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<tr><td colspan="5">16. Abstract

Barriers are one of the essential components in bridges to ensure safety for vehicles and redirect the errant vehicles passing over bridges. Several attempts were taken place to develop prefabricated barriers with connection to the bridge deck using post-tensioned thread rods and stainless-steel bars. However, those connections are associated with higher cost and durability issues. A new prefabricated barrier system utilizing UHPC connection to deck overhangs was developed under an on-going project [ABC-UTC-2016-C3-FIU05]. To further enhance the developed prefabricated barrier system, the barriers, in this proposed project, will be fabricated from all lightweight concrete with a unit weight of 100 pounds per cubic yard. The use of all lightweight concrete in barriers and in some cases bridge overhangs provides a reduction in the total weight of the barriers by almost 33% allowing the transportation of more barrier units on one truck and easy handling. Furthermore, in seismic regions, lighter barrier contributes to a lesser total mass of bridge superstructures which is beneficial in many cases. In this research project, a thorough understanding of the behavior of all lightweight concrete barrier is performed through numerical investigations. Generally, lightweight concrete barriers present several advantages which include its reduced weight making them an easier option for transportation or installation, increased strength-to-weight ratio, and improved stability. Several other benefits are also associated with enhanced impact absorption, reduced risk of accidents and improved road safety. All these advantages make them a viable option considering their reduced material usage, economical costs, simplified maintenance and extended service life.</td></tr>
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Use of All Lightweight Concrete in Conjunction with UHPC Connection for Prefabricated Barrier System

Final Report

January 2025

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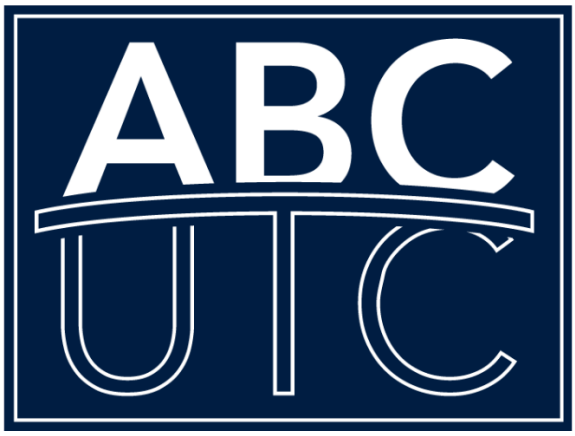

ACCELERATED BRIDGE CONSTRUCTION
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ACKNOWLEDGMENTS

This project was supported by the Accelerated Bridge Construction University Transportation Center (ABC-UTC at www.abc-utc.fiu.edu) at Florida International University (FIU), as lead institution, Iowa State University (ISU), University of Washington (UW), University of Oklahoma (OU) and the University of Nevada-Reno (UNR) as partner institutions. The authors would like to acknowledge the ABC-UTC support.

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CHAPTER 1: INTRODUCTION

1.1. Project Motivation

Barriers are one of the essential components in bridges to ensure safety for vehicles and redirect errant vehicles passing over bridges. Several attempts were made to develop prefabricated barriers with connection to the bridge deck using post-tensioned thread rods and stainless steel bars. However, those connections are associated with higher cost and durability issues. A new prefabricated barrier system utilizing Ultra-high Performance Concrete (UHPC) connection to deck overhangs was developed under project ABC-UTC-2016-C3-FIU05 [1]. To further enhance the developed prefabricated barrier system, the barriers in this proposed project will be fabricated from all lightweight concrete with a unit weight of around 100 pounds per cubic yard. The use of all lightweight concrete in barriers and, in some cases, bridge overhangs provide a reduction in the total weight of the barriers by almost 33%, allowing the transportation of more barrier units on one truck and easy handling. Furthermore, in seismic regions, a lighter barrier contributes to a lesser total mass of bridge superstructures, which is beneficial in many cases. In this project, a thorough numerical investigation is conducted on an all lightweight concrete barrier to understand their structural behavior and associated advantages.

1.2. Research, Objectives, and Tasks

The primary objectives of this research project are the following:

1. Verification of the suitability of the developed UHPC connection for all-lightweight concrete barrier systems,
2. Conducting detailed finite element modeling on the proposed all-lightweight concrete barrier system and connections,

3. Developing detailed finite element models for the proposed all-lightweight concrete barriers with UHPC connections for better understanding of system performance, therefore, extending the study to analyze other specimens which will not be possibly tested.

These objectives were accomplished through the following research tasks:

- **Task 1** – Verification of the proposed UHPC connection for all-lightweight concrete barrier systems
- **Task 2** – Preliminarily finite element modeling for the proposed all-lightweight concrete barrier system
- **Task 3** – Final Report

1.3. Report Overview

The final report is presented in chapters as per the outlined tasks as above, these include the verification of the experimental study of a proposed UHPC connection, preliminary numerical analysis of an all lightweight barrier and the conclusions and recommendations for the study.

CHAPTER 2. REVIEW OF THE EXPERIEMTAL STUDY FOR PROPOSED UHPC CONNECTIONS OF A PREFABRICATED BARRIER SYSTEM

The research study includes a thorough understanding of the proposed UHPC connections [2]. The main aim is to properly synthesize the information in order to apply the conceptual framework to an all lightweight concrete barrier system for the proposed UHPC connection.

In this chapter, the experimental phase of the recessed connection is discussed in detail as it presents several advantages over the others [2]. A total of four barriers were constructed and tested: one Cast-in-place (CIP) barrier, U-shape connection and recessed connection involving two barriers of different lengths, both designed with the same details to test their capabilities, observe their behavior, and highlight the differences developed under project ABC-UTC-2016-C3-FIU05 [1]. There were similar other connections that were tested at the FIU's structural laboratory as well and the aim of these projects is to determine the best suggestions for enhancing our transportation system. The focus of the present research study will be on the 5ft long specimen with a recessed connection barrier systems that were constructed using normal concrete. The study is also supported by understanding the overall construction procedure and demonstrate how all the objectives of this project have been achieved.

2.1. Experimental Tests

Two new barrier system designs were developed and tested in the FIU's Structural Laboratory alongside a traditional cast-in-place barrier system. This enabled to compare the results and observe the differences in strength that can be achieved by using UHPC at critical locations. The tests were conducted on 3ft long prefabricated barrier with CIP components, followed by a 3ft long prefabricated barrier with U-shape connection, both subjected to a transverse load at a height of 39 inches, corresponding to the deck overhang. Later, the study was extended to a barrier system

with a proposed recess connection, with 5ft and 15ft long barriers, constructed and tested. The figure below shows the structural drawings of these connections.

