Polymer-Concrete Bridge Deck Overlays

MICHAEL E. DOODY AND RICK MORGAN

The results of a survey of polymer-concrete bridge deck installations (test patch and overlay) in New York and the results of a canvassing of the experiences of other states with these overlays are summarized. In New York two types of polymer overlay materials—thin epoxies and a thicker polyester—are used, with one thin epoxy used in New York State Department of Transportation Region 1 (Albany), two polyesters used in Region 10 (Long Island), and two thin epoxies used in Region 11 (New York City). In inspections during the summer of 1991 the conditions and performances of most of these overlays were found to be satisfactory.

Polymer-concrete (PC) overlays are an alternative bridge deck treatment that can be used to correct or prevent the corrosion of reinforcing steel. The objective of the study reported here was to document their performances to date in New York and other states. This paper describes the conditions of the PC overlays used in rehabilitating bridge decks in New York after various periods of service and summarizes the results of an informal survey of the experiences of other states with such overlay materials.

BACKGROUND

Bridge deck deterioration due to reinforcement steel corrosion caused by chloride infiltration continues to be a major problem for most state highway agencies. The methods currently used by New York to protect the existing steel in rehabilitation work include overlays with low-slump, silica fume, and latex-modified concrete and coating of the reinforcing steel with epoxy for new deck construction. The limitations of concrete overlays include their use in (a) situations in which the existing structure cannot adequately support the additional dead load of a concrete overlay, (b) instances in which reduced clearance cannot be tolerated, and (c) urban areas where rapid construction is essential because of heavy traffic, excessive costs for traffic control, or both.

PC overlays overcome many limitations of other types of overlay materials because of their high early compressive strength and excellent bond strength (*1,2*). These overlays are used on bridges with dead load or vertical clearance restrictions. Most interest is in urban areas because of the quick-curing, high-early-strength characteristics of PC overlays, which result in shorter times for detouring traffic and lane closures, which are extremely costly. Also attractive are their lighter weight, their flexibility, and their ability to restore skid resistance to polished decks (*3*). Thin overlays [up to 125 mm (0.5 in.)] have an additional advantage, in that modification of expansion joints or building up the approaches can be dispensed with, which can result in significant cost savings (*4*).

PC consists of a resin binder and an aggregate filler. Initially polyesters and epoxies are polymers in which the initial polymerization of the liquids is terminated at some point while they are still in the liquid phase. After the addition of an initiator they become a solid through a chemical reaction called *polymerization*. Methylmethacrylates (MMAs) are monomers that are polymerized by adding promoters and initiators. The rate of polymerization or cure depends on many factors, including temperature, humidity, and chemical additives.

Engineering Research and Development Bureau, New York State Department of Transportation, Albany, N.Y. 12232.

There are two types of PC overlays: epoxy PC and polyester PC. Epoxy PC overlays can be MMA or epoxy concrete. Epoxy and MMA overlays have been used on bridges at thicknesses of from 6.5 to 40 mm (0.25 to 1.5 in.), and polyesters have been used on bridges at thicknesses of from 6.5 to 80 mm (0.25 to 3 in.) or more. The PC types used in New York State have included both thin epoxy and thick polyester. One of three methods of construction is typically used:

1. *Multiple layer*, which consists of two or more layers of polymer binder and gap-graded, clean, dry angular broadcast aggregate.
2. *Slurry*, which is a polymer aggregate slurry struck off with gauge rakes and covered with broadcast aggregate.
3. *Premixed*, which is a PC mixture consolidated and struck off with a vibratory screed.

Although the first two methods have been used, New York now prefers a premixed automated application.

MATERIALS

Early Work

New York has tried various PC types in overlays since 1961 (*5–8*). A wide variety have been used, with most containing epoxies or polyesters. Also tried were a few applications of polyurethanes, latexes, neoprenes, and silicone rubbers. Periodic inspections of early installations determined that surface overlays developed appreciable distress within 2 to 3 years after application. Thin overlays could not withstand exposure to the damaging effects of traffic and weather (*5*). A new generation of products was introduced in the late 1970s, but overlays once again exhibited distress in the form of debonding and cracking within 2 to 3 years of application (*6*).

