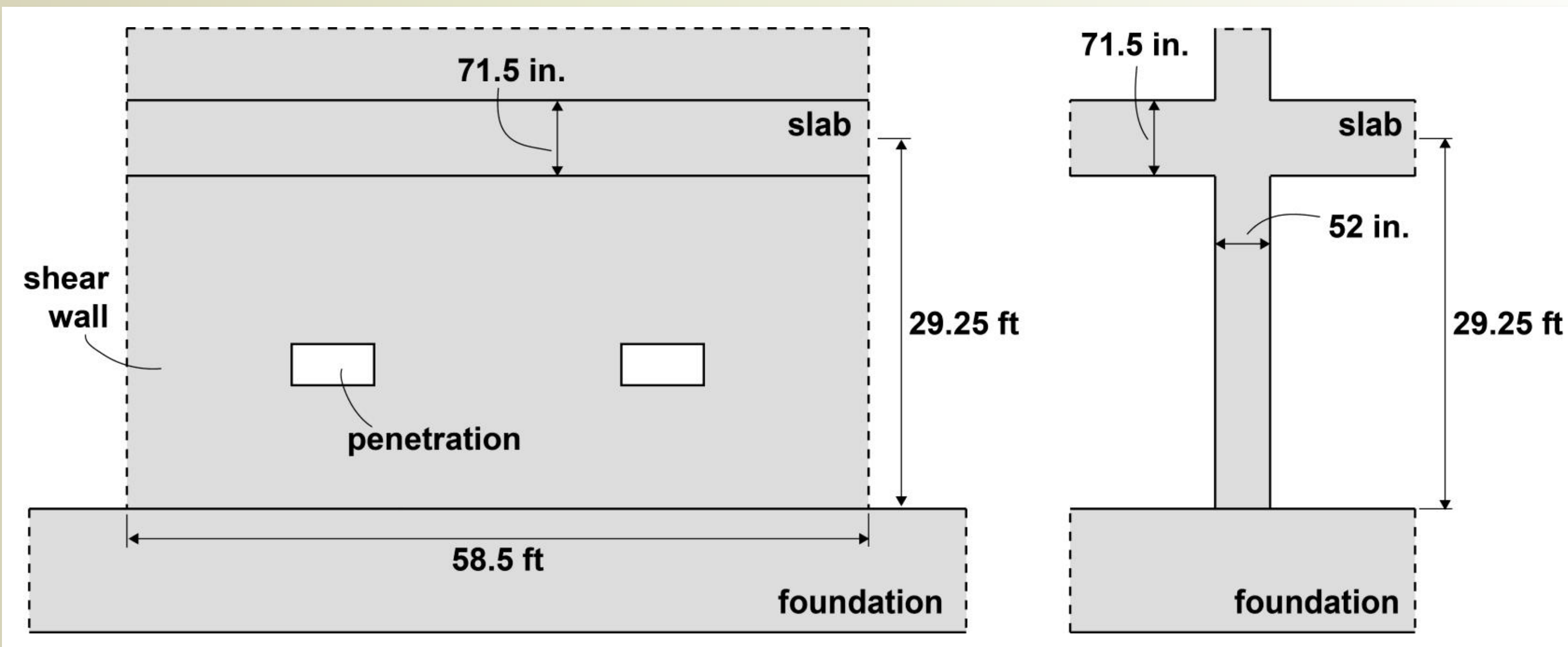
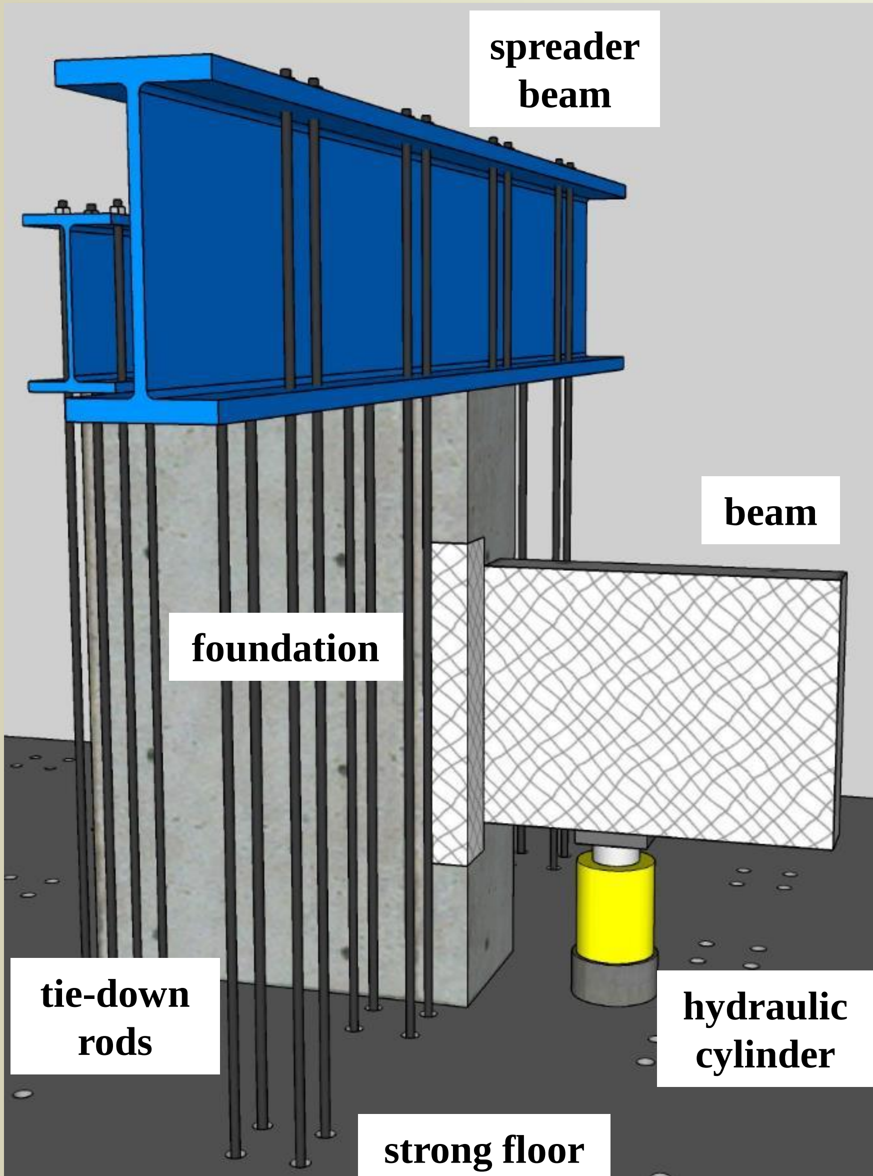
