2018 STIC Incentive Project (BFRP-RC Standardization) – Final Report (December 2021)

Federal Project No: STIC-004-A; FPID 443377-1

This is the seventh and final report for the Basalt Fiber-Reinforced Polymer (BFRP) Bar Standardization for Reinforced Concrete (RC) with the FHWA allocation memorandum dated March 1, 2018. Part 1 of this report details progress from June 2021 to December 2021. Part 2 of this report summarizes the goals and achievements from the entire project period March 2018 to December 2021.

Part 1 – Progress for final interim period: June 2021 to December 2021.

i. Demonstration Project #1 (Link-Slab) – The final report under Research Contract ***BDV34 986-02*** for has been completed and is included in ***Appendix B.*** This report found that BFRP reinforcing performed adequately in restraining shrinkage cracking of the link-slab during approximately one-year after construction.

Part 2 – Final Report Summary: March 2021 to December 2021.

Description of the work:

This project intended to develop standard (guide) design specification, and standard material and construction specifications for basalt fiber-reinforced polymer (BFRP) bars for the internal reinforcement of structural concrete. Tasks involved:

i. **Goal 1:** Establishing initial design and durability parameters using current state-of-the-art BFRP test data with ***ACI 440.1R*** as a design model framework, supplemented with ***AASHTO's LRFD Bridge Design Guide Specification for GFRP Reinforced Concrete - 2nd Edition (BDGS-2)*** published December 2018.
Achievement 1: It was determined to initially implement BFRP design and durability parameters using the same criteria as that for glass FRP reinforcing. FDOT Research Project ***BDV30 986-01 Final Report*** provided recommendations for design and future refinement *(see **Appendix A**)*.

ii. **Goal 2:** Develop any necessary FDOT design modifications to ***BDGS-2*** criteria for inclusion of BFRP reinforcing in the ***Structures Design Manual***.
Achievement 2: ***BDV30 986-01 Final Report*** – Chapter 6 design recommendations were incorporated into the ***2020 Structures Manual*** published January 2020, by including

BFRP in ***Volume 4 – Fiber Reinforced Polymer Guidelines****, Chapter 2*. No increase in BFRP design parameters above those currently established for GFRP were proposed, until additional testing is performed to refine the environmental reduction factors under different limit states. One limitation for BFRP reinforcing was added to avoid using this material in continuously submerged applications until additional research was completed. This requirement is included in ***Structures Manual*** *– Volume 4, Section 2.1*. The limitation was included due to inconclusive long-term performance in submerged saltwater applications due to the presence of iron oxides in the basalt fibers. Additional investigation on long-term durability reduction factors is ongoing under the separately funded FDOT research project ***BE694 - Improving Testing Protocol and Material Specifications for BFRP Bars*** to investigate these issues.

iii. **Goal 3:** Develop FDOT material specification for acceptance similar to the 2017 ***ASTM D7957*: *Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement***.
Achievement 3: Incorporated BFRP reinforcing into ***FDOT Standard Specification Section 932-3*** in the July 2020 Workbook. The requirements are identical to GFRP reinforcing except the inclusion of an additional qualification test in ***Table 932-8*** to include Horizontal Shear Strength testing under ASTM D4475, with a minimum strength limit of 5.5 ksi.
Additional chemical constituent requirements to define basalt fibers, was included in FDOT ***Materials Manual*** *– Section 12.1, Table 1,* until ASTM material specifications for basalt fibers can be established.
All these requirements where based on ***BDV30 986-01 Final Report*** – Chapter 6 recommendations.

iv. **Goal 4:** Develop any modifications to the FDOT Construction Specifications based on the current GFRP reinforcing requirements in ***BDGS-2*** and ***FDOT Specification Section 415.***
Achievement 4: No changes to ***Section 416*** were necessary since the same requirements applicable to GFRP reinforcing where applicable to BFRP reinforcing, and FRP rebar is identified generically in this section without reference to a specific fiber material type.

v. **Goal 5:** Develop BFRP Reinforcing Database for collection of current and future test results.
Achievement 5: It was determined not to pursue a permanent databased due to lack of sustained funding and resources. Results for BFRP testing are publicly available under this project research in Final Report ***BDV30 986-01,*** Chapter 3; previous research in 2014 under ***BDK-977-05 "Degradation Assessment of Internal Continuous Fiber Reinforcement in Concrete Environment"****,* Chapter 5; and a separate ongoing research project ***BE694 "Testing Protocol and Material Specification for BFRP Rebars"*** *Chapter 4*.

vi. **Goal 6:** Deliver a designer focus live workshop in central Florida (and national event if funding permits). Post the delivered training material on ***FDOT FRP Innovation*** website for broader access and future updating.