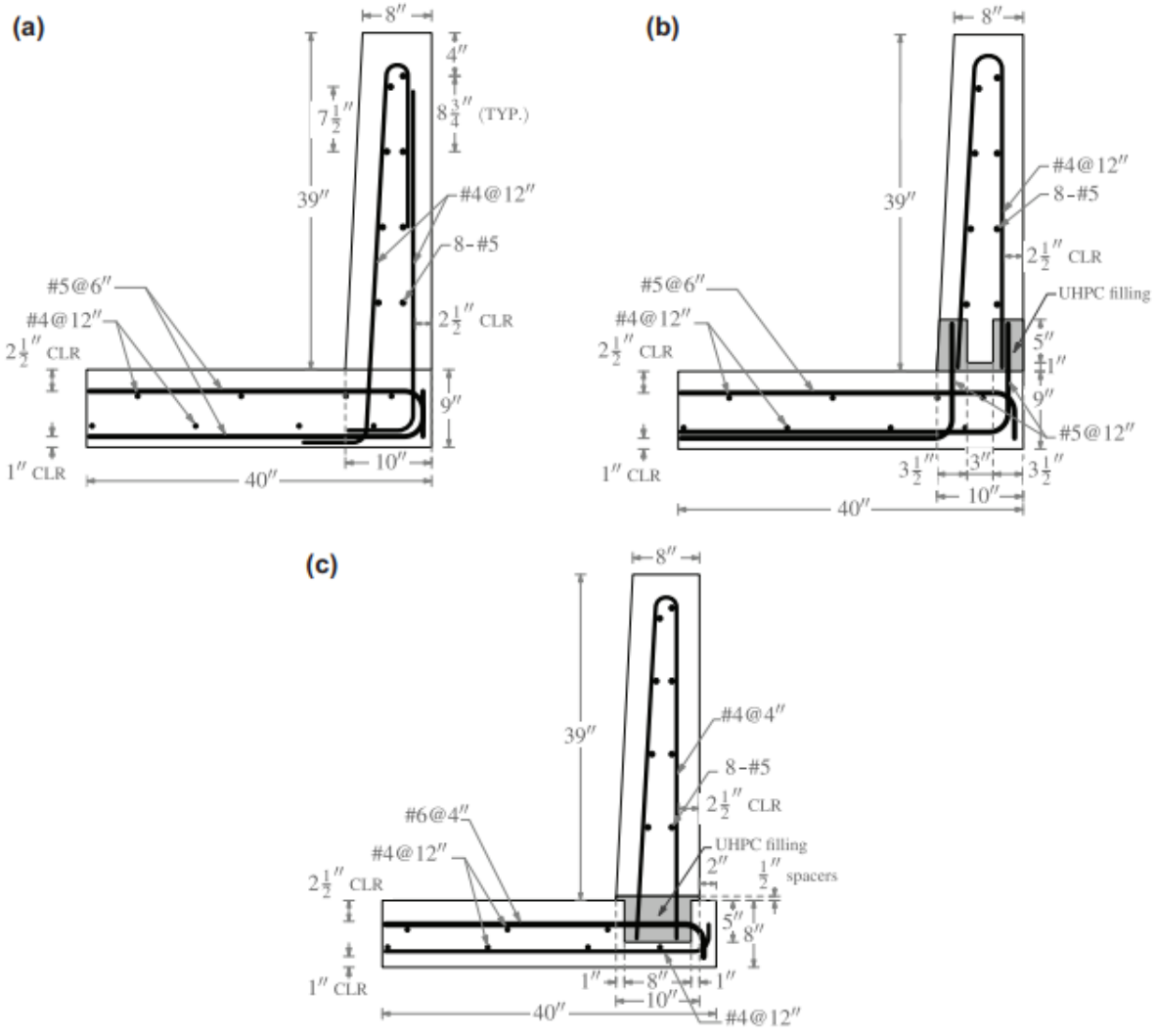


Figure 1. Proposed connection details for the prefabricated barrier systems (a) Cast-in-place barrier system; (b) U-shaped UHPC barrier system and (c) Recessed UHPC connection barrier system

2.2. Connection Details

This section presents information on the cross-sectional view of the recessed connection as shown in Figure 2. The deck features top transverse rebars with a #6 diameter, spaced at 4 inches along its length, and bottom transverse rebars with a #4 diameter, spaced at 12 inches. Additionally, there are eight longitudinal rebars spaced 12 inches across the width. It is already understood that the top of the slab will be subjected to tension, making it an optimal choice to upsize the steel rebars with a more confined spacing to ensure adequate strength is achieved. The bridge deck overhang has a thickness of 8 inches, a typical choice that accounts for a trough, which will later be utilized to cast with UHPC to complete the full barrier system. The barrier includes transverse rebars that extend through the UHPC, along with eight long rebars to ensure proper load transfer. The UHPC portion as shown in Figure 2, is embedded more than 90% within the deck, ensuring a very strong bond between the precast elements.

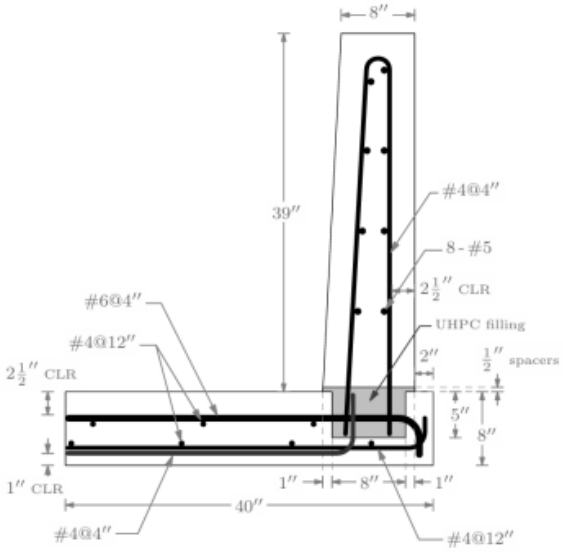
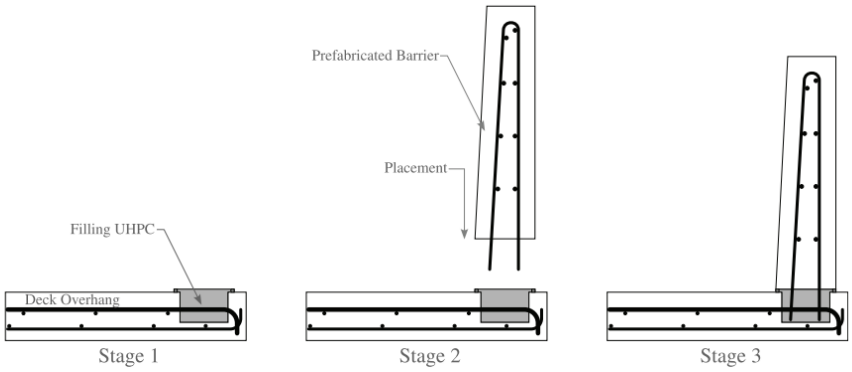


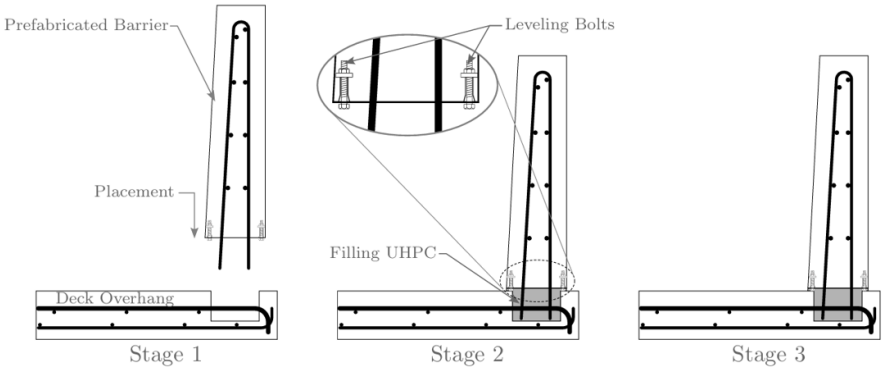
Figure 2.Structural Detail of the Modeled Barrier, per reference

2.3. Construction Process

Two methods were suggested for constructing the above outlined recess connection. The method used in the structural lab involves separately prefabricating the slab and barrier, then filling the opening with UHPC and placing the barrier on top. This approach ensures a strong bond, but achieving perfect alignment remains a challenge. Alternatively, another method involves placing adjustable bolts at the bottom of the barrier to ensure proper leveling and stability of the system before casting the UHPC. Figure 3 shows the procedure and possible options for the construction of the recess UHPC connection.



