Secondary Reinforcement for FRP Reinforced Concrete Panels

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Objectives

- To develop an empirical based secondary reinforcement ratio which controls shrinkage and temperature cracks in applications such as bridge decks and other areas where durability is of concern.

- To investigate possible standard test methods for secondary reinforcement that includes boundary restraint.
Background

- According to the 2002 FHWA National Bridge Inventory, 27% of U.S. bridges are either structurally deficient or functionally obsolete.

- Statistic increases to 37% for the State of Missouri.

- Typically, bridge decks have the shortest service life compared to other components (15 to 20 year service life compared to over 40).

- Corrosion of steel reinforcement is commonly the primary source of problems.
Secondary Reinforcement

- Cracks can only be controlled, not prevented by reinforcement

- With proper reinforcement, more cracks with smaller widths are formed instead of fewer cracks with larger widths

- The finer the crack width, the less likely it is to contribute to durability problems
Current Code/Recommendations

ACI 318

- R7.12–Shrinkage & Temp. Reinforcement
- $\rho_{\text{min}} = 0.0018$ (Grade 60 Steel)
- Max Spacing = 18” or 5 x Slab Thickness

ACI 440

- Chapter 10-Temp. & Shrinkage Reinforcement
- $\rho_{\text{min}} = 0.0018 \times \frac{60,000 \ E_s}{f_{\text{fu}} \ E_f}$
- Max Spacing = 12” or 3 x Slab Thickness
ACI 440

- Current ratio based on material stiffness comparison
- No experimental data available
- In most applications,
  Secondary Reinforcement > Primary Reinforcement
- Considered excessive by many experts
Project Description

- Study was separated into three phases which examined both early-age and late-age effects of various reinforcement ratios on the formation of shrinkage/temperature and flexural cracks

- Phase I – Early age tensile test subjected to environmental cycles

- Phase II – Late age tensile test

- Phase III – Crack control of panels tested in flexure
Test Program – Phase I

Specimen Description

- Dimensions: 5” x 12” x 48”
- #3 GFRP and steel rebar
- Reinforcement placed at mid-depth (2.5” cover)
- Steel angle used to predetermine crack location
- Strain gauge attached to rebar 24” from the end
- Two 3/4” threaded steel rods with washer and nut were cast in both ends of the specimen
Test Program – Phase I

Test Setup
Test Program – Phase I

Test Procedure

- Specimens cast and allowed to cure for 30 hours
- Specimens were subjected to axial restraint
- Environmental cycles performed for three days
- Restraint load, rebar strain, and crack widths recorded throughout the environmental conditioning
- After chamber cycling, load was increased until failure
Test Program – Phase II

Specimen Description

- Dimensions: 5” x 12” x 48”
- #3 and #4 GFRP and steel rebar
- Reinforcement placed at mid-depth (2.5” cover)
- Grooves cut predetermine crack location
- Strain gauge attached to rebar 24” from the end
- Two ¾” threaded steel rods with washer and nut were cast in both ends of the specimen
Test Program – Phase II

Test Setup
Test Program – Phase II

Test Procedure

- Specimens cured at room temperature for 3 weeks
- Specimens loaded in tension in increments of 1000 lbs. until failure
- For each load increment, deflection, rebar strain, and crack widths were recorded
Test Program – Phase III

Specimen Description

- Dimensions: 5” x 23.25” x 72”
  7” x 25.25” x 72”
  7” x 32” x 72”
- #2, #3, #4, and #5 GFRP and steel rebar
- Four strain gauge specimen: 2 rebar at mid-span and quarter point
- Five grooves cut on both sides of tensile surface
- 1” concrete clear cover
Test Program – Phase III

Test Setup
Test Program – Phase III

Test Procedure

- Specimens cured at room temperature for 5 to 7 weeks
- Depending on the calculated ultimate capacity, the panels were loaded in flexure in increments of 250 to 2000 lbs. until failure
- For each load increment, deflection, rebar strain, and crack widths were recorded
Conclusions

- At early-age, three times for reinforcement cross-sectional area is required to produce similar crack control characteristics when subjected to similar axial loads and concrete area.

- At later-age, steel reinforcement is 1.3 times more efficient (tensile load per crack area) at crack control than GFRP.

- When tested in flexure, twice as much GFRP reinforcement is required to produce similar crack control as steel reinforcement.
Thank You!

Questions?