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Abstract

Previous research of GRFP reinforcement as an alternative to steel re-bar for decks has shown better durability in highly corrosive environments. This project showed an alternative deck design to an ongoing design project of the Puerto Rico Highway Authority substituting traditional R/C deck design with GRFP reinforcement. It shows that the alternative is cost effective for construction and can be implemented in Puerto Rico for bridges in zones considered of higher corrosion risk as those close to marine environments.

Introduction

In this study an alternative Glass Reinforced Fiber Polymer (GRFP) reinforced concrete deck was designed and compared to the conventional steel reinforced concrete bridge deck design from the project AC-826579 Land Slide Repairs on PR-10 in Utuado P.R., structure BR-01 of the Puerto Rico Highway and Transportation Authority (PRHTA). The use of GRFP will allow the design to use 501 PRHTA Concrete which has less corrosion resistant requirements than the 934 PRHTA Concrete required when using steel reinforcement. The main project objective is to determine if this alternative is cost effective.

Background

This study is supported by a comprehensive literature and field data review. Technical documentation and test reports from **MST-BAR®** were analyzed to understand the mechanical and durability properties of GFRP #5 bars. Concrete mix designs were developed and tested with and without corrosion-related admixtures, and compressive strength tests were conducted at **Segarra Engineering** laboratories. These tests included aggregate gradation, air content, temperature, compression, and slump evaluation.

The bridge deck design was validated using **Altair S-LINE**, a software platform referenced in the literature (Asadian, 2021) for its accuracy in modeling GFRP-reinforced concrete per AASHTO and ACI 440 guidelines.

Additionally, international case studies of GFRP-reinforced cast-in-place bridge decks provided precedent and performance benchmarks under marine and humid conditions, which align closely with the environment in Puerto Rico.



Problem

Steel-reinforced bridge decks in Puerto Rico require complex concrete designs with corrosion inhibitors, slag, and permeability testing, increasing both material cost and long-term maintenance. The need to reduce costs and improve durability in coastal environments led to the exploration of GFRP bars as an alternative to traditional steel.

Methodology

The research methodology involved a comparative evaluation between the original deck design of bridge BR-01 (AC-826579) and a proposed alternative using GFRP reinforcement and simplified concrete. The process included:

Design Analysis:

Extracted geometry and load data from original PRHTA plans. Applied AASHTO LRFD and ACI 440.1R-15 to develop a GFRP-based deck design. Structural modeling performed in **Altair S-LINE** using HL-93 loading.

Concrete Trial Mixes:

Developed two mix designs: one per Spec 934 (with corrosion inhibitors and slag)

Jonathan Hernandez, MSCE		Design PSI (f'): 5000		Placement:		Agg. Gradation Limits	
SOPAVN2FRX6-A		Design Slump: 6		Location: MSCE		#4 ACI 302-04 (22-B)	
Jonathan Hernandez - MASTER		Location: MSCE					
SPECIFICATION 934							
Cementitious Materials		Weight	Abs. Vol.	% Vol.	Cost	Admixture	Oz/yard
Cemex - Type II	504	2.69	72.0	--	--	EUCON RETARDER 75	49.00
Slag Cement	196	1.09	28.0	--	--	EUCON SPJ	35.00
						EUCON STASIS	21.00
						EUCON CIA	384.00
						SRA-XT	128.00
						EUCON SPJ	25.40
Total Cementitious	700	3.79					
AGGREGATES CAROLINA	1700	9.84	53.9%	--	--		
ORIENTAL S&G - NAT SAND	1373	8.43	46.1%	1.00	--		
	0						
Design Air Content	2.0	0.54					
Water	29.5 Gal	246	3.94				
Totals + admix water Vol & Wt	4048	27.00					
Plastic Density - Cu.Ft.	149.92						
Paste Fraction	29.6%						
Paste Fraction + Air	30.6%						
Mortar Fraction	54.0%						
Air Vol / (Cementitious + water)	7.0%						
Sand / Agg ratio (Vol)	0.46						
Workability Factor (Fines)	34.5						
Coarseness Factor	75.5						
W-Adj (Workability-Adjustment)	38.2						
O.L.F.	1033						
Vol Water / Vol Cement	1.164						
Water + AdmixWater / CM Ratio	0.393						

one per Spec 501 (without such additives)

