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Improved Endurance Limits for GFRP Reinforcement of Concrete

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Abstract

Recent bridge rehabilitation projects in coastal areas like Florida have demonstrated the use of glass fiber-reinforced polymer (GFRP) in building longer lasting, maintenance free infrastructure. Bridge core analysis of GFRP rebar from over 20 years of service life exceed the implications of accelerated durability test specifications for AASHTO and ACI standards. Improvements in GFRP rebars have demonstrated the ability for higher creep rupture and fatigue endurance limits. This paper examines the ACI440.3R-B.8 creep rupture strength data from state-of-the-art GFRP rebar supporting higher endurance limits for the industry. The second edition of AASHTO LRFD “Bridge Design Guide Specifications for GFRP Reinforced Concrete” modestly increased the creep endurance limit, and now owners may require manufacturers to certify endurance limits with testing if higher limits are proposed. Industrywide endurance limit characterization curves would allow manufacturers to assure that a product meets established endurance limits through simple, short duration verification testing. ASTM D7957-17: “Standard Specification for Solid Round GFRP Bars for Concrete Reinforcement” could provide creep rupture or cyclic fatigue verification tests. Refinements in design criteria are explored in retaining-wall applications for the expanded use of GFRP reinforced concrete in coastal bridge, marine port infrastructure, and masonry structures.

Keywords: GFRP Rebar, Durability, Creep Rupture, Endurance Limits, Service Life

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Introduction

Recent bridge rehabilitation projects in coastal areas like Florida have demonstrated the potential of glass fiber-reinforced polymer (GFRP) rebar in building longer lasting, maintenance-free reinforced concrete (RC) infrastructure. The ACI Strategic Development Council (SDC) durability study of 15-20 year, GFRP-RC bridge core sampling, confirmed GFRP-RC exceeds the implications of accelerated durability tests from AASHTO and ACI standards with less than 0.5% reduction in strength per year [1]. Improvements in state-of-the-art GFRP rebar materials have demonstrated higher creep rupture and cyclic fatigue endurance limits. Sustained loads are an important consideration in concrete and masonry structures, and ACI 440.3R B.8 test criteria are used for creep rupture limit stress analysis. Fatigue cyclic loads are usually not as critical for building design. However, in RC bridge design, the cyclic fatigue load limit often controls near the region of contra-flexure for bending inflection along continuous spans [2].

AASHTO LRFD "Design Guide Specification for GFRP-Reinforced Concrete Bridge Decks and Traffic Railings" (BDGS-1) was recently expanded to include all RC members under the 2nd edition (BDGS-2). As part of the BDGS-2 specifications, owners may require manufacturers to certify that their products meet endurance limits based on testing, if they propose using a higher limit [3]. It is impractical to require each manufacturer to develop their own endurance limit curves. The current ASTM D7957-17: "Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement" does not provide tests methods or acceptance criteria for creep rupture or cyclic fatigue. Therefore, new industrywide endurance limit characterization curves would allow manufacturers to assure that a product meets the established limits through simple short duration verification testing. Refinements in endurance design limit should be linked to creep rupture at 75, 100, and a maximum time up to 150-year service life, or based on fatigue at 2, 3, or 4 million cycles, as appropriate for GFRP-RC bridge design specification and consistent with pending AASHTO Service Life Design Guide expectations proposed in NCHRP project 12-108.

Retaining Wall Application

Several FDOT projects under design have existing bridge abutment utilizing combination soldier pile end bent wing walls with driven prestressed piles and precast RC panels, in lieu of traditional jetted prestressed sheet piles. The first project, US41 over North Creek [4], is founded upon highly weathered limestone interbedded with dense silt at a half meter below the 100-year scour elevation to depths of 3-5 meter below the rock surface, making for challenging traditional sheet pile installation. The second project, NE 23rd Ave over Ibis Waterway [5] shown in Figure 1, and third project Barracuda Blvd over Indian River North [6], have relatively easier installation conditions. One past concern with GFRP-RC retaining wall structures is the prevalence of sustained loading due to lateral soil and ground water pressure, coupled with the conservative design limits imposed by ACI 440.1R [7]. Free-draining backfill or weep-hole drainage systems mitigate groundwater hydrostatic pressure, but sustained lateral soil pressure can still be significant.

