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Experimental and numerical study of the structural and cracking behavior of an overlaid slab panel under cyclic flexural loading

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HIGHLIGHTS

- The horizontal cracks progressing along the interface the overlay/the substrate slab.
- The flexural crack significantly impacted the stress field near the overlay interface.
- The finite element modeling revealed the same results on the impact of stress field.
- The perpendicular stress to the interface in the area located near the flexural crack.

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ABSTRACT

This paper presents an investigation on the origin and magnitude of the internal stresses at the interface between an overlay and an underlying reinforced-concrete slab subjected to cyclic flexural loading. Internal stresses were analyzed with finite-element modeling of two configurations of reinforced-concrete slab panels measuring $3.3 \times 1.0 \times 0.2$ m: an intact reference slab and a repaired slab with a 40-mm-thick bonded overlay. The research project included experimental testing to measure the evolution of the structural capacity and the cracking behavior of two slab panels with the same configuration and dimensions. Under laboratory cyclic loading, the overlaid slab panel showed some fine horizontal cracks progressing along the interface between the overlay and the substrate slab. The finite-element modeling revealed that the flexural crack pattern significantly impacted the stress field near the overlay interface. Flexural cracking generated stress perpendicular to the interface (normal) in the area located near the flexural crack. The magnitude of the normal stress at the interface increased with bending moment. This can produce local debonding at the overlay interface located near a flexural crack. Cyclic loading was found to promote this possible interface cracking mechanism resulting from fatigue rupture of the bond between the overlay and substrate.

1. Introduction

Reinforced-concrete structures severely exposed to chlorides and/or freeze–thaw cycles can be damaged by loss of the cover concrete protecting the steel reinforcement [1,2]. Steel corrosion and freeze–thaw degradation resulting in concrete spalling are two main causes of this type of deterioration. In North America, parking-garage and bridge decks are the most common structures needing surface repairs to replace lost cover concrete. In most cases, the deterioration depth of the surface concrete is less than 100 mm, which can be repaired with a thin bonded overlay [3,4]. The technique involves removing only the deteriorated concrete and replacing it with a thin bonded concrete layer. Good overlay performance requires perfect bonding with the substrate and preventing cracking of the overlay concrete.

The overall performance of a bonded overlay depends on a number of parameters, including overlay geometry (thickness), location (intrados, extrados), surface preparation, concrete mixture design, internal reinforcement (fiber, steel bars), and mechanical loading of the overlaid concrete element [5–8]. Laboratory testing and service monitoring of overlaid bridge deck slabs have shown the structural capacity of the repaired structural element can be completely restored while achieving very good repair durability [3,9]. For a thin bonded overlay to achieve its full structural and durability performance, it is essential to prevent cracking at the interface between the overlay and substrate, and to inhibit external cracking due to structural loading and restrained shrinkage.

The loss of bonding at the overlay-substrate interface is generated by internal stresses perpendicular (pullout) and parallel

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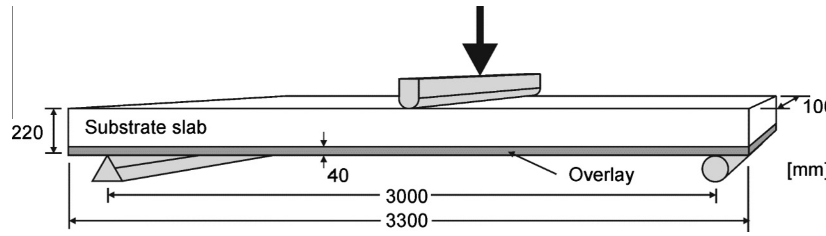

Fig. 1. Point-load flexural test at midspan used for static and cyclic loading.

(sheer) to the interface [6,11,10]. The magnitude of this stresses is influenced by differential shrinkage between the overlay concrete and substrate, and by flexural loading of the overlaid structural element [6,12,13]. In a cracked overlay, the higher interface stress occurs nearby flexural cracks [6]. Cyclic flexural loading increases the risk of interface cracking (loss of bond) due to a possible fatigue rupture of the bond between the overlay and substrate [5,14,11].