Jonathan Hernandez, MSCE		Design PSI (f'): 5000		Placement:		Agg. Gradation Limits	
SOPAVN6-JN		Design Slump: 6		Location: MSCE		#4 ACI 302-04 (22-B)	
Jonathan Hernandez - MASTER		Location: MSCE					
SPECIFICATION 501							
Cementitious Materials		Weight	Abs. Vol.	% Vol.	Cost	Admixture	Oz/yard
Cemex - Type II	700	3.74	100.0	--	--	EUCON RETARDER 75	49.00
						EUCON SPJ	35.00
						EUCON STASIS	21.00
						EUCON CIA	384.00
						SRA-XT	128.00
						EUCON SPJ	25.40
Total Cementitious	700	3.74					
AGGREGATES CAROLINA	1700	9.84	53.9%	--	--		
ORIENTAL S&G - NAT SAND	1370	8.41	46.1%	1.00	--		
	0						
Design Air Content	2.0	0.54					
Water	32.5 Gal	271	4.34				
Totals + admix water Vol & Wt	4049	27.00					
Plastic Density - Cu.Ft.	149.97						
Paste Fraction	29.9%						
Paste Fraction + Air	31.9%						
Mortar Fraction	55.2%						
Air Vol / (Cementitious + water)	6.7%						
Sand / Agg ratio (Vol)	0.46						
Workability Factor (Fines)	34.5						
Coarseness Factor	75.5						
W-Adj (Workability-Adjustment)	38.1						
O.L.F.	1810						
Vol Water / Vol Cement	1.196						
Water + AdmixWater / CM Ratio	0.389						

Materials and Suppliers:

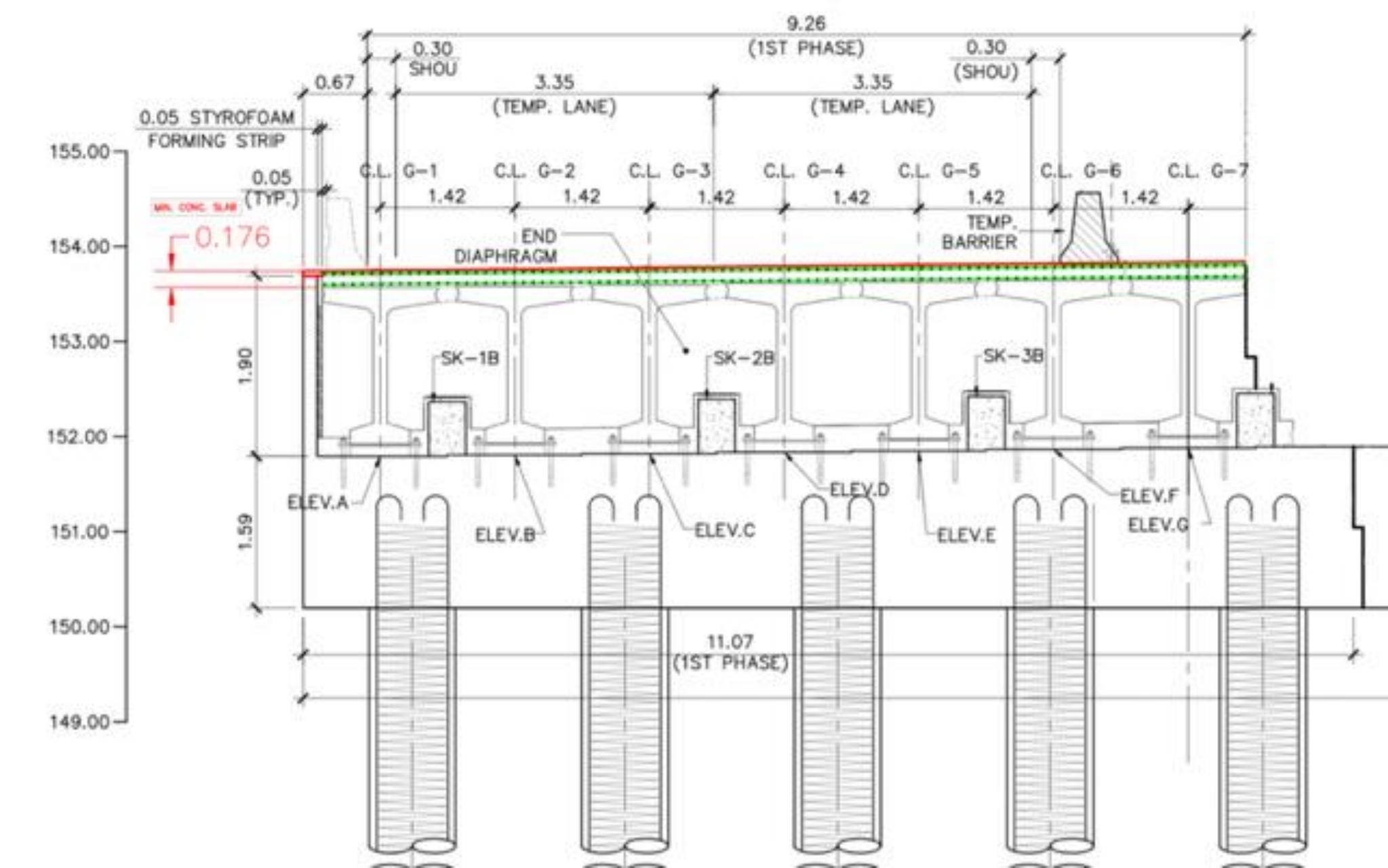
GFRP reinforcement supplied by **MST-BAR®**. Concrete and admixtures provided by **Concretos del Atlántico** and **BTA Concrete**. Slag tested by **SGS TEC Services** per ASTM C989. Test Results by **Segarra Engineering and Consulting**.