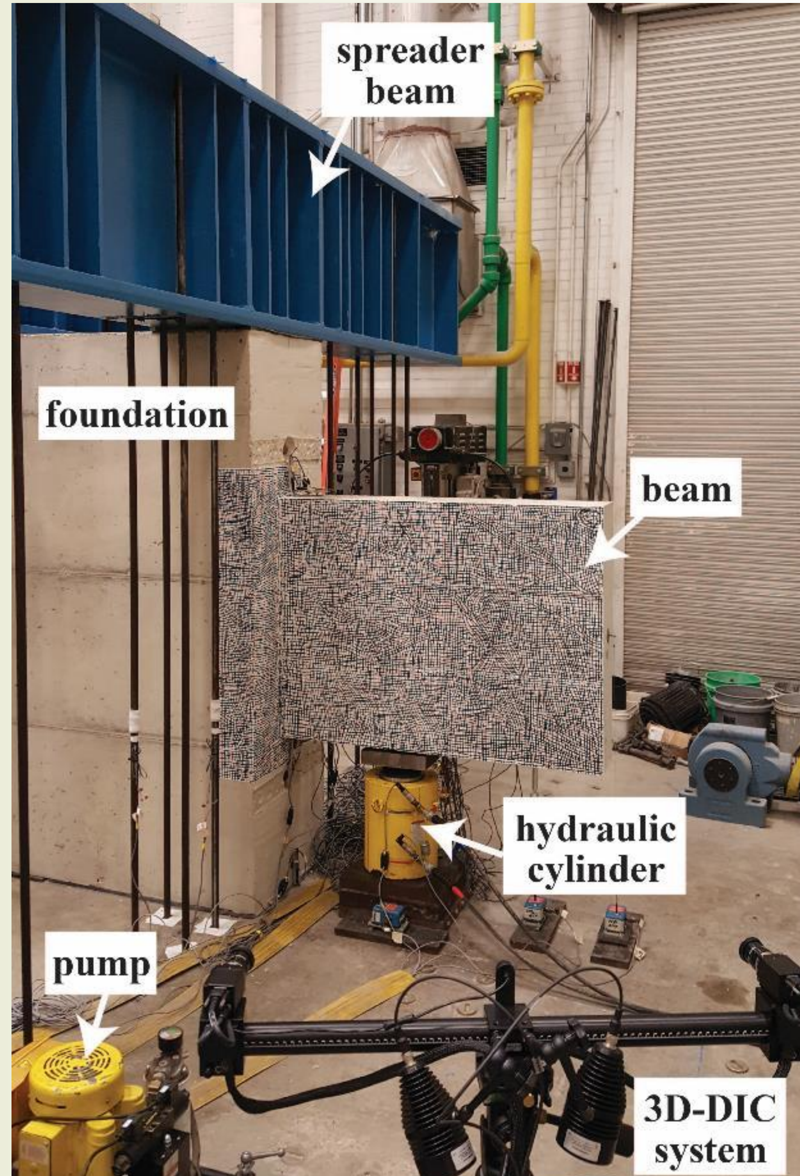
Experimental Testing of High Strength Materials

