Response to Request for Additional Information: Proposed Use of Fiber-Reinforced Polymer System at Oconee Nuclear Station

Presentation to
United States Nuclear Regulatory Commission
Rockville, MD
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Duke Participants

- Rich Freudenberger, Tornado-HELB Design Basis Group
- Stephen Newman, Regulatory Compliance
- Clifford Davis, Major Projects Group
- Lawrence Llibre, Major Projects Group

Speaking on behalf of Duke:

- Ed Fyfe, Fyfe Company, LLC
- Zach Smith, Fyfe Company, LLC

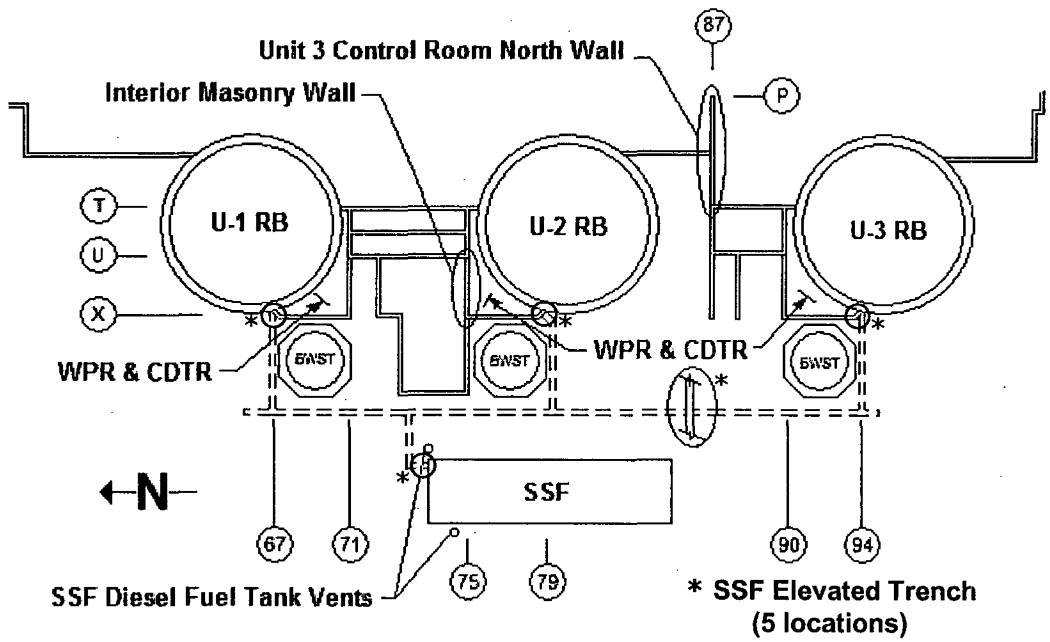
Agenda

- Introductions
- Purpose of Meeting
- Brief Description of Natural Phenomenon Barrier System (NPBS) Modifications
- Proposed Solution Using Fiber-Reinforced Polymer (FRP) System
- Discussion of Response to NRC Request for Additional Information (RAI) on FRP License Amendment Request (LAR)
- Closing Remarks

Purpose of Meeting

- Briefly review NPBS modifications.
- Review proposed use of FRP system within NPBS modifications.
- Discuss Duke's draft response to RAI on FRP LAR and obtain NRC feedback.

Brief Description of NPBS Modifications



Proposed Solution Using FRP System

- **Application**: Bond-critical application for flexural strengthening of non-load bearing, infill masonry walls to resist higher design loads.

  Note: Application is similar to traditional technique of employing externally bonded steel plates.

- **Loading Condition**: Uniform pressure on masonry wall resulting from tornado-induced differential pressure and possibly tornado wind causing tensile stresses in FRP system.

  Note: FRP system will not be relied upon as a compressive reinforcement.

Proposed Solution Using FRP System

- **Example Location**: Exterior surfaces of selected Units 1, 2, and 3 West Penetration and Cask Decontamination Tank Room walls.

