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Numerical modeling of the behavior of overlaid slab panels for reinforced concrete bridge decks

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Abstract

This paper presents the results of a comprehensive numerical investigation to assess the effect of some base parameters that govern the performance of overlaid slab panels for rehabilitated bridge decks under monotonic loading. A finite-element study was carried out to investigate the behavior of overlaid reinforced concrete panels and the evaluation of contact between the substrate and the repaired layers. The performance of different configurations of overlaid slabs was evaluated in terms of ultimate load capacity, debonding load, type, amount, and extension of debonding at the interface between the existing and the repaired layers. Based on the results of the investigation, it was found that the type of surface preparation, the mechanical properties of the repaired concrete (compressive and tensile strength), the location and the thickness of the repaired layer have an important influence on the performance of overlaid slab panels under monotonic loading. The results of this study can also be used as a basis for evaluating the performance of overlaid slabs under cyclic loading.

Keywords: Bridge deck; Concrete repair; Thin overlays; Load transfer; Finite-element method

1. Introduction

Everywhere around the world, there is a need for significant investment to repair civil infrastructures, which are deteriorating under heavy use, severe exposure conditions, and age. A large proportion of this infrastructure consists of plain or reinforced concrete pavements and bridge decks. The rehabilitation of this type of surface-deteriorated element can be carried out with the use of overlay techniques. Overlay techniques can also be utilized to upgrade the capacity of the pavement/deck. This technique involves removing only the deteriorated concrete near the surface and replacing it with a thin bonded concrete layer. In order to achieve good substrate-overlay bonding, it is extremely important to understand the origin of normal and shear stresses at the interface and keep them within certain limits.

The interface quality is of major concern, since it ensures strain continuity between the concrete substrate and the repair layer. Bond compatibility can be defined as the development of a satisfactory level of bond between the substrate concrete and a repair material. Bond durability is the maintenance of this bond with time. The performance of any concrete repair is highly dependent on the quality of the bond of the repair material to the substrate concrete [1]. As noted by Delatte et al. [2], an interface bond consists of two components: interlock and adhesion. The effectiveness of interlock is determined by the roughness of the prepared surface. Adhesion is produced by the development of chemical bonds between concrete paste and the cured substrate concrete. Bonding agents, such as Portland cement grout, latex-modified Portland cement grout, and epoxy resins, are sometimes used to improve the bond [3].

The performance of the repair layer can also be enhanced by the use of fiber-reinforced concrete for overlays. The very small crack opening found in steel fiber-reinforced concrete overlays was found to improve the durability of the pavement structure by reducing the ingress of deteriorating substances. A finite-element study was carried out by Granju [4,5] to investigate

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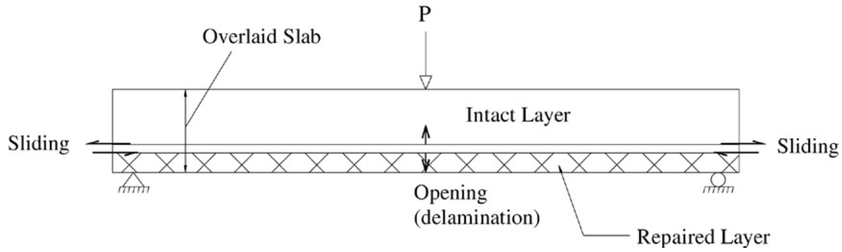

Fig. 1. Two debonding types: sliding and opening at the interface between the intact and repaired layers.

the role of fiber reinforcement on the limitation of debonding for thin overlays. The results of the investigation showed that, in the case of plain concrete overlays (well-developed cracks), the passage of a vehicle induces shear stresses and debonding tensile stresses, which are very detrimental to durability. In the case of fiber-reinforced overlays (limited cracking), the extra stresses are drastically reduced.

Comprehensive studies were carried out by Seible et al. [6, 7] to determine the structural response of a bridge deck in which the interlayer can delaminate and to investigate how the flexural behavior and the interlayer slip behavior interact. The investigations showed that, due to the in-plane stiffness of both the original deck slab and the overlay, relative slip and a change in flexural behavior can occur if large areas of the bridge deck between the point of load application and the support regions delaminate [8].

Designers presently have no quantitative rules for evaluating which of several proposed repair strategies is the most appropriate in a given situation. The main objective of the present study is to investigate the effect of some base parameters that govern the performance of overlaid slabs for bridge deck rehabilitation projects such as: the bonding stresses in horizontal and vertical directions at the interface, the mechanical properties of repaired concrete (compressive and tensile strengths), the thickness of the concrete overlay, the addition of fibers to the concrete mix design, and the location of the repaired layer in tensile or compressive zones. To achieve this objective, finite-element models with different configurations of overlaid slabs are developed. The nonlinear analysis is carried out using the finite-element program ABAQUS [9].

2. Numerical modeling

To investigate the nonlinear interlayer delamination in an overlaid reinforced concrete bridge deck in conjunction with the nonlinear flexural behavior, finite-element models are developed. Overlaid slab panels are modeled with two different types of element: solid elements (C3D8I) which are used to model the intact and repaired layers, and connector elements (CONN3D2) which simulate the contact behavior between the existing concrete and the new concrete. The smeared cracking model in ABAQUS [9] is used to take into consideration the nonlinear behavior of reinforced concrete under monotonic loading. The smeared cracking model has proved to be numerically more efficient compared to the discrete cracking model due to strain localization effects.

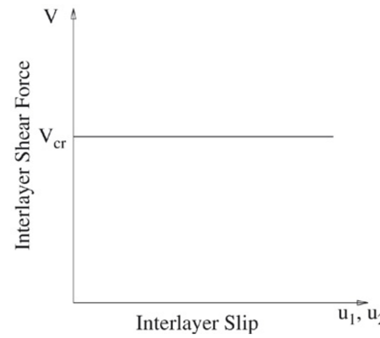

Fig. 2. Shear force versus sliding for the definition of the interlayer behavior in the horizontal directions.

2.1. Debonding types

Two types of failure modes exist at the interface between the repaired and intact layers: these are shear and tensile failures. When the shear stress at the interface exceeds the maximum allowable shear stress, shear failure happens. The result of shear failure is the sliding of two layers relative to each other. Tensile failure occurs when the tensile stress at the interface between the two layers exceeds the maximum allowable tensile strength. This type of failure creates opening (delamination) between the two layers. Fig. 1 illustrates these two failure types at the contact surface.

2.2. Nonlinear contact behavior

Connector elements are used to model the contact behavior between the intact and repaired layers. Based on the type of failure modes, two different connector behaviors are introduced into the model. Connector friction is used to model the horizontal shear resistance at the contact surface. Fig. 2 shows the interlayer behavior in the horizontal direction. Sliding between two layers occurs when the shear force at connectors exceeds the maximum allowable shear force V_{cr}.

The value of V_{cr} is calculated on the basis of the maximum shear stress (CH) at the contact surface. The value of CH depends on the type of surface preparation. For the present case, the results of an experimental study performed by Seible et al. [7] on shear block test specimens are used to determine CH. To take into consideration the vertical tensile (compressive) resistance, elastic connectors (nonlinear springs) are used in the finite-element model (Fig. 3). Since the vertical connector can be under tensile or compressive forces, two different force–deformation curves