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Impact Test of GFRP Reinforced Concrete Bridge Barriers

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Secretary for Research and Technology

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16. Abstract

The main goal of this research is to design a barrier with GFRP materials and compare it with steel. The MoDOT Type D concrete barrier with steel bar reinforcing forms the basis for the design. Constructability requirements are also considered, and these are related to the pragmatic elements of the building, like ease of installation, harmony with pre-existing buildings, and conformity to industry norms. These conditions must be met to guarantee that the GFRP components can be successfully integrated into the building project. The sizes and dimensions are modified in this design to conform to the characteristics of GFRP reinforcements. This reinforcement material swap aims to increase the resistance to corrosion-induced degradation and damage by utilizing the preservation qualities of GFRP materials.

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Summary

The main goal of this research is to design a barrier with GFRP materials and compare it with steel. The MoDOT Type D concrete barrier with steel bar reinforcing forms the basis for the design. Constructability requirements are also considered, and these are related to the pragmatic elements of the building, like ease of installation, harmony with pre-existing buildings, and conformity to industry norms. These conditions must be met to guarantee that the GFRP components can be successfully integrated into the building project. The sizes and dimensions are modified in this design to conform to the characteristics of GFRP reinforcements. This reinforcement material swap aims to increase the resistance to corrosion-induced degradation and damage by utilizing the preservation qualities of GFRP materials.

Keywords: GFRP Reinforced barrier, Steel Reinforcement design, Deck, Barrier, Impact.

Abstract

This report includes experimental studies, numerical modeling of glass fiber reinforced polymer (GFRP), and reinforced concrete bridge barriers under different MASH loads. Considering theoretical and practical factors, the GFRP designs were carefully constructed to fit effectively into the already-existing MoDOT Type D barrier constructions. Constructability evaluations were conducted throughout the experimental phase to ensure that GFRP reinforcement could be applied in real life circumstances.

Chapter 1 Introduction

Concrete bridge barriers are an essential component of road infrastructure that plays a crucial role in reducing accidents and guaranteeing the safety of both cars and pedestrians. Though functional, typical materials like steel and conventional reinforced concrete have drawbacks, including corrosion susceptibility, frequent maintenance needs, and limited resistance to extreme weather conditions. Given these difficulties, the building sector looks at creative solutions, and glass fiber reinforced polymer (GFRP) stands out as a leading option. Concrete barriers are designed to be the last line of defense when a vehicle loses control. They should be able to stop the vehicle from crossing the opposing lane or entering a road-adjacent field, which could result in more serious accidents than just hitting the barrier. It is crucial to comprehend how concrete barriers behave and potentially fail in various situations, including varying vehicle kinds and impact angles, among the many variables that could affect the impact results.

Furthermore, the majority of steel bars used to reinforce contemporary concrete barriers have outstanding strength, as demonstrated by several experiments and numerical analysis. One major drawback of this type of reinforced concrete is the corrosion-induced degradation and damage, which can be greatly reduced by switching the reinforcement to non-corrosive high-strength materials like GFRP.

This project mainly aims to determine the impact values of the cracking of the barrier with the rational design of the GFRP concrete barrier that can tolerate the MASH (Manual for Assessing Safety Hardware) loading. In this study, a literature survey, analysis of papers, and some collaborated discussions helped to design bars in the transverse direction and the longitudinal direction as well as the barrier itself. To ensure safety among all the factors, much research has been conducted and developed with experimental analysis and approaches that should ensure the security and safety of bridge concrete barriers. NCHRP project 22-2 was started at the Southwest Research Institute in 1973 to address various questions related to vehicular impact, but it was not perfect. Later, another final report, which is related to the experimental results of several accident crashing approach tests involving various vehicle types on various barriers, was published in NCHRP Report 350.

Non-linear finite element crash simulations were used to study the safety performance of concrete medium barriers [1]. These simulations assessed the safety performance of concrete median barriers (CMB), focusing on the impact of single-unit trucks in Test 4-12 from NCHRP Report 350. Key factors influencing CMB performance, including vehicle speed and barrier height, were identified. LS-DYNA facilitated cost-efficient simulations, validating results and informing potential retrofit options for CMB designs in light of proposed national crashworthiness standards updates.

