Steel reinforcement in concrete bridge decks is prone to corrosion caused by chloride ions from deicing materials. Various types of overlays are used to delay or postpone corrosion. Transportation agencies are implementing accelerated bridge construction methods, including half-depth and full-depth precast concrete bridge-deck panels. Bridge decks constructed using the accelerated bridge construction method could undergo installation-induced stresses, which may cause cracking that promotes chloride penetration. The purpose of this research is to compare the performance of three types of overlay systems for precast concrete panels used in bridge decks. These include five separate overlay systems: three thin bonded polymer overlays, one polyester polymer concrete overlay, and one methyl methacrylate overlay. In addition, the research addresses the sequence of applying the overlay on the concrete panels, specifically applying the overlay before or after placement of the precast concrete panels on the bridge girders.

In concrete bridge decks constructed using accelerated bridge construction methods, leakage and chloride penetration could occur at joints between precast concrete bridge-deck panels and at locations where cracking may already have occurred due to lifting and placement. Previous research has been conducted regarding the performance of precast concrete bridge decks, including several overlay systems for precast concrete decks used in accelerated bridge construction.

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systems. The present research focuses on initial cracking due to lifting and placement sequence of the overlay on the precast concrete panels and its effect on the performance of the overlay system.

**Previous research**

Studies have been performed on full-depth precast concrete bridge-deck-panel systems. A field investigation of several bridges using full-depth precast concrete bridge decks in several states showed that these systems had an excellent overall performance record. In some cases, the decks did not perform well due to lack of longitudinal posttensioning across the joint, poor construction procedures and materials, specific panel-to-panel configuration, and type of connection between the deck and girders.

For a bridge-deck-joint system to be considered acceptable, it must meet several requirements:

- limited effect on surrounding traffic flow
- sufficient seismic capacity
- no cracks under repeated service load
- no water leakage from water on the deck
- the ability to transfer live load

To improve the integrity and longevity of joints between deck panels and meet the previous criteria, research has been performed on the use of bridge-deck overlays, specific joint configuration, material used in the joint, and longitudinal posttensioning across the joint.

Initiation of corrosion from chloride diffusion can be delayed for decades by using high-performance concrete with low diffusion coefficients. The use of overlays addresses problems associated with construction procedures and materials to delay chloride intrusion from deicing salts that lead to steel corrosion in the concrete deck. Overlays create a protective barrier and a smooth riding surface. The majority of research on overlays has been performed for cast-in-place concrete bridge decks. Overlay systems are required to have a long-term stable bond, sufficient wear resistance, sufficient resistance to freezing and thawing, and protection of the reinforcement from chloride intrusion to attain a sufficient service life.

Different topical protection systems for bridge decks and the associated life-cycle cost have been evaluated. Core samples were taken from five existing bridge decks and tested for chloride concentrations. All bridge decks tested had no corrosion, with chloride concentration at the reinforcing bar much lower than the critical level. The difference in the effectiveness of topical protection systems was not significant; in addition, inspection results could not be directly used to evaluate topical protection methods for later stages of corrosion. Decks with a waterproofing membrane had a longer service life than bare decks.

One method of postponing chloride penetration to the reinforcing steel is hydrophobic treatment of the concrete to further reduce its permeability. Laboratory research on chloride intrusion of concrete with hydrophobic treatment has been performed. The specimens underwent a year of cyclic chloride testing with one 24-hour period of ponding with a 10% sodium chloride solution (by mass) and six days of dry exposure at 20°C and 50% relative humidity. Hydrophobic treatment of concrete strongly reduces the penetration of chloride under deicing salt and drying cycles.

The Illinois Department of Transportation (DOT) evaluated two thin-lift polymer bridge-deck overlays on two adjacent bridges. Half-cell potential tests were performed prior to overlay placement, and pull-off tests were conducted on test patches prior to full use of the overlay systems. Performance evaluation of the systems concluded that “polymer overlay systems had the potential to provide an impermeable and durable surface with high skid resistance for 15 or more years.”