- "Generic wall" dimensions determined using publicly-available design control documents
- Provided basis for deep beam and shear wall tests

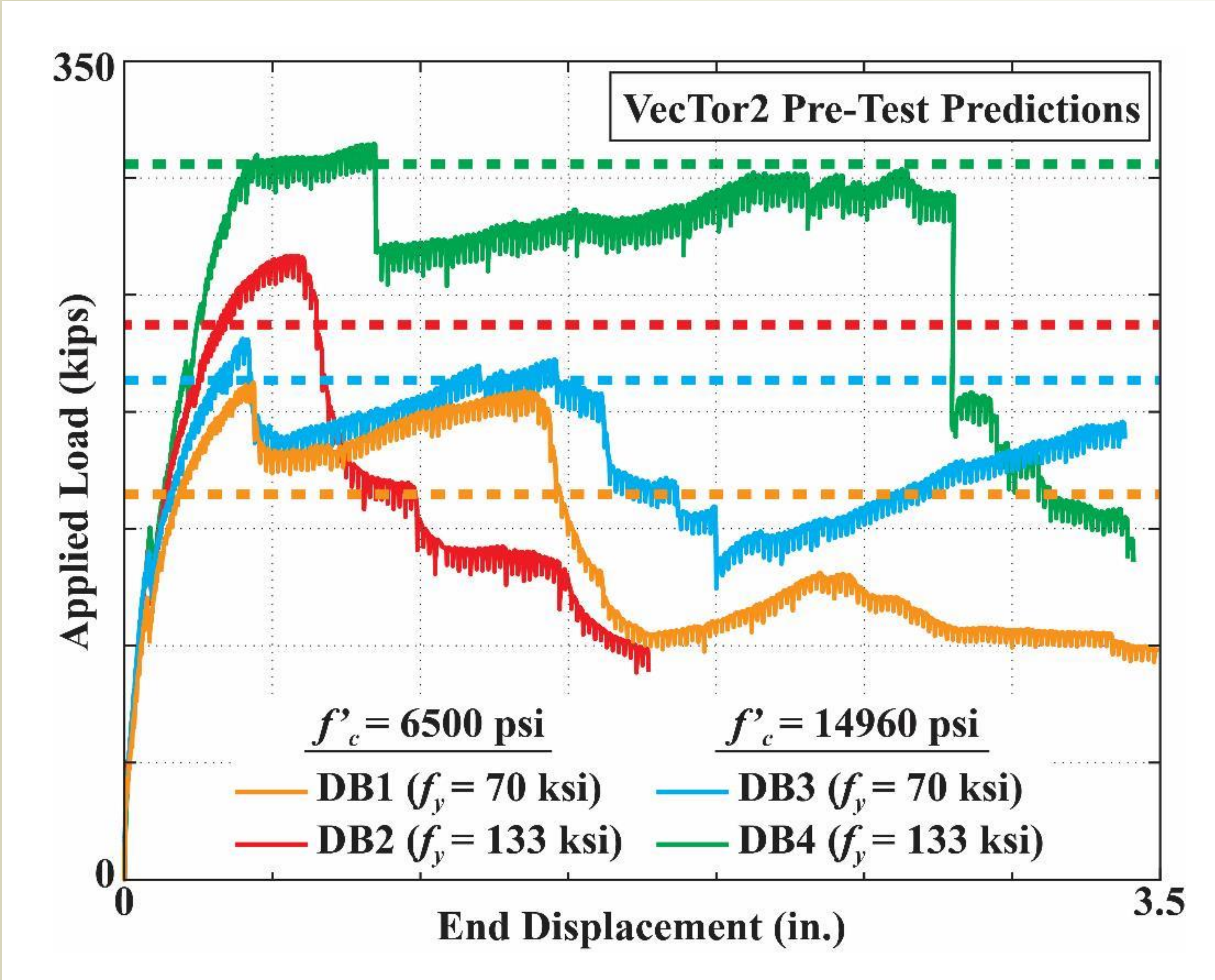


Deep Beam Test Setup





Deep Beam Specimen Response



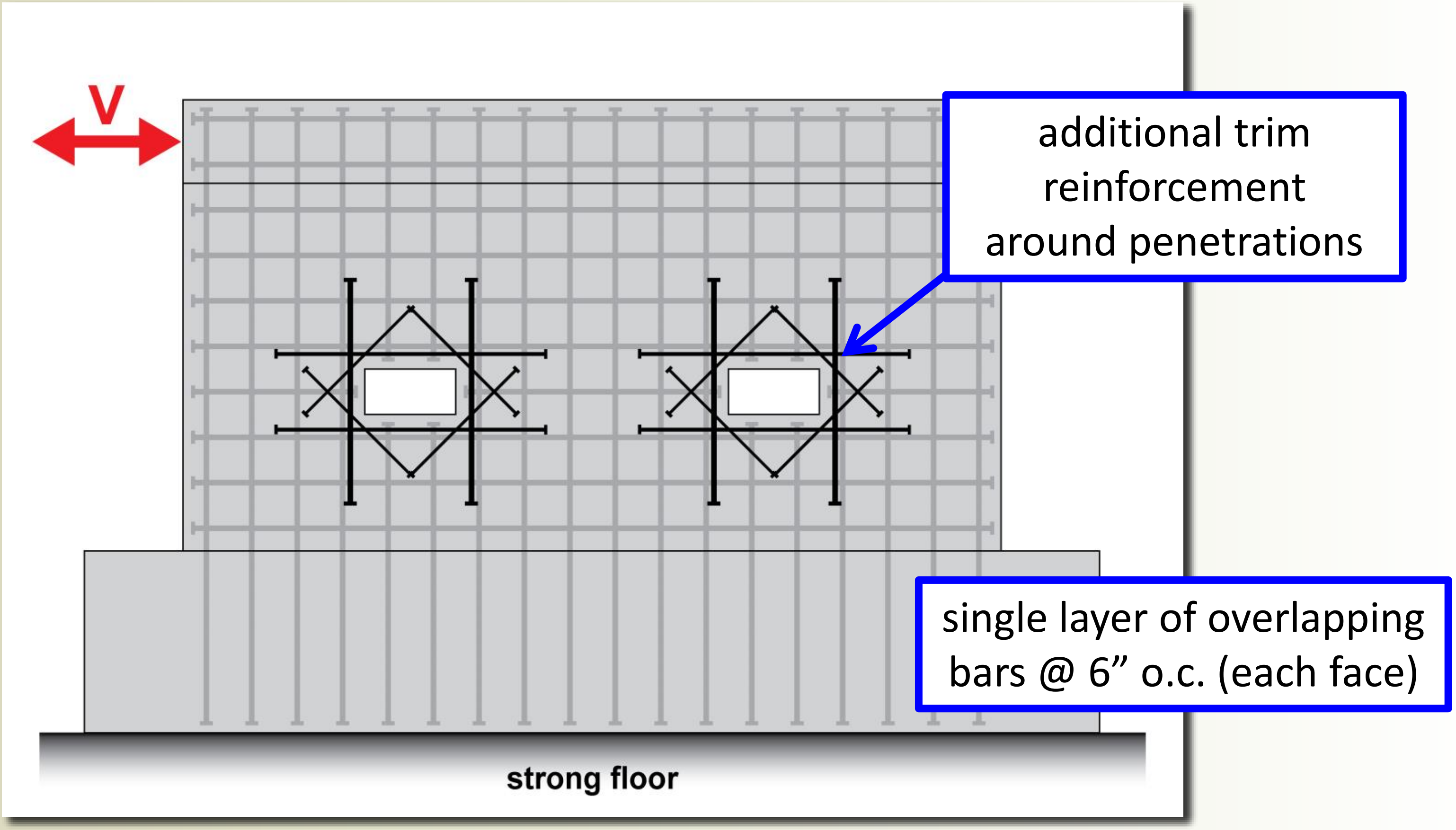
Summary of Deep Beam Tests