Steel bar reinforcement is still the most popular material in concrete construction. Large-scale buildings and other structures can be constructed with excellent results due to the exceptional mechanical qualities of these kinds of constructions. However, corrosion is a significant issue that all steel bar-reinforced concrete constructions must deal with. This is because corrosion has emerged as one of the most significant issues regarding reliability with our aging civil infrastructure. The solid, porous character of concrete materials accelerates the corrosion process initiated by the entry of oxygen and chloride ions. When electrode reactions occur at the interface between the reinforcement and concrete components, they consume iron and produce rust, also known as ferric oxide. The problem could develop far worse for structures if there is seawater, frozen soil, or other corrosive circumstances. Every year, hundreds of billions of dollars are spent on maintenance and repair initiatives connected to corrosion. Furthermore, corrosion-related deterioration can cause bridge structures to fail catastrophically, which might be fatal. Much research has also been done to understand the corrosion process at the interfaces of reinforcement and concrete to find a theoretical, computational, and experimental method for prediction and protection. The impact of various levels of steel corrosion on the adhesive between steel bars and the surrounding concrete was examined. Pullout tests and finite element analysis were also used in the results, and the outcomes were contrasted.

Glass fiber reinforced polymer (GFRP) reinforcement has recently attracted much attention in engineering practice due to its resistance to corrosive issues. The amount of work currently required to address corrosion-related issues might be greatly reduced with this class of materials.

Chapter 2 Research Significance

This project aims to design a MoDOT Type D barrier with GFRP reinforcement. The design's viability and safety will be confirmed, and the understanding of how this GFRP-reinforced concrete barrier functions when struck by various vehicle types will be analyzed. In the later stages, finite element modeling will be conducted using different software. To achieve the previously specified goals, the project's tasks are compiled and presented as follows:

The main design foundation for the GFRP-reinforced concrete barrier is the MoDOT Type D barrier design. The diameters and bends are adjusted to meet the glass fiber rebar requirements. The two-piece design includes a barrier and deck, connected with a spiral reinforcement. Stirrup 1 is a hook-shaped bar primarily intended to reinforce the upper portion of the barrier. The barrier and deck are connected by Stirrup 2, a spiral stirrup. The stirrup's minimum radius of 3.0 inches and minimum number of bends are intended to be met in all positions. These stirrups are positioned every six inches along the cross-sectional directions. A total of 13 straight bars were aligned along the barrier. Two key factors to consider while working with GFRP materials in construction are:

- **Concrete cover**: When GFRP components are integrated into a Type D barrier construction, the concrete's thickness encloses and safeguards them. Maintaining the strength and lifetime of the GFRP elements requires an adequate concrete overlay.
- **Constructability requirements**: These relate to the pragmatic elements of the building, like ease of installation, harmony with preexisting buildings, and conformity to industry norms. These conditions must be met to guarantee that the GFRP components can be successfully integrated into the building project.

The entire design is carried over in AUTOCAD software during this phase.

Chapter 3 Experimental Program

3.1 Test program (parametric study)

For the first specimen, the deck is 10 feet long and divided into two barriers along both sides. These barriers are six feet long and GFRP bars serve as the complete reinforcement. The two-piece design is designed and constructed to make the interconnection between the barrier and the deck. The design requirements are met; the upper portion of the barrier has hook-shaped bars, and the connection with the barrier, which is the deck, has a spiral stirrup. For the entire design, the concrete cover is the required dimensions of 1.5 inches so the reinforcement bars do not come out of the concrete. The height of the barrier is 2’10”, and the deck is 8”. There are 13 total straight bars along the barrier’s length.

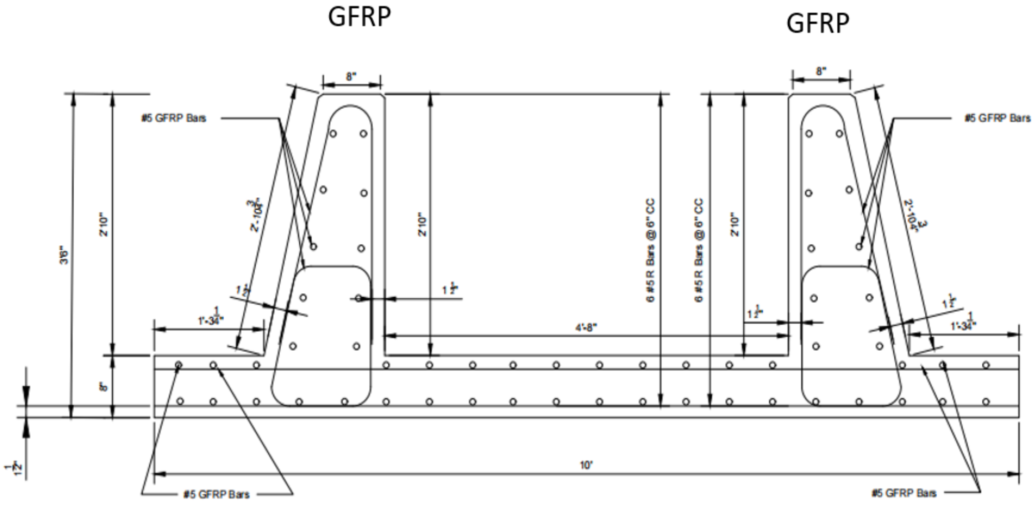

Figure 3.1 GFRP reinforcement design based on MoDOT (both sides same)