Achievement 6: The following training was delivered during the project and now accessible from ***FDOT FRP Innovation*** website:
(a) FRP-RC Designer Training held under 3 sessions at the FDOT Transportation Symposium (FTS-2019) on June 4th, 2019 (see ***FDOT Transportation Symposium*** FRP-RC Design - **Part 1**, **Part 2**, & **Part 3**);
(b) Peer Exchange BFRP-RC Designer Training was provided to Hawaii DOT Bridge Office on July 22, 2019 (see BFRP-RC Design - **Part 1**, **Part 2**, **Part 3**, & **Part 4**) in conjunction with ***BEI-2019***;
(c) ***BEI-2019*** FRP Composites II (Session B-9) on BFRP-RC for coastal and marine structures was provide as the Bridge Engineering Institute conference July 23-25. Additionally, several papers on BFRP-RC were presented and published in the ***Conference Proceedings*****:**

- pp 514-523, "Basalt FRP-RC Standardization for Florida DOT Structures".
- pp 527-531, "Effect of the Fiber Content on the Tensile Strength Properties of Basalt Fiber Reinforced Polymer Rebars".
- pp 551-562, "Bond-to-Concrete Characteristic of Basalt Fiber Reinforced Polymer Rebars".

vii. **Goal 7:** Demonstration #1 (BFRP-RC Link-Slab) – Develop small demonstration application for use of BFRP reinforcing, and monitor shrinkage and temperature effects overtime.
Achievement 7: Plans where developed and construction completed for FRP-RC link-slab on pedestrian bridge in Port Charlotte, FL (along US 41) where BFRP longitudinal reinforcing was used in place of GFRP reinforcing. Construction of BFRP-RC link slab on Morning Star Waterway bridge was completed in April 2020, with embedded strain gages and data loggers installed March 6-7. Temperature and strain data in the longitudinal BFRP bars was recorded hourly over two periods first from 3/7/2020 to 8/2/2020, then from 11/14/2020 to 2/28/2021. The final report for Research Contract ***BDV34 986-02***. (See ***Appendix B***), contains construction information and monitoring data results. Concrete strains in the link-slab varied daily by approximately 500 microstrains, but surface cracking on the link-slab was very minimal. District 1 Bridge Maintenance will continue to visually monitor this link-slab every 2-years as part of the routine bridge inspection program.

viii. **Goal 8:** Demonstration #2 (BFRP Closed Stirrup Fabrication) - An additional demonstration project was added in early 2021 to show the feasibility of fabricating BFRP bent bars with good mechanical performance. Currently for standard GFRP stirrups under Index 415-010, two overlapping U-shaped bars are utilized for building up closed shapes. A closed stirrup with 5 ~ 90-degree corner bends, similar to steel stirrups (Index 415-001, Type 4) was to be fabricated and tested to determine if the minimum mechanical performance for bent bars could be achieved with this more complex shape. The bent shape was based on those typically used for seawall-bulkhead caps, but could possibly be scaled up for pile bent caps.
Achievement 8: Laboratory testing of stirrups was able to verify that the BFRP stirrups exceeded current GFRP/BFRP specification requirements for use on FDOT projects. The straight portion of the bent #4 bar exceeded the minimum requirements for

straight bars (21.6 kips). The bent portion of the stirrup was not tested since the specimen size was too small. See ***Appendix C*** for Final Test Report.

Project Breakdown and Schedule

The project was broken into three phases, although there was significant overlap between Phases 2 & 3 due to delays in Demonstration #1 due to COVID-19, and addition of Demonstration #2 later in the project as funding became available. **Table 1** shows a summary of the project Phases. There were two research contracts with Florida Universities (Florida State University and North Florida University) and separate testing service performed by the University of Miami's, Structures & Material Laboratory for Demonstration #2.

Phase 1 - was the most extensive and involved the development of BFRP reinforcing standards through evaluation the various tasks of: Existing information collection and curation; Testing of 3 different manufacturers BFRP rebar and two sizes (#3 & #5); Test data and analysis; and Recommendations for Design, Construction and Materials specifications.
Phase 2 - involved two demonstrations for BFRP applications: Monitoring of a link-slab construction project; and fabrication of closed stirrup bent bars with physical testing. The initial conceived test result database for BFRP rebar, was not pursued.
Phase 3 - involved Technology Transfer through presentation of material at several events, and posting this material on the FDOT Structures FRP-Innovation webpage as detailed in Achievement 6.