The New Hampshire DOT performed field research on two thin-overlay bridge-deck systems. The two overlay systems were applied on the precast concrete full-depth bridge decks that had replaced the original decks. One overlay system was inspected 25 months after placement, and the second was inspected 34 months after placement. One system showed cracks and snowplow damage at the expansion joints but had not suffered significant deterioration; the other system had significant bond loss between the overlay and the deck, with large areas of the overlay missing.

**Overview of experimental investigation**

The focus of the present research is to evaluate the ability of various overlay systems to improve the integrity of joints between precast concrete bridge-deck panels under static deflection, under cyclic loading, and after 90 days of ponding with a 3% sodium chloride solution by mass. Three overlay types were tested with a total of five different systems: a thin polymer overlay (three different systems), a methyl methacrylate overlay system, and a polyester polymer concrete overlay system (Fig. 1).

In this research, concrete panels were built and subjected to cyclic loads to evaluate the pull-off strength of several overlays; additional concrete blocks were built to evaluate chloride penetration of the overlays. Two criteria are used to compare the five overlay systems: bond strength...
Figure 1. Overlay systems. Note: 1 in. = 25.4 mm.
Laboratory concrete specimens

A total of ten specimens were constructed, five per type I and five per type II. Type I and type II specimens consisted of two 8 ft × 1 ft 6 in. (2.4 × 0.46 m) precast concrete panels (Fig. 2) grouted together across the transverse joint to construct an 8 ft × 3 ft 1 in. (2.4 × 0.94 m) specimen. The additional 1 in. (25 mm) was the thickness of the grout for the shear key. The panels for type I and II specimens were reinforced with no. 6 (19M) grade 60 (420 MPa) steel bars. The laboratory specimen surface preparation was sandblasting of the top surface and subsequent removal of the film layer.

In addition, 18 × 18 in. (0.46 × 0.46 × 0.15 m) type III concrete blocks were built for ponding tests (Table 1). The 28-day concrete compressive strength of the concrete panels and blocks was obtained from standard compression tests as 11,000 psi (76 MPa).

The Utah DOT requires posttensioning of all bridge decks constructed with precast concrete panels. Before the cyclic test loading was applied, the specimens were posttensioned with two ⅜ in. (10 mm) carbon-fiber-reinforced-polymer (CFRP) rods with a tensile strength and modulus of 27.5 kip (122 kN) and 22,500 ksi (155 GPa), respectively, and 1.2% elongation at break. CFRP rods were used to assess their constructibility and the potential of their use in posttensioning bridge decks. The CFRP rods were anchored with a device developed at the University of Utah. Posttensioning was applied with a four-bolt plated anchoring system to generate tensile strains in the CFRP rods. Posttensioning forces were determined through recorded readings from strain gauges on the CFRP rods.

Table 1 provides the test matrix for the laboratory tests. Five overlay systems were used: TP1, TP2, and TP3 were thin polymer overlay systems from three different manufacturers, MM1 was a methyl methacrylate overlay system, and PC1 was a polyester polymer concrete overlay system. Each overlay underwent testing protocols for type I and II panels and type III blocks. A plain concrete type III block with no overlay underwent chloride penetration testing as a control specimen for baseline comparison.

<table>
<thead>
<tr>
<th>Specimen type</th>
<th>Specimen size</th>
<th>Test</th>
<th>Overlay</th>
<th>Specimen name</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>3 ft 1 in. × 8 ft composite specimen</td>
<td>Bond chloride intrusion</td>
<td>Thin polymer</td>
<td>TP1-I, TP2-I, TP3-I</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Methyl methacrylate</td>
<td>MM-I</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Polyester polymer concrete</td>
<td>PC-I</td>
</tr>
<tr>
<td>II</td>
<td>3 ft 1 in. × 8 ft composite specimen</td>
<td>Bond chloride intrusion</td>
<td>Thin polymer</td>
<td>TP1-II, TP2-II, TP3-II</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Methyl methacrylate</td>
<td>MM-II</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Polyester polymer concrete</td>
<td>PC-II</td>
</tr>
<tr>
<td>III</td>
<td>1 ft 6 in. × 1 ft 6 in.</td>
<td>Chloride intrusion</td>
<td>Thin polymer</td>
<td>TP1-III, TP2-III, TP3-III</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Methyl methacrylate</td>
<td>MM-III</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Polyester polymer concrete</td>
<td>PC-III</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>No overlay</td>
<td>BASE</td>
</tr>
</tbody>
</table>

Notes: 1 in. = 25.4 mm; 1 ft = 0.305 m.
The induced strain from posttensioning was from 2500 to 3000 με, which correlates to a stress of approximately 23% of the rod design tensile capacity. This posttensioning corresponds to a force of 6.2 kip (28 kN) for each rod and a compressive stress of approximately 15 psi (100 kPa) in the panel, which is less than the specified stress of 200 psi (1380 kPa). This posttensioning was present during cyclic test loading and was removed prior to the ponding tests.

