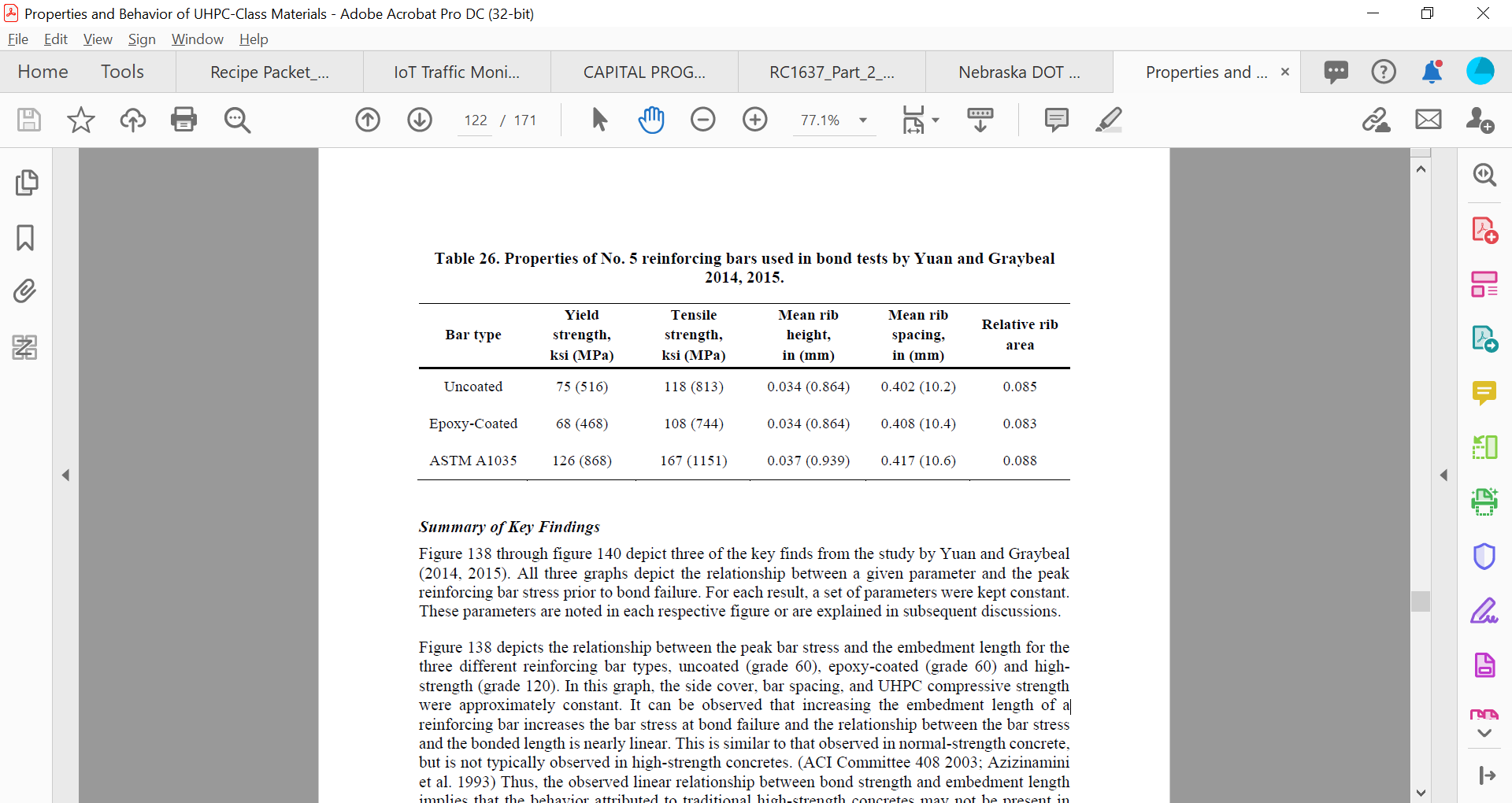
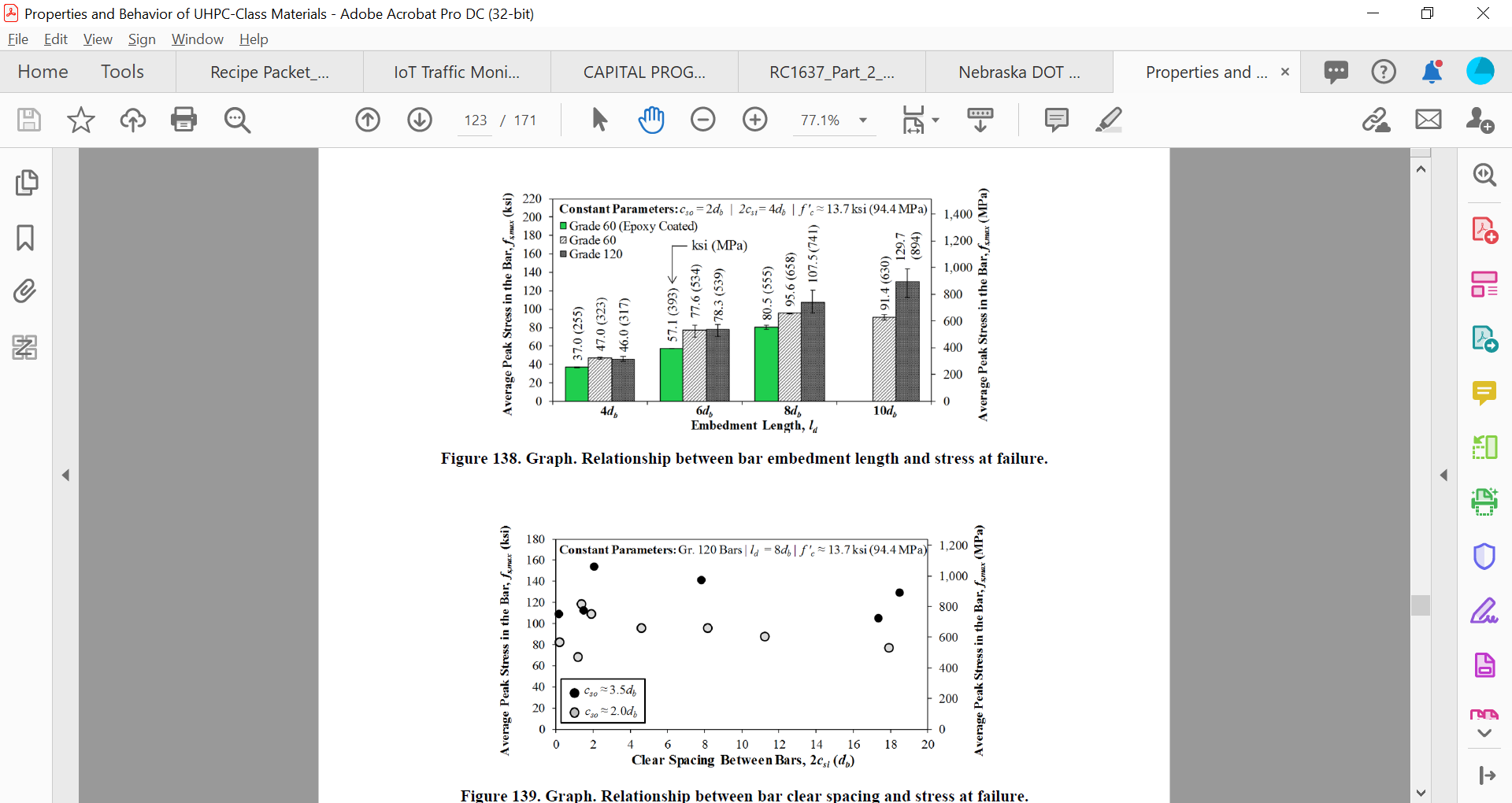
Existing Research Topic 17

