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Ultra-high Performance Concrete Superstructure for Railroad Overpasses

* Cender Osorio[1] and C. Shawn Sun[2]

[1], [2] *Department of Civil Engineering and Construction Management, California State University, Northridge, USA*

[1] *cender.osorio.734@my.csun.edu*

ABSTRACT

Railroad overpasses in the United States use steel plate girders largely as the primary load-carrying members. Despite their widespread use, steel overpasses are often associated with high initial costs due to the expense of structural steel. More importantly, steel overpasses are susceptible to localized cracking attributable to corrosion, fatigue, and brittle fracture, which necessitates frequent inspections and costly routine maintenance. Historically, steel structures have been dominant in railroad overpasses because concrete structures are unable to match their capacities efficiently. However, the recent development of the next generation of concrete, referred to as ultra-high performance concrete (UHPC), has made concrete a plausible alternative for railroad overpasses.

The goal of this research is to develop a UHPC alternative that can compete favorably with the dominant steel railroad overpasses. This paper introduces the initial phase of the research, focusing on the conceptual design of a UHPC superstructure. It details the key components, including prefabricated edge girders, deck panels, and cast-in-place connections between adjacent members. A small-scale demonstration specimen is also presented to illustrate the individual components and construction sequence. The proposed UHPC overpass system is anticipated to completely eliminate the concerns related to corrosion, fatigue, and brittle fracture attributable to steel overpasses. Furthermore, the need for frequent maintenance is negligible because of UHPC's exceptional durability and resistance to concrete deterioration and steel corrosion. The proposed UHPC alternative is expected to provide owners and designers with an entirely new vision of future railroad overpasses.

[1] Undergraduate Student
[2] Assistant Professor

1. INTRODUCTION

Steel plate girders are used predominantly in railroad overpasses. Their primary disadvantages include: 1) relatively high cost, particularly when steel prices increase; 2) a fracture-critical structure; 3) potential fatigue failure; and 4) the need for frequent maintenance because of steel corrosion. Structural failures have occurred as a result of fatigue and brittle fracture. To overcome these challenges, the authors proposed an ultra-high-performance concrete (UHPC) alternative for the railroad overpasses. UHPC is made of Portland cement, mason sand, high-range water-reducing admixture, fly ash, silica fume, steel fibers, and water (Fig. 1). Because only dense and fine aggregates are used, UHPC can achieve exceptional flowability and superior strength — typically at least four times stronger than ordinary concrete (Graybeal 2011; Graybeal 2013; Ahlborn et al. 2008; Fehling et al. 2004; Naaman et al. 1996). Therefore, it has attracted growing interest worldwide and is being researched for potential implementation in highway bridges and buildings (Abdal et al. 2023; Alawneh et al. 2022; Babarinde et al. 2023; Sun et al. 2020).

Fig. 1 UHPC's primary constituents

This research proposed a conceptual design of the UHPC superstructure intended to match the structural capacity of a steel option while eliminating the concerns about fatigue and brittle fracture failures, minimizing the routine maintenance cost, and enhancing structural durability. To the best of the authors' knowledge, this research is the first attempt to explore a UHPC alternative for railroad overpasses in the United States.

2. System Development

The proposed railroad overpass superstructure consists of prefabricated edge girders, voided deck panels, and minimal cast-in-place joints between the precast members. As a result, it is anticipated that accelerated overpass construction will be allowed and traffic disruption will be minimized. More importantly, the proposed system leverages UHPC's exceptional properties to extend service life. Fig. 2 presents a conceptual illustration of the proposed UHPC railroad overpass superstructure, including the prefabricated edge girders and deck panels and cast-in-place (CIP) joints between adjacent precast members. The primary load-bearing components in the superstructure are the prefabricated UHPC I-girder. The use of an I-section for edge girders allows steel molds to be removed easily during girder production. A full-length edge girder can be installed on abutments for rapid construction. To achieve a weight reduction of the superstructure and save the volume of the UHPC materials, voided deck panels are incorporated to transfer loads to the edge girders. The use of prefabricated panels can minimize the superstructure's depth and result in adequate overhead clearance for traffic beneath railroad overpasses. The individual panels will be installed consecutively along the edge girder length. Short joints (e.g., 6 in.-long) will be poured between adjacent precast members to minimize the on-site concrete volume and accelerate the overpass construction. Transverse post-tensioning will be applied to connect the edge girders and panels after the joints achieve the desirable strength.

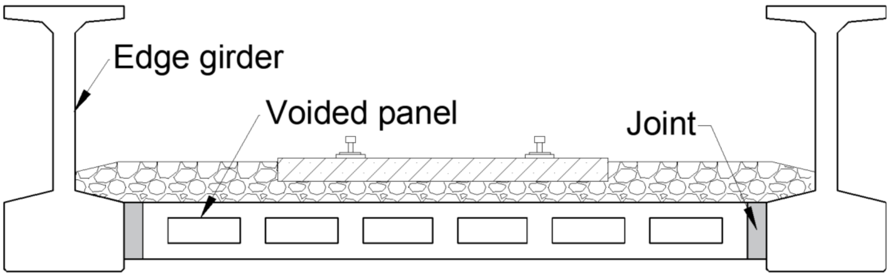

Fig. 2 Superstructure cross section

3. DEMONSTRATION SPECIMEN

A U-shaped assembly was made in the laboratory to demonstrate individual fabrication components and construction steps. This assembly represented one transverse segment of the superstructure. The UHPC assembly included two edge girders and two voided panels (48 in. x 10 in. x 4.5 in.), which were joined together by framing the components and casting in place the joints (Fig. 3). The assembly is 76-in.-long, 26 in.-wide, and 16-in.-deep (Fig. 4). Each panel included three 8 in. x 6 in. x 1 in. voids and all joints are 6 in.-wide. The voids were formed using Styrofoam^{TM} boards that were secured by steel rebar tie wires. The panels and I-beams included projected #4 overlapped bars in the joints. Two layers of #4 bars were provided in the panels and joints, which simulated the reinforcement layout in actual railroad overpass panels. The formwork of the specimens was made with oriented stranded boards and sanded plywood boards, reinforced with 2 ft x 4 ft pieces of lumber, and sealed with painter caulk, which was sufficient for the pouring individual components since UHPC flows seamlessly and self-consolidates. An IMER MIX 750 vertical shaft mixer was used to mix the UHPC.

Fig. 3 Placement of panels and I-girders prior to joint pour

Fig. 4 Demonstration specimen

4. CONCLUSIONS

This paper presents a conceptual design for a UHPC alternative that could potentially compete with dominant steel railroad overpasses. The proposed UHPC system aims to completely resolve issues associated with steel alternatives, such as sudden fatigue failures and frequent maintenance needs. It is anticipated to offer owners a new vision for designing and building railroad bridges, significantly differing from the conventional steel system.

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