Benchmarking:

Researched international GFRP-reinforced bridge decks to validate feasibility and durability in marine environments similar to Puerto Rico.

Results and Discussion

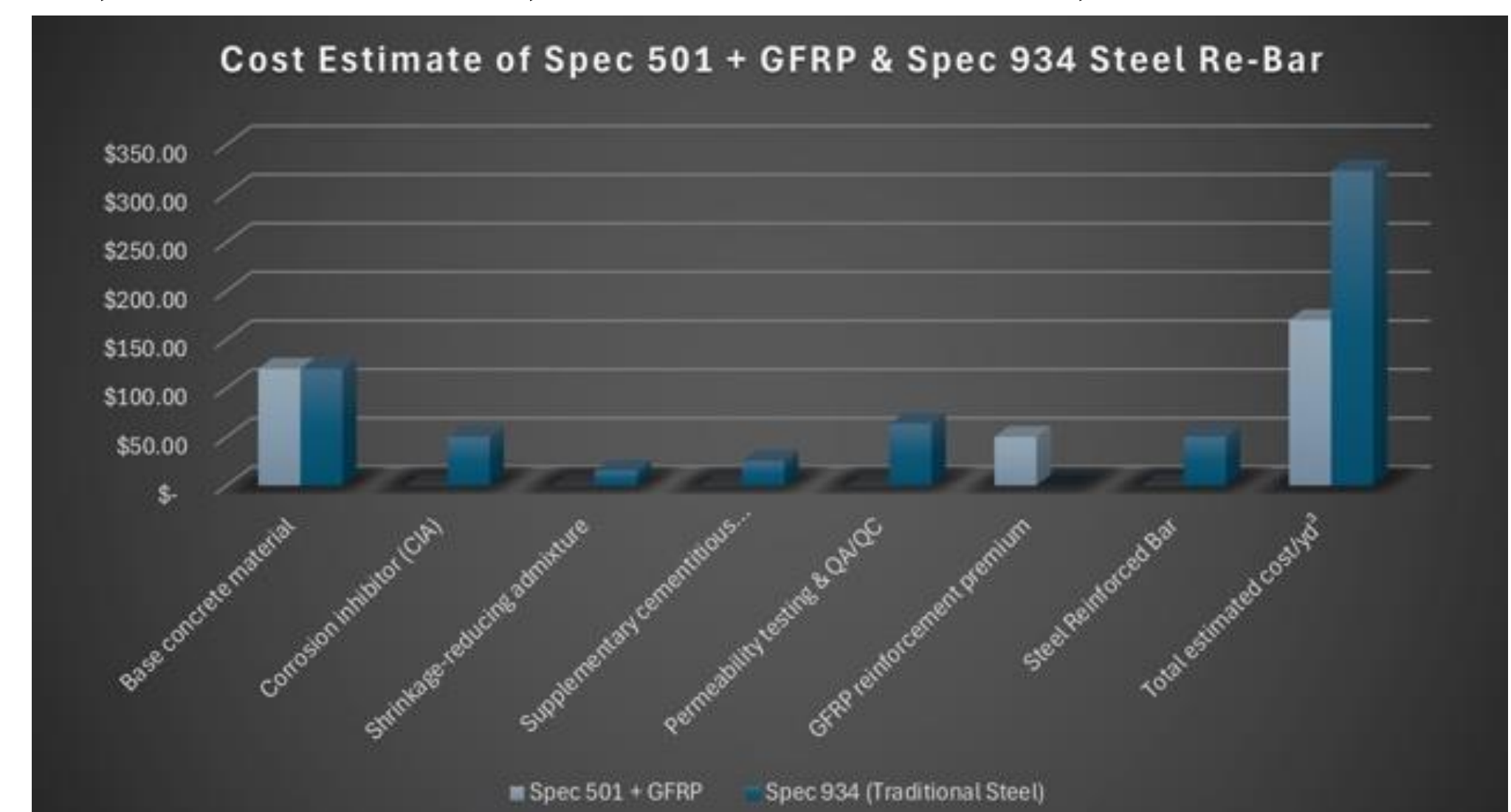
All structural verifications were conducted using Altair's S-LINE software in compliance with ACI 440.1R-15 and AASHTO LRFD. The reinforcement design on the bridge deck was a double-layer reinforcement layout using MST-BAR #5 spaced at 4 inches top and bottom further enhances structural capacity, crack distribution, and long-term performance. This configuration aligns with successful case studies where durability and performance outweighed cosmetic crack control concerns.