Bond Behavior Epoxy Coated Reinforcing Bars in Non-proprietary UHPC

2018 FHWA Properties and Behavior of UHPC-Class Materials

<https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/structures/innovation/uhpc/fhwa-hrt-18-036--uhpcpropertiesandbehavior.pdf?sfvrsn=f396ea01_2>





2017 Factors affecting bond development between Ultra High Performance Concrete (UHPC) and steel bar reinforcement

<https://www.sciencedirect.com/science/article/abs/pii/S0950061817304658>

and MDOT 2016 DURABILITY PERFORMANCE OF UHPC

<https://www.michigan.gov/documents/mdot/RC1637_Part_2_526890_7.pdf>

The advent of Ultra High Performance Concrete (UHPC) has led to strong interest in developing new structural applications for the material. While UHPC’s tensile and compression behaviors are relatively well understood, an in-depth analysis of UHPC’s behavior at the component level, specifically the bond strength between UHPC and steel bar reinforcement is lacking and the published data shows large scatter. In the presented study, a series of bar pull out tests was performed to characterize the bond strength of a non-proprietary UHPC blend. The tests were conducted using plain and epoxy-coated grade 60 bars with nominal diameters of 13 mm, 16 mm, and 19 mm. Other experimental parameters include three development lengths (50, 75 and 100 mm), two casting orientations (longitudinal and transverse to the steel bar reinforcement), two steel fiber volume contents (1% and 2%) and early age bond strength at 1, 3 and 7 days curing. Results from pull out testing show that bond strength decreases with increased embedment length suggesting a non-uniform distribution of bond strengths. Differences in steel fiber content yielded significant differences in bond strength of up to 36% when using 1% vs. 2% fiber volumes. Early age testing showed that 75% of compressive and bond strength in UHPC is developed within 7 days of casting.

