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Laboratory assessment of nine methods for nondestructive evaluation of concrete bridge decks with overlays

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HIGHLIGHTS

- Systematical assessment of 9 NDE methods was performed with 7 overlay specimens.
- GPR is effective for both bonded and debonded overlays.
- Acoustic methods are effective for bonded overlays except asphalt overlays.

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ABSTRACT

Overlay systems have been extensively used to extend the service life of concrete bridge decks. There is, however, a lack of systematic studies on nondestructive evaluation (NDE) of concrete bridge decks with various overlays. This study assesses nine NDE methods for evaluation of concrete bridge decks with seven different types of overlays through laboratory concrete specimens. The nine NDE methods are sounding, ultrasonic surface waves (USW), impact echo (IE), ultrasonic testing (UT), impulse response (IR), ground-penetrating radar (GPR), electrical resistivity (ER), half-cell potential (HCP), and infrared thermography (IRT). The seven types of overlays are epoxy, latex modified concrete, silica fume modified concrete, polyester polymer, asphalt with a liquid membrane, asphalt with a sheet membrane, and asphalt without a membrane. Eight concrete specimens with various defects were built and nondestructively evaluated to acquire the detailed information of all embedded defects before placing overlays. One concrete specimen was kept bare as a reference, and the other seven specimens were covered with seven different overlays, respectively. Half of each overlay was bonded to the underlying concrete specimens, whereas the other half was debonded. NDE tests were carried out on the top of overlays. Based on the NDE test results, the applicability of each NDE method for concrete bridge decks with overlays is summarized as follows: (1) GPR and HCP are two effective methods for evaluation of the underlying concrete decks through both bonded and debonded overlays; (2) USW, IE, and UT can image the defects in the underlying concrete decks under bonded overlays, with the exception of the three asphalt overlays; (3) sounding, IR, and IRT can identify overlay debonding; and (4) ER is not effective due to electrical insulation of the overlay materials.

1. Introduction

Overlay systems have been used in the United States since 1960 to extend the service life of deteriorated concrete decks and improve rideability. Decks with overlays suffer various deteriorations after years of service. Overlay debonding has been identified as the most common defect [1–3]. But even if the overlay looks intact, the underlying concrete deck may have growing deteriorations (e.g., rebar corrosion and delamination). Thus, it is necessary to identify these deteriorated areas through overlay using nondestructive evaluation (NDE) methods.

Various NDE methods have been employed to assess concrete bridge decks with overlays [1–12]. However, there have been no systematic studies on the applicability of various NDE methods for evaluation of bridge decks with different types of overlays. Sounding has been used to locate debonding for Portland

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cement-based concrete overlays [1,2], but its performance has not been examined for detecting the debonding of the other types of overlays and the delamination in the underlying bridge decks through bonded overlays. Ultrasonic surface waves (USW) method has been used to detect overlay debonding [2] and measure modulus [3,4], but the method's capability for detecting defects in the underlying decks through the bonded overlays has not been evaluated. Although impact echo (IE) can detect overlay debonding [2,5] and delamination in the underlying bridge decks through bonded overlays [6–8], its applicable temperature range for asphalt overlays is still undetermined. Ultrasonic testing (UT) and electrical resistivity (ER) have been commonly used for bare decks [9], but their applicability for bridge decks with different types of overlays has not been studied. Impulse response (IR) has been used to detect debonding for Portland cement-based concrete overlays [2,3,5], but its performance has not been examined for detecting the debonding of the other types of overlays and the delamination in the underlying bridge decks through bonded overlays. Half-cell potential (HCP) has been used to evaluate the protection of latex-modified and silica fume-modified concrete overlays for slowing down rebar active corrosion [1], but its performance for the other overlays has not been investigated. Ground-penetrating radar (GPR) has been used to image delamination in bridge decks with overlays [10,11], but its applicability for mapping corrosive environment in the underlying decks with various overlays has not been studied. Although infrared tomography (IRT) could evaluate the overlay bonding condition [10,12], its applicability for detecting delamination in underlying decks through bonded overlays has not been examined. Thus, many unanswered questions still exist regarding the use of NDE methods for bridge decks with overlays.