The Spec 501 (without corrosion inhibitors or slag) meets and exceeds strength targets, confirming GFRP allows a simplified mix.

Age	Control Mix (Spec 934, Psi)	Modified Mix (Spec 501, psi)	Improvement (%)
3	1870	3170	+69%
7	2990	4340	+45%
28	4890	5410	+11%
56	5530	5760	+4%

The bridge deck with 934 Concrete and Steel Reinforced Bar with dimensions of 30 m x 9.61 m x .125 m is approximately 47.14 CuY. Assuming a 15% of waste it will be 54.21 CuY. The cost of the Steel Rebar is approximately \$0.50 the Lb. Placing #5 bar @ 6" it will be roughly 195 #5 bar one end and 196 at the short length. With approximately 391 Bars. This, in Lbs. will be approximately 10,792 Lbs. The total cost will be \$5,396. Using GFRP with the same outcome but #5 @ 4" T&B the total of bar will be 190 in the long direction and 592 in the short direction. The total of Lbs in the deck will be 7,958 Lbs @ \$0.50 the cost will be \$3,979.00. The total cost using 934 with steel Re-Bar will be \$14,817.22 in Concrete and 5,396.00 with Steel Re-Bar with a total of \$20,213.22. In the other hand using 501 Concrete will cost \$9,215.70 + GFRP \$3,979.00 for a total of \$13,194.70



Conclusions

The study demonstrated that an alternative deck design using GFRP and a more economical 501 PRHTA concrete to the required 934 PRHTA concrete required for R/C deck is cost effective for construction and can be implemented in Puerto Rico for bridges in zones considered of higher corrosion risk as those close to marine environments.

Future Work

Because the alternative deck is thicker than the original design a further study of the total bridge construction cost with GFRP deck alternative is recommended for another study as the design of other elements of the bridge could be affected by this change. If, as we believe, the cost is still more economical or competitive, it is recommended to PRHTA to implement this design in a pilot project to validate the long-term performance and cost saving that can be achieved by this technology.

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