FHWA 2014 Bond Behavior of Reinforcing Steel in Ultra-High Performance Concrete - CHAPTER 5. CONCLUSIONS

<https://www.fhwa.dot.gov/publications/research/infrastructure/structures/bridge/14090/005.cfm>

The research discussed herein focused on assessing the bond strength of deformed reinforcing steel in UHPC. Deformed reinforcing steel, including ASTM A615 Grade 60 uncoated No. 5 bar and epoxy coated No. 5 and No.8 bars and ASTM A1035 Grade 120 No.4, No.5, and No.7 bars, were tested. The specific UHPC material used in this study had a steel fiber content of two percent by volume and an average compressive strength of 13.5 ksi (93 MPa) at one day, 17.0 ksi (117 MPa) at three days, 19.4 ksi (133 MPa) at seven days, and 21.3 ksi (147 MPa) at 14 days. The main factors affecting bond performance, including the structural characteristics like the embedment length, concrete side cover, bar spacing, bar size, and bar type, and materials properties such as UHPC compressive strength and bar yield strength are investigated. The summary of the findings are presented in this chapter. Design details for using deformed reinforcing steel in UHPC are then recommended.

**CONCLUSIONS**

The following conclusions are based on the research presented in this report for deformed reinforcing steel embedded in UHPC.

* Increasing the embedment length of the bar increases bond strength.
* The relationship between the bond strength and the bonded length for reinforcing bar embedded in UHPC is nearly linear, indicating that UHPC exhibits enhanced performance as compared to conventional high strength concrete.
* Bond strength increases as the side cover increases.
* Non-contact lap splice specimens, where the bar spacing is less than *lstan(θ)†*, exhibit higher bond strength than contact lap splice specimens; when the bar clear spacing is bigger than *lstan(θ)*, the bond strength decreases as compared to those having lesser spacing.
* The decrease in bond stress for contact lap splice specimens is probably due to decreased contact area between the reinforcing bar and UHPC materials. Tight spacing between bars limits the ability of the fiber reinforcement to locally enhance the mechanical resistance of the UHPC.
* When the bar clear spacing is bigger than *lstan(θ)*, the induced diagonal cracks from the pullout force will not intersect with the adjacent bar. The adjacent bar will not help stop the propagation of the diagonal cracks. The bond strength becomes a function of the mechanical properties of the UHPC.
* Models that use bar spacing and bar cover to predict bond stress may need to be reevaluated in consideration of the added crack propagation resistance provided by fiber reinforcement in UHPC.
* An increase on the compressive strength of the UHPC results in an increased bond strength.
* The effect of UHPC properties on bond strength cannot be effectively represented by the compressive strength *f’c*, or the square root of its compressive strength *f’c1/2*. Other UHPC mechanical properties, particularly those relevant to the post-cracking tensile behavior of UHPC, may be more appropriate for evaluating the bond strength of reinforcing bar in UHPC.
* For bars with larger diameter, the bond strength decreases.
* Bars that yield before bond failure have less ultimate bond strength than high strength bars that do not yield before bond failure; the reduction in bond strength is amplified as the ultimate bond strength increases.
* The epoxy coated bar had lower bond strength than uncoated bar; the reduction was minimized when there is a sufficient embedment length that the bar yields before bond failure.

**RECOMMENDED DESIGN**

One of the main goals of the research is to develop design recommendations for reinforcing bar embedded in UHPC, thus providing guidance for designers using reinforced UHPC in innovative applications. This study focused on a widely available UHPC product containing 2% steel fiber (by volume). Reinforcing bar sizes ranging from No. 4 to No. 8 and bar type including A615 Grade 60 uncoated and epoxy coated bar and A1035 Grade 120 bar were included in the study.

Deformed reinforcing bar embedded in UHPC can attain the lesser of the bar yield strength or 75 ksi (517 MPa) at bond failure when the following conditions are met:

* Bar size from No. 4 to No. 8,
* Uncoated or epoxy coated bar,
* Minimum embedment length of 8*db*,
* Minimum side cover of 3*db*,
* Bar clear spacing between 2*db* and *ls*, and
* Minimum UHPC compressive strength of 13.5 ksi (93 MPa).

