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Development of alternative concrete bridge superstructure systems for short and medium span bridges

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ABSTRACT

Two new concrete bridge superstructure systems for short and medium span bridges are presented. The investigated systems consist of adjacent hollow precast concrete beams with and without concrete topping. The proposed configurations are compared with traditional adjacent box beam and decked bulb tee systems for spans that range from 24.4 m to 45.7 m. It is demonstrated that the proposed system that features concrete topping (PS2) is lighter than the adjacent box beam system, requires fewer strands, provides shallower superstructure depths, and exhibits lower cambers for spans equal to 24.4 m and 30.5 m. PS2 addresses the reflective cracking problems manifested in adjacent box beam systems by shifting the location of the longitudinal connections to the bottom flange and away from traffic loads. The system that features no topping (PS4) is slightly heavier than the decked bulb tee system, but features shallower superstructure depths, requires fewer strands, and exhibits lower live load deflections and camber. Transverse bending moments demand in PS4 are reduced compared to the decked bulb tee system due to the smaller span provided by the two web supports. Live load distribution factors (LLDF) for PS2 and PS4 can be conservatively estimated using AASHTO provisions for adjacent box and decked bulb tee systems, respectively.

1. Introduction

Bridge superstructures with shallow depths are in high demand in sites with stringent vertical clearance requirements. Examples include bridges built over existing highways, or bridges crossing various bodies of water. The adjacent box and decked bulb tee systems are uniquely positioned to provide shallow superstructure depths for spans ranging from 24.4 m to 45.7 m although the decked bulb tee system can span as far as 51.8 m [1]. For spans shorter than 18.3 m the voided slab, multi stem, and double stem systems provide shallower superstructure depths [2,3]. Spans greater than 45.7 m are near the upper bound of the decked bulb tee system [1].

Adjacent box structures are efficient because they utilize the strength and stiffness of several structural components placed adjacent to one another. One salient feature of this bridge system is that they provide a working platform for placing a concrete topping or other types of overlay, which are needed to provide a smooth riding surface. However, adjacent box structure systems have exhibited problems related to reflective cracking, which occurs as a result of the failure of the connection between the adjacent precast members [4]. The female-to-female type shear keys traditionally used in these systems may provide an efficient mechanism in resisting shear forces, but when the keyed joint is subject to transverse bending moments, the only resisting mechanism is primarily the tensile bond between the grout in the shear key and the precast concrete. Transverse post-tensioning helps in resisting transverse bending moments [5] but is an operation that needs to be carried out in the field and works against the concept of accelerating bridge construction.

Huckelbridge et al. [6] conducted several field tests on box girder bridges to investigate the performance of the shear keys and concluded that all bridges tested exhibited relative displacements across at least some of the joints, which indicated a fractured shear key. Miller et al. [7] conducted several full scale tests of shear keys between adjacent box beams and concluded that thermal stresses sometimes caused cracking in the shear keys before any loading was applied. Additionally, details in which the shear key was closer to the neutral axis performed better than those in which the shear key was closer to the top surface.

One of the causes that can lead to reflective cracking is the transverse bending of the bridge when subject to concentrated

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loads such as vehicular loads. El-Remaily et al. [5], Badwan and Liang [8], and Hanna et al. [9] proposed grillage methods of analysis to quantify the amount of post-tensioning needed to address reflective cracking problems due to the transverse bending of the bridge. Additionally, several parametric studies were conducted to investigate the influence of various parameters on the required amount of transverse post-tensioning such as: bridge width, beam depth, span-to-depth ratio and skew angle. As stated earlier, while transverse post-tensioning helps reduce tensile stresses in the shear keys caused by transverse bending of the bridge, it also works against the concept of accelerating bridge construction and requires specialty contractors.

Decked bulb tees are another superstructure system that features adjacent precast members ideal for sites with stringent vertical clearance requirements. The use of this superstructure system accelerates construction by eliminating the need to install a cast-in-place deck because the deck is an integral part of the precast beams. Despite the benefits offered by this bridge system its use has been limited in the United States because of concerns about the performance of the longitudinal joints [10]. Stanton and Mattock [11] and Martin and Osborn [12] reported problems in decked bulb tee systems that featured longitudinal joints capable of transferring shear only. The longitudinal connections in these cases featured either discrete steel plate connections or a partial depth continuous shear keys. Oesterle et al. [13] and French et al. [10] investigated new types of longitudinal connections and demonstrated that full depth doweled connections filled with site cast concrete are capable of emulating monolithic action by transferring both shear and moment across the longitudinal joint. From a stability perspective the decked bulb tee system benefits from the placement of end or intermediate diaphragms such that work related to longitudinal connections can be performed on a more stable platform.