The second specimen also has a two-barrier design in a single 10-foot long deck. One side of the deck has a barrier with steel reinforcement, and the other with GFRP reinforcement. The deck reinforcement is divided into two halves and then spliced along them. The steel and GFRP bars are both longitudinal and 6 feet long. Both bars (steel &

GFRP) are spliced together along one foot, as shown in Figure 3.2. The steel design has the same conceptual design as the GFRP because of the dimensions taken for the GFRP bars; as per the design process and the criteria requirements, the concrete cover is 1.5 inches.

As shown in the below figures, there is a two-part design; one is a hook-shaped straight bar, and the other is a spiral-shaped bar. There are 13 hook-shaped bars along the barrier, matching the number of rotations in the singular spiral bar.

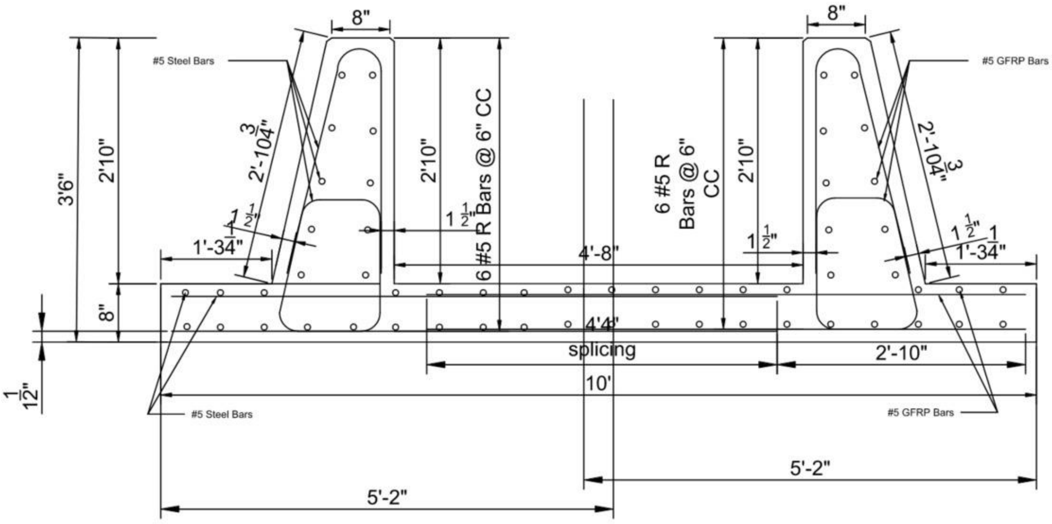

Figure 3.2 Steel & GFRP reinforcement design based on MoDOT (both sides different)

3.2 Mix Proportions (Concrete)

There are two different mix proportions for the slab and the barrier for the specimens. Per MoDOT specifications, the mix design is B1 for the barrier and B2 for the slab.

Table 3.1 B1-Mix Design for one yard

B1	Cement	Ash	Sand	C/A	Water	Air
Weight	**580**	**0**	**1220**	**1860**	**26gallon**	**5.8oz**

Table 3.2 B2-Mix Design for one yard

B2	Cement	Ash	Sand	C/A	Water	Air
Weight	**529**	**176**	**1257**	**1788**	**30gallon**	**5.8oz**

Table 3.3 Specimen 1,2 (Slab)

	Slab (14 days)	Slab (28days)
Sample 1	**3230**	**4794**
Sample 2	**4453**	**5171**
Sample 3	**4513**	**4841**

Table 3.4 Specimen 1,2 (Barrier)

	Barrier (14 days)	Barrier(28days)
Sample 1	**4603**	**5610**
Sample 2	**5156**	**5301**
Sample 3	**5067**	**5469**

Table 3.5 Specimen 3,4 (Slab)

	Slab (14 days)	**Slab (28days)**
Sample 1	**5533**	**6679**
Sample 2	**5657**	**6269**
Sample 3	**5537**	**2834**

Table 3.6 Specimen 3,4 (Barrier)

	Slab (14 days)	**Slab (28days)**
Sample 1	**3116**	**3565**
Sample 2	**3166**	**3431**
Sample 3	**3009**	**3479**

3.2.1 Material properties

The increased strain rate values increase the material’s yield stress and change the material's stress-strain behavior in the plastic domain. The Johnson-Cook material model considers three key factors: temperature, strain, and strain rate.

