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The optimum overlay thickness of prefabricated full-depth precast concrete bridge deck panel system – 3D non-linear finite element modeling

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ABSTRACT

Segmental construction of prefabricated full-depth concrete bridge deck systems results in numerous transverse and longitudinal joints as well as shear connector pockets that receive cast-in-place concrete or grout. In such systems, it is necessary to overlay the bridge deck to provide smooth riding surface and to protect the underlying deck reinforcement from the deicing salts-induced corrosion and consequent spalling and delamination of the concrete.

This paper reports on results and findings obtained from a non-linear finite element analysis (NLFEA) of a prototype prefabricated full-depth precast concrete bridge deck panel system before and after being overlaid with various plain and fibrous latex-modified concrete (LMC) and microsilica concrete (MSC) overlays. The NLFEA were validated with experimental results obtained from full-scale testing of the prototype bridge system. The benefits of the NLFEA can be highly appreciated when visualizing the substantial time and cost savings, the ability to change any parameter of interest, and the capability of demonstrating any interesting response at any load value and at any location in the system. The most attractive results were: (1) adequately bonded LMC or MSC overlay significantly improves the stiffness, cracking load, and ultimate strength capacity of the system, (2) AASHTO HS20 truck induced bond stresses were below the bond strength of bonded LMC and MSC overlays, (3) the fibrous overlay has desirable crack arresting characteristic.

1. Introduction

The prefabricated full-depth precast concrete bridge deck system is a very effective and economic design concept for rehabilitation of existing highway bridges as well as for new bridge constructions. The system is typically composed of high performance prefabricated full-dept precast, post-tensioned concrete panels, high strength longitudinal post-tensioning strands and/or bar systems typically run between the precast concrete deck panels through the joints, shear stud connectors aligned inside shear pockets, and transverse joints [1–14]. In stage construction, longitudinal joints along with transverse post-tensioning will be required. The full-depth concrete panels can be either precast or precast/prestressed in the transverse direction depending on the bridge width and/or the type of staged construction involved. Full composite action between the deck and the supporting system (either steel stringers or concrete girders) is achieved by means of shear stud connectors aligned appropriately inside shear pockets. The transverse and longitudinal joints as well as the shear pockets are the only components that receive cast-in-place concrete or grout. In such systems, application of protective overlay is necessary in order to provide smooth riding surface, to protect the underlying concrete deck from deterioration, and more importantly to protect the steel reinforcement and the post-tensioning strand/bar systems from the deicing salts-induced corrosion.

Typically, segmental bridges are designed to last more than 75 years, while the typical target service life of a concrete overlay ranges from 20 to 25 years under the exposure to the application of deicing chemicals and thermal movements as well as fatigue live loading. In terms of cost, time, and effort, replacing the overlay every 20–25 years after becoming contaminated with deicing salts and functionally-obsolete is much more economical than replacing or repairing the bridge deck system. Moreover, the overlay will keep the underlying precast concrete deck system in a high quality condition. Protective overlays that include Latex Modified Concrete

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(LMC), Micro Silica Concrete (MSC), and epoxy overlays are being employed as corrosion protection strategies on bridge decks. The overlay must be free of severe cracking to fulfill its intended functionality. The bond between the overlay and the bridge deck is the key factor that insures such functionality. Once the overlay is debonded, it will be severely cracked and delaminated within a short period of time under the aggressive environmental exposures and fatigue live loadings and impact [10]. Successful application of an overlay can be accomplished through the use of well-proportioned overlay mixtures along with acceptable construction practices in terms of the deck surface preparation, mixing, casting, finishing, and curing. Unfortunately, most of the previous and recent overlay projects were experienced severe deterioration after less than 10 years and in many cases within 1–3 years as a result of poor construction practices and inappropriate mixture design proportioning [15–17]. In order to have a durable overlay-deck system, the overlay must be sufficiently bonded to the base concrete, resistant to cracking, and have low permeability to prevent chloride ion penetration and the associated corrosion of the deck reinforcement.

2. Significance of the study

Protective overlays with high performance and bond characteristics are essential and provide substantial benefits for segmental bridge deck panel systems. NLFEA was carried out to model a prototype full-depth precast concrete deck panel system and to simulate its structural response with and without concrete overlay. The NLFEA results were validated with experimental results and observations obtained from two pioneering projects related to the full-depth system and different plain and fibrous LMC and MSC overlay types. The effectiveness of the NLFEA into considering and demonstrating various parameters of interest in minimal time and cost were enlightened.

3. Brief description

3.1. Prototype bridge components

A full-scale prototype bridge system (Fig. 1) was designed and built by Issa [17] to evaluate its constructability and structural behavior. The prototype bridge system is 5.5 m wide and 25 m long having two equal span lengths of 12.2 m each and composed of 11 prefabricated full-depth precast, post-tensioned concrete panels installed on three W18 × 86 steel stringers. The segmental deck panels were made fully composite with the supporting stringers using shear stud connectors designed according to AASHTO Standard Specifications [18] and AASHTO LRFD Specifications [19] and aligned inside beveled shear pockets; three rows spaced at 610 mm center to center. The precast concrete panels were 5.5 m wide (full width) and 200 mm in depth designed for transverse flexure with conventional mild reinforcement according in accordance with the current AASHTO deck design provisions [18,19] for a slab design with the main reinforcement perpendicular to traffic. The two identical end panels were 1.46 m long, while the nine middle panels were 2.44 m long and have different end configurations due to the post-tensioning requirements and sequence of construction. This arrangement of the panels was designed to avoid location of a transverse joint directly over the central support. The transverse joints between the adjacent panels were of female-to-female type and received non-shrink cementitious grout. Leveling screws were used to adjust the panels over the supporting system to provide a minimum haunch of 25 mm.

The 28-day compressive strength of the panels was 50 MPa. After 60 days, the panels were delivered to be installed on the prototype bridge system. Longitudinal post-tensioning strand and bar systems were used to provide continuity between the panels. The post-tensioning systems were placed at the mid-height of the panels to provide a uniform stress distribution across the depth. The average post-tensioning stress levels at the central support and at 0.4 L (from each span) were about 3.4 MPa and 2.3 MPa, respectively. Detailed information and demonstration figures of the system components, fabrication of the system, the post-tensioning sequence, the transverse joints, the shear pockets and shear stud connectors, and the concrete and grout materials properties are well-documented in several publications [2–10].

The LMC and MSC overlay mixtures were designed with desired workability, 28-day compressive and flexural strength greater than 41 MPa and 4.5 MPa; respectively, drying shrinkage less than 600 $\mu\varepsilon$ at 90 days, low permeability, and adequate hardened air-void system parameters. In comparison, the LMC showed shrinkage and permeability values lower than the MSC. The fibrous LMC and MSC mixtures experienced a post-cracking residual strength of 30% of the modulus of rupture and had lower shrinkage than identical mixtures without fibers. Both types of overlay showed high bond strengths as a result of the excellent surface preparation using water-jet blasting as well as the careful implementation of the right procedures of mixing, placing, finishing, and curing. Detailed information about the mechanical properties and durability aspects of the LMC and MSC overlays can be found in a previously published paper [20].

Fig. 1. Overall view of the full-scale two-span, two-lane, continuous prototype bridge.