Design Endurance Limits

Traditionally ACI 440.1R limited the allowable sustained stress for GFRP rebar to 20% of the "aged" guaranteed ultimate tensile strength (GUTS), which was effectively 13% of GUTS for outdoor exposed RC elements. Recent studies on accelerated testing [8], have shown that

a)  b) 

Figure 1a, b: Elevation view of existing combination bridge end bent and abutment bulkhead

GFRP rebar conforming to ASTM D7957 [9] using E-CR glass fibers to ASTM D578, vinyl-ester resins, and higher fiber volume content, can safely resist higher sustained stress for 100-year service-life. The BDGS-2 allows a 50% increase in this resistance, and with additional refinements in the sustained service load combination, bond factors (k_b or C_b = 1/k_b), and tensile elastic modulus (E_f), further increases the efficiency under the creep-rupture limit state. The new creep-rupture reduction factor (C_C = 0.30) is based on inclusion of an integral resistance factor 0.6 [8] applied to the average minimum resistance of the log-normal extrapolated test results. The creep rupture load combination was also partially addressed in the BDGS-2 by relaxing the 1.0 load factor on the service load component of the variable truck loading to 0.2. For the fatigue limit state load combination, the full sustained dead load must still be included with the fatigue 1.0 live load factor, until further endurance limit testing is completed. It was partially addressed by raising the fatigue-rupture reduction factor (C_f) from 0.20 to 0.25.

The testing of bars in air per ACI 440.3R B.8 at 26°C under sustained load up to 876,000 hours represents 100-year service life. Figure 2a shows an increase in creep-rupture limit from about 40% to 70% of sustained load ratio in GFRP bars with higher fiber content. The creep-rupture limit strength at about a million hours improved from 507 MPa to 831 MPa for higher E-CR glass fiber content. The higher fiber content improved tensile elastic modulus and met rebar specifications in ASTM D7957 and CSA S807 provisional SSP 999S02 [10].

Sustained load testing of GFRP bars in alkaline pH12.8 at 60°C conditions to accelerate the aging effects of a concrete environment, has a similar regression trend to alkaline pH12.8 at 26°C in Figure 2b. The ASTM D7705M testing is for correlation with a short-term material test method or surrogate measure like Figure 2c for fast reliable supplier product acceptance. The Figure 2d SEM typical micrograph cross-section shows E-CR vinyl-ester bar had negligible fiber matrix de-bonding or resin hydrolysis after 5000 hours in 60°C alkaline pH12.8 solution. This work under the FDOT State Materials Office research project BDV30 977-18 [11] supports the use of GFRP in both tidal and submerged zones for bridge substructures and seawalls. Additionally, it supports future refinement of the creep-rupture reduction factor to improve design efficiency and development of parallel service-life design guidance for GFRP-RC structures in work nearing completion under NCHRP Project 12-108 [12], SHRP2-19B and *fib* Commission 8, Durability [13].

