VDOT Virginia Department of Transportation
VTRC Virginia Transportation Research Council
Research Brief
VCTIR 15-R10RB June 2016

Structural Design Guidelines for Concrete Bridge Decks Reinforced With Corrosion-Resistant Bars

Perspective Concrete slab bridge decks can deteriorate if the reinforcing steel bars within the concrete corrode. Maintaining and repairing a deteriorating deck use up time and money. In September 2010, the Structure and Bridge Division of the Virginia Department of Transportation (VDOT) required that all concrete bridge deck projects be designed with higher strength corrosion-resistant reinforcing bars, rather than corrosion-prone bars of Grade 60 epoxy-coated reinforcing steel that has a minimum yield strength of 60,000 pounds per square inch.

Various types of corrosion-resistant reinforcement bars that VTRC has tested, some of which are now routinely used by VDOT.

VDOT concrete bridge deck designers have met this requirement by substituting corrosion-resistant reinforcing bars with the same diameter as the epoxy-coated reinforcing steel bars used previously.

A study initiated by the Virginia Transportation Research Council (VTRC), VDOT's research division, showed that for corrosion-resistant reinforcing bars made of ASTM A1035 steel (a low carbon, chromium steel) and UNS 32304 steel (a type of stainless steel), VDOT could reduce the bar diameter by one size and remain in compliance with the American Association of State Highway and Transportation Officials (AASHTO) design requirements for Grade 60 steel reinforcing bars. With this recommended change to the design guideline for the diameter sizing of these corrosion-resistant reinforcing bars, the quantity of reinforcing steel in a deck could be reduced by as much as 36 percent, at a cost savings to VDOT.

Virginia Tech researchers, contracted by VTRC, came to that conclusion after testing various physical properties of mockup concrete bridge decks. Each mockup deck incorporated a different type of corrosion-resistant reinforcement and one of several schemes of bar size and spacing that differed from the AASHTO requirements. The researchers focused on how well the mockup held up when subjected to a range of load conditions, which simulated traffic loads all the way to overload and deck slab failure.

The research team used six types of corrosion-resistant reinforcing bars in the mockup bridge decks: three steel types — ASTM A1035, UNS S24100 (another type of stainless steel) and UNS S32304 — and three composite rod types — reinforced with fibers of either glass (GFRP), carbon (CFRP) or basalt (BFRP). These corrosion-resistant fiber-reinforced polymer composites are not routinely used by VDOT for reinforcement in concrete, but they were tested as such to assess their possible future use.

In addition to determining which corrosion-resistant reinforcing bars could be used in a concrete bridge deck at a diameter smaller than that required by AASHTO for Grade 60 steel, this study provided important information on how the different corrosion-resistant materials influence the behavior of reinforced concrete and the changes in design and construction practices that can be considered for their use in bridge deck applications.

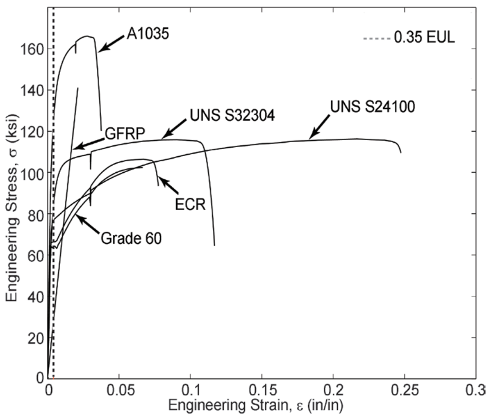
VDOT began construction in June 2015 of a reinforced concrete bridge over Wolf Creek near Virginia Tech. This is the first VDOT bridge to be built with the reduction in the diameter of ASTM A1035 corrosion-resistant reinforcing steel recommended by this study; this will reduce the amount of deck steel required for the project. Bridge construction will be documented for VTRC by Virginia Tech researchers.

Background VTRC performed a series of studies of concrete reinforcement starting in the early 1990s, inspired by observations of epoxy-coated reinforcement failures in Florida. A summary report published in 2006 (VTRC 06-R29) recommended that VDOT stop using epoxy-coated reinforcement in their highway bridges and instead use steels alloyed specifically to improve their corrosion resistance. The alloying process — combining carbon steel with certain chemical elements — can simultaneously change other material properties — such as strength and ductility — as compared to Grade 60 steel bars.

VTRC published a study in 2011 (VCTIR 11-R21) that characterized the new corrosion-resistant reinforcing bars. That research set the stage for the current study into the physical behavior of corrosion-resistant reinforcement in concrete, which will make its use more efficient and less costly.