- Increasing the rebar strength had a greater effect on lateral strength (26% increase) than increasing the concrete compression strength (9% increase)
- Increase in lateral strength (48% increase) was greatest when using high-strength materials together
- Combination of high-strength materials also resulted in greatest deformation capacity
- Pre-test analyses provided reasonable and conservative predictions for all specimens

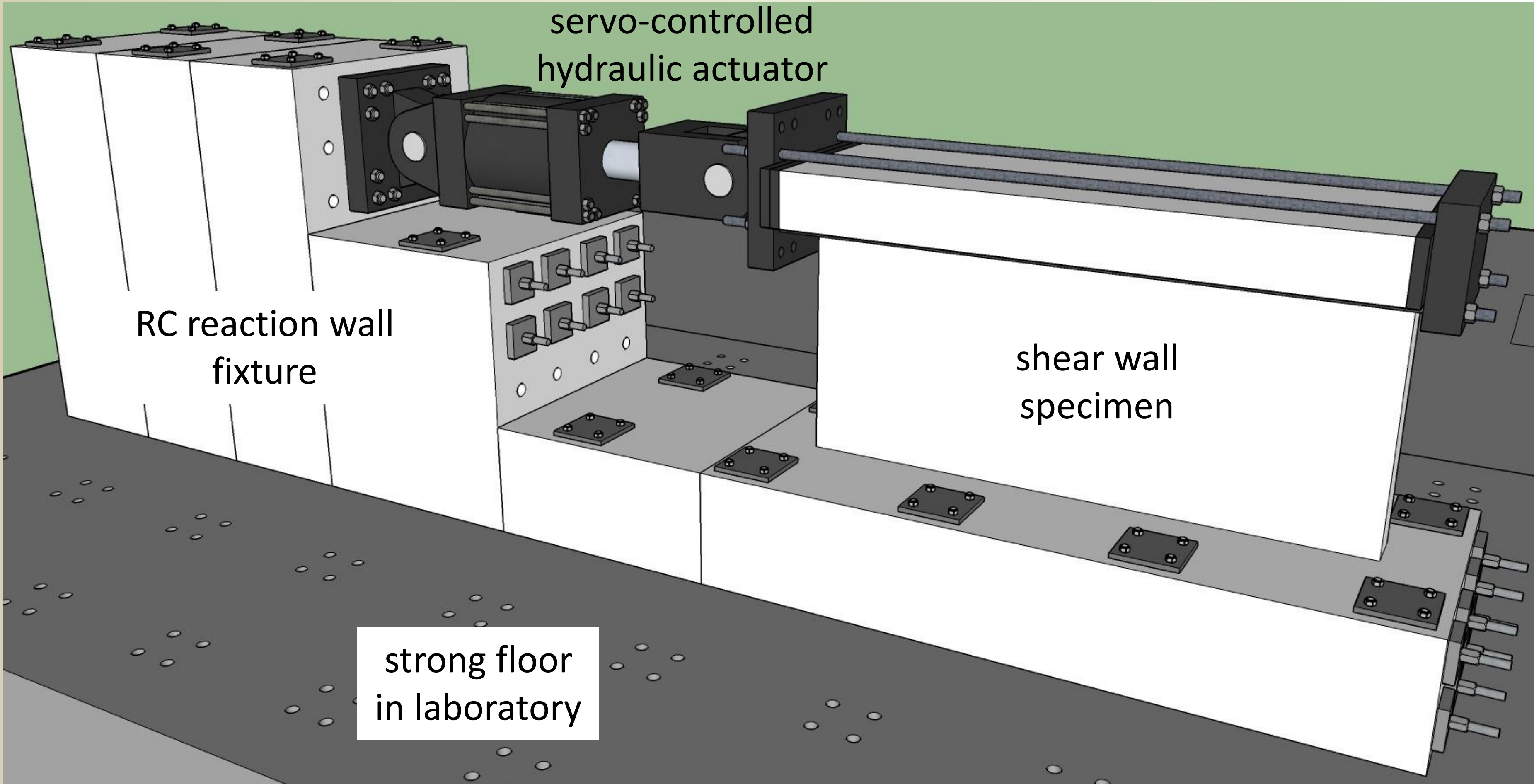
Devine, RD, Barbachyn, SM, Thrall, AP, and Kurama, YC "Experimental Evaluation of Deep Beams with High-Strength Concrete and High-Strength Rebar," *ACI Structural Journal*, In Review.