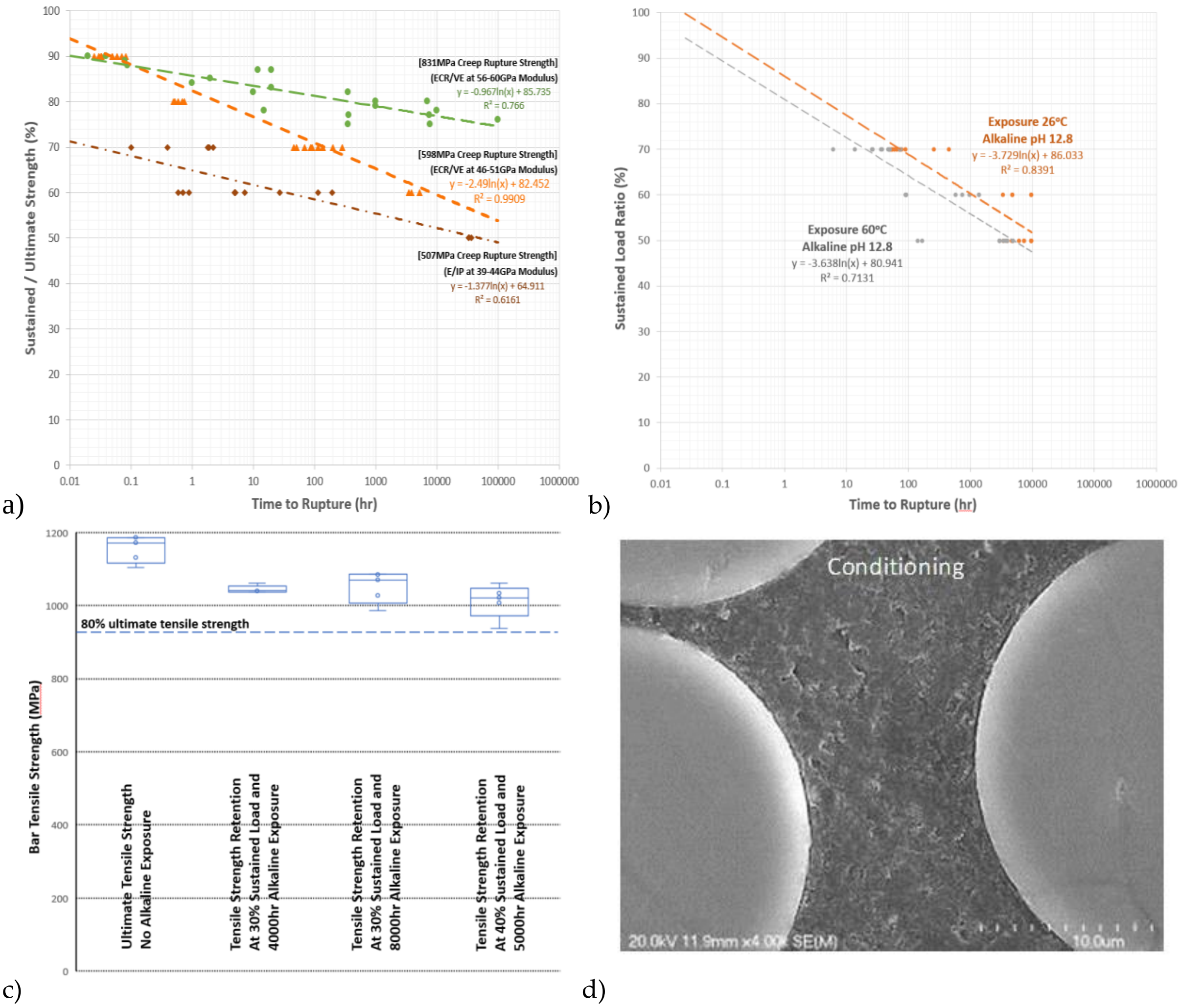

Figure 2: Calculated 100-year creep rupture strength to ACI 440.3R B.8: a) by glass/resin type and glass content (tensile elastic modulus) b) with alkaline pH12.8 solution at 26°C and 60°C; c) tensile strength retention after exposure d) ECR/VE SEM after 5000hr pH12.8 60°C

Conclusions

This paper examined the use of innovative GFRP-RC structures with recent refinements in design criteria applicable to retaining walls. Results from on-going creep-rupture testing for over 100-year service life will contribute to the further refinement of creep-rupture reduction factors in chloride-rich environments. The modified GFRP-RC soldier pile and panel system would benefit from these refined properties and is proposed for future projects. The confluence of design criteria refinement, manufacturer process improvement, and contractor experience can lead to more effective retaining-walls, such as seawall-bulkheads, while simultaneously meeting the emerging demands from asset owners for longer maintenance-free service life of seaport and coastal bridge infrastructure.

References

[1] Nanni, A., et.al., 2019, "Durability Study of GFRP Bars Extracted from Bridges with 15 to 20 Years of Service Life," Report for Strategic Development Council of the American Concrete Institute, Farmington Hills, MI, pp. 70.

[2] Nolan, S., Perez, J., Hartman, D., and Ellis, K., 2019, "Bakers Haulover Cut Bridge: Seawall-Bulkhead Rehabilitation and New GFRP-RC Solutions," Transportation Research Board, Paper 19-05552R1, Washington DC, pp. 7-8.

[3] AASHTO, 2018, "LRFD Bridge Design Guide Specification for GFRP Reinforced Concrete," 2nd Edition, AASHTO Committee Bridges and Structures, Burlington, VT.

[4] Florida Department of Transportation, 2019, "US-41 over North Creek Bridge Replacement," 2019 Financial Project ID: 433550-3, Sarasota County, FL.

[5] Florida Department of Transportation, 2019, "NE 23rd Ave over Ibis Waterway Bridge Replacement," 2019 Financial Project ID: 434359-1, City of Lighthouse Point, FL.

[6] Florida Department of Transportation, 2019, "Barracuda Ave over Indian River North Bridge Replacement," 2021 Financial Project ID: 437935-1, City of New Smyrna, FL.

[7] ACI Committee 440, 2015, "Guide for the Design and Construction of Structural Concrete Reinforced with FRP Bars," ACI 440.1R-15, ACI, Farmington Hills, MI.

[8] Benmokrane, B., Mohamed, K., 2018, "Recommended Value in ACI 440-H XXX for the Creep-Rupture Stress Limit of GFRP Bars," Technical Report submitted to Technical Subcommittee ACI 440-H, Farmington Hills, MI.

[9] ASTM International, 2017, "Standard Specification for Solid Round GFRP Bars for Concrete Reinforcement," ASTM D7957/D7957M-17. West Conshohocken, PA.

[10] Ontario Ministry of Transportation, 2018, "Special Provisional No. 999S02 Requirements for GFRP Reinforcing Bar," SSP 999S02, Section 5, Ontario, Canada.

[11] Kampmann, R. and De Caso, F., 2018, "Performance Evaluation of GFRP Reinforcing Bars Embedded in Concrete Under Aggressive Environments," FDOT Research Project BDV30 977-18, Deliverable Task II a, b & c, Miami, FL.

[12] NCHRP, 2019, "Guide Specification for the Service Life Design of Highway Bridges: Project 12-108", Modjesky & Masters for National Cooperative Highway Research Program, Washington DC.

[13] fib Commission 8, 2017, "Durability", International Federation for Structural Concrete (Fédération Internationale du Béton), Lausanne, Switzerland.