3.2.2 Specimen 1,2 preparation

The Specimen is divided into two parts: the first part is the construction of the deck, and the second part is the construction of the barrier sitting on the deck. The deck’s B2 concrete mix is a prototype for the real materials used in construction. The deck was constructed to be 10 feet long, 6 feet wide, and with a thickness of 8 inches. The dimensions were achieved with a framework of two 12 by 8 and two 6 by 8 boards along the four sides. Prior to casting, reinforcements of #5 GFRP bars are placed in the longitudinal and transverse directions at spacings of six inches, leaving room for a concrete cover of 1.5 inches along the deck's four sides. When casting, the framework must be flat, strong, and firmly fastened to prevent movement as the concrete is poured carefully to avoid segregation and give better strength properties. The use of suitable vibration techniques ensures adequate compaction and eliminates air pockets.

Figure 3.3 deck formwork/reinforcement

Figure 3.4 GFRP reinforcement (barrier)

The second part of the concrete pour is the barrier that sits on the deck. The framework used for the barrier is made up of 14 2 by 4 and 4 4 by 8 plywood beams. The concrete is reinforced with spiral- and hook-shaped GFRP bars in which the spiral bars are set with 13 rotations and 13 hook-shaped bars are spaced six inches apart along the barrier length. 1.5 inches is left along the framework edges to serve as the concrete cover.

Figure 3.5 Concrete pour (deck)

Figure 3.6 Formwork (barrier)

3.2.3 Specimen 3,4 preparation

The Specimen 3,4 is constructed in two halves. One side has GFRP while the other is constructed with steel reinforcement. The specimen is divided into two parts: the construction of the deck and the construction of the barrier sitting on the deck. The deck’s B2 concrete mix is a prototype for real materials used in construction. The deck is cast in dimensions of 10 feet long, 6 feet wide, and 8 inch thickness. One side of the deck is reinforced with GFRP bars (#5) in the longitudinal and transverse directions. The other side of the deck is reinforced with steel (#5) bars in the longitudinal and transverse directions. The bars are spaced 6 inches apart and leave room for a concrete cover of 1.5 inches along the four sides of the deck.

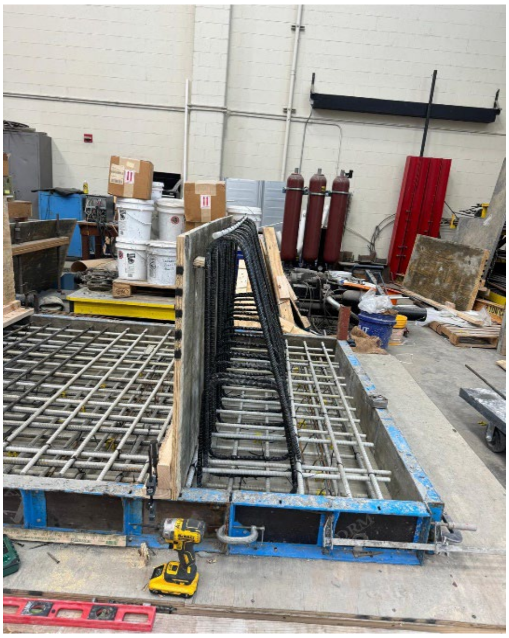

Figure 3.7 GFRP Reinforcement (barrier)

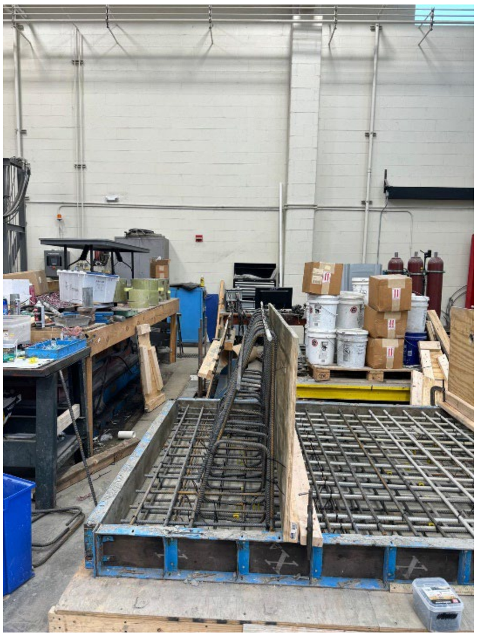

Figure 3.8 Steel Reinforcement (barrier)