Test Patch Program

Further refinements from 1980 to 1984 resulted in the highly flexible epoxies and MMAs now being used. As manufacturers continued to improve their products, New York has continued to be a site of PC testing. Three test patches were installed on the lower roadway of the Queensboro Bridge in May 1980 (Duracryl and Flexolith by Dural International Corp. and Silikal R7 by Transpo Materials). In September and October 1983 a test section [2800 m^2 (30,000 ft^2) of Flexolith] was placed on the Brooklyn Bridge, and test patches (Silikal Urethane Modified Acrylic Overlay by Silikal North America, Dural 317 and Flexolith by Dural International, Concresive 2020/2042 by Adhesive Engineering, T17XA by Transpo Industries, and Flexogrid by Roadway Safety Service/ Polycarb) were placed on the lower roadway of the Manhattan Bridge. In August 1985 five test patches (Transpo T17X, Dural Flexolith, Dural Coal Tar Epoxy, Dural Methyl Methacrylate, and Polycarb Flexogrid) were installed on the westbound I-90 bridge over I-787 in Albany.

The St. Lawrence Seaway Authority has a program to evaluate test patches on the Cornwall Bridge and Thousand Island Bridges over the St. Lawrence River between New York and Ontario, Canada. The products installed on the Cornwall Bridge in August and September 1991 included Nitobond (Fosroc), FX781 (Fox Industries), Sternflex, Transpo T-38 and T-48, Degadur 330, Sikadur 81-32, Flexolith, Flexogrid, and Bridge Master. Those installed on the Thousand Island Bridges included Sikadur, Flexolith, and Transpo T-45 and T-48 in September 1992, with Flexogrid, Degadur, and Bridge Master scheduled for installation in May 1993.

As these new products were developed and laboratory testing proceeded (*3,9–18*), experimental overlays were installed to relate test results to field performance. Two types of PC bridge deck overlays are now in place in New York: (a) thin PC, which uses either epoxy or MMA as a binder and which is placed in a thin layer [6.5 to 13 mm (0.25 to 0.5 in.)], and (b) blended polyester in an overlay 20 to 40 mm (0.75 to 1.5 in.) thick.

Polyester Overlays

Two overlay sites in Suffolk County on Long Island used polyester resin with basalt aggregate. An overlay consisting of 145 m^2 (15,500 ft^2) was placed on Yaphank Avenue (BIN 1064160) over the Long Island Expressway in 1982. In 1983 1125 m^2 (12,100 ft^2) was placed in another overlay near Yaphank, on east Main Street (BIN 1064180) over the Long Island Expressway. Seven additional polyester overlays of various designs are in Suffolk County near the Robert Moses Causeway (Deer Park Avenue over the Sunrise Highway, Higbie Lane over the Sunrise Highway, the Sunrise Highway over Howells Road, Fifth Avenue over the Sunrise Highway, Brook Avenue over the Sunrise Highway, and Brentwood Road over the Sunrise Highway). After the premature failure of the Brook Avenue overlay, the others were overlaid and the project was discontinued. Sealing of the decks was this project's primary objective.

Thin Epoxy Overlays

On the basis of the successful results of the thin overlay test patch program, 8305 m^2 (89,388 ft^2) of Flexolith was placed on the south upper roadway of the Queensboro Bridge under Contract D250039, with work starting in October 1984. A small area near the Manhattan anchor pier was completed in June 1985, and the bridge opened to traffic that July (*7*). In July 1985 work began on the suspended-span Manhattan-bound and Brooklyn-bound roadways of the Brooklyn Bridge. Under Contract D251251, 17 050 m^2 (183,500 ft^2) of Flexolith was placed (*8*). In July 1988, 8315 m^2 (89,500 ft^2) of Flexolith was installed on the north upper roadway of the Queensboro Bridge under Contract D500191. In October 1990 5325 m^2 (57,342 ft^2) of Transpo T17X was to be placed on the Crown Point Bridge to Vermont under Contract D253114; this work was only partially completed, with the remainder installed in September 1991. In July 1991 1215 m^2 (13,077 ft^2) of Flexolith was placed on the West 207th Street Bridge over the Harlem River (the University Heights Bridge) under Contract D500777. Polymer systems currently on the New York State Department of Transportation Materials Bureau's Approved List are manufactured by Dural (Flexolith), Transpo (T17X), and Silikal (urethane-modified acrylic overlay). All are thin overlay materials.