Reduced-Scale Shear Wall Tests

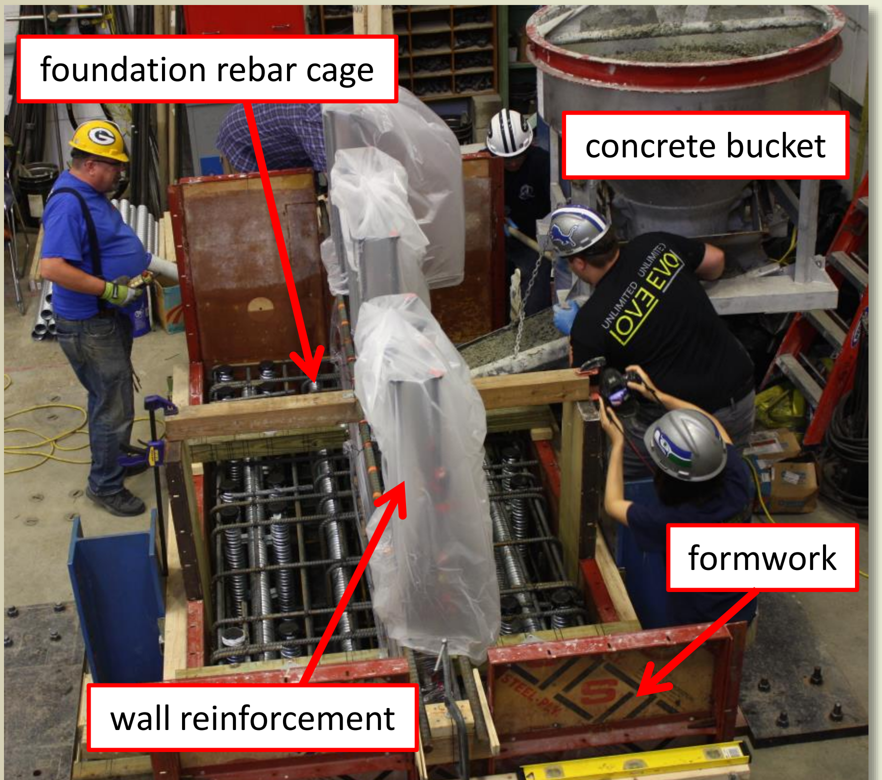
- 1:6.5 scale of "generic wall"
- To be tested under cyclic lateral loads



