North Carolina Department of Transportation

PROJECT INFORMATION	
High Value Project Title	CFRP Strands in Prestressed Cored Slab Units
Project ID	RP2014-09; FHWA/NC/2014-09
Project Cost	$106,032 (Research) + $111,726 (Materials) = $217,758 (TOTAL)
Duration	20 months
SUBMITTER	
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RESEARCH PROGRAM	
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RESEARCH AND RESULTS	
Brief Summary of the Research Project	Steel-cable, prestressed concrete cored slab superstructures are commonly used for bridges in coastal North Carolina (NC). This type of bridge is subjected to an aggressive marine environment, so corrosion of the internal reinforcement is of significant concern. Several of these bridges in NC are in need of repair or replacement after having been in service for little more than 40 years. To prevent corrosion in future cored slab superstructures, the North Carolina Department of Transportation (NCDOT) chose to evaluate the performance of cored slabs reinforced with non-corroding Fiber Reinforced Polymer (FRP) instead of traditional steel. The objective of the study was to investigate the performance of cored slabs prestressed with carbon FRP (CFRP) strands and reinforced with glass FRP (GFRP) stirrups. The structural performance of these experimental cored slabs was compared to that of steel control specimens to evaluate their suitability with respect to the current standard design. The general objective was accomplished through the following specific tasks: • Previous research in the field of FRP reinforcement was reviewed, with an emphasis on FRP prestressing. • FRP material tests were performed to confirm manufacturers' design values. • The bond properties of the CFRP prestressing strands were comparatively measured using tests on beam-end specimens • The current standard NCDOT cored slab design was reviewed and an all-FRP substitute reinforcing scheme for cored slabs was designed.

Reinforcing layout for FRP prestressed cored slabs

FRP reinforced cored slabs on casting bed

- Three full-scale, 45 ft. long cored slabs were cast and tested to failure in flexure. Two of the specimens were reinforced with FRP and a third served as a steel-reinforced control specimen.

Flexural test setup at NCSU-CFL

FRP flexural specimen during testing

FRP flexural specimen after failure

- Three full-scale, 15 ft. long cored slabs were cast and tested to failure in shear. Two of the specimens were reinforced with FRP and the third served as a steel-reinforced control specimen.

Shear test setup at NCSU-CFL

FRP shear specimen during testing

FRP shear specimen after failure

- The tests of the steel and FRP reinforced specimens were compared to each other and to their calculated design strengths.

This report presents the findings from the literature review, testing, and analysis of the test data. Specific findings include the following:

- A large body of research exists on the topic of FRP prestressing. Test results have shown that the capacity of FRP prestressed concrete members can equal or exceed that of equivalent steel prestressed members.
- A growing number of FRP prestressed bridge decks and piles are being implemented by Departments of Transportation across the country and abroad.
- The manufacturers' reported values for the mechanical properties of the CFRP strand and GFRP rebar used in this project are accurate.
- The voids in a hollow cored slab can float during casting, which has been observed by others, and dramatically weakens the cored slab section. Care must be taken to prevent this phenomenon during construction when using either steel or FRP reinforcement.
- The experimental flexural capacity of the properly manufactured FRP reinforced cored slab was 9% greater than the capacity of the steel reinforced control cored slab, however, this capacity was 10% lower than the unfactored ACI 440.4R (2004) capacity.
- The presence of closely spaced, large diameter GFRP stirrups in the compression zone of the

	FRP reinforced cored slabs appears to have triggered premature compression zone failure in one of the specimens. • Even with the postulated effect from the GFRP stirrups, ACI 440.4R (2004) predicts a safe flexural design strength that is 8% lower than the experimental flexural capacity. • The GFRP stirrups remained intact after all full-scale tests. • ACI 440.4R (2004) provided conservative predictions for shear strength. • Due to the nature of the prestressed cored slab section studied, shear failure is unlikely to be a design concern, as the flexural failure mode dominates the behavior for this section. Based on these findings, the all-FRP reinforcement scheme for cored slabs should be a suitable structural replacement for the current design using steel reinforcement. However, the GFRP stirrups may have had a deleterious effect on the strength of the cored slabs. This effect should be explored further so that it may be quantified, and perhaps mitigated. An alternative arrangement of corrosion resistant shear reinforcement would likely address this situation.
Impact, or Potential Impact, of Implementing Research Results	Revise Documents: CFRP strands could be added to the ASTM Specifications and the Bridge Design Specifications. • Write or revise Specifications • Write Special Provisions • Develop new or revise written policies and procedures • Develop languages for legislation and for BOT Application to Processes: Design tool for highly corrosive sites. • Establish new design procedures • Stop out-of-date processes • Recommend to external agencies and/or organizations • Develop agreements / partnerships • Form a Working Group • Establish need for additional equipment, parts, materials, etc. Application to Projects: Possible application of CFRP in highly corrosive sites where the bridge is close to the saltwater environment. • Apply results to meet permit commitments or requirements or to avert legal challenges • Trial use on specific projects (TIP No., Contact No., locations, etc.) • Seek additional funds for construction innovations • Develop cost estimates • Engage upper level management • Meetings with Division personnel A life cycle assessment to evaluate the true economic benefit of replacing corrosive steel-reinforced structural systems in aggressive environments with more durable FRP alternatives is recommended.
Benefits of Research Results	• Based on the research results, it can be said that the FRP reinforced cored slab design demonstrates equivalent or superior performance in monotonic flexure and shear compared to traditional steel reinforced cored slabs. • The performance demonstrated by the FRP reinforced sections in this experimental program, along with the excellent durability of the FRP reinforcement, should make the proposed cored slab design an effective and sustainable solution in highly corrosive sites where the bridge is close to the saltwater environment and could result in longer lasting bridges.
Web Links	https://connect.ncdot.gov/projects/planning/Pages/ProjDetails.aspx?ProjectID=2014-09