INVESTIGATIVE PROCEDURES

Survey of Other States

An electronic mail (e-mail) survey was conducted to determine other states' experiences with these products.

Adhesion Testing

Overlay bonding to an existing concrete surface (substrate) is an extremely important consideration in placing any overlay, because any bond deficiencies may lead to later delamination or punchout of the overlay. To test this tensile bond of the epoxy overlays, equipment was built to specifications established by the American Concrete Institute (*9*). The apparatus used for this surface adhesion test is shown in Figure 1. Tests involved partial-depth coring through the overlay into the existing slab. After cleaning and drying the overlay surface, steel plugs were epoxied to the surface of the partial-depth core. A reaction frame and calibrated load cell measured the direct force to pull the overlay from the existing substrate.

Distress Survey

The PC overlays in place in New York were visually inspected by two project engineers in August and September 1991. Overlay condition was classified as (a) good, (b) peeled because of a poor bond, (c) cracked or worn, or (d) patched. Estimates of the surface area of each type of distress were mutually agreed upon by the two engineers. No chain drag or other means were used to determine delaminated areas. Each type of overlay distress is shown in Figure 2.

RESULTS AND DISCUSSION OF RESULTS

Survey of Other States

Several different PCs have been used in various parts of the country on projects involving several types of polymers with various properties and methods of application (*16,17*). An informal survey to evaluate their experiences produced responses from 25 agencies (60 percent) that varied in form (fax, phone, e-mail, reports, specifications), as summarized in Table 1. Of the respondents, only 4