(a) Casting UHPC prior to placing the prefabricated barrier

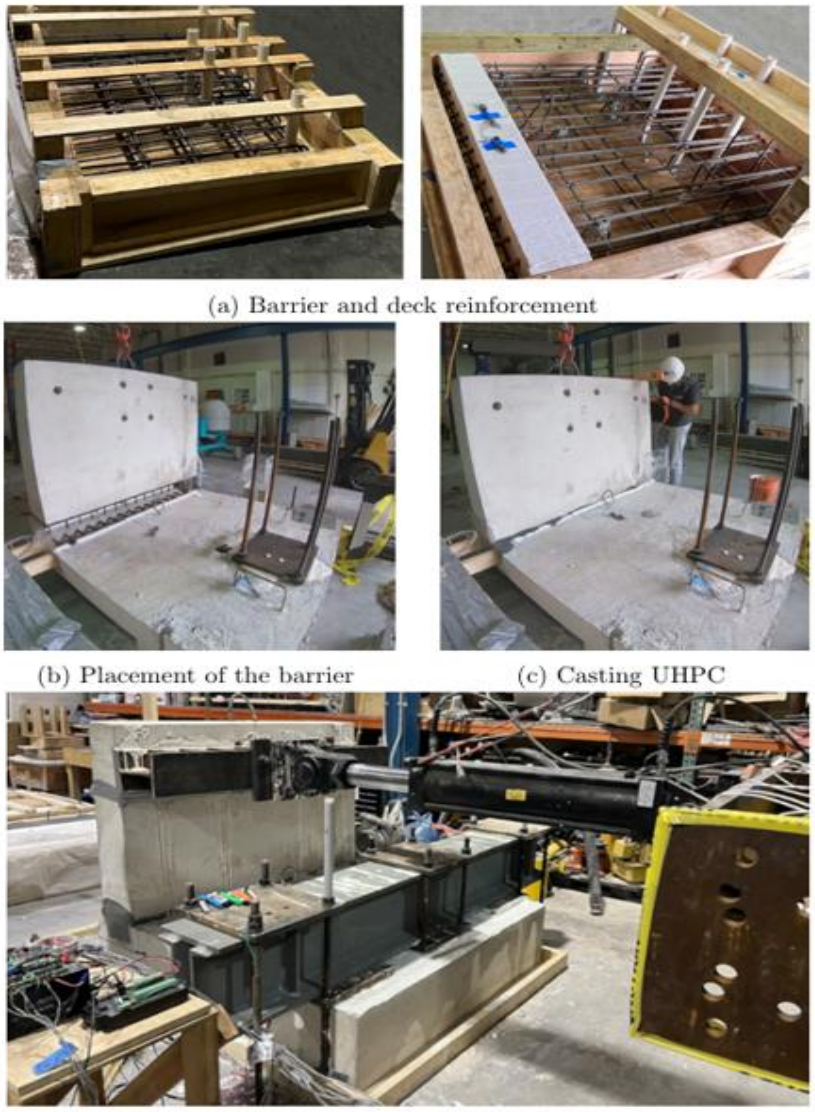


(b) Placement of the prefabricated barrier with adjustable bolts before casting UHPC

Figure 3. Possible choices for construction of the proposed recessed connection.

The first stage involved setting up of the formwork, placing the rebar steel reinforcement, and installing strain gauges at critical locations. Next, the surfaces at the contact points between the Normal Strength Concrete (NSC) and UHPC were prepared by sandblasting to ensure a rough texture for better bonding. The final step was to position the structural elements as planned and pour the UHPC in the designated areas, carefully following specifications to ensure a successful casting. For example, the flowability of the UHPC mix was crucial in determining the locations that could be used for pouring. To manage this, two endpoints were chosen for the UHPC pour. Additionally, there were special handling requirements, such as ensuring the concrete deck slab to be considerably wet before casting in order to avoid the absorption of water from the UHPC pour and adopt a pressure head to avoid air pockets that could affect the bonding. All these factors were considered during the construction of both the 5ft long and 15 ft long barrier specimen tests. This careful planning was reflected in the test results, as there were no issues with debonding or unexpected problems.

A key challenge in constructing such a system is effectively connecting the two precast elements while ensuring the UHPC pour is carefully managed. Utilizing adjustable bolts can be a practical solution for leveling the system, and employing various bracing forms for the formwork can facilitate a more controlled casting process for the UHPC. Figure 4 presents an overview of the construction procedure.



(a) Barrier and deck reinforcement

(b) Placement of the barrier

(c) Casting UHPC

(d) Constructed specimen at the testing location

Figure 4. Construction sequence for the prefabricated barrier system with recessed UHPC connection

2.4. Test Setup

Two boundary conditions were applied to the barrier system to simulate a lateral pushover test. A monotonic load is applied 30 inches for recess connection type and 39 inches for U-Shape and CIP connection types from the surface of the slab, distributed across the entire length. The deck overhang is secured with a beam, three plates, and 1-inch rods, all positioned on the extra overhang

to replicate the fixation condition of the slab on the road. The load is expected to be resisted by the deck overhang where ultimate failure has been developed. It is reasonable to have this response since the barrier is being subjected to a plate along it is length which would make load transfer properly to the slab.

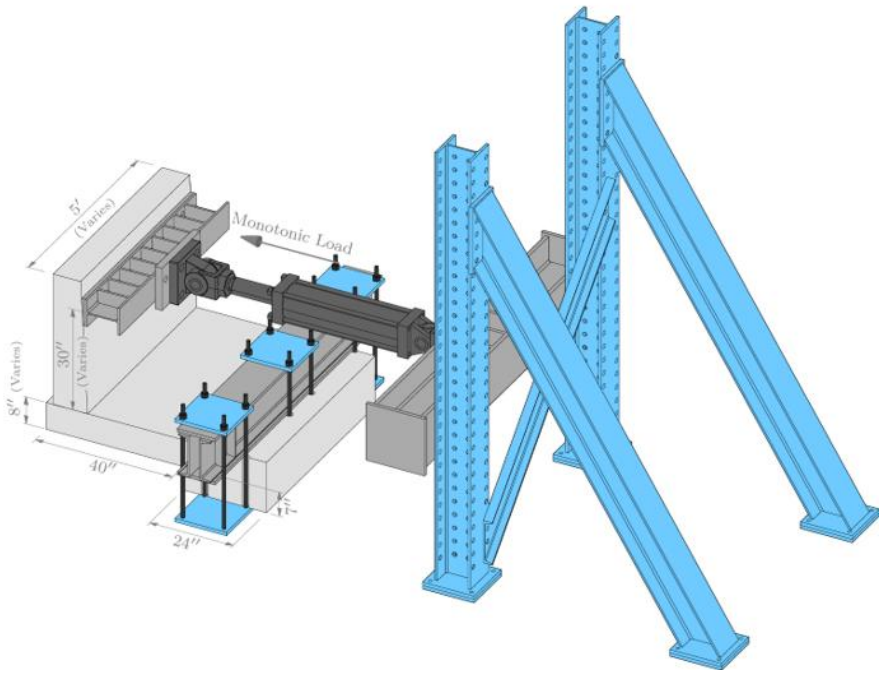


Figure 5. Experimental Test Set-up

2.5. Experimental Results

This section presents the testing of three barrier systems: CIP, U-shape, and Recess connection as outlined in the above sections. To account for varying lengths and changes in load height, normalized data were used, though properly analyzing the data can still be quite challenging. Nevertheless, the recessed connection was expected to perform better since the UHPC is oriented within the slab. Figure 6 presents the comparison of moment-drift curves for all of the proposed connections. In Figure 6, the y-axis represents the load, normalized with respect to the length

multiplied by the effective height, which is also a variable. The x-axis shows the lateral displacement divided by the effective height, which equivalent quantity to the drift ratio. It is important to note that both the CIP and U-shape connections have the same length and height of load application, and the normalized method is used to adjust the data for comparison with the recessed connection.