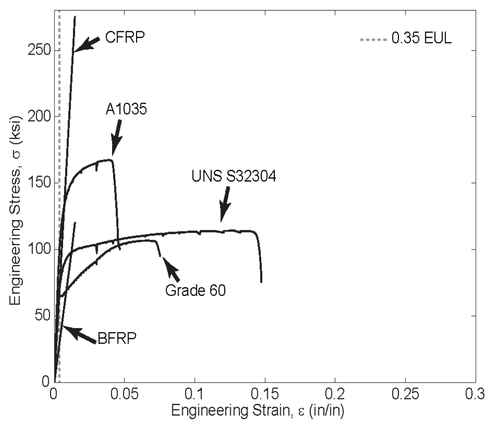
For the full report, search 15-R10 at vtrc.virginiadot.org. For more information about the study, contact Stephen R. Sharp, Ph.D., P.E., VTRC senior research scientist, Stephen.Sharp@vdot.virginia.gov.

At the start of the current study, it was known that different corrosion-resistant reinforcing bars met the ASTM standards for reinforcing steel bars, but some of the bars also exhibited a much higher yield strength than Grade 60 steel bars; this created possibilities for structural design change. VTRC researchers proposed that reducing the bar diameter by one size for corrosion-resistant reinforcement with much higher strength than Grade 60 steel could reduce VDOT concrete deck construction costs and make on-site fabrication adjustments easier, without compromising the integrity of the deck.



Stress-strain diagrams for each bar type in phase I of the study

Stress-strain diagrams for each bar type in phase II of the study



VTRC initiated this study with Virginia Tech to test the assertion that reducing a bar size was a viable option. To leverage the results of this study, the Virginia Tech researchers used the study's laboratory results to validate the output from a sectional analysis program — a type of design simulation software — called Response 2000. Response 2000 could potentially make designing bridges using corrosion-resistant reinforcement easier and more effective if it were to become an AASHTO- and VDOT-accepted method for reinforced concrete design.

Research and Recommendations In a two-phase experiment, the researchers built mockup concrete bridge decks (14 feet by 3 feet by 8.5 inches) each with a different one of the six studied corrosion-resistant materials as reinforcement. The research team compared the performance of these mockup bridge decks under a range of loads to that of control mockup decks with reinforcing bars of either plain or epoxy-coated Grade 60 reinforcing steel. During phase I, reinforcement bar sizes included Nos. 4 and 5 with bar spacings between 4 inches and 7 inches; during phase II, bar sizes included Nos. 3, 4 and 5 with a single bar spacing of 6 inches.

In phase I, the researchers performed flexural (bending) tests on the mockup concrete bridge decks that contained a single layer of reinforcement. This simulated the flexural performance of a bridge deck's top reinforcing mat in tension. This tension can occur over a bridge girder and is assumed in a bridge design method commonly used by VDOT called the strip design method. The researchers used this single tension layer to provide a low bound on the measurements of the structures' strength and ability to perform as intended with corrosion-resistant reinforcement. In phase II, the flexural tests were similar to those in phase I except that the concrete deck slab samples had two layers of reinforcing bars — one for tension and one for compression — like the reinforcement configuration in an actual VDOT bridge deck.

Researchers measured the effectiveness of the various corrosion-resistant reinforcing bars in the mockup concrete bridge decks according to the ultimate flexural capacity, the width of the cracks that formed and the deformability and ductility of the reinforced concrete deck slabs. All of these features are important considerations in the design of a bridge deck.

The study showed that the behavior of fiber-reinforced composite rods can greatly differ from that of steel reinforcing bars. For example, mockup bridge decks using GFRP rods presented a higher flexural capacity but less deformability and larger crack widths than the decks using traditional Grade 60 reinforcing steel. Additional research is recommended to pinpoint more accurately where VDOT would benefit from the use of GFRP, CFRP or BFRP composite rods.

The study's recommendation to reduce the diameter of ASTM A1035 and UNS S32304 corrosion-resistant reinforcing bars in concrete bridge deck design will allow VDOT to make cost-saving decisions about their use by taking advantage of their particular material properties. The Wolf Creek field test bridge, with the reduction of one bar-size in ASTM A1035 reinforcing steel, will provide insight into implementation considerations for this suggested change in guidelines for reinforced concrete bridge deck design.

The Virginia Transportation Research Council (VTRC) is proud to contribute to VDOT's reputation as a national transportation leader.
VTRC greatly appreciates the cooperation and support of VDOT and the Federal Highway Administration.

Virginia Transportation Research Council—VDOT's research division since 1948
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