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Four high performance nonproprietary concrete deck configurations for movable bridges

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ABSTRACT

Four high performance nonproprietary concrete bridge deck configurations are presented for Louisiana's movable bridges as an alternative to traditional steel grid decks, which have exhibited durability problems. These concrete decks are as light and as deep as the traditional steel grid decks and meet the maximum weight limitation of 0.96 kN/m^2 imposed by the capacity of the mechanical systems that operate the movable bridges. The four concrete deck configurations feature unique nonproprietary concrete mixtures that possess high strength and low unit weight. The development of each concrete mixture is presented. All reinforcement is corrosion resistant and consists of glass fiber reinforced polymer (GFRP) bars and a two-way carbon fiber mesh. Several nonlinear finite element analyses are performed to simulate the behavior of all four concrete deck configurations from the onset of loading to failure and to ensure that the developed deck configurations meet AASHTO's load and deflections requirements. AASHTO's ultimate load demand is met regardless of whether the deck system is made continuous for live loads. Two deck configurations meet AASHTO's deflection requirements when continuity for live loads is established. The failure mode of the concrete deck panels is dominated by shear. The presented deck configurations offer the departments of transportation various feasible options and thus more flexibility for to how to address problems related to the deterioration of steel grid decks using locally available materials, and provide guidance as to what experimental testing to perform in the future.

1. Introduction

Louisiana is one of the states with the highest inventory of movable bridges in the nation featuring approximately 160 movable bridges mostly in the southern part of the state. The majority of the movable bridges in Louisiana are either swing-span or lift-bridge type structures and their deck system features open steel grids with either diagonal or rectangular configurations (Fig. 1). The diagonal grids were first introduced in 1920s and are typically supported by steel stringers at 1.22 m on center [1,2]. Records show that the proximity of steel grid decks to humid environments have led to durability problems, such as steel grid panels becoming loose and causing extreme noise when vehicles cross over them. The generated noise is exacerbated by the trapping of foreign debris throughout the deck grids and has created concerns in the nearby residential communities. Other problems associated with steel grid decks are unpleasant ride quality caused by the panels becoming loose, and possible safety issues caused by a reduction in the skid resistance due to use and deterioration.

The durability problems manifested by the steel grid decks have created a need for alterative deck systems for movable bridges. The states of Florida and Louisiana have explored various deck systems [2–6]. The primary challenge when developing an alternative deck system for movable bridges is that any decking used to replace or rehabilitate the existing steel grid decking should match at least the weight of the existing steel grid such that the mechanical system operates as designed. This cannot be achieved using normal strength concrete because its weight to strength ratio cannot match that offered by steel.

In Florida, the investigated deck systems include a sandwich plate system, an FRP composite deck, an aluminum orthotropic deck, a prismatic concrete deck with FRP tubes, a non-prismatic concrete deck with FRP tubes, a FRP deck, and a waffle slab UHPC deck. The concrete deck systems feature the proprietary concrete mix *Ductal* marketed by Lafarge.

Baghi et al. [3] explain that there are some differences between the characteristics of the steel grid decks used in Florida's movable bridges

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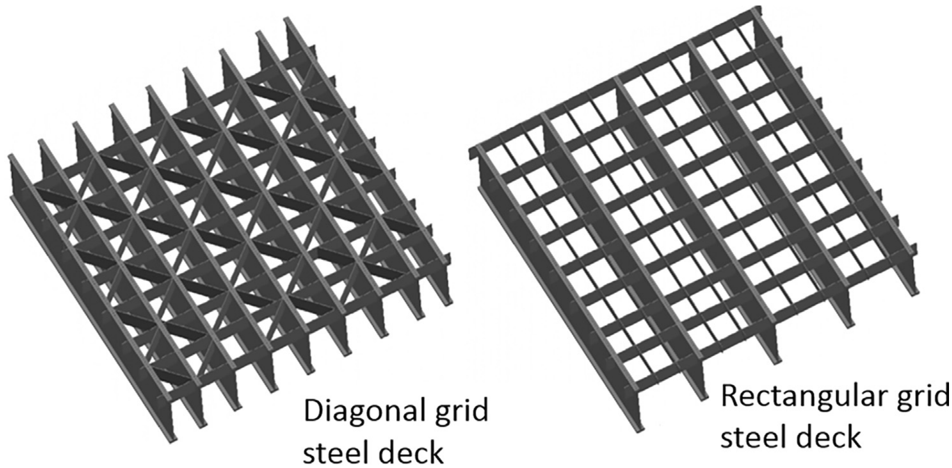

Fig. 1. Typical configuration of steel grid decks for movable bridges.