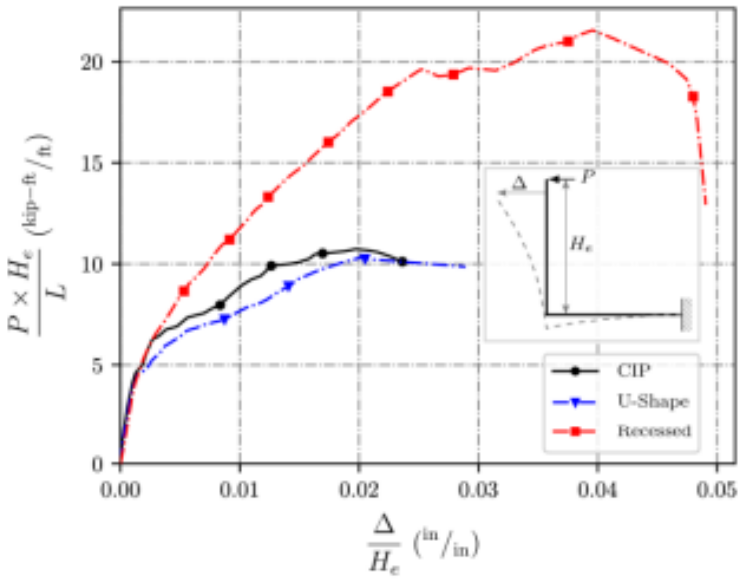


Figure 6. Moment-drift curves for the connections

As shown, there is a significant difference in performance between the recessed connection and other barrier systems. One reason for this can be interpreted from the U-shape connection, where the UHPC is only located above the surface of the deck overhang. This setup could lead to premature shear failure of the slab, which could be prevented by adding more diagonal steel rebars to ensure a more ductile response in resisting shear forces. Another indication lies in the recessed connection, where the UHPC is embedded within the slab. The UHPC plays a critical role in resisting the shear forces been developed in the deck overhang, changing the crack behavior and eliminating the need for additional diagonal bars. UHPC should be placed in areas where ultimate

failure or high stress is expected, to fully take advantage of its unique material properties. It is the optimal choice in terms of durability, strength, and ductility.

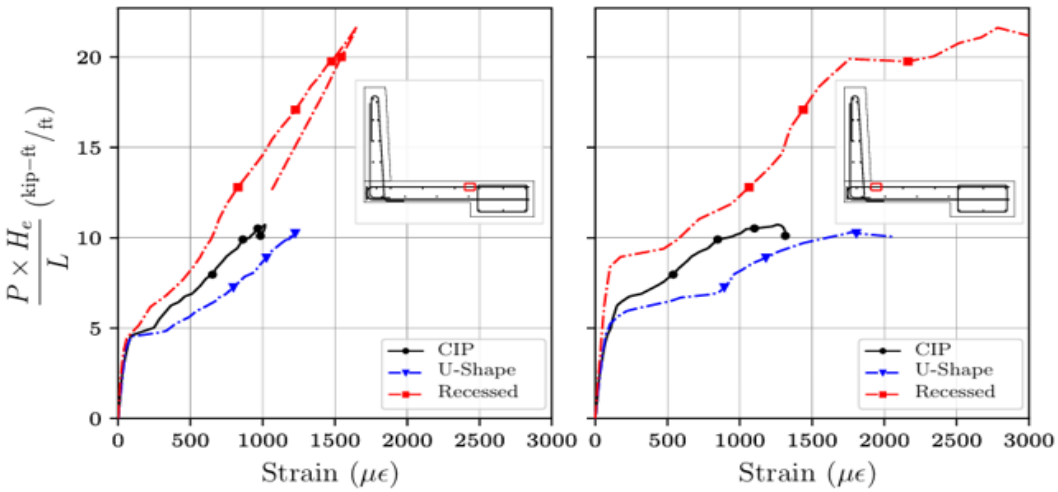


Figure 7. Moment-strain curves for the top transverse deck reinforcements of the proposed connections

Figure 7 illustrates the normalized load corresponding to strain measurements taken at fixed locations. It is evident that the highest strain values are recorded near the deck-barrier interface, where significant stresses are concentrated. The transverse rebars in the recess connection have yielded prior to reaching the ultimate load capacity. Additionally, it is important to note that the U-shape connection experiences a considerable reduction in stiffness after resisting the first crack. This reduction indicates that premature shear failure caused the slab to undergo significant stress without fully utilizing the strength of the UHPC.

2.6. Mode of failures

The failure of these structural components could offer valuable insights into predicting and anticipating the ultimate stage when UHPC is used within these barrier systems. In the CIP

connection, the failure of the deck overhang was primarily driven by tension and compression. Tension forces led to the formation of a final horizontal crack at the interface, while compression forces created localized shear at the back of the barrier, extending into the overhang. In the U-shape connection, tension remains dominant at the top of the slab, while shear extends over a wider area due to the higher compression forces being resisted. The failure mode shifted primarily from the interface to premature shear failure, which can be attributed to the implementation of UHPC at the interface, providing high strength in that region. However, this did not significantly affect the overall behavior, as the high shear forces developed in the slab were not adequately accounted for. On the other hand, for the recess connection, the crack pattern exhibits the crucial role that the UHPC has to offer. It effectively controls and resists shear cracks, enabling the structure to perform and reach its ultimate capacity. There are two primary things that the UHPC is providing in the case of a recess connection: Firstly, it covers the interface region where high tension is being implemented and minimize horizontal cracks that can be developed and control the failure mode. Secondly, integrating the UHPC inside the slab is mainly effective in resisting premature failure that may occur. Interpretation of the various failure modes in barrier systems can be complex, as these structural components are subjected to different loading mechanisms, and failure can occur in multiple ways depending on the design requisites. In traditional applications, rebar tends to develop cracks, but the use of innovative materials, such as UHPC, has shown that cracks can be distributed differently, especially in areas of high distress. While failure may still occur in UHPC, it would not significantly compromise the overall strength of the system. Figure 8 presents the crack pattern that was observed at different stages of loading for the recessed UHPC connection type.

Figure 8. Crack patterns at different stages of loading for the recessed UHPC connection

2.7. Numerical Validation

Comparison of the numerical results with the experimental findings from the 5ft specimen of the CIP and Recess connection are presented in this section [2]. As shown in Figure 9, the model successfully captures the behavior of the traditional reinforced concrete model for the cast-in-place

connection, with both the experimental and numerical results demonstrating similar levels of ductility and strength. For the case of recessed connection, we can observe that the finite element model (FEM) differs in terms of its final response. During the linear elastic stage, both the FEM and experimental results show similar stiffness. After the first crack, the FEM exhibits a higher second stiffness compared to the experimental results, even though the first crack appears earlier in the FEM model. Capturing all the details can be challenging when using FEM software, as the cementitious material behavior involves many nonlinearities. The difference in cracked stiffness may be due to an overestimation of the UHPC strength in the FEM model. The model still provides an acceptable validation by correctly predicting the maximum strength and the corresponding deflection, which is often the most difficult aspect of any numerical analysis. Additionally, the FEM and experimental results show an identical response in the 15ft long recess connection, further demonstrating the effectiveness of the numerical model that was used. It's also important to note that the 5ft long recess connection may have encountered unexpected events during the loading process, or the material properties might not have been accounted for accurately in the Model.