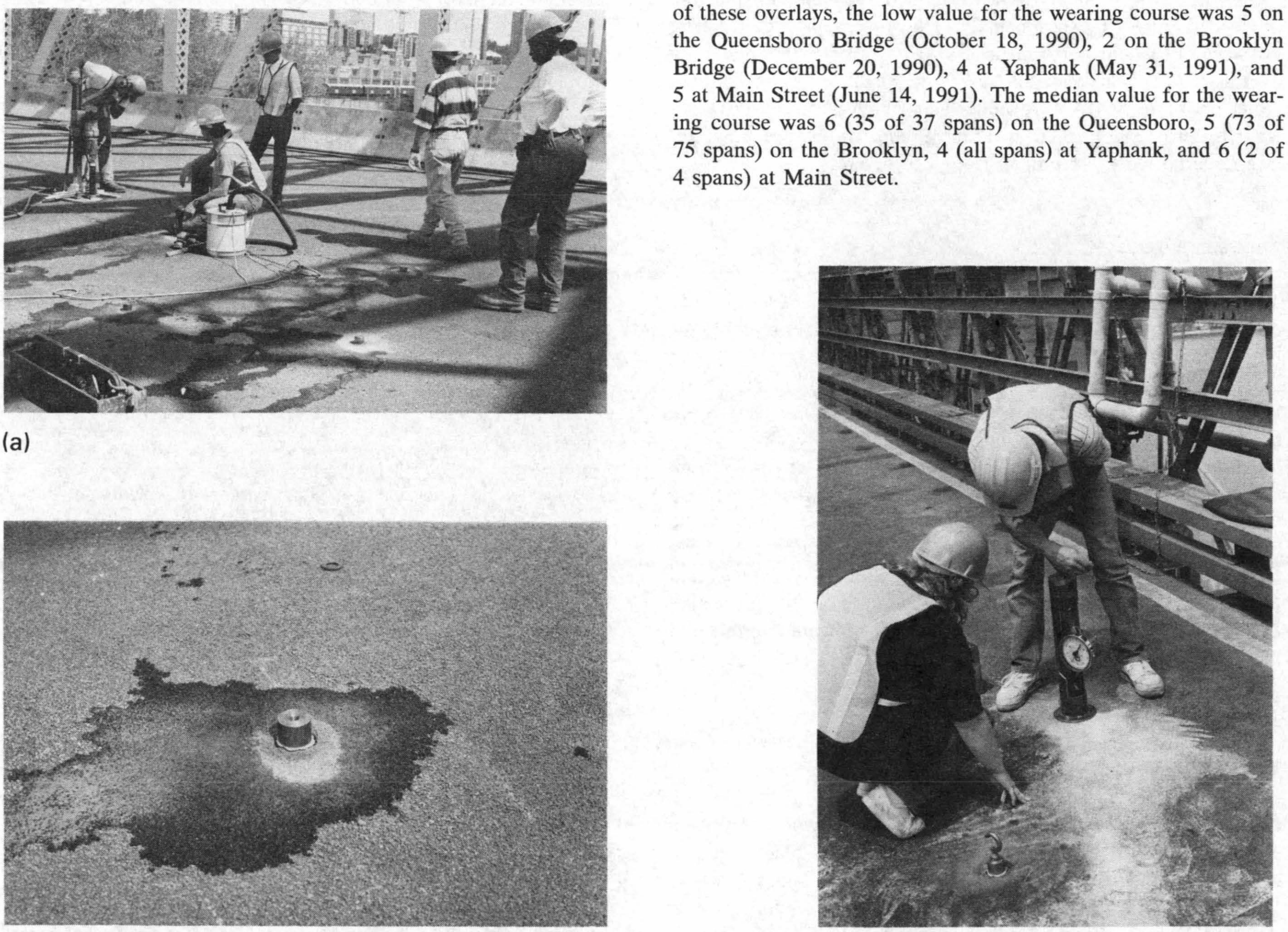
(16 percent) use PC overlays as a standard treatment and 10 (40 percent) use no PC overlays of any type. Two states—Wisconsin and Oklahoma—use no PC overlays, after experiencing failures of experimental installations. Idaho uses a polymer material (MMA) as a crack sealer but not as a deck overlay. The other states with the most experience with these materials and the most extensive programs are California and Virginia. California uses polyester routinely. Virginia is the leading user of thin epoxy overlays (about $1 million to $2 million annually since 1989), but it has discontinued use of polyester. Polyester overlays seem to be the optimum choice for concrete decks, but epoxy bonds as well to steel as to concrete, and adhesion should thus be as uniform on steel-grid decks and epoxy should be the choice for those installations.

PC Overlay Performance in New York

PC deterioration occurs in many forms because of structural deficiencies, thermal stresses, moisture, or other factors. Common forms of early deterioration are raveling or delamination and cracking, which can occur anywhere over the deck. Where the surface cracks, the potential for accelerated deterioration is present because moisture can cause the overlay to delaminate from the deck surface. Typical comments during the visual inspections included the following:

- Coating badly peeled and cracked;
- Surface worn, with abrasive material missing;
- Wear, some peeling of coating;
- Some wear of coating, worn away at patches;
- Peeling at joints, some shrinkage cracks; and
- Satisfactory except for small spalls at transverse joints.

As these comments illustrate, distressed areas often exhibited more than one type of distress. Such localized, ''patchy'' failures with multiple distress types are probably related to construction practices, with material failures likely to be more uniform across the deck. The visual distress survey is summarized in Table 2. Overlay construction was observed on the Crown Point and University Heights bridges, but distress was not surveyed because they had not been opened to traffic. In the most recent inspections of these overlays, the low value for the wearing course was 5 on the Queensboro Bridge (October 18, 1990), 2 on the Brooklyn Bridge (December 20, 1990), 4 at Yaphank (May 31, 1991), and 5 at Main Street (June 14, 1991). The median value for the wearing course was 6 (35 of 37 spans) on the Queensboro, 5 (73 of 75 spans) on the Brooklyn, 4 (all spans) at Yaphank, and 6 (2 of 4 spans) at Main Street.