Gagné et al. [12] studied the structural behavior of overlaid slab panels subjected to cyclic flexural loading. The flexural tests involved locating the overlay under the slab (Fig. 1) to simulate the stresses generated in an overlay at the top of a concrete deck under negative bending moment. Laboratory cyclic loading tests show that, for some overlay configurations (thickness, concrete type), horizontal cracking occurs where flexural cracks cross the overlay interface plane.

2. Research objective

This research investigated the origin and magnitude of internal stresses generated at the interface between an overlay and concrete substrate of a reinforced concrete slab subjected to flexural loading. The results will help define the basic mechanisms underlying these stresses and will support the development of design guidelines to reduce the risk of overlay debonding under service loads.

Internal stresses were analyzed with finite-element modeling of two configurations of reinforced concrete slab panels measuring $3.3 \times 1.0 \times 0.2$ m: an intact reference slab and a repaired slab with a 40-mm-thick bonded overlay. The nonlinear behavior of reinforced concrete was simulated with the smeared cracking model in ABAQUS 6.10 [15]. The research project also included experimental work to measure the evolution of the structural capacity and the cracking behavior of the two slab panels. These experimental results will be used to validate and complement the results of finite-element modeling.

The slab panels tested in the lab were subjected to flexural loading under static and cyclic modes. Cyclic loading (up to 500,000 cycles at a frequency of 2 Hz) simulates the structural loading of a bridge deck under traffic loads. This type of cyclic loading can promote overlay debonding by fatigue rupture at the interface between the overlay and reinforced concrete substrate [5,14]. Once laboratory cyclic testing ended, the cracks were mapped in detail to locate flexural cracking (perpendicular to the neutral axis) and interface cracking (parallel to the neutral axis). The experimental cracking data was compared with the prediction and results from numerical modeling. The final model was used to analyze internal stresses and to define the main mechanisms that could produce a loss of overlay bond.

3. Experimental program

3.1. Test slabs

The experimental program included two intact reinforced concrete slab panels (REF1 and REF2) and a third slab repaired with a 40-mm-thick overlay (REP). All the slabs were 3300 mm long by 1000 mm wide. Slabs REF1 and REF2 were 200 mm thick; slab REP was 220 mm thick. All the slabs had 15 M bars spaced at 130 mm

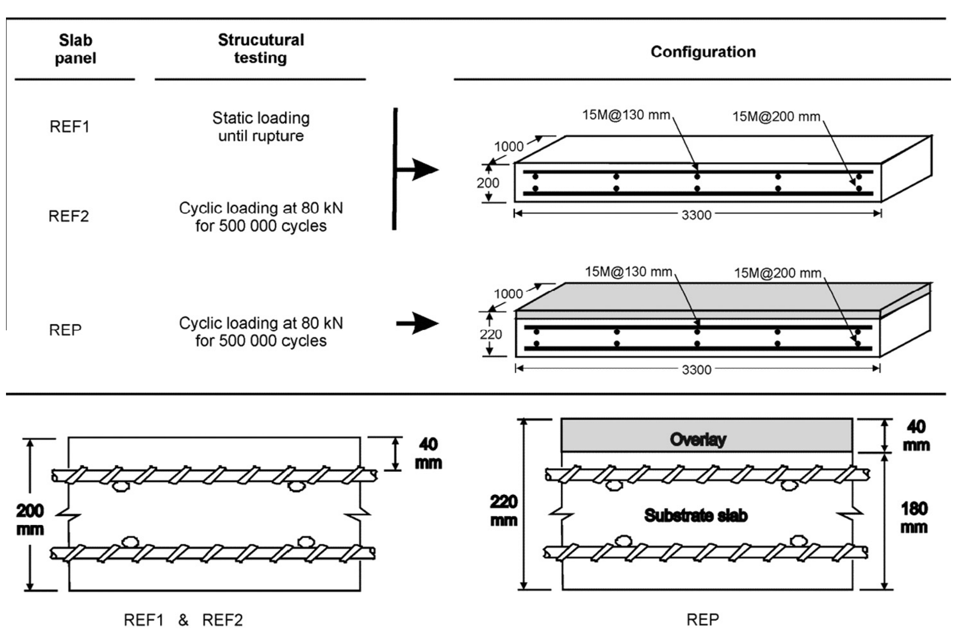

Fig. 2. Overview of the test program and slab configuration.