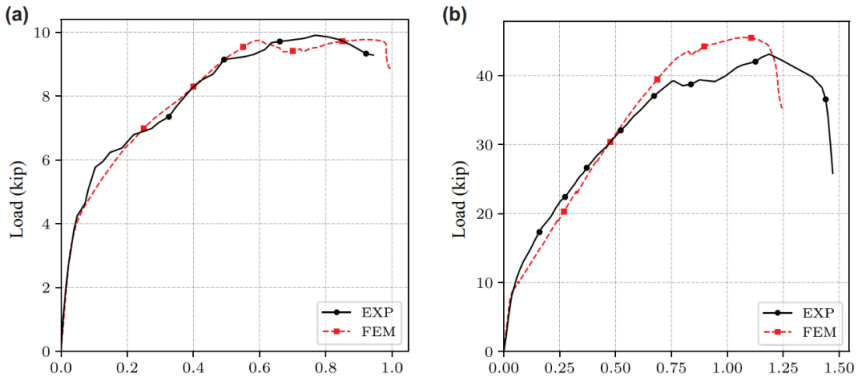


Figure 9. Comparison of numerical and experimental load-deflection curves for (a) cast-in-place and (b) recessed connection

2.7.1. Discussions

The conceptual and construction details on the three barrier systems have been presented. In this project, innovative materials have also been used and implemented which helped understand the overall behavior of the connections. The following discussions will emphasize on some of the critical outcomes from the experimental tests:

1. The recessed connection demonstrated better performance and meet the required standards. It can be effectively implemented using ABC, which would minimize traffic interruptions while enhancing road safety.
2. UHPC may be adopted in critical locations to take full advantage of its high strength and ductility, helping to control the ultimate failure mode.
3. Understanding the failure modes of barrier systems is crucial for making informed decisions when implementing ideas in practical applications. Design improvements can be developed based on crack behavior in altering the entire design to achieve the desired outcome.
4. UHPC should have a minimum compressive strength of 22 ksi in any practical applications. The primary reason for this is that the high stiffness provided by UHPC ensures that greater strength is achieved, as the connection is primarily controlled during its final stage of casting.

CHAPTER 3. NUMERICAL INVESTIGATIONS

3.1. Barrier Finite Element Modeling

As mentioned earlier in the introduction, the main reason to study the response of lightweight concrete barriers is because of its reduced weight-to-strength ratio and increased service design life. The present study presents the preliminary finite element modeling and analysis results of a lightweight barrier with a recessed UHPC connection. Figure 10 shows the modeled barrier, its reinforcement and the UHPC connection.

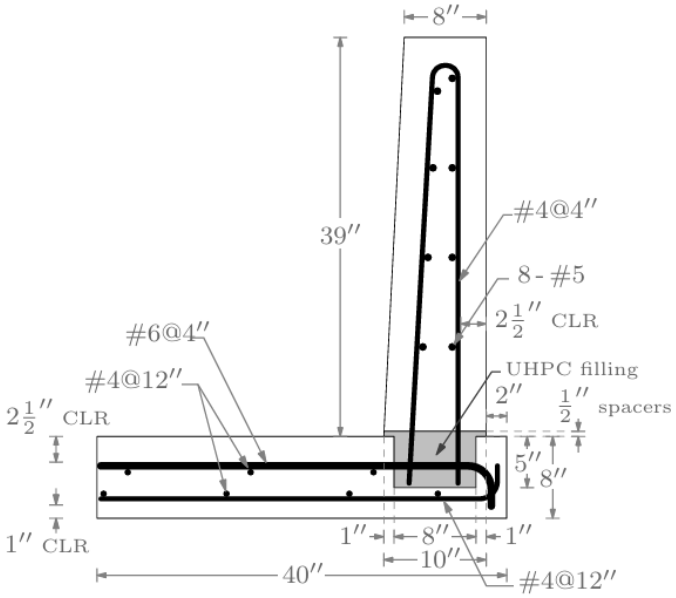
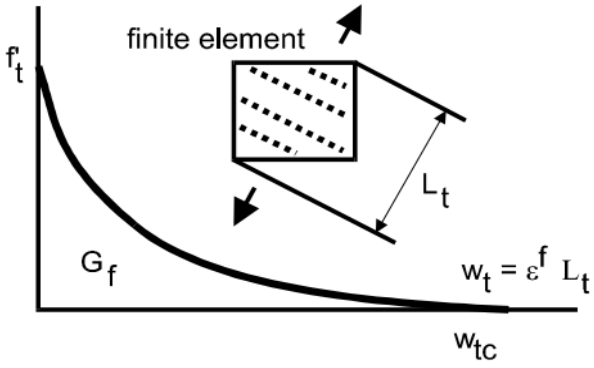


Figure 10. Structural Detail of the Modeled Barrier, per reference

Two barriers were modeled in total, one using normal-weight concrete and the other one using light weight concrete components. The barriers were modeled using ATENA 3D finite element software with loading applied at 30 inches from the surface of the deck, following NCHRP 22-20(02) [3] for a recessed connection, and were analyzed using static push-over non-linear analysis.

3.1.1. Constitutive theories

ATENA software employs advanced concepts to accurately represent the distinct behavior of composite materials and is commonly used for non-linear analysis of cementitious materials. In the tension zone, the material initially behaves in a linear manner until it reaches the effective tensile stress. Beyond this point, it starts to release energy based on crack width, following an exponential curve, as illustrated in Figure 11.A user-defined model is employed to simulate UHPC behavior, considering both the strain-hardening stage and the softening response. To accurately capture the compressive behavior and failure mechanisms of concrete, a combined approach integrating plasticity and fracture energy is used. This framework effectively represents the material's hardening response under loading and its subsequent softening, as shown in Figure 12. The material model formulation is based on the strain decomposition into elastic, plastic, and fracturing components (DE BORST 1986) [3].



(a): CC3DNonLinCementious2 model

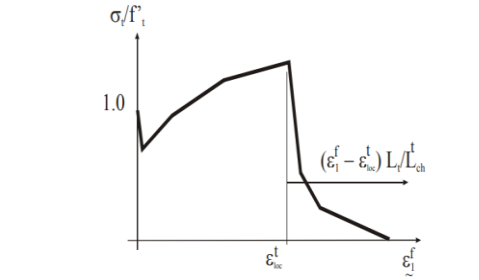


Fig. 2-24. An example of a user defined tensile behavior for CC3DNonLinCementitious2User material.

