Prefabricated High-Strength Rebar Systems with High-Performance Concrete for Accelerated Construction of Nuclear Concrete Structures
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
Notre Dame Research Team

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Scope

• Explore effectiveness, code conformity, and viability of existing high-strength materials

• Focus on shear walls (ACI 349) – 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.
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
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

headed rebar (HRC-USA)
**Potential Benefits**

**Most Congested (current)**
- Multiple layers of hooked Grade 60 bars

**Least Congested (envisioned)**
- Fewer layers of hooked high-strength bars
- Fewer layers of headed high-strength bars
Project Tasks

1. High-strength Materials
   - Limit-benefit analysis

2. Prefabricated Rebar
   - Cost-benefit analysis

3. Optimization, Modeling, and Design
   - Optimization method for design
   - Finite element modeling/pre-test analyses
   - Design of prototypes

4. Experimental Testing
   - Material (concrete, steel)
   - Deep beam
   - Stub wall (pure shear)
   - Wall panel (shear + flexure)
   - Post-test simulations/comparisons

5. Recommendations
   - ACI Code recommendations
   - Design Procedure Document
   - Modeling guidelines
   - Field procedures
1- High-Strength Materials

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 research on ACI 349 requirements that have greatest impact on design
2- Prefab Rebar Cages

- Evaluate prefab headed rebar cages for:
  - transportability
  - liftability
  - modularity

- Develop field procedures
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
4- Experimental Evaluation

- Testing of:
  1) high-strength concrete and rebar materials
  2) deep beams to establish basic characteristics of shear-controlled behavior
  3) stub walls for pure shear strength of joints
  4) wall panels for combined shear+flexure behavior

- Validation of analytical modeling and design
- Post-test analyses to extend results
4.1- Material Testing

- ASTM tests for concrete and rebar materials
  - preliminary concrete mixes and rebar samples
  - materials from laboratory specimen construction
4.2- Deep Beam Tests

- Varying V/M ratios within shear span to establish basic characteristics of shear-controlled behavior.

![Diagram of beam and foundation with arrows indicating shear forces.](chart.png)
4.3- Stub Wall Tests

- Shear-wall-to-foundation joints under pure shear to establish shear friction strength
4.4- Wall Panel Tests

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

- Limit/cost-benefit Analyses
- Analytical Modeling
- Prototype Design
- Experimental Testing
- Design Procedure Document

Recommendations:
- Modeling
- Simulations

Design & Practice:
- Design
- Practice

Additional logos and affiliations are present at the bottom of the page.
Questions?

http://phsrc-nuclearwalls.nd.edu