(a) (b) (c)

FIGURE 1 Adhesion testing included (*a*) partial-depth coring through overlay to underlying slab, (*b*) epoxying a steel plug to core, and (*c*) usng a reaction frame and load cell.

Queensboro Bridge, South Upper Roadway

The delamination and patching that occurred on one deck section are attributable to malfunction of the contractor's automated mixing equipment and are not included in the distress analysis because they are not a materials problem.

Queensboro Bridge, North Upper Roadway

The section is performing well.

Brooklyn Bridge

Cracking was observed at the roadway relief joints and was found to result from structural inadequacies of the floor system at the roadway joint, but not from any inherent deficiencies of the Flexolith (*8*). These cracks have since been patched (Figure 3) and also are not included in the distress analysis since they are not a materials problem.

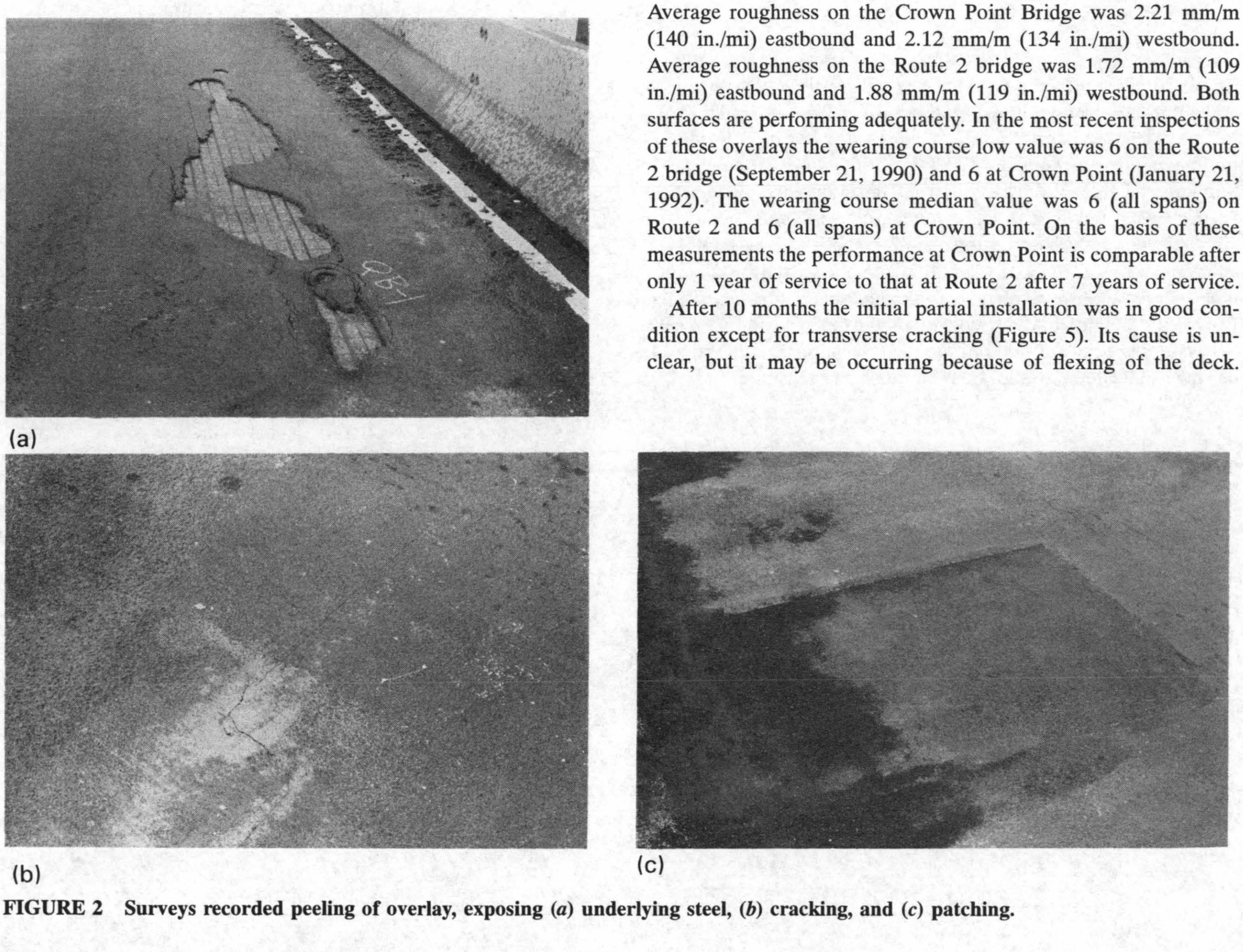
Crown Point Bridge

The PC wearing course was not well suited to this bridge. The product on the Approved List was obsolete, and the manufacturer had to prepare a special batch for this job. Because of the bridge's steep grade and the PC's flow characteristics it tended to run, and it proved difficult to achieve a smooth riding surface. Part of the first application of the wearing course was leveled off or removed and replaced because of an unacceptable riding surface caused by the product's tendency to run. The manufacturer modified the product a number of times to try to minimize this problem.

To characterize the resulting ''washboard'' effect (Figure 4), roughness was measured with a Soiltest road roughness indicator (roughometer). Measurement of pavement roughness is a primary indicator of riding quality, a general reading that translates the effect of all distress into the road user's frame of reference. Roughness caused by any factor can lead to additional deterioration by inducing more vertical movement of vehicles, producing more frequent and increasingly severe impact loads.