Table 1
Recommendations for UHPC/HPC deck panels (Baghi et al. [3]).

Recommendations		Reason/comment
Description	Value	
Panel thickness (mm)	132	Consistency with existing grid deck thicknesses
Max. panel weight (kN/m^2)	0.96	Calculated based on stringer reactions
Max. span length (mm)	1270	Covers most of existing steel grid deck spans
Continuity	3+	Min. of three spans or simple span made continuous
Stringer	W410 × 53	Most common stringer

compared to those in Louisiana. The predominant depth of the existing steel grids in Louisiana is 132 mm compared to the 102–127 mm range investigated in Florida. The maximum weight limitation for Louisiana's movable bridge decks is 0.96 kN/m^2 compared to the 1.01 kN/m^2 weight limit for Florida's bascule bridge decks. The majority of movable bridges in Louisiana featured steel grid spans less than or equal to 1.27 m compared to 1.22 m in Florida. At first glance these differences may appear small or negligible taking into the consideration the accuracy typically employed in structural engineering work. However, given the strict limitation on the maximum weight imposed on the mechanical system, such small differences required the development of unique deck configurations for Louisiana's movable bridges. Baghi et al. [3] developed a concrete deck configuration for Louisiana's movable bridges using the proprietary concrete mix *Ductal*, marketed by Lafarge, and fiber reinforced polymer reinforcement. Table 1 provides a summary of the recommendations by Baghi et al. [3] for Louisiana's movable bridges in terms of the panel thickness, maximum panel weight, maximum span length, continuity, and steel stringer sizes. This information was collected from existing bridge drawings for several movable bridges in Louisiana.

The deck system developed by Baghi et al. [3] using *Ductal* featured minimum flange and web dimensions equal to 22 mm. Feedback from precast fabricators indicated some concerns regarding the feasibility of mass producing such deck configurations due to the tight tolerances on maximum deck weight, thin flange and member dimensions, ease of fabrication, material availability, removal of forms and cost of *Ductal* premix. As a result, there was an interest from the Louisiana Department of Transportation to develop alternative deck configurations that feature nonproprietary concrete mixes that can be formulated using locally available materials, simpler geometries that facilitate fabrication and form removal, and thicker flange and web dimensions to allow greater fabrication tolerances.

The goal of this research is to develop four HPC deck systems for Louisiana's movable bridges using nonproprietary concrete mixes. The deck configurations presented in this paper offer the departments of transportation four more options for to how to address problems related to the deterioration of steel grid decks using locally available materials. Additionally, the unique combination of high strength and low unit weight offered by the nonproprietary concrete mixes allow the presented deck configurations to feature thicker flange and web dimensions compared to the *Ductal* configuration developed by Baghi et al. [3]. This allows greater fabrication tolerances and alleviates any concerns that may be associated with the thin flanges featured in the *Ductal* configuration. The development of the four HPC deck systems for movable bridges is achieved by using high fidelity validated finite element analyses and paves the way for future physical testing. The proposed HPC deck systems are intended to provide a continuous driving surface that mimics monolithic construction, provide integral connections with the supporting stringers as well as between adjacent deck panels, and provide traction, which should improve traffic safety. The performance requirements for these deck configurations are: (1) they need to meet the limitations on weight and overall depth for Louisiana's movable bridges, (2) they need to meet load and deflections demands specified in AASHTO [7], and (3) they need to feature corrosion resistant reinforcement.

2. Mix development and material characterization

Four nonproprietary HPC mixes were developed with the purpose of using them in the development of alternative deck panel configurations for Louisiana's movable bridges. The investigation included a material characterization study in terms of compressive strength, tensile strength, modulus of elasticity, Poisson's ratio, flow, and unit weight. The objective was to develop nonproprietary mixes that were similar in composition with generic formulations of UHPC, which has been proven to possess superior performance in terms of durability [8], but also feature low unit weights and high strengths. A low unit weight helps meet the 0.96 kN/m^2 maximum panel weight limit, and high strength helps meet AASHTO's load requirements at ultimate.

The four investigated mixes are called VHPC, LWHPC140, LWHPC130, and LWHPC120. Table 2 provides the mix designs for all four concrete mixes. VHPC stands for very high performance concrete and features a mix that was originally developed by Halbe [9] with the exception that the 25 mm long steel fibers were replaced with 13 mm long and 0.2 mm thick steel fibers. The compressive strength of the VHPC mix at 28 days was expected to be less than 150 MPa, which is the required compressive strength for a mix to be classified as ultra-high