The posttensioning stress used in the tests was significantly lower than that used in construction so that initial hairline cracks would occur.

**Type I: Application of overlay system after lifting and placement of precast concrete panels**

Type I specimens followed the application procedure used in bridge construction. To construct the type I specimens, two single 1 ft 6 in. × 8 ft (0.46 × 2.4 m) concrete panels were turned upside down and deflected using a hydraulic actuator to induce hairline cracks. This simulates the formation of cracking during lifting and placement. The two single panels were then turned over and were grouted and posttensioned together to construct an 8 ft × 3 ft 1 in. (2.4 × 0.94 m) specimen. The deck overlay system was subsequently applied per manufacturer’s specifications on the top face of the specimen where initial hairline cracks had formed. Thus, for type I specimens the hairline cracks were created before placement of the overlay.
The specimens underwent the cyclic test loading protocol described in Table 2. The loads were applied to one side of the grouted connection (Fig. 3). After each day of the five-day cyclic test loading, two pull-off tests were performed adjacent to the grouted joint of the type I specimens. After the five-day cyclic test loading, the posttensioning was removed and an accelerated ponding test was performed over the grouted transverse joint to evaluate chloride penetration at the transverse joint. The accelerated ponding test consisted of ponding a 3% sodium chloride solution by mass to an average depth of 1/2 in. (13 mm) in a 11 × 11 in. (280 × 280 mm) section for 90 days over the transverse joint. An acrylic wall was installed around each section, and a 3% sodium chloride solution by mass was placed on the designated section to an average depth of 1/2 in. (13 mm) for 90 days. A 3% sodium chloride solution was used based on the requirements for the accelerated chloride ponding test AASHTO T259-02-UL. After completion of ponding, the solution was removed and the overlay (if present) was ground off the concrete. Concrete samples below the ponded section were taken and checked for chloride content per ASTM C1218-99 (2008). The bond strength and percentage of chloride penetration were used to compare the five overlay systems.

Type II: Application of overlay system prior to lifting and placement of precast concrete deck panels

Type II specimens follow the proposed application procedure for precast concrete bridge deck construction where the precast concrete panels have the overlay applied prior to placement of the panels on the bridge. After placement and grouting of the transverse joint, an overlay splice is applied over the transverse joint. Prior to grouting of the type II specimens, the overlay was applied to the top of the single 8 ft × 1 ft 6 in. (2.4 × 0.46 m) concrete panels, per the manufacturer’s specifications. The two panels were then turned upside down and deflected using a hydraulic actuator to induce initial hairline cracks. This simulates the formation of cracking during lifting and placement. Thus, in the case of the type II specimens, the hairline cracks were created after placement of the overlay. The two single panels were then turned over and grouted together at the transverse joint. An overlay splice with a maximum 6 in. (150 mm) overlay onto the panel was then applied across the transverse joint, and posttensioning was applied for the same five-day cyclic test loading used for the type I specimens. The grouted precast concrete specimen then underwent the same cyclic, ponding, and chemical tests as type I specimens.

Type III: Small sample chemical test

The 18 × 18 × 6 in. (0.46 × 0.46 × 0.15 m) type III blocks with and without overlays were subjected to a chemical test. An 11 × 11 in. (0.28 × 0.28 m) section of each specimen was used for the ponding test. An acrylic dike was installed around each section, and a 3% sodium chloride solution by mass was placed on the designated section to an average depth of 1/2 in. (13 mm) for 90 days. A 3% sodium chloride solution was used based on the requirements for the accelerated chloride ponding test AASHTO T259-02-UL. After completion of ponding, the solution was removed and the overlay (if present) was ground off the concrete. Concrete samples below the ponded section were taken and checked for chloride content per ASTM C1218-99 (2008). The bond strength and percentage of chloride penetration were used to compare the five overlay systems.
A (50 mm) diameter steel disk was attached to the top of the specimen with an epoxy adhesive. After curing, the tensile load was applied. Test results were evaluated based on the pull-off pressure and on whether failure occurred in the concrete, in the bond between the overlay and the concrete, or in the overlay. Figure 5 shows the tensile device used in the pull-off tests.