The goal of this project is to develop alternative concrete bridge superstructure systems for short to medium-span bridges, which are lightweight, efficient in flexure and shear and can be used in sites with stringent vertical clearance requirements while being able to accelerate construction by eliminating the need for site installed formwork. Two new bridge systems are investigated. Both systems are intended to provide competitive alternatives to the traditional adjacent box and decked bulb tee system and are therefore compared with them in terms of structural efficiency for spans that range from 24.4 m to 45.7 m. The span range of 24.4 m to 45.7 m was chosen because the adjacent box and decked bulb tee systems are uniquely positioned to provide shallow superstructure depths for this span range. While the proposed systems may be used for spans as low as 60 ft and longer than 150 ft the scope of the work was contained to address span configurations that are most commonly covered by the traditional adjacent box and deck bulb tee systems.

2. Methodology

Two new bridge superstructure systems are proposed for use in short and medium span bridges with spans ranging from 24.4 m to 45.7 m. The investigated systems consist of adjacent hollow precast concrete beams with and without topping. The proposed systems are compared with traditional adjacent box and decked bulb tee systems in terms of span to depth ratios, weight, number of strands, live load deflection and camber. To be consistent in the comparison with traditional systems, live load distribution factors (LLDFs) for all systems are calculated using 3D finite element analysis. These live load distribution systems are then used in the structural design of the bridge superstructure for gravitational loads. The analysis and design of the bridge superstructure is performed based on AASHTO LFRD Specifications [14] using a combination of mathematical and analysis software such as Mathcad [15], Conspan [16] and Abaqus [17]. Flexural stress, flexural strength, shear strength and deflection checks are implemented to ensure that the proposed bridge systems comply with AASHTO LFRD Specifications [14].

For each span length the depth of the superstructure for the traditional systems was chosen using the design aids in the PCI Bridge Design Manual [1]. The superstructure depth for the proposed systems was kept the same so that a comparison could be made in terms of weight, number of strands, live load deflection and camber.

The next step was to determine how much shallower could the superstructure depth be for the traditional systems if LLDFs for moment computed from FEA were used instead of those calculated based on AASHTO LFRD Specifications [14]. This information is useful when determining how big of a benefit does a more accurate computation of live load distribution factors provides in terms of supplying a shallower superstructure depth. Once the shallowest superstructure depth for the traditional systems was obtained, the proposed systems were designed to maintain the same depth and a comparison in terms of weight and the number of strands required was performed.

The final exercise in terms of comparison was to determine whether the proposed systems could supply a shallower superstructure depth compared to the absolute minimum obtained for the traditional systems. The superstructure depth for the proposed systems was made 51 mm shallower than the absolute minimum for the traditional systems and the required number of strands was determined. It was outside the scope of work to determine the absolute minimum superstructure depth for a given span for the proposed systems because the main goal was to demonstrate that the proposed systems are competitive with the traditional systems.

Because the proposed systems feature either discrete or continuous connections along the longitudinal joints, it is important to quantify the forces that these connections will be subject to. As a result, tension forces and bending moments created due to the transverse bending of the bridge were quantified and tabulated so that they can be used in the design of these connections.

3. Description of the proposed bridge systems

Fig. 1 illustrates the transverse cross-sections of the proposed bridge superstructure systems. One system features concrete topping (PS2) and the other features no topping (PS4). The individual precast beams for each system are magnified so that they can be better illustrated.

PS2 features adjacent flanged box precast beams with the larger base at the bottom and addresses the reflective cracking problems manifested in adjacent box beam systems by shifting the location of the longitudinal connections towards the bottom and away from the traffic loads. Such a shift in the location of longitudinal connections is intended to emulate monolithic action without the need for transverse post-tensioning. Additionally, shifting the location of longitudinal connections in the bottom precast flange increases the moment arm between compressive and tensile forces created as a result of transverse bending due to vehicular loads. The cast-in-place topping is supported by 51 mm. thick stay-in-place (SIP) precast concrete forms reinforced with a two-way carbon fiber mesh called C-grid supplied by Chomarat [18]. C-grid is an epoxy coated composite grid made with cross-laid and superimposed carbon fiber [18]. The thickness of the topping is 152 mm. A continuous bearing pad is envisioned for PS2. PS2 provides a rather stable platform during the erection of the beams, installation of longitu-