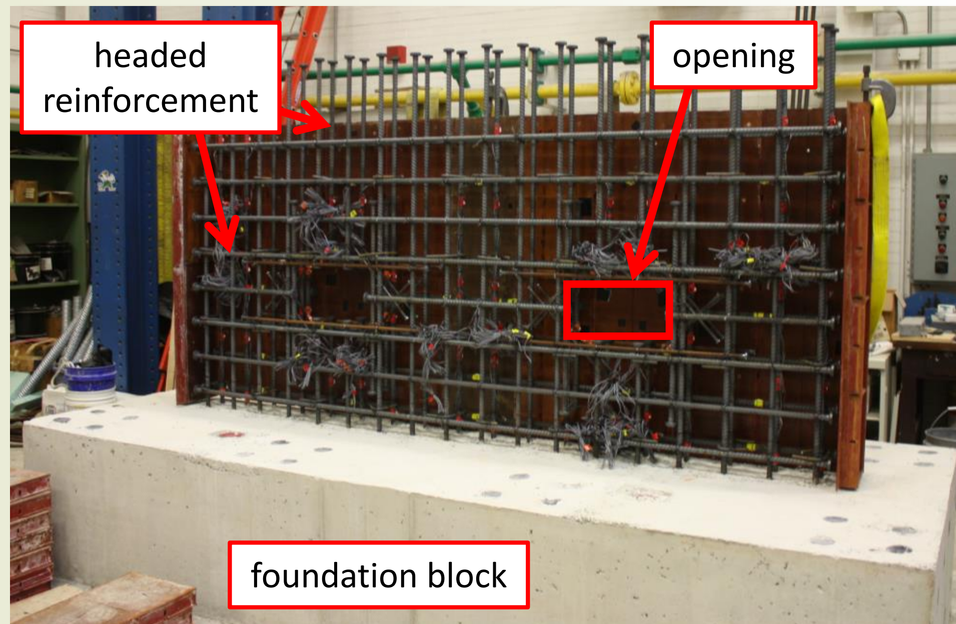
Shear Wall Test Setup and Parameters



Construction Progress



Concrete Placement in Wall Foundation Block



Shear Wall Reinforcement Prior to Concrete Placement

Conclusions to Date

- High-strength steel more effective when combined with high-strength concrete, resulting in greatest increase in lateral strength and deformation capacity
- Prefabricated rebar assemblies can improve construction safety, improve construction schedules, and reduce construction costs
- Experimental evaluation of effect of tripping prefabricated assemblies on bar spacing found that:
  - Largest changes in spacing between bars in prefabricated assemblies were on bars involved in tripping/movement
  - Spacing changes between all bars not directly involved in the tripping/moving of the specimens were typically small
  - Number of rebar layers, type of transverse reinforcement, and thickness of cage had no significant impact on bar spacing
- Project tasks on schedule

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Department of Energy United States of America

Completed Project Tasks

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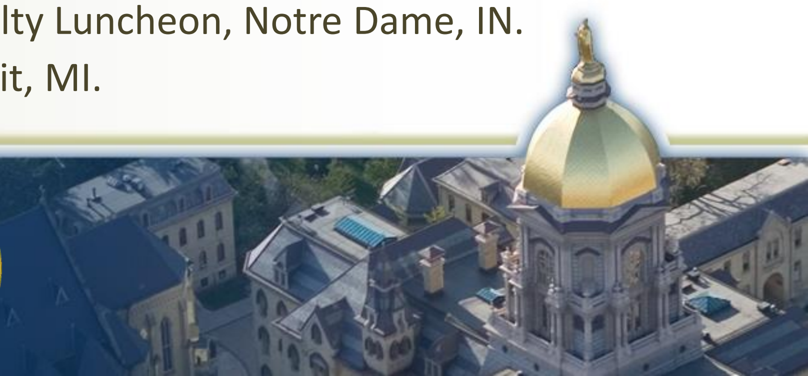
5. Design/Modeling/Construction Recommendations

Research Products

- Journal Papers (published):
  - "Effect of High-Strength Materials on Lateral Strength of Stocky Reinforced Concrete Walls," *ACI Structural Journal,* 2017.
  - "Economic Evaluation of High-Strength Materials in Stocky Reinforced Concrete Shear Walls," *ASCE Journal of Construction Engineering and Management*, 2017.
- Journal Papers (in review):
  - "Experimental Evaluation of Deep Beams with High-Strength Concrete and High-Strength Rebar," *ACI Structural Journal*
  - "Effect of Tripping Prefabricated Rebar Assemblies on Bar Spacing," *ASCE Journal of Construction Engineering and Management*
- Presentations:
  - Presentation, 2015 Fall ACI Convention, Denver, CO.
  - Poster, 2015 Energy Week, Center for Sustainable Energy, Notre Dame, IN.
  - Presentation, 2016 Fall ACI Convention, Philadelphia, PA.
  - Presentation, 2016 American Nuclear Society Winter Meeting and Nuclear Technology Expo, Las Vegas, NV.
  - Presentation, Center for Sustainable Energy Faculty Luncheon, Notre Dame, IN.
  - Presentation, 2017 Spring ACI Convention, Detroit, MI.



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Dayton Superior Corp.	MMFX Steel
Essve Tech, Inc.	Nucor Corporation
Harris Rebar	Sika Corp. U.S.
HRC, Inc.	

Questions?

<u>Notre Dame Team</u>

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http://phsrc-nuclearwalls.nd.edu

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