All chloride tests were performed per ASTM C1218-99 (2008). Four samples were taken per hole at depth increments of 0.125 in. (3 mm) for a total depth of 0.5 in. (13 mm). A titration test was performed on each sample to determine the percentage of chlorides per unit mass. The percentage of chloride for each sample is determined from Eq. (1):

$$\text{Cl}\% = \frac{3.545(V_1 - V_2)N - 0.10}{w}$$

where:

- \(V_1\) = volume of silver nitrate (AgNO₃) solution, mL
- \(V_2\) = volume of silver nitrate of the blank solution (deionized water)
- \(N\) = normality of the silver nitrate titration solution
- \(w\) = mass of the sample, g

**Evaluation of experimental results**

Hairline cracks on the underside of the specimens were detected after cyclic loading. These cracks were spaced approximately 8 in. (200 mm) apart over the entire width of the specimens. The cyclic displacements were applied to simulate typical in-service damage before the pull-off and chloride tests.

**Pull-off tests**

Pull-off tests were performed using a tensile loading device (Fig. 5), and the failure mode was recorded. Two different failure modes occurred: overlay failure and concrete failure. Overlay failure corresponds to failure within the overlay or failure of the bond between overlay and concrete. Concrete failure corresponds to the tensile capacity of the concrete and is considered preferable because it indicates that the bond strength is higher than the concrete tensile capacity. Figure 6 shows a typical pull-off test as well as the concrete and the overlay failures. Failure in the concrete is the only failure mode acceptable to the Utah DOT.

**Figure 5.** Tensile loading device for pull-off tests.

Table 3 shows a comparison of the average pull-off values for the various overlay materials from type I and type II
chloride-penetration results with type I and type II specimens, which had undergone cyclic displacements. Type I and type II specimens and type III blocks with overlays had no measurable chloride content in the concrete under the overlay regardless of the overlay material. For type III blocks without any overlay, ponding results showed an average chloride content of 2.96 lb/yd$^3$ (1.76 kg/m$^3$) in the first $\frac{1}{8}$ in. (3 mm) below the concrete surface and an average chloride content of 2.51 lb/yd$^3$ (1.49 kg/m$^3$) at a depth from $\frac{1}{8}$ in. to $\frac{1}{4}$ in. (6 mm) for the same specimens.

**Summary**

Two methods of application of different overlay systems on precast concrete panels were investigated: application of the overlay after installation of the precast concrete deck panels on the bridge and application of the overlay before installation of the precast concrete deck panels on the bridge. In the tests, the panels were cracked before the overlay application in the case after installation and panels were cracked after the overlay application in the case before installation. Two properties were tested and compared to determine the performance of five different overlay materials. Pull-off tests were used to compare the mechanical characteristics of the overlay, specifically the bond between overlay and concrete. Ponding tests were also conducted to compare the ability of the overlay to resist chloride intrusion from deicing salts.

**Table 3. Average pull-off stress test results**

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Type</th>
<th>Average pull-off stress, psi</th>
<th>Concrete failure, %</th>
<th>Number of tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP1</td>
<td>I</td>
<td>580</td>
<td>100</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>517</td>
<td>100</td>
<td>6</td>
</tr>
<tr>
<td>TP2</td>
<td>I</td>
<td>621</td>
<td>100</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>444</td>
<td>67</td>
<td>9</td>
</tr>
<tr>
<td>TP3</td>
<td>I</td>
<td>673</td>
<td>83</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>530</td>
<td>75</td>
<td>7</td>
</tr>
<tr>
<td>MM1</td>
<td>I</td>
<td>477</td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>330</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>PC1</td>
<td>I</td>
<td>572</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>521</td>
<td>33</td>
<td>6</td>
</tr>
</tbody>
</table>

Note: 1 psi = 6.895 kPa.