PROJECT PHASE	1	2	3
PROJECT WORK TASKS	Develop Standards: ***(BDV30 986-01)*** • Design Specification • Materials Qualification and Verification Test Procedures • Construction Specification	• Demo #1: Full-scale Link-Slab and Monitoring; ***(BDV34 986-02)**** • Demo #2: Seawall-bulkhead cap closed BFRP stirrup fabrication and Bar Testing	• Technology Transfer ***(FTS-2019 & BEI-2019)*** • Final Report
PROJECT DELIVERABLES	• LRFD Guide Design Specification • Testing Specification • FDOT Construction Specification updates • Research Report BDV30 986-01 including Test Results for BFRP straight bars. (Appendix A)	• ~~Electronic Database of physical and mechanical properties~~ • Research Report BDV34 986-02 (Appendix B) • Test Report for Bent Bars (Appendix C)	Technology Transfer Presentations and posting on FDOT *FRP-Innovation webpage* for information dissemination and training.
PROJECT TIMELINE	Month 1-11	Month 7- ~~15~~ *45**	Month *15*-17 *&* ~~*24*~~ *45**

Table 1- Project Summary ***(added 11/30/20)****, * completion delayed due to COVID-19.*

Budget

1. BDV30 986-01 – Performance Evaluation, Material and Specification Development for Basalt Fiber Reinforced Polymer (BFRP) Reinforcing Bars Embedded in Concrete ($80,446.35).
2. BDV34 986-02 - Instrumentation and Monitoring for BFRP-RC link-slab ($38,992.15). Cost of BFRP Bars from Basalt World Corp., two invoices ($644.48 + $342.20).
3. BFRP Rebar Closed Stirrup Laboratory Testing at University of Miami's Structures Research Laboratory, two invoices ($1104 + $1308 = $2,412).
4. Additional FDOT staff hours for project oversight and training not included in total.

Project Line Item	FHWA STIC Funds	FDOT Funds (20% match)	Total Budget
Phase 1 *BDV30 986-01 – Performance Evaluation*	$80,446.35	$0.00	$80,466.35
Phase 2 *BDV34 986-02 Demo #1 Monitoring* *Demo #1 BFRP Rebar Materials* *Demo #2 Bent Bar Testing*	$14,591.75 $986.68 $1,308.00	$24,400.40 $1,104.00	$38,992.15 $986.68 $2412.00
Phase 3 *Technology Transfer & Final Report*		Cost not tracked (include in overhead)	
Total Project	**$97,332.78**	**$25,504.40**	**$122,837.18**

Table 2- Project Phase Funding Distribution as paid 12/31/2021.

Project Schedule

Work Phase	Month																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	18	22	32	33	34	35	36	42	45*
1a. Develop Design, Materials and Construction Specifications																									
1b. BFRP straight bar testing																									
2a. Demo #1: Full-scale slab instrumentation and monitoring																									
2b. Demo #2: bulkhead cap closed stirrup fabrication and testing																									
3. Technology Transfer Workshop and Final Report																									

Table 3- Project Timeline: Month 1 = April 2018; Month 45 = December 2021.
**** Completion delayed, due to COVID-19.***

Appendices included:

Appendix A - ***BDV30-986-01*** Final Report – "Performance Evaluation, Material and Specification Development for Basalt Fiber Reinforced Polymer (BFRP) Reinforcing Bars Embedded in Concrete" (170 pages)

Appendix B - ***BDV34-986-02*** Final Report – "Instrumentation and Monitoring of FRP bars in Bridge Deck Link-Slab" (93 pages)

Appendix C – ***Test Report Number: R-5.10_12-08-20_FDOT*** - "Evaluation of Non-Metallic Fiber Reinforced Polymer (FRP) Bars For Concrete Reinforcement" (BFRP Closed Stirrups) (10 pages)

Appendix A

BDV30-986-01 **Final Report – "Performance Evaluation, Material and Specification Development for Basalt Fiber Reinforced Polymer (BFRP) Reinforcing Bars Embedded in Concrete"**

(170 pages)

Appendix B

BDV34-986-02 Final Report – "Instrumentation and Monitoring of FRP bars in Bridge Deck Link-Slab"

(93 pages)

Appendix C

Test Report Number: R-5.10_12-08-20_FDOT **- "Evaluation of Non-Metallic Fiber Reinforced Polymer (FRP) Bars For Concrete Reinforcement" (BFRP Closed Stirrups)**

(10 pages)

*** END OF REPORT ***