(b): CC3DNonLinCementious2User,

Figure 11. Failure criteria of tension zone per reference

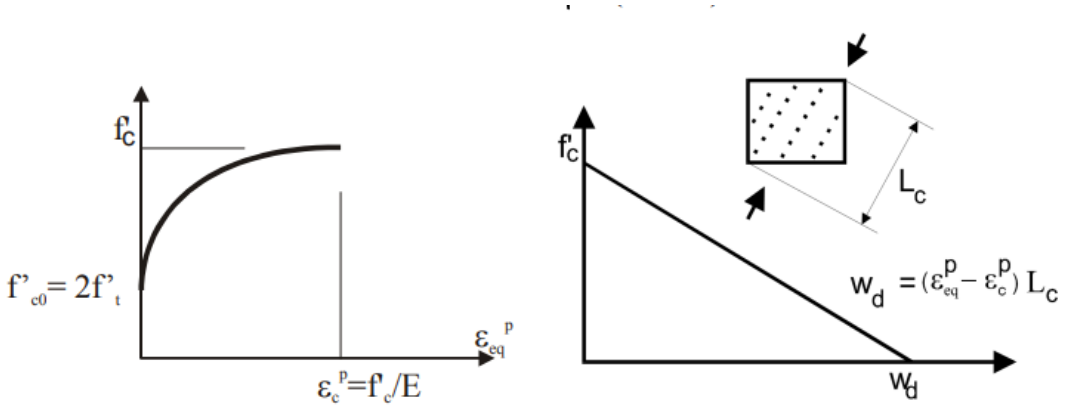


Figure 12. Failure criteria of compression zone per reference [4]

3.1.2. Concrete Modeling

The concrete behavior was modeled in ATENA 3D using a CC3DNonLinCementious2 model. It follows Menetry-Wiliam model to represent the non-linear behavior of the compression zone and Rankine criteria for tension which is mainly calculated based on the fracture energy and tension properties. It is called the fracture plastic model due to its ability to capture cracks, based on the band crack law. For lightweight concrete, the Young's modulus, tensile strength, and energy are reduced by 25% compared to normal weight concrete as it is shown in table 1. The properties of a lightweight barrier can vary based on the mix content and the assumptions made in reducing material properties with respect to normal weight concrete. In the Finite Element Model, conservative assumptions were made to ensure a worst-case scenario, specifically for a mix with a specified f'c of 5 ksi for lightweight concrete. Both the barrier and deck were modeled using the properties of lightweight concrete. Based on the work of other researchers, it can be inferred that my assumptions were conservative in nature[5],[6]. CC3DNonLinCementitious2 allows the incorporation of a hardening regime before the compressive strength is reached [3]. In contrast, the UHPC was modeled using a custom cementitious material CC3DNonLinCementious2User, with Young's modulus E=7500 Ksi, Poisson Ratio=0.2, Tension Rupture (fr) =1.2ksi, and

compressive strength of *f'c* =22ksi. CC3DNonLinCementious2User allows the use of user defined constitutive laws for the UHPC, such as tensile and softening behavior, shear retention, and lateral compression on tensile strength. It is an enhanced version of the fracture plastic model which also can be used to capture UHPC if the parameters were chosen correctly. There can be different aspects of modeling UHPC to exhibit the intended response in tension or compression. The new idea in the user-defined model is capturing the strain-hardening effect after the first crack of UHPC without neglecting it is high compression behavior. It accurately captures the response of UHPC in both the tension and compression zones.

Table 1 Parameters used in the modeling of normal-weight and lightweight concrete..

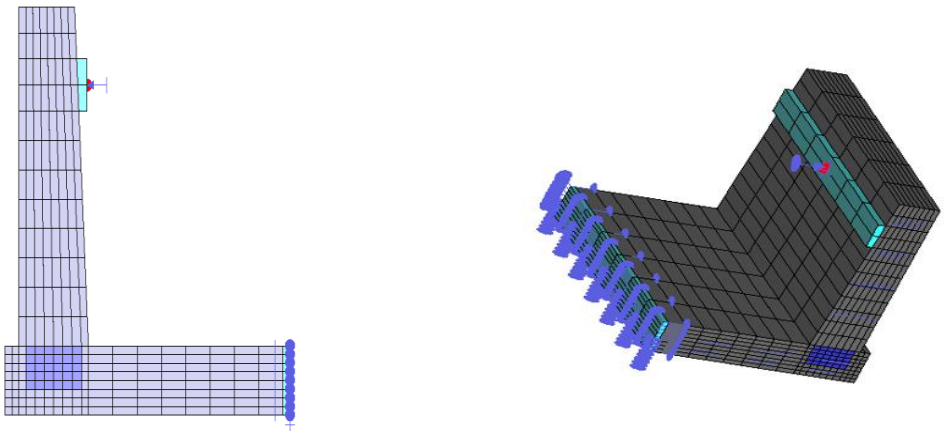
Property	**Normal-Weight Concrete**	**Light-Weight Concrete**
Density (lb/ft^3)	150	110
Poisson's ratio	0.20	0.20
Young modulus (ksi)	4,050	3,100
f'c (ksi)	5	5
fr (ksi)	0.35	0.26
Fracture energy needed to create a unit area of stress-free crack, Gf (lbf/in)	0.65	0.51

3.1.3. Reinforcement Modeling

The steel reinforcement was modeled using the CCReinforcement material, with a yield stress of Fy=60 ksi, and Young's modulus E=29,000 ksi. The steel is embedded inside the Cementous material using line body. Strain hardening effects are included as well. The material model implemented allows for the deactivation of the compression capacity of the reinforcement, but this was not implemented [4]. In this model, multi-linear plasticity behavior is incorporated with an ultimate strength up to 90ksi.

3.1.4. Boundary Conditions and Mesh Considerations:

In the FEM model, the barrier is subjected to increasing deformation due to a point load applied at the center of the steel plate. Additionally, the barrier is fixed at the end of the deck overhang, where no displacement or rotation is allowed, as shown in Figure 13. The mesh is refined at the connection location to capture all the necessary details. The concrete is modeled using a 3D solid brick element with 8 nodes at the corners, while the rebar is represented by a 1D line element with full bond interaction within the concrete.



(a) (b)

Figure 13. View of the connection with applied constraints in the barrier model.

3.2. Results

3.2.1. Overall Behavior

Figures 14 and 15 show the response of the barrier when subjected to the applied load. The first figure shows the deflection of the barrier when subjected to the applied load, while the latter figure shows the maximum strain in the top transverse rebar inside the deck overhang. In the lightweight concrete barrier, the first crack happens at an applied load of 7 kips, while in the normal-weight

concrete barrier, the first crack happens at 9kips. Both barriers performed similar after that with a cracked stiffness following closely to each other. However, the lightweight concrete barrier only sustained a maximum strain of approximately 0.004 before failure, meanwhile in the normal-weight concrete barrier the strain reached up to 0.008. The difference in strain can be explained by the difference response of the steel rebars. In conventional concrete, it is evident that the stress is primarily concentrated on the upper transverse rebars in the deck, which explains why the strain reached up to 0.008. In contrast, in the lightweight barrier, it is noticeable that the stress is distributed between the upper transverse rebars and the dowel rebars, making it reasonable for the strain to be lower at the final stage of loading. The primary reason for this new behavior is that UHPC sustained greater deformation within the lightweight barrier. It is rational to assume that UHPC would develop more cracks when positioned inside the slab, particularly in the region where the ultimate failure occurred during the experimental testing of the 5ft specimen. Incorporating the tensile effect of UHPC is crucial in this model. However, achieving the intended behavior cannot be guaranteed through numerical efforts alone. It requires a thorough analysis of the results and a detailed explanation of what is depicted. For instance, it is logical to expect the first crack to occur in the lightweight barrier at lower load, as this is consistent with its weaker material properties. At the same time, it is apparent that the maximum strength was not precisely captured, and it is likely that full verification cannot be achieved through numerical work alone. That said, it remains a valid assumption to attribute the ultimate strength to UHPC and to conclude that the overall strength would not be significantly compromised.