**Figure 6. Failure of pull-off tests.**

**Chloride tests**

Chloride tests were performed after 90 days of ponding for type I and type II specimens and type III blocks. Type III blocks with overlays served as controls to compare the chloride-penetration results with type I and type II specimens, which had undergone cyclic displacements. Type I specimens had slightly higher tensile capacity than the type II specimens for all overlay materials. The thin polymer and methyl methacrylate overlays had higher percentages of concrete failure for the type I than the type II specimens. The reason is that the pull-off tests for the type II specimens, which were conducted along the overlay splice (Fig. 7), had an additional boundary between the two overlays at the splice region.

**Figure 7. Pull-off-test locations for type II specimens along overlay splice.**
### Conclusion

The following conclusions can be drawn from this research:

- In pull-off tests for thin polymer overlays, the majority of failures occurred in the concrete, which is the desired failure mode. This proves that the thin polymer overlay and the bond between the overlay and concrete deck panel had a higher capacity than the tensile strength of the concrete.

- In pull-off tests for the methyl methacrylate overlay and polyester polymer concrete overlay systems, the majority of failures occurred in the overlay. This indicates that the overlay and the bond strength between the overlay and concrete deck panel had a lower capacity than the tensile strength of the concrete.

- In all tests, the average pull-off strength ranged from 330 to 673 psi (2300 to 4600 kPa), which is higher than the required Utah DOT minimum of 200 psi (1380 kPa). This shows that although in some cases bond failure did not occur in the desired failure plane, the minimum bond tensile strength was still achieved.

- Bond strength for all overlay systems tested was higher for type I (overlay application after lifting and placement of the precast concrete deck panels on the entire bridge) compared with type II panels (overlay application prior to lifting and placement of the precast concrete deck panels on the bridge). However, both type I and type II panels satisfied the requirements of 200 psi (1380 kPa) pull-off strength, which indicates that application of overlays prior to panel placement is a plausible application method.

- There was a small but consistent difference in the performance of the laboratory-tested overlay systems when the overlay was applied before or after the simulated placement of the precast concrete deck panels. Both methods satisfy the Utah DOT minimum required bond tensile strength; however, construction time can potentially be shortened if the overlay is applied before the precast concrete panels are placed.

- Results for all overlays showed no measurable chloride concentration in the concrete beneath the overlays. Control specimens with no overlays had an average chloride content of 2.96 lb/yd³ (1.76 kg/m³) for the first ⅛ in. (3 mm) below the concrete surface and 2.51 lb/yd³ (1.49 kg/m³) for a depth from ⅛ to ¼ in. (3 to 6 mm). This indicates that all overlays were sufficient to prevent chloride intrusion during the test period.

### Acknowledgments

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### References


**Notation**

- $N$ = normality of the silver nitrate titration solution
- $V_1$ = volume of silver nitrate (AgNO$_3$) solution, mL
- $V_2$ = volume of silver nitrate of the blank solution (deionized water)
- $w$ = mass of the sample, g
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Abstract

In accelerated bridge construction, bridge decks are constructed using precast concrete elements ranging from half-depth or full-depth precast concrete panels to decks constructed on entire bridge superstructures moved with self-propelled modular transporters or slide-in bridges. The ability of different bridge-deck-overlay materials to protect the concrete against intrusion of chloride ions is investigated. Two panel configurations were tested considering accelerated bridge construction methods: application of the overlay before movement of the bridge-deck panels and application of the overlay after movement of the bridge-deck panels. Three types of bridge-deck-overlay materials were investigated: thin bonded polymer, polyester polymer concrete, and methyl methacrylate. Criteria used to evaluate the three types of overlay materials included bond strength between the overlay and precast concrete bridge-deck panels and chloride penetration into the deck panels. Although the overlays had slightly different bond performance, they offered similar protection against chlorides. There was no significant difference between the performance of the overlays applied prior to placement of the precast concrete deck panels and that of overlay systems applied after the placement of the precast concrete deck panels.

Keywords

Bond, bridge, carbon-fiber-reinforced polymer, CFRP, chlorides, corrosion, deck, overlay, posttensioning.

Review policy

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