RiP Database:

2020 (“active”) Design and Construction of Wide-Flange Precast Concrete Deck Girders with Ultra-High Performance Concrete Connections for Prefabricated Bridge Elements and Systems/Accelerated Bridge Construction

<https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4204>

<https://rip.trb.org/Results?txtKeywords=UHPC%20epoxy&txtTitle=&txtSerial=&ddlSubject=&txtReportNum=&recordStatus=&projectStatus=&ddlTrisfile=&txtIndex=&states=&specificTerms=&txtAgency=&sourceagency=&txtAuthor=&ddlResultType=&chkFulltextOnly=&subjectLogic=or&dateStart=&dateEnd=&rangeType=emptyrange&sortBy=publisheddate&sortOrder=DESC&rpp=25#/View/1407194>

In spite of the benefits of deck girder bridge systems for prefabricated bridge elements and systems (PBES)/accelerated bridge construction (ABC), their usage has been limited to relatively short span and low traffic bridges because of their long term performance of their connections, and difficulties in accommodating super-elevation transitions on bridge decks, pier skews, differential camber, shipping, and handling stability. Skewed girders cause bridge deck profile problems because the cambers in adjacent girders do not align. The diaphragms are then difficult to connect and/or quite big forces are induced if they are used to bring the girders into line. In order to optimize the decked bulb tee design, the longitudinal joint between flanges must have sufficient stiffness such that the same live load distribution factor can be used as for I-girder bridges with cast-in-place decks. There are a myriad of potential variables for the joint including width, bar size, bar spacing, bar detailing (straight, bent, or headed), and black or epoxy bars. The variable flange thickness (thicker near the web) will help the ultra-high performance concrete (UHPC) joint, by attracting much of the total static moment due to a wheel load toward the negative moment region at the web and away from the mid-span region where the UHPC joint is located. Research is needed to investigate design, fabrication, transportation, and construction of precast deck girder bridges. Other factors such as connections between adjacent units, longitudinal joints, live load distribution, continuity for live load, skew effects, and suitability of lightweight aggregates concrete need to be addressed by this research. The research should focus on optimizing the joint width. This project should address the constructability aspects and suggest methods of leveling the girders, how to determine the size of the leveling equipment needed, and means of holding the girders in the level position to allow the leveling equipment to be removed before the flange connections are fully cured. The objective of this research is to implement design, fabrication, transportation, and construction algorithms and to develop suitable details for the connection for prefabricated deck girders with UHPC for PBES/ABC.

TRID/TRIS Database

Washington State DOT (2017) Investigation of Ultra-High Performance Concrete for Longitudinal Joints in Deck Bulb Tee Bridge Girders <https://rosap.ntl.bts.gov/view/dot/37152>

Also a journal paper (same topic/authors, 2018): Bond behavior of epoxy-coated rebar in ultra-high performance concrete

<https://www.researchgate.net/publication/332301297_Bond_behavior_of_epoxy-coated_rebar_in_ultra-high_performance_concrete>

In recent decades, many state departments of transportation (DOTs) have implemented ultra-high performance concrete (UHPC) in bridge construction because of its advanced mechanical properties beyond those of conventional concrete. The Federal Highway Administration (FHWA) has extensively tested a proprietary class of UHPC, but the Washington State Department of Transportation (WSDOT) has been hesitant to adopt this mix because of its high cost and associated high risk. In this study, a mix design developed by Washington State University was tested for its structural performance when used in a reinforced spliced connection between adjacent concrete deck-bulb tee (DBT) bridge decks. The important parameter for this application is the bond strength of epoxy-coated reinforcing bars to the UHPC as well as the tension strength of the UHPC when the rebar in the connection is stressed axially in tension. ASTM-standard test procedures in this study showed that compressive strengths up to 16 ksi, tension strengths above 2 ksi, and bond strengths up to 7 ksi can be achieved with this particular UHPC, all with improved ductility beyond that of conventional concrete due largely to the steel fiber reinforcements. Structural experiments were performed on idealized “bond curbs” as well as a section of deck representing actual DBT girders to determine the available bond strength and the corresponding required joint width. These experiments and the subsequent analysis showed that a UHPC joint width of 7.11 inches, corresponding to a splice length of 5.11 inches, is satisfactory to fracture the reinforcement within the connection. To account for construction tolerances, this joint width should, in practice, be increased to 10 inches.

RNS Database: There are five (5) projects listed for UHPC since 2015, but none reference epoxy coated bars <https://rns.trb.org/search/search.aspx?f1=k%3A%3AKeywords+%28Title%2C+Description%2C+or+Index+Terms%29&ddlType=RNS&orgType=S&status=&date_params=&lower_date=1900&upper_date=2099&sb=&so=a%3A%3AAscending&sc=xx%3A%3AAll+Categories&t1=UHPC>