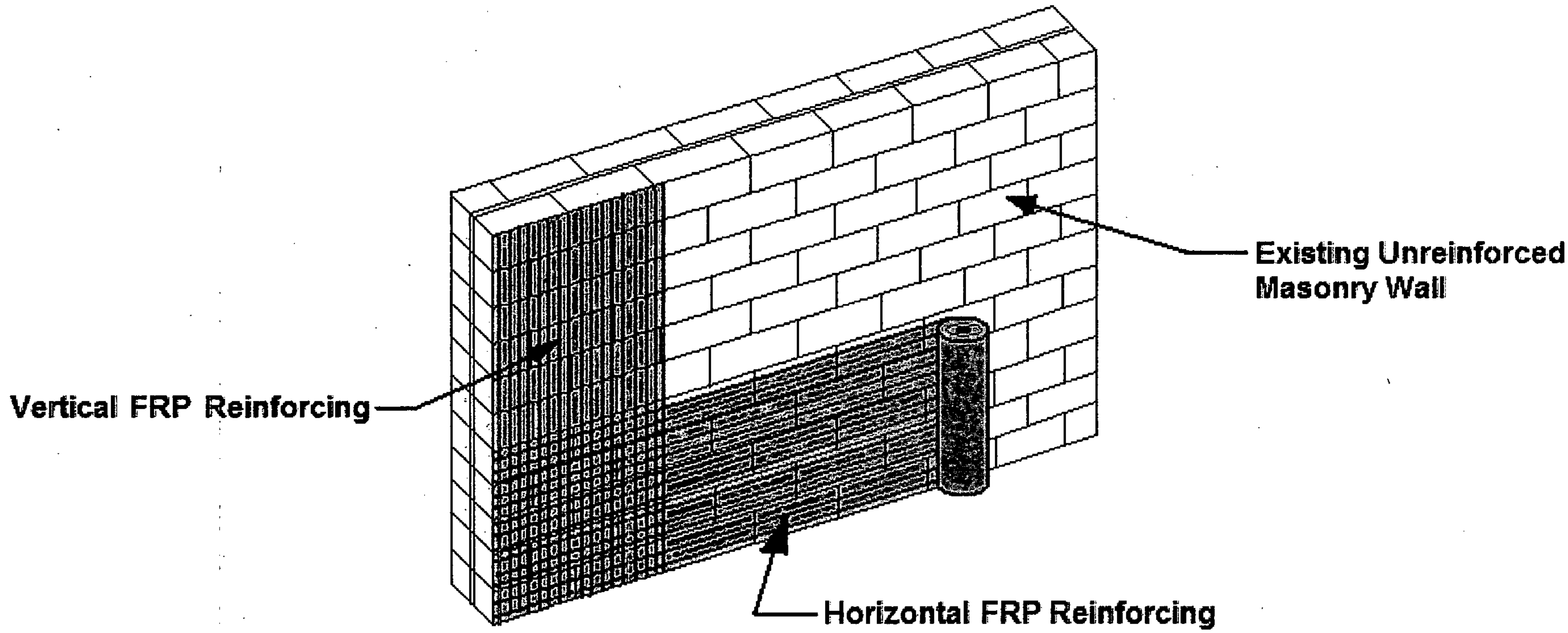
  Note: FRP system will be shielded from sunlight (i.e., UV) by siding.

- **Environment**: Ambient temperature and humidity conditions associated with local climate and Auxiliary Building equipment rooms.

  Note: FRP system will not be located in a high radiation environment or exposed to high temperature gas and/or liquid.

Proposed Solution Using FRP System

Typical FRP Application



Discussion of Response to RAI Question 1

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Areas Identified by Reviewer:

- Qualification Testing Program
- Variables Influencing FRP-Strengthened Masonry Walls
  - method of masonry construction
  - wall end conditions
  - wall aspect ratios

Discussion of Response to RAI Question 1

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Qualification Testing Program:

- ICC AC125 qualification testing and reporting for selected FRP system
- Relevant industry performance testing of FRP systems

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Qualification Testing Program:

- ICC AC125 qualification testing and reporting for selected FRP system
  - Establishes minimum set of acceptance criteria for issuance of ICC-ES evaluation reports for proprietary FRP systems
  - Acceptance criteria are developed by ICC-ES technical staff and approved by the Evaluation Committee
  - Meets ACI 440.2R-02 requirement that sufficient test data is available to demonstrate adequate performance of FRP system

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Qualification Testing Program (cont.):

- Relevant industry performance testing of FRP systems – Carney et al. (2003)
  - Construction: twelve URM walls, 3 ft. wide x 4 ft. high, 4 in. two-core hollow concrete block
  - Height:width aspect ratio: 1.3
  - End conditions: simple, top and bottom
  - FRP composite (two schemes): vertically placed laminate strips of varying width and rods
  - Loading: out-of-plane, static, uniform (air bag)
  - Results:
    - strengthening URM walls with FRP composites improves ultimate static strength
    - URM walls reinforced with glass FRP laminates result in a more ductile system
    - primary identified mode of failure due to delamination propagated by tensile failure of masonry near location of FRP (for Oconee both field testing during installation and in-service inspection of FRP system will include tension adhesion testing as per ASTM D4541 or ACI 530R-02)