To assess the applicability of various NDE methods for evaluation of bridge decks with different types of overlays, this study focuses on validating the applicability of nine commonly used NDE methods for condition assessment of bridge deck specimens with seven types of overlays in laboratory. The nine NDE methods are sounding, USW, IE, UT, IR, GPR, ER, HCP, and IRT. The seven overlays are epoxy, latex modified concrete, silica fume modified concrete, polyester polymer, asphalt with a liquid membrane, asphalt with a sheet membrane, and asphalt without a membrane. Eight identical specimens were built with various artificial defects including delamination at the upper and lower rebar levels, honeycombing, voids, vertical cracks, pre-corroded rebar, active rebar corrosion, and elevated chloride content environment (i.e., corrosive environment). After the concrete specimens cured for 28 days, the eight specimens were first tested with the nine methods to gain the detailed information of all defects before placing overlays. Seven specimens were covered with the seven overlays, respectively, and one concrete specimen was kept bare as a reference. Half of each overlay was bonded to the underlying concrete specimens, whereas the other half was debonded. After the overlays sufficiently cured, sounding, USW, UT, IR, and IRT tests were carried out on the top of the overlays to verify if these five methods could detect delamination, voids, and honeycombing in the underlying decks through the bonded overlays. IE tests with the specimens in a temperature chamber were performed to identify the applicable temperature range for asphalt overlays. GPR and ER tests were carried out to examine their performance in detecting corrosive environment in the underlying decks with different types of overlays. HCP tests were performed to check the method's applicability to detect rebar active corrosion in underlying decks through different types of overlays. All NDE results were summarized to assess the applicability of the nine NDE methods for the seven types of overlays.

2. Specimen construction

Design of the specimens with artificial defects is shown in Fig. 1. To simulate actual concrete bridge decks, the specimens have a dimension of 120″ × 40″ × 8″ (length × width × thickness), use a normal-weight concrete mix with a 28-day compressive strength of 4665 psi from laboratory tests of concrete cylinders, and have two mats of uncoated steel reinforcement with No. 5 bars at a spacing of 8 in. in both longitudinal and transverse directions. Each specimen has eleven artificial defects: two shallow delaminations, two deep delaminations, two honeycombings, two voids, one vertical crack, and two pre-corroded rebar mats in an elevated chloride content environment (Fig. 1).

The appropriate methods for creating these artificial defects in the specimens were referred to the references (e.g., [9,13–15]). Details for creating these defects are briefly summarized as follows. The artificial delamination was built with two layers of plastic gutter guard placed between plexiglass sheets to create an air gap to simulate the split of concrete along a delamination. The artificial honeycombing was simulated by a bag of loose aggregates covered by a thin layer of concrete to reproduce concrete mixtures with a lack of integrity. The artificial void was simulated with a soft styrofoam board with a dimension of 12″ × 8″ × 2″ to approximate the low wave impedance of air. The artificial vertical crack was simulated with corrugated plastic sheets with heights of 2.5″ in the center and 6″ close to the edge to reproduce different depths of open cracks. An accelerated corrosion setup [13,16] was employed to introduce corrosion to intact rebar. After pouring concrete, another accelerated corrosion setup [13,17] was employed to introduce active corrosion to the pre-corroded rebar for HCP tests and an elevated chloride content environment to the surrounding concrete for GPR and ER tests. The rebar cage and formwork with artificial defects before and after casting are shown in Fig. 2. Eight specimens were named as S1 to S8.

Seven of the eight specimens were randomly selected for placing overlays. The specimens and the respective overlays are listed in Table 1. The abbreviations for the specimens with overlays are also listed in Table 1 and used hereinafter.

Epoxy, latex, silica fume, and polyester polymer overlays were placed on the surface of S1, S3, S6, and S8 by a group of experts in the Virginia Transportation Research Council (Fig. 3). These expert had extensive experience with these four overlays in several projects [1,18,19]. For each specimen, one half of the surface was covered by plastic sheets to replicate debonding of the overlays from concrete substrates, and the other half was shot blasted for proper bonding of the overlays. The overlays were placed within 24 h after shot-blasting to minimize the carbonation of the blasted concrete and eventually to ensure good bonding. Epoxy polymer overlay [20] was placed on S1 in two layers. Polyester polymer overlay [21] was placed on S8 with a thickness of 0.75 in. and a 28-day compressive strength of 6,240 psi from concrete cylinder tests. Latex and silica fume modified concrete overlays with a thickness of 1.5 in. were placed on S3 and S6, respectively, with the concrete surface being fully saturated with water before the placing of the overlays. These two overlays had typical mixtures used on concrete bridge decks in Virginia. The 28-day compressive strengths of the latex and the silica fume overlays from concrete cylinder tests were 5490 and 9430 psi, respectively.

Samples of liquid and sheet membranes are shown in Fig. 4a and b, respectively. Liquid membrane [22] was placed on S5 by a contractor from Wellsville, New York. Sheet membrane [23] was placed on S4 by a contractor from Reston, Virginia. Parchment paper that can withstand temperature up to 420 °F was used to create debonding under half of each asphalt overlay. Construction