The roughometer ran twice on the approach section, midspan, and leave sections in both eastbound and westbound directions, and the readings were averaged to determine average roughness in millimeters per meter (inches per mile). Reading less than 3 mm/m (190 in./mi) are considered ''good.'' For comparison readings were taken on a bridge with similar geometry on Congress Street (Route 2) over the Hudson River in Troy (BIN 1004279). Average roughness on the Crown Point Bridge was 2.21 mm/m (140 in./mi) eastbound and 2.12 mm/m (134 in./mi) westbound. Average roughness on the Route 2 bridge was 1.72 mm/m (109 in./mi) eastbound and 1.88 mm/m (119 in./mi) westbound. Both surfaces are performing adequately. In the most recent inspections of these overlays the wearing course low value was 6 on the Route 2 bridge (September 21, 1990) and 6 at Crown Point (January 21, 1992). The wearing course median value was 6 (all spans) on Route 2 and 6 (all spans) at Crown Point. On the basis of these measurements the performance at Crown Point is comparable after only 1 year of service to that at Route 2 after 7 years of service.

After 10 months the initial partial installation was in good condition except for transverse cracking (Figure 5). Its cause is unclear, but it may be occurring because of flexing of the deck.



(a) (b) (c)

FIGURE 2 Surveys recorded peeling of overlay, exposing (*a*) underlying steel, (*b*) cracking, and (*c*) patching.

TABLE 1 Responses to E-Mail Survey (*19*)

State	PC Used?	PC Type Used	Remarks
Alabama	Provisionally (4 yr)	Polyester	"No problems"
Arkansas	Not used		
California	Standard (10 yr)	Polyester	Used extensively
	Experimental	Epoxy	
Idaho	As crack sealer only	MMA	No Overlays
Illinois	Special installations	Epoxy	"Not truly impermeable"
Indiana	Standard (12 yr)	Polyester	"Success with only one thin overlay"
Kansas	Not used		
Kentucky	Not used		
Louisiana	Experimental	Epoxy	Being evaluated
Minnesota	Not used		
Missouri	Experimental (2 yr)	Epoxy	30± bridges
Nebraska	Not used		
Nevada	Standard (3 yr)	Polyester	"No problems"
New Mexico	Not used		
N. Carolina	Experimental	Epoxy	1 installation
N. Dakota	Experimental	MMA	4 years service
Oklahoma	Not used		1 experimental deck (replaced)
Pennsylvania	Experimental	Epoxy	3