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Qualification Testing Program (cont.):

- Relevant industry performance testing of FRP systems – Hamilton et al. (2001)
  - Construction: six URM walls, four 2 ft. wide x 6 ft. high and two 4 ft. wide x 15 ft.-4 in. high, 8 in. hollow-core concrete block
  - Height:width aspect ratios: 3.0 and 3.8, respectively
  - End conditions: simple, top and bottom
  - FRP composite: vertically placed laminate strips (under-reinforced condition)
  - Loading: out-of-plane, static, uniform (air bag)
  - Results:
    - used conventional reinforced concrete design equations to predict flexural strength (derived from basic mechanics principals)
    - ratio of predicted to actual flexural capacity ranged from 0.73 to 1.0 (application of environmental-reduction and strength-reduction factors as per ICC AC125 and ACI 440.2R-02 reduces analytically predicted capacities to values well below test results)
    - demonstrates use of conventional flexural strength design equations to predict flexural capacity of FRP-strengthened masonry walls is valid

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Qualification Testing Program (cont.):

- Relevant industry performance testing of FRP systems – Hamoush et al. (2001)
  - Construction: fifteen URM walls, 4 ft. wide x 6 ft. high, 8 in. hollow-core concrete block
  - Height:width aspect ratio: 1.5
  - End conditions: simple, top and bottom
  - FRP composite (two schemes): two layers of unidirectional bands (TYFO SEH51), one in horizontal direction and one in vertical direction, and two layers of continuous, bi-directional web fabric
  - Loading: out-of-plane, static, uniform (air bag)
  - Results:
    - employed simplified analytical method to predict flexural strength (derived from basic mechanics principals)
    - ratios of predicted to average test results for unidirectional and web FRP-strengthened walls were 1.26 and 1.56, respectively (application of environmental-reduction and strength-reduction factors as per ICC AC125 and ACI 440.2R-02 reduces analytically predicted capacities to values well below test results)
    - strengthening of URM walls with FRP composites predictably increases flexural strength; however, premature failure by shear at support(s) must be controlled by maintaining stresses below Code allowable values
    - demonstrates use of conventional flexural strength design equations to predict flexural capacity of FRP-strengthened masonry walls is valid

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Qualification Testing Program (cont.):

- Relevant industry performance testing of FRP systems – Tan et al. (2004)
  - Construction: thirty URM walls, 3.28 ft. wide x 3.28 ft. high, 2.75 in. x 3.94 in. x 9 in. solid clay bricks
  - Height:width aspect ratio: 1.0
  - End conditions: simple, four sides
  - FRP composite (multiple schemes): unidirectional fabrics oriented at varying angles (0, 45, 90, and 135 degrees) to mortar joints and bidirectional fabrics; varied number of layers and anchorage methods
  - Loading: out-of-plane, static, concentrated (spherical platen) or distributed (air bag)
  - Results:
    - developed analytical models to predict ultimate load-carrying capacity (based on principals of strain compatibility and force equilibrium)
    - ratios of test to predicted capacities ranged from 0.81 to 1.15 for flexural compression failure and from 0.74 to 1.44 for flexural bond failure (application of environmental-reduction and strength-reduction factors as per ICC AC125 and ACI 440.2R-02 reduces analytically predicted capacities to values well below test results)
    - general load-deflection response of FRP-strengthened masonry walls remains unchanged and use of conventional flexural strength design equations to predict the flexural capacity of FRP-strengthened masonry walls remains valid even when method of masonry construction (i.e., solid clay brick versus hollow-core concrete block) and wall support configuration (i.e., simply supported on four sides versus simply supported at the top and bottom) are varied

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Qualification Testing Program (cont.):

- Relevant industry performance testing of FRP systems – Tumialan et al. (2003)
  - Construction: four existing URM walls (decommissioned building), 8 ft. wide x 8 ft. high x 13 in., double-wythe (interconnected) consisting of cored clay units, solid clay bricks and clay tiles
  - Height:width aspect ratio: 1.0
  - End conditions: simple, top and bottom
  - FRP composite: vertically placed laminate strips
  - Loading: out-of-plane, static, two-point loading mechanism (at mid-height)
  - Results:
    - developed analytical model to predict ultimate load-carrying capacity (takes into account restraining forces in supports, originated by arching action, leading to increased out-of-plane resistance of URM walls)
    - ratio of predicted to average test result was 1.04
    - general load-deflection response of FRP-strengthened masonry walls remains unchanged and use of analytical models based on rigid body and material linearity to predict flexural capacity of FRP-strengthened masonry walls remains valid even when method of masonry construction is varied (i.e., double-wythe construction using a combination of cored clay units, solid clay bricks and clay tiles versus single-wythe construction using hollow-core concrete block) and other load resisting mechanisms are present (i.e., arching action)

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Qualification Testing Program (cont.):

- Relevant industry performance testing of FRP systems – Portland State University (1998)
  - Construction: three URM walls, 4 ft. wide x 11 ft. high, 6 in. x 12 in. x 4 in. hollow clay tile units
  - Height:width aspect ratio: 2.75
  - End conditions: simple, top and bottom
  - FRP composite (multiple schemes): vertically placed laminate strips – 12 in. on tension face, 48 in. on tension face, 48 in. on both tension and compression faces
  - Loading: out-of-plane, static and reversed cyclic, two-point loading mechanism (at third points)
  - Results:
    - ratios of predicted to actual flexural capacities were 1.086 (12 in. strip) and 1.017 (48 in. strip) under static loading
    - wall response for reversed cyclic loading was hysteretically stable response (i.e., nearly linear with relatively minor energy dissipation) demonstrating that FRP-strengthened wall maintained its integrity even when subjected to cyclic loading up to 85 percent of ultimate capacity
    - further demonstrates that the general load-deflection response of FRP-strengthened masonry walls remains unchanged and that the use of conventional flexural strength design equations to predict flexural capacity of FRP-strengthened masonry walls is valid for various types of masonry construction

Discussion of Response to RAI Question 1

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Influencing Variables - Wall End Conditions:

- Walls idealized for analysis (and correspondingly strengthened using FRP system) as:
  - simply-supported, one-way spans
  - simply-supported plates based upon actual wall construction
- Analytical methods developed during Oconee's response to IE Bulletin No. 80-11.
- Hence, type of wall end conditions (e.g., fixed, hinged, or guided) will not be a variable.

Discussion of Response to RAI Question 1

Influencing Variables – Wall Aspect Ratios:

- Test data show that neither application method of FRP composite systems (i.e., unidirectional or bidirectional) nor minor differences in wall aspect ratios alter general load-deflection response of FRP-strengthened masonry walls.
- These factors only influence distribution of stresses within masonry wall.

Discussion of Response to RAI Question 1

Influencing Variables – Method of Construction:

- Test data show that differences in method of construction (i.e., single or multiple wythe, hollow or grouted concrete blocks or solid concrete bricks, and type of mortar) do not alter general load-deflection response of FRP-strengthened masonry walls.
- Mechanical properties (e.g., tensile properties, compressive properties, etc.) and geometric properties (e.g., masonry unit thickness (solid brick), face shell thickness (hollow block), face-shell or full mortar beds, etc.) must be accurately quantified to design FRP strengthening system.

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Conclusion:

- Qualification testing and reporting for selected FRP system will be performed as per ICC AC125.
- Duke selected the previously discussed investigations because of their relevance to Oconee's proposed use of an FRP system in the areas of:
  - method of masonry construction,
  - wall end conditions, and
  - wall aspect ratios.

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Conclusion (cont.):

- In addition, these tests:
  - employ FRP composite systems comparable to the specific FRP system that Duke plans to use – Tyfo® Fibrwrap®;
  - simulate tornado differential pressure and wind induced loading conditions (i.e., static, monotonic, and uniform); and,
  - validate use of analytical methods, derived from basic mechanics principals, to predict flexural strength of FRP-reinforced walls.
- Together, these tests evaluated seventy URM walls of varying:
  - masonry construction (single- and double-wythe, 4 and 8 in. hollow-core concrete block, cored clay units, solid clay bricks and clay tiles),
  - aspect ratios (ranging from 1.0 to 3.8), and
  - FRP-reinforcing schemes (vertically and/or horizontally oriented unidirectional fabric and bi-directional web fabric applied using a range of anchorage methods and number of layers).
- Test data support utilizing the methodology proposed for application of an FRP composite system at Oconee.

Discussion of Response to RAI

- Responses to RAI questions 2 and 3 revised to address NRC concerns identified during 9/14/2006 teleconference.
  - QA Condition 1 application of FRP system
  - Process for establishing the required total number of FRP sample sets

Closing Remarks

- Additional Questions
- Action Items