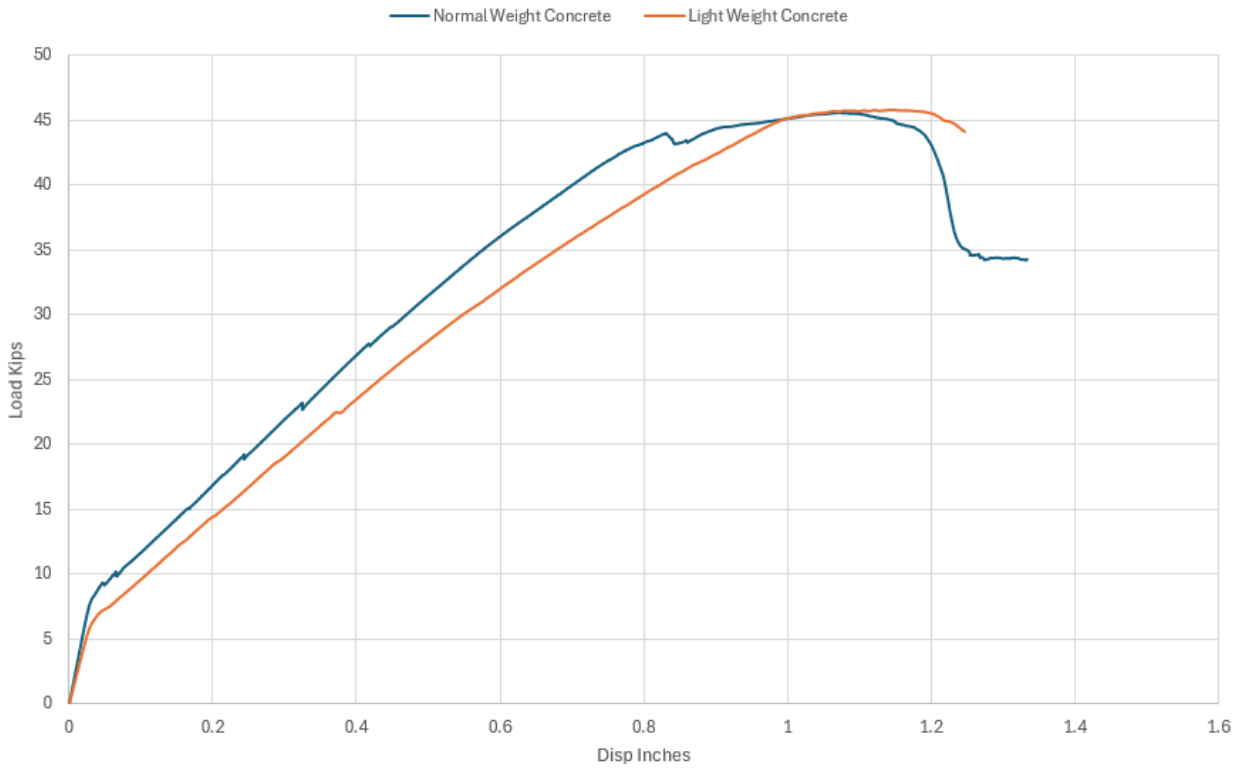


Figure 14. Load versus deflection plot of the response of the barrier implementing normal-weight and lightweight concrete

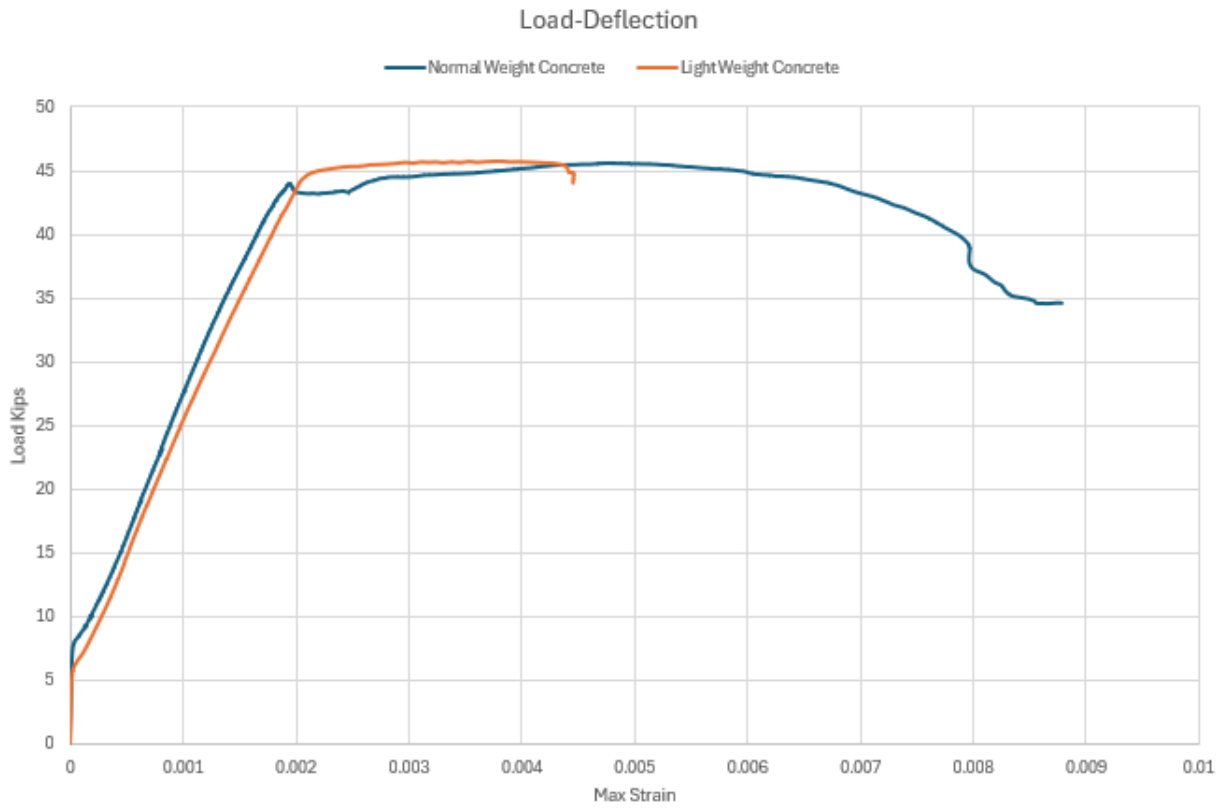


Figure 15. Load Deflection

Load versus maximum strain plot of the response of the barrier implementing normal-weight and lightweight concrete. Note: the strain gauge is located inside the deck overhang in the top transverse rebar.

3.2.2. Steel Reinforcement Behavior

Figures 16 and 17 show the uniaxial stress diagram of the barrier's reinforcement when subjected to the out-of-plane load. In lightweight concrete, shown in Figure 16, the dowel rebar plays a more critical role in load distribution and endures more stress along its length compared to the dowel rebar in normal weight concrete (see **Error! Reference source not found.**). The reinforcement in t he normal-weight barrier reached a higher peak stress compared to the lightweight barrier. In normal weight concrete, the steel stress reaches up to 63 ksi at a strain of 0.006, while in

lightweight concrete, the steel stress reaches 61 ksi at a strain of 0.004. In the previous discussion we talked about this behavior. The higher stresses and strains observed in the rebars within the normal concrete model suggest that UHPC plays a more crucial role in the lightweight barrier. In this case, failure occurs in the UHPC itself rather than causing the rebars to fail in the NCS. Also, a lower fracture energy might be the reason of underestimating steel behavior. But even with that,

the model showed stability and prove that it can adapt for different situations if UHPC is managed correctly.