Figure 3.9 Concrete pour (slab)

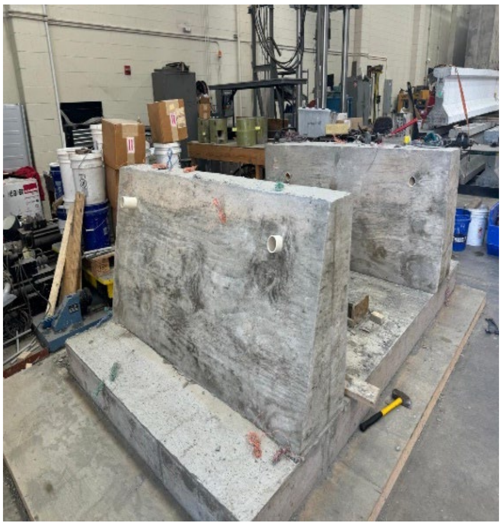

Figure 3.10 barrier with deck

3.3 Test Set-up and Instrumentation

When strain gauges are installed on GFRP bars, sensors determine how much the material has deformed or strained under different loading conditions. It is recommended chosen gauges align with the anticipated strain levels and the characteristics of the GFRP material while ensuring no contaminants on the GFRP bars' surface could prevent the strain gauges from adhering. To clean the surface and strengthen the bond, the proper solvent must be used. The instrumentation for the deck is located at the edges and in the middle. The impact height is 27” from the bottom of the slab, and the strain gauge height is 27” from the barrier. Five strain gauges on the barrier (B-SG-1 to B-SG-5) along the length are at the same height. Six strain gauges on the edge of the slab portion, i.e., the 16” curb. A-SG-4, -5, and -7 have two strain gauges, one on the longitudinal bar and one on the transverse bar. A-SG-1 and -3 contain six strain gauges on the slab at the spiral bars (three longitudinal bars and three transverse bars).

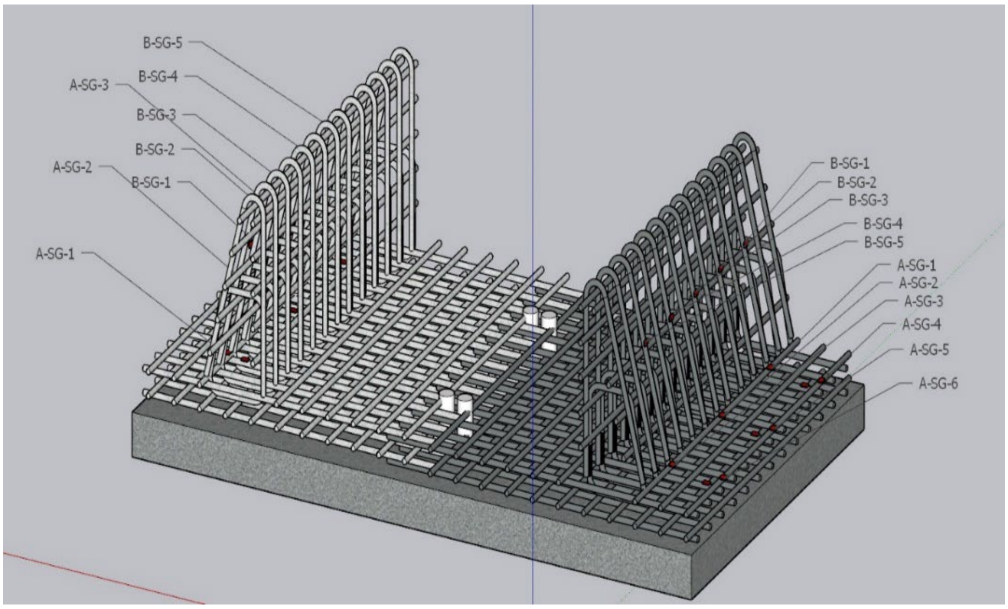

Figure 3.11 Instrumentation of Strain Gauges

Figure 3.12 strain gauge installation

Figure 3.13 total number of strain gauge installation

3.4 Impact test

The impact test setup contains a cart with weights that impact the specimen.

Figure 3.14 Instrumented sledge ready for impact test

Chapter 4 Results

At the time of reporting, the research team is ready to conduct the impact test. The outcome will be summarized and reported in the next report.