Development of GFRP Reinforced Single Slope Bridge Rail

12th Annual FDOT Structures Research Update (Aug. 9-10, 2022)


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Outline

- Background / research motivation
- Project objectives
- Scope of work
- Conclusions
- Closing discussion

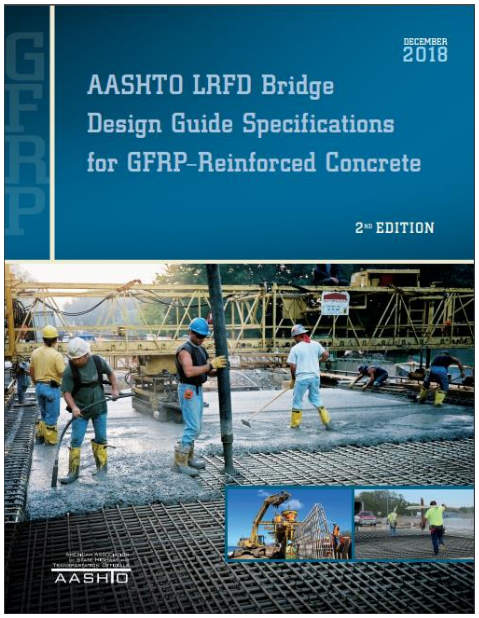
Background / research motivation

- Corrosion of steel reinforcing bars can cause deterioration of concrete bridge components
    - Decks, pile caps, pier columns, bridge rails, etc.
    - Particular problem in coastal / saltwater areas
- Fiber reinforced polymer (FRP) reinforcing bars offer a corrosion-resistant alternative to steel bars
- Glass-FRP (GFRP) reinforcing bars
    - Successfully deployed by FDOT in many areas of bridge construction (decks, pile caps, pier columns, etc.)

Background / research motivation

- Advantages of GFRP reinforcing bars
  - Corrosion resistant
    - Delay/eliminate rehabilitation necessitated by corrosion
    - Reduce maintenance costs
  - High tensile strength
  - Lightweight / ease of handling

- AASHTO LRFD Bridge Design Guide Specifications for GFRP-Reinforced Concrete
  - Addresses a range of issues related to the design of structures with GFRP



GFRP

DECEMBER
2018

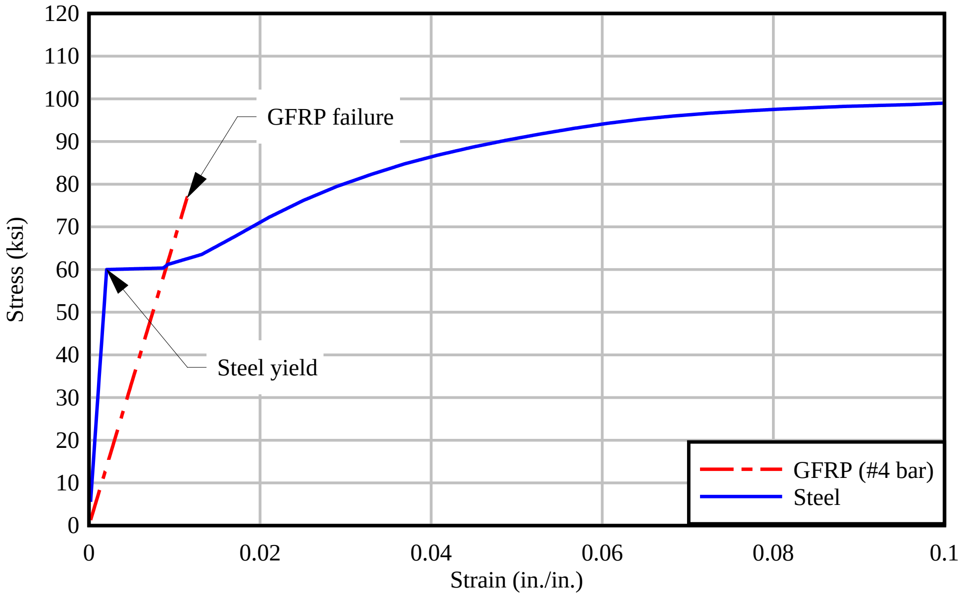
AASHTO LRFD Bridge
Design Guide Specifications
for GFRP-Reinforced Concrete

2nd EDITION

AASHTO

Background / research motivation

- Differences in material behavior
  - Mild steel vs. GFRP
- Elastic modulus
  - $E_{GFRP} < E_{steel}$
- Failure strain
  - $\varepsilon_{ult\ GFRP} < \varepsilon_{ult\ steel}$



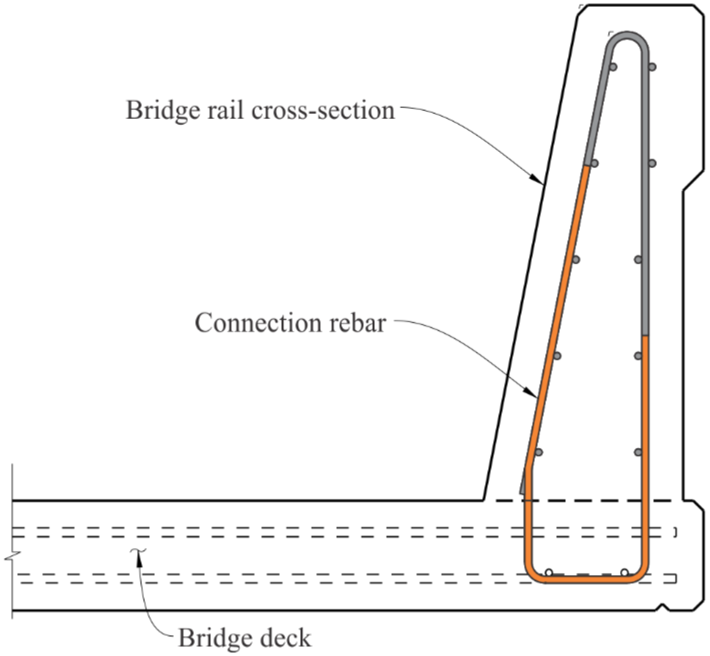
(Note: environmental reduction factor applied to GFRP curve)

- Yield line analysis
  - Strength of steel R/C bridge rails typically evaluated using yield line analysis
  - GFRP reinforcing bars lack ductility that is assumed by yield line analysis

- How well would a GFRP R/C bridge rail perform under impact loading?

Project objectives

- FDOT 36” single slope traffic rail (SSTR)
  - Develop a GFRP R/C alternative to the traditional FDOT steel R/C bridge rail
  - Use steel-to-GFRP, bar-for-bar replacement wherever feasible
  - Use GFRP rebar in bridge deck and rail
  - Evaluate relative performance using pendulum impact testing



FDOT steel R/C traffic railing design

Scope of work

Technical:

Task 1 – Develop impact testing protocols

Task 2 – Design rail specimens for impact testing

Task 3 – Construction and experimental testing

Administrative:

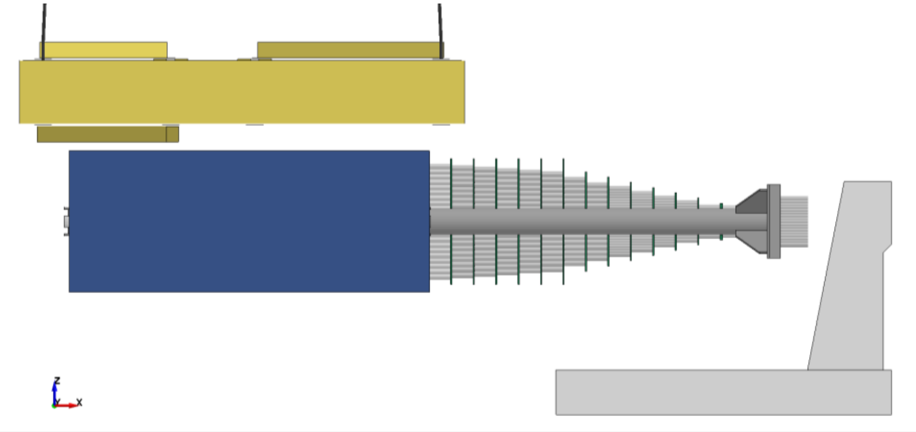
Task 4 – Draft Final and Closeout Teleconference

Task 5 – Final Report

Task 1 – Develop impact testing protocols

- Protocols for pendulum impact testing

(Source: TTI Report No. 9-1002-5)



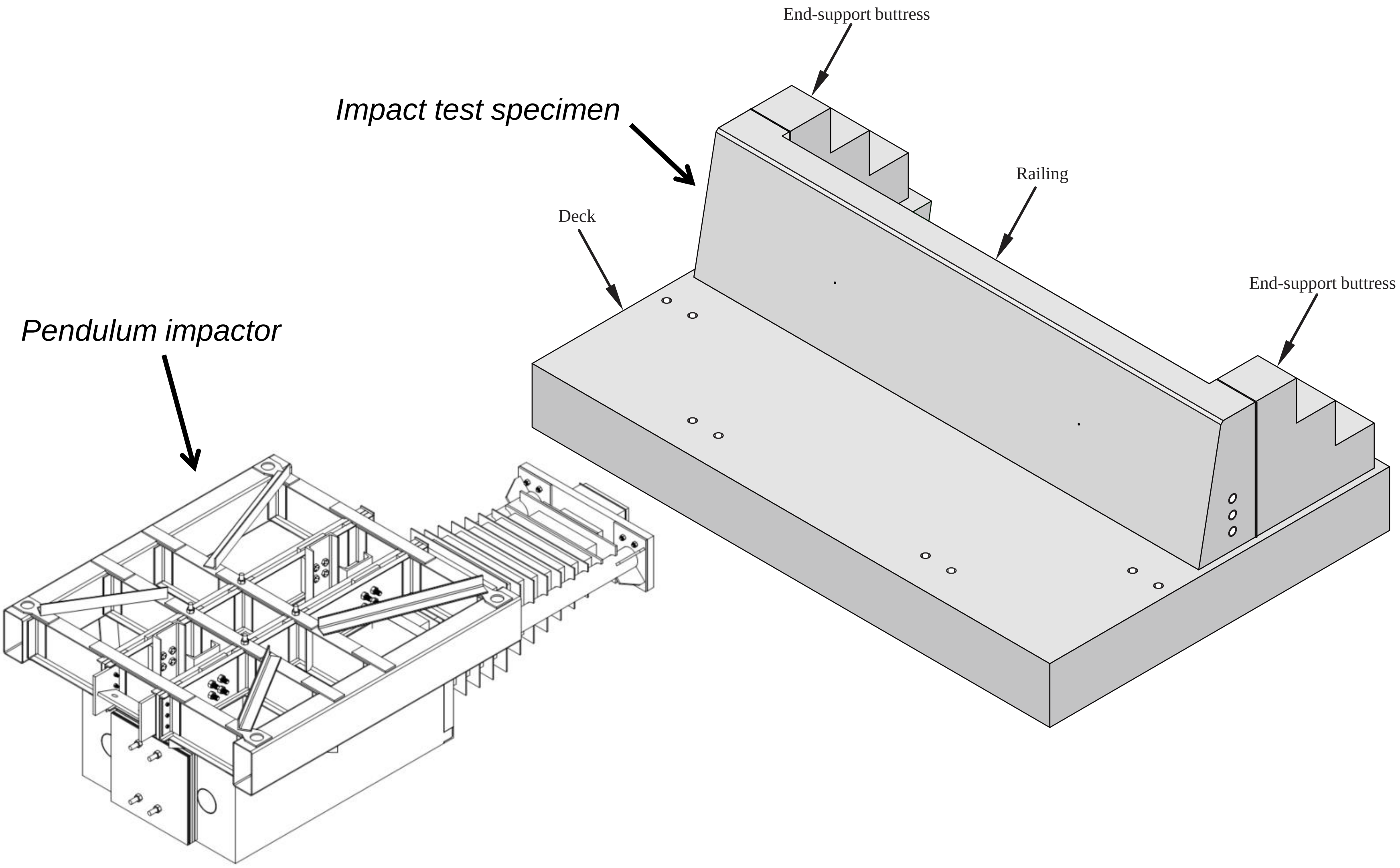
	MASH TL-4 SUT impact test	*Pendulum impact test*
Mass	*22,000 lb*	*10,000 lb*
Drop height	*N/A*	*15.5 ft*
***Transverse** velocity*	*14.5 mph*	*21.5 mph*
Impact energy	*155 kip-ft*	*155 kip-ft*
Peak impact load	*~65 kip*	*~65 kip*
Impact load rise time	*0.1 sec*	*0.1 sec*

Task 1 – Develop impact testing protocols

- Crushable-nose impactor:

- FDOT impact pendulum
  - Marcus H. Ansley Structures Research Center

Task 1 – Develop impact testing protocols



Impact test specimen

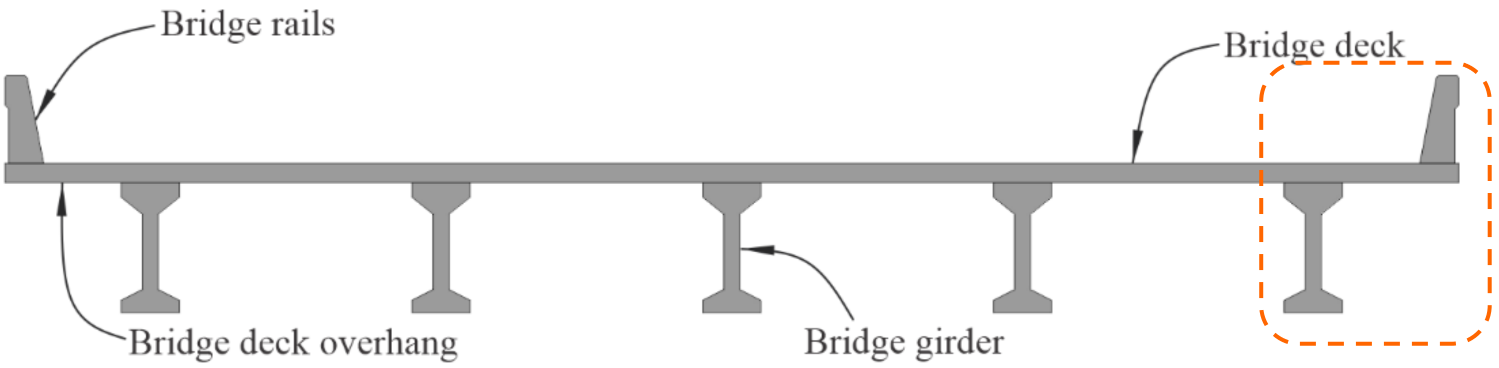
Pendulum impactor

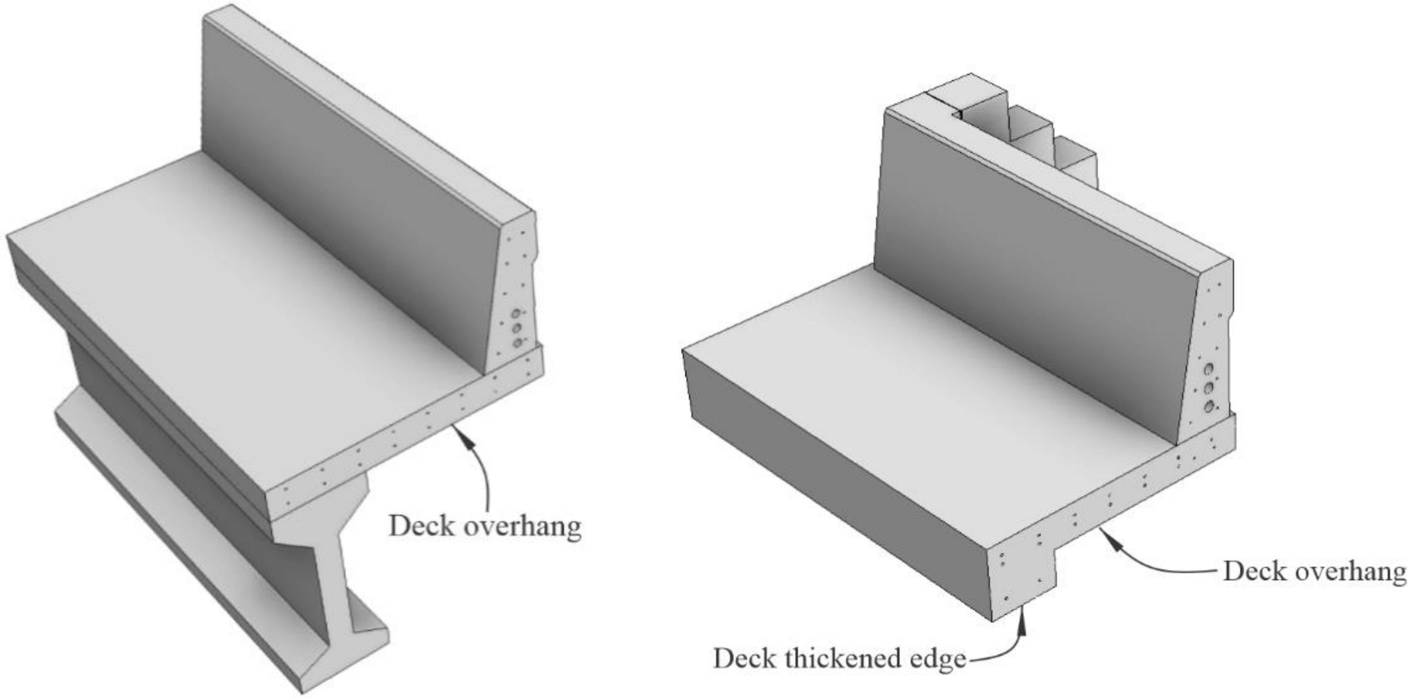
Task 2 – Design rail specimens for impact testing

- Design bridge rail test specimens
  - Steel R/C bridge rails (control)
  - GFRP R/C bridge rails (alternative)
  - Approach:
    - Use steel-to-GFRP, bar-for-bar replacement wherever feasible

Task 2 – Design rail specimens for impact testing

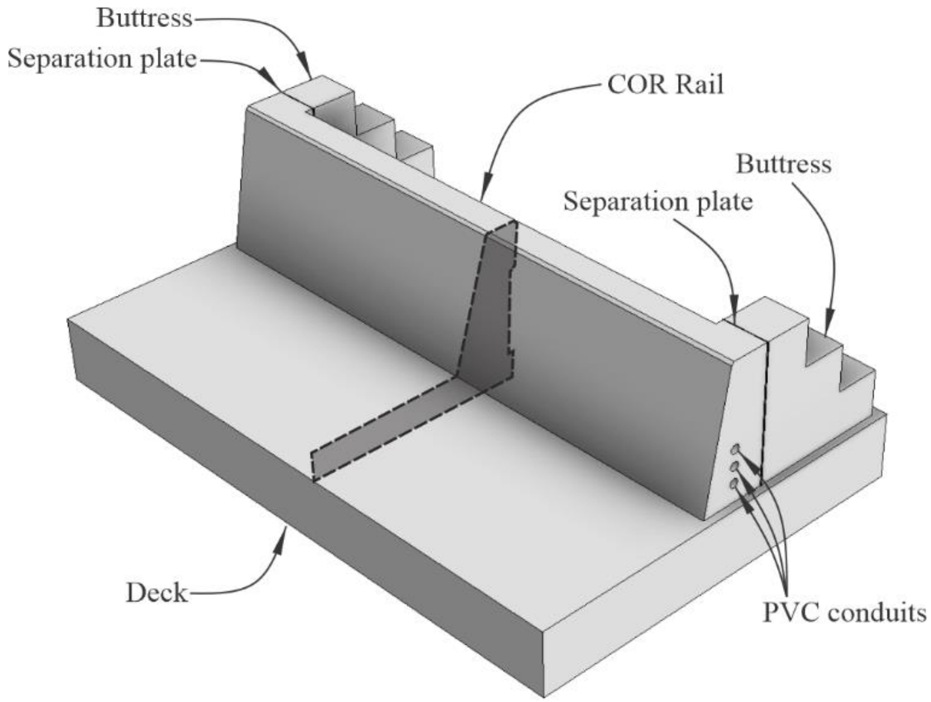
- Integrated bridge deck & bridge rail test specimen



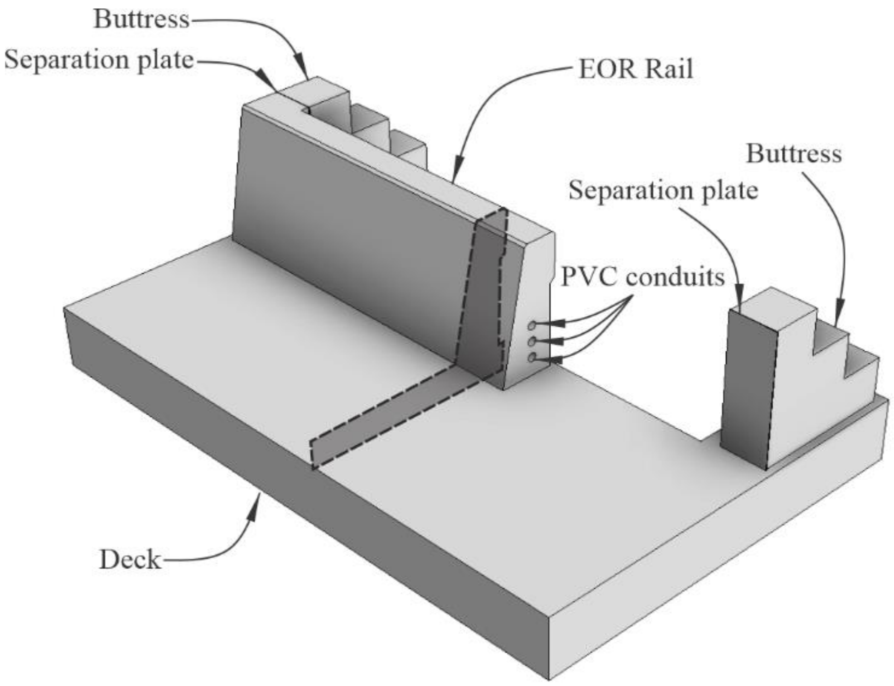


Task 2 – Design rail specimens for impact testing

- Center-of-rail (COR) test specimen



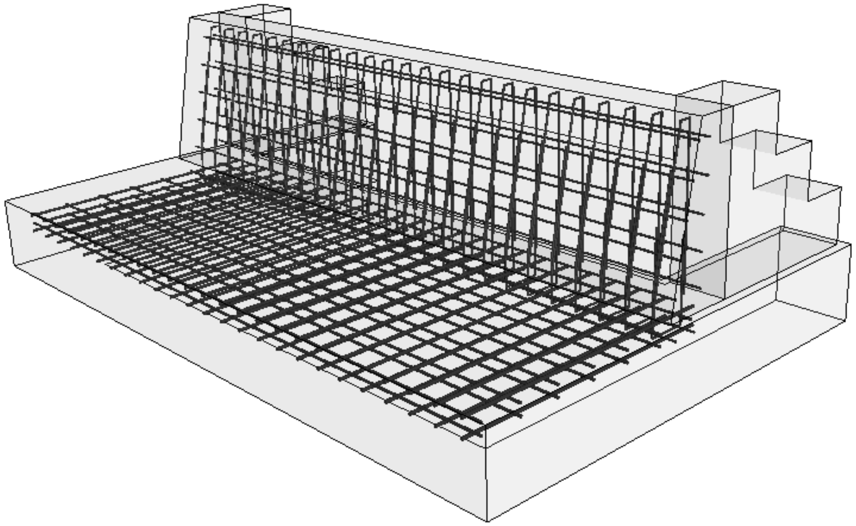
- End-of-rail (EOR) test specimen

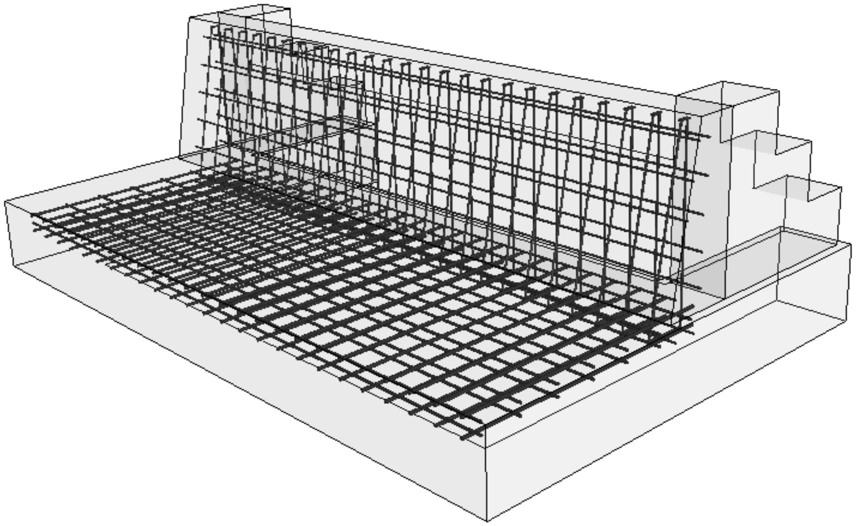


Task 2 – COR test specimens

- Rebar in steel R/C COR specimen

- Rebar in GFRP R/C COR specimen





Task 2 – COR test specimens

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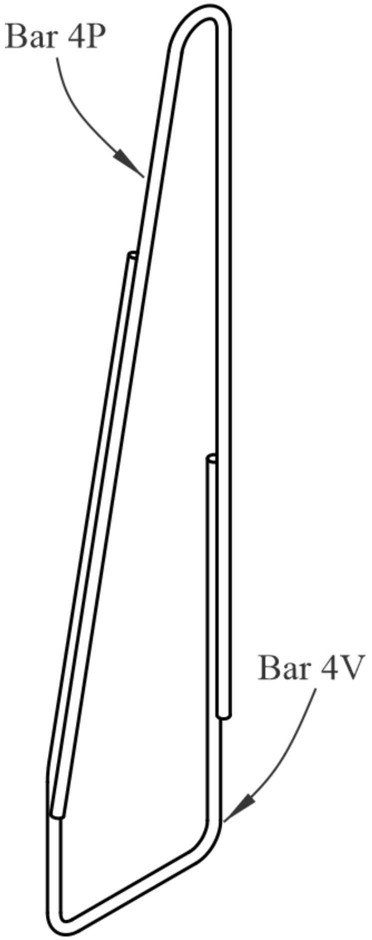
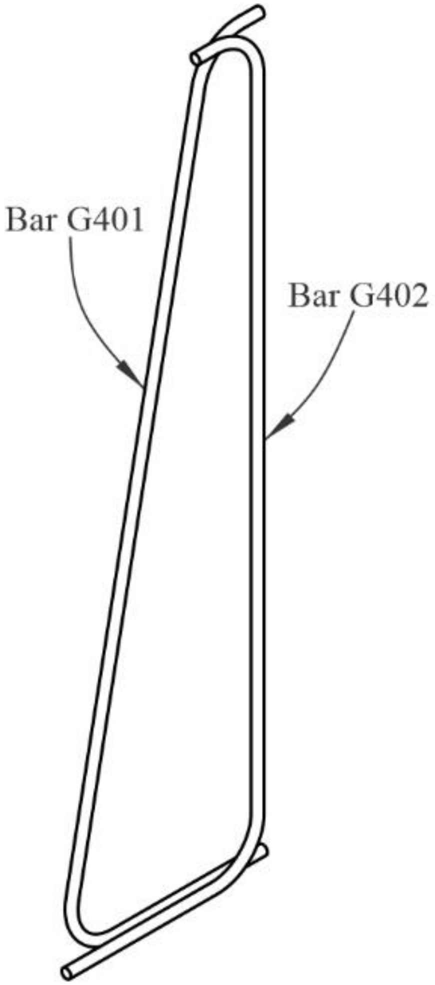
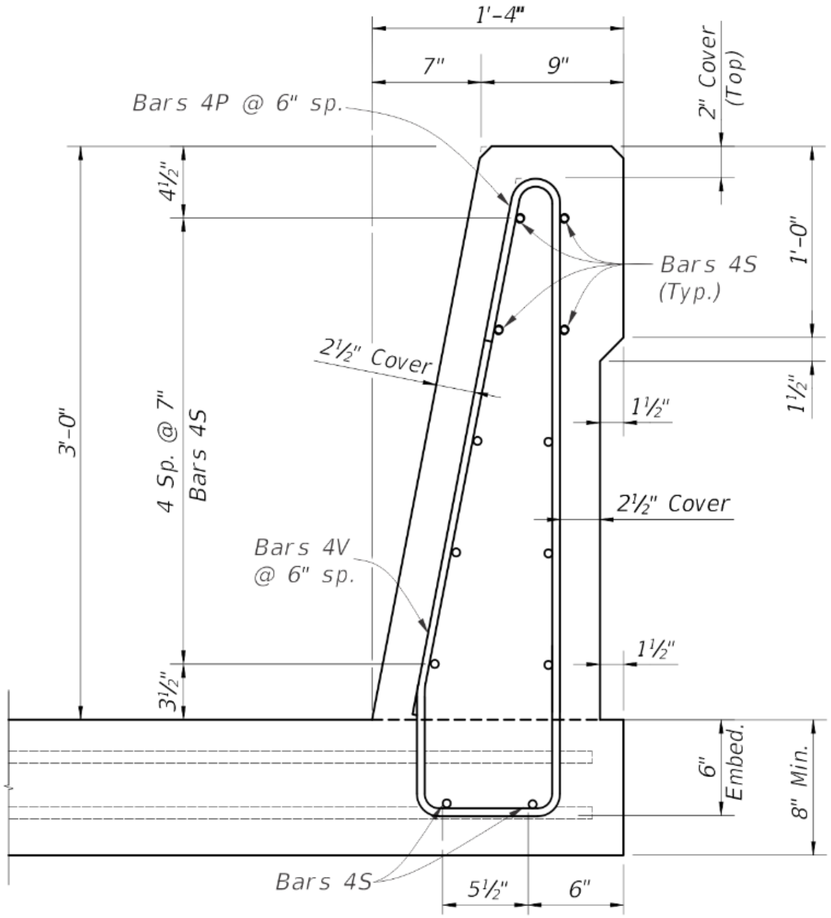


- Rebar in GFRP R/C COR specimen

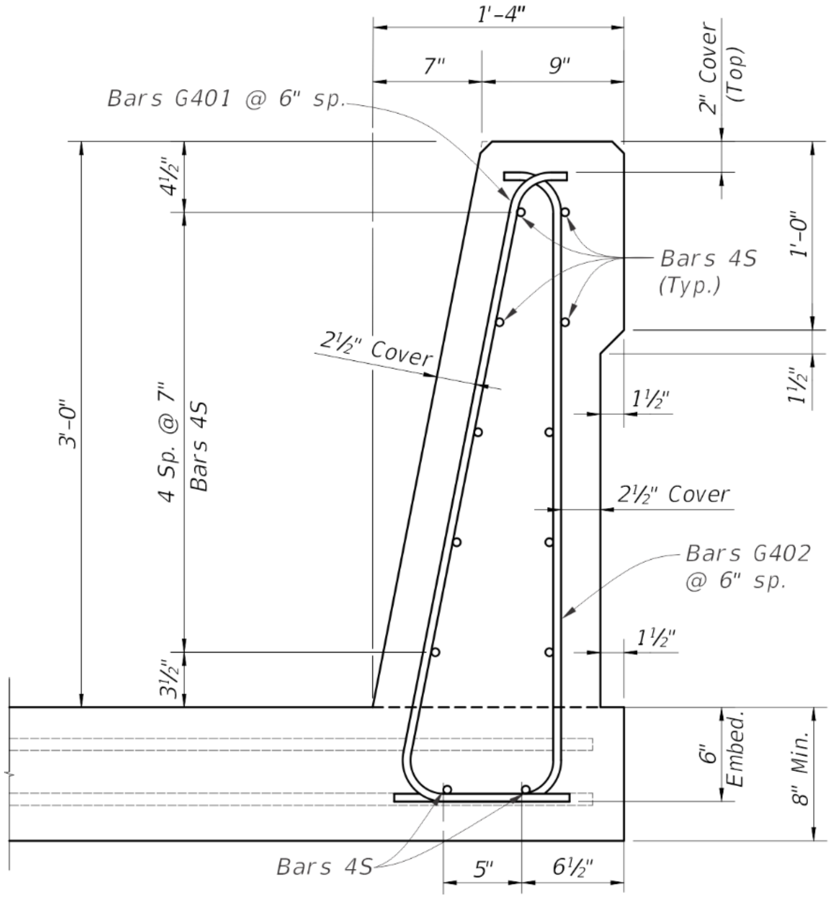


Task 2 – COR test specimens

- Rebar in steel R/C COR specimen

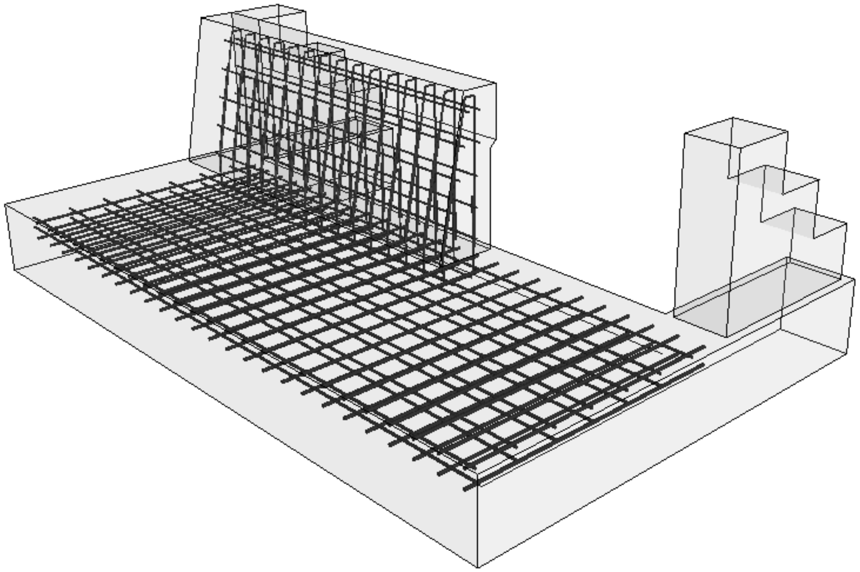


- Rebar in GFRP R/C COR specimen

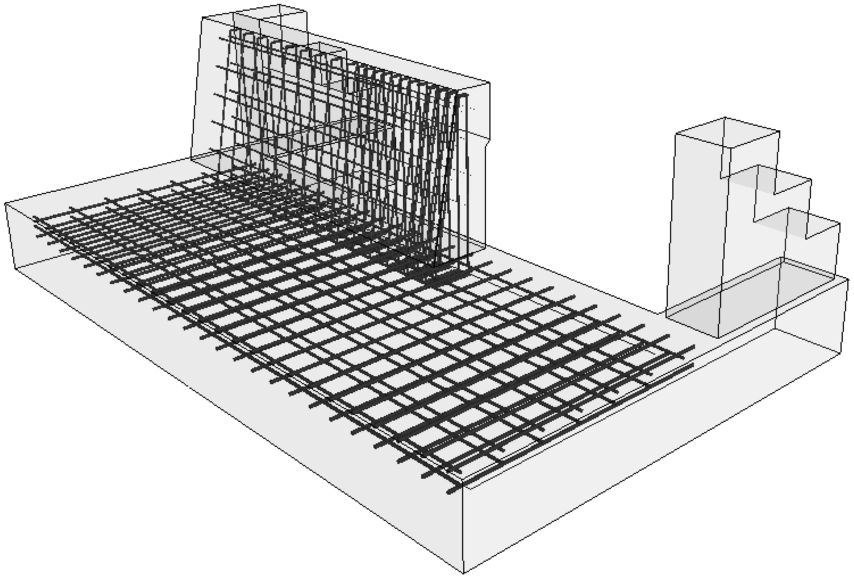


Task 2 – EOR test specimens

- Rebar in steel R/C EOR specimen

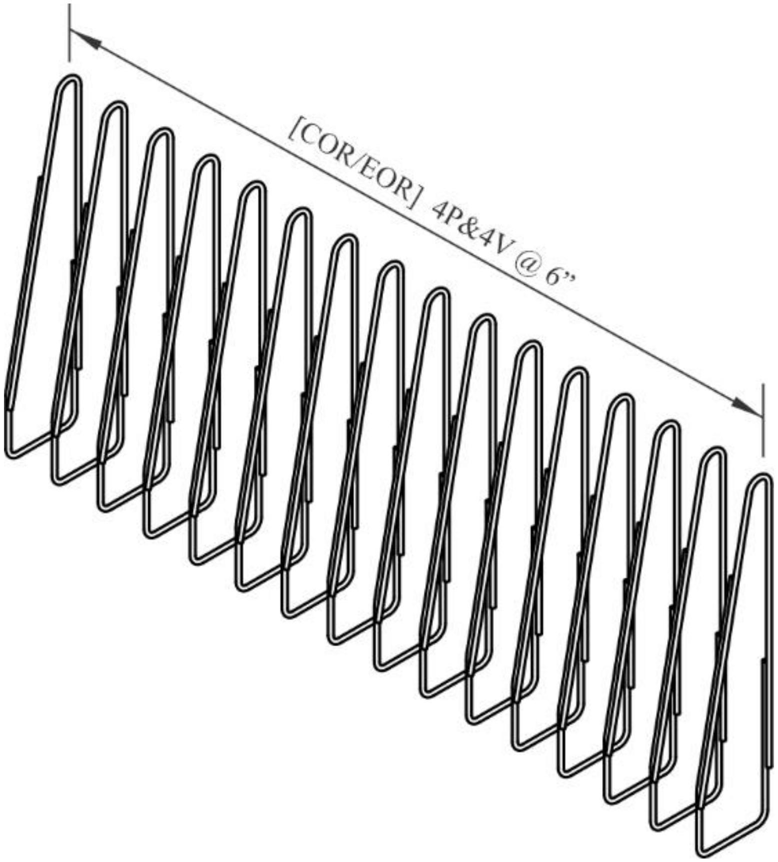


- Rebar in GFRP R/C EOR specimen

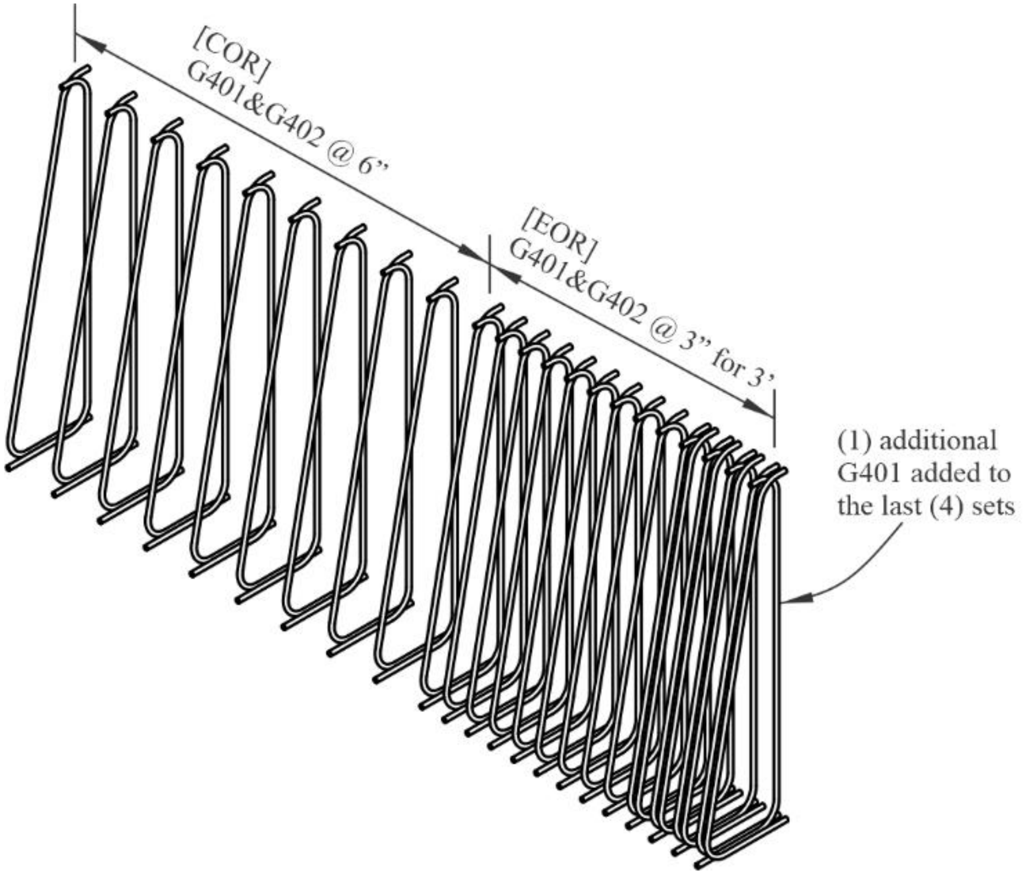


Task 2 – EOR test specimens

- Rebar in steel R/C EOR specimen

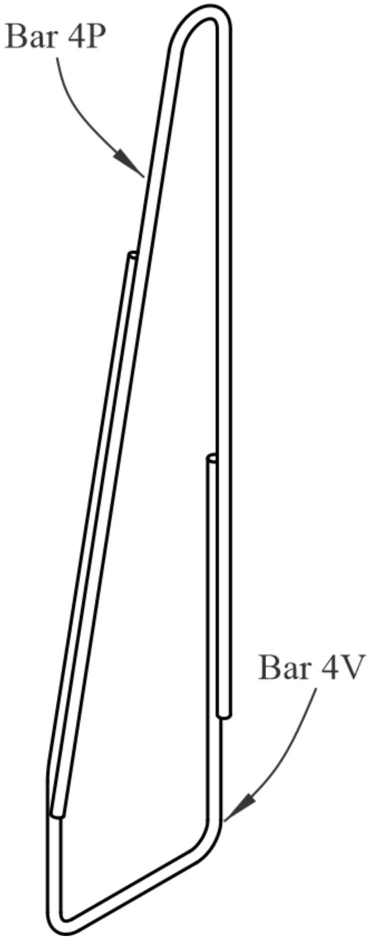


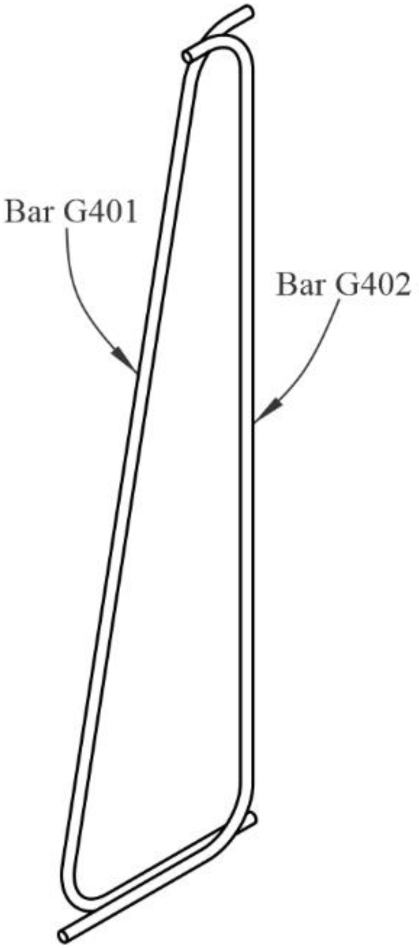
- Rebar in GFRP R/C EOR specimen

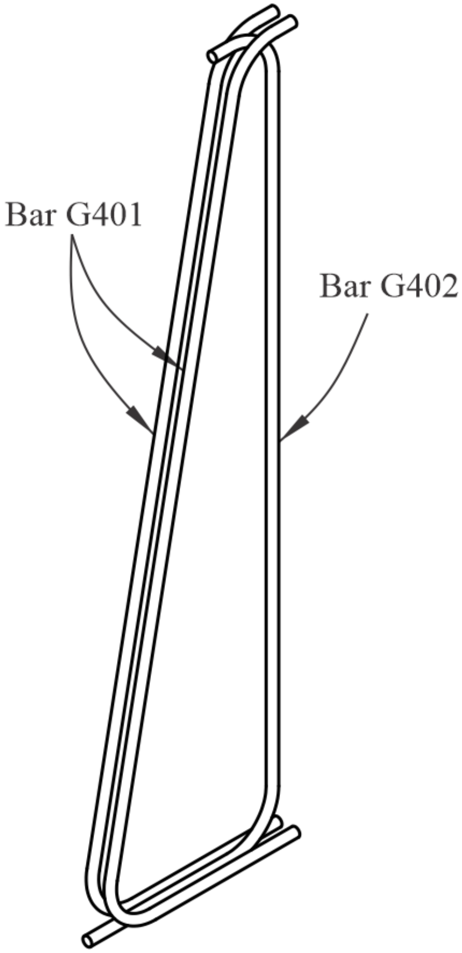


Task 2 – EOR test specimens

- Rebar in steel R/C EOR specimen
- Rebar in GFRP R/C EOR specimen







Task 3 – Specimen construction

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Task 3 – Instrumentation & test matrix

Pendulum impact tests:

- Instrumentation:
  - Accelerometers
  - Laser displacement transducers
  - Strain gages
  - High speed cameras
  - Optical break beams
  - Contact tape switches
- Center-of-rail:
  - Steel R/C COR rail #1
  - Steel R/C COR rail #2
  - GFRP R/C COR rail #1
- End-of-rail:
  - Steel R/C EOR rail #1
  - GFRP R/C EOR rail #1
  - GFRP R/C EOR rail #2

Task 3 – Experimental testing

- GFRP COR #1 impact test

Task 3 – Experimental testing

- GFRP EOR #1 impact test

Task 3 – Experimental testing

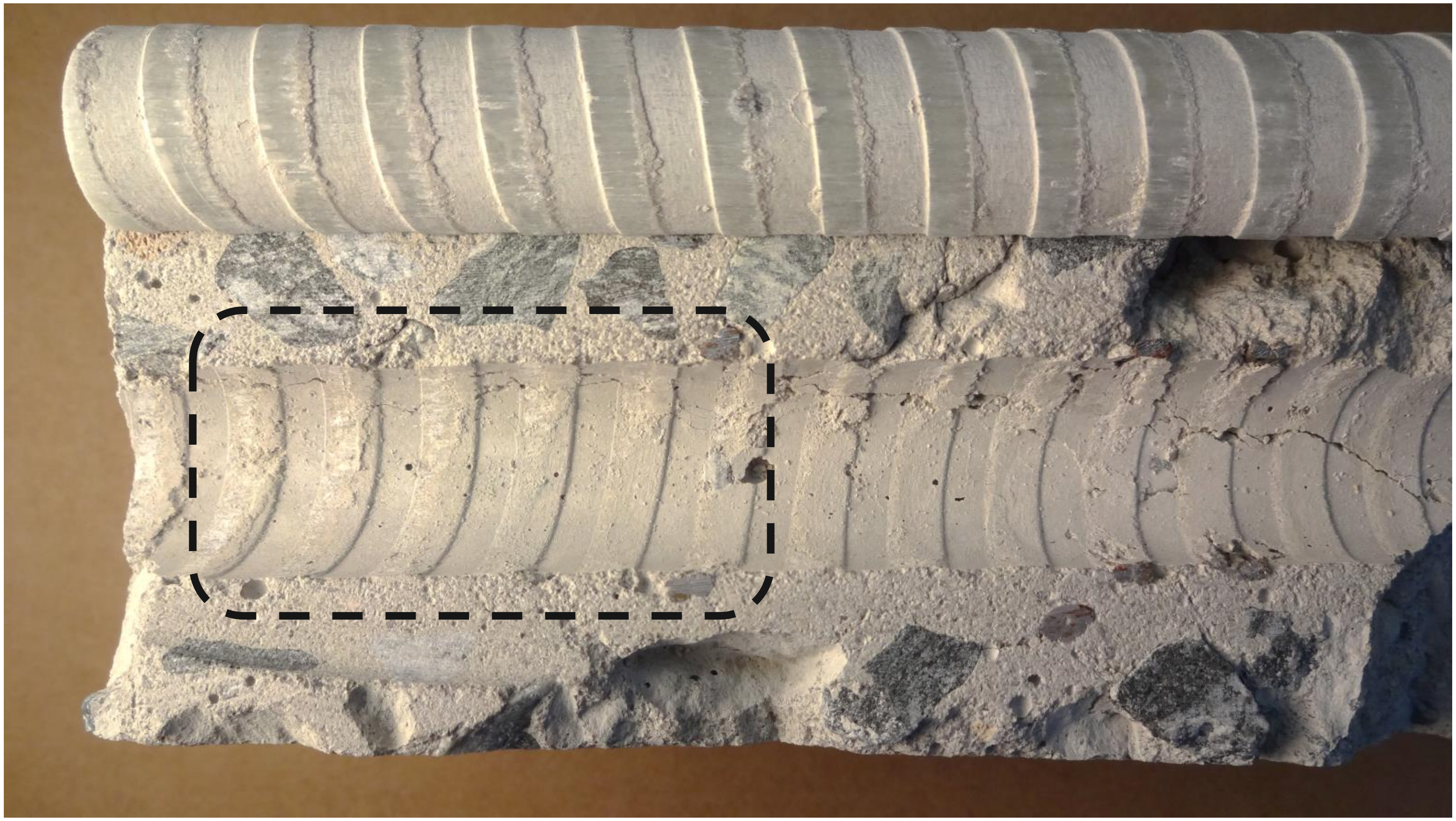
- GFRP EOR #1 impact test
  - Max Δ ≈ 1.9 in.
  - Max crack width > 0.1 in.

Task 3 – Experimental testing

- GFRP EOR #1 impact test
  - Max Δ ≈ 1.9 in.
  - Max crack width > 0.1 in.

Task 3 – Experimental testing

- GFRP EOR #1 impact test
  - Strain gage data did not suggest GFRP bar rupture
  - Hypothesis: partial bond failure (slip) at ends of transverse #6 deck bars



Task 3 – Experimental testing

- GFRP EOR #2 modifications
  - Added 90-deg hooked #4 bars between primary transverse #6 deck bars
  - Extended the 3” o.c. G401 & G402 rail bars for two additional positions

Task 3 – Experimental testing

- GFRP EOR #2 impact test

Task 3 – Key experimental results

- Center-of-rail:
  - Steel R/C COR rail #1
    - Max Δ ≈ 0.07 in.
    - No discernable cracking
  - Steel R/C COR rail #2
    - Max Δ = N/A
    - No discernable cracking
  - GFRP R/C COR rail #1
    - Max Δ ≈ 0.09 in.
    - Max crack with < 0.004 in.
- End-of-rail:
  - Steel R/C EOR rail #1
    - Max Δ ≈ 0.42 in.
    - Max crack width≈ 0.016 in
  - GFRP R/C EOR rail #1
    - Max Δ ≈ 1.9 in.
    - Max crack width > 0.1 in.
  - GFRP R/C EOR rail #2
    - Max Δ ≈ 0.67 in.
      (Residual Δ ≈ 0.25 in.)
    - Max crack width ≈ 0.035 in.

Conclusions

- For center-of-rail (centrally located) impacts
  - Bar-for-bar replacement of steel with GFRP worked adequately
- For end-of-rail impacts
  - Adequate impact performance was achieved by:
    - Increasing the number of GFRP bars in the rail (relative to steel R/C)
    - Decreasing the spacing of GFRP bars in the rail (relative to steel R/C)
    - Adding 90-deg. hooked GFRP bars between the primary transverse deck bars
  - No evidence of GFRP bar rupture was observed in any GFRP test
- Performance measures: rail deflections & crack widths
  - GFRP R/C rails exhibited larger deflections & crack widths than steel R/C rails
  - GFRP R/C rail deflections remained at an acceptably low level to provide continued service
  - GFRP R/C rail crack widths were of manageable size (i.e., cracks could, if necessary, be injected and repaired)

Closing

- Thank you for your attention
- Discussion / questions?