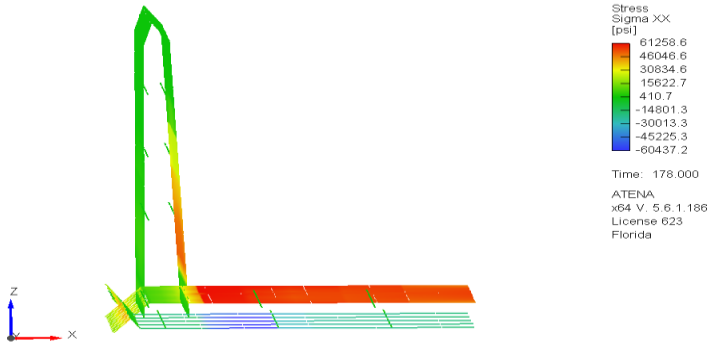


Figure 16. Resulting steel reinforcement stress from the applied load for the lightweight concrete barrier.

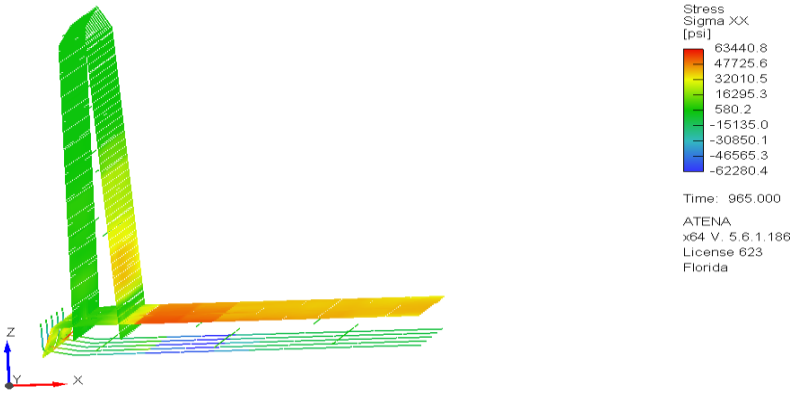
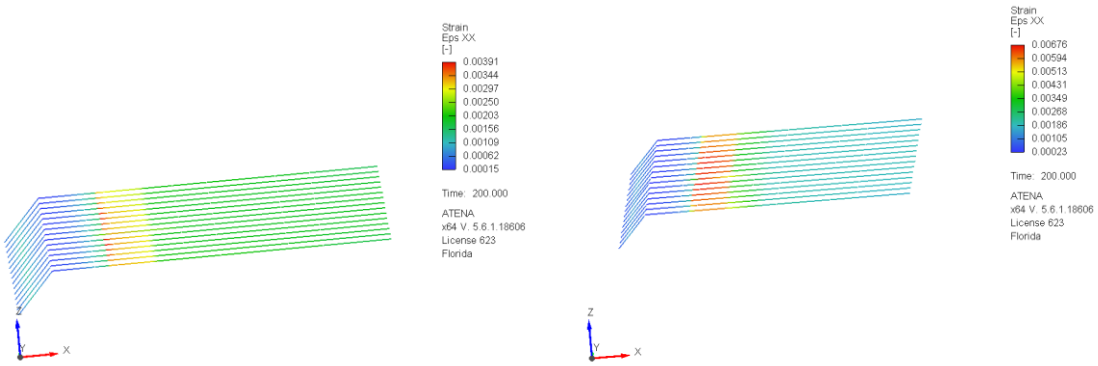


Figure 17. Resulting steel reinforcement stress from the applied load for the normal-weight concrete barrier.

This discussion presents another indication of the greater contribution of dowel rebars in Lightweight Concrete (LWC). The figure 18 illustrates the maximum strain observed in the top transverse rebar of both models before reaching the ultimate capacity. In the case of LWC, a

significant strain is evident in the steel rebar at the interface location. In contrast, Normal Weight Concrete (NWC) demonstrates a more uniform strain distribution along the rebar within the deck overhang. This behavior indicates that LWC effectively directs the high stress at the interface into the Ultra-High-Performance Concrete (UHPC) and dowel rebars.

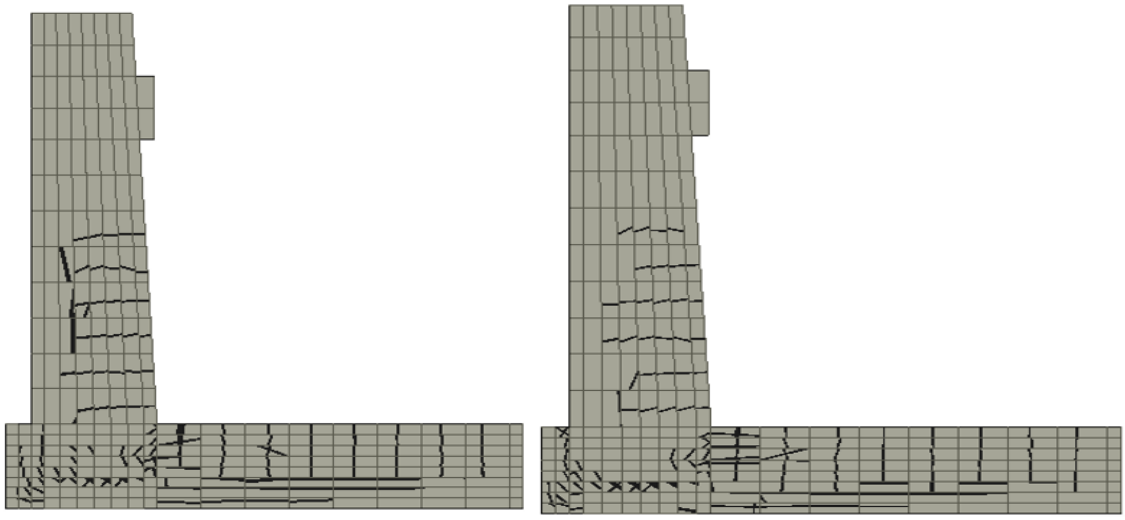


(a) Light Weight Model (b) Normal Weight Model

Figure 18. Resulting steel reinforcement strain from the applied load of the barrier model

3.2.3. Concrete Cracking Analysis

Figure 19 displays the crack patterns observed in the lightweight and normal-weight concrete barriers. By visually comparing the crack patterns and distribution, one can observed that the UHPC is undergoing to more cracking in the lightweight concrete model than in the normal-weight concrete model. This also visually explains why the dowel rebars engage more across their length in the lightweight model compared to the normal-weight concrete one. Moreover, this behavior also shows that even if there is a drop in the material properties of concrete, there will be UHPC providing additional strength, stiffness, and stability to the system.



(a) (b)

Figure 19. Crack patterns and distribution in the lightweight (a) and normal-weight (b) concrete barriers

CHAPTER 4. CONCLUSIONS AND FUTURE WORK

The result of numerical shows that the barrier going to be stable regardless of having normal or light weight. The UHPC provide extra stability and make the steel transfer in a better way where we have dowels rebars. However, the numerical work cannot guarantee an accurate estimation of max load without validation with large-scale testing, but it gives an overall picture of the response and the difference in the crack-propagation mechanism and load transfer when changes in base material occur. In addition, the following conclusions can be made about the finite element modeling and analysis:

1. The first crack happens at a lower load when having light weight barrier.
2. The second slope of both models are almost identical which mean there is not much difference between there stiffness drops.
3. The UHPC underwent to more cracks in the case of light weight barrier which mean it is providing a global stability of the system.
4. When modeling the barrier, one needs to also include the difference between steel in the normal and light weight barrier based on the figures provided in this report.
5. The failure happened in the UHPC instead of the rebars which can represent the worst-case scenario and yet, it did not affect it is overall performance.

Future Work

Based on the numerical studies, more finite element modeling will help understand the importance of having used a lightweight concrete in the proposed barrier system. Additionally, experimental studies may be conducted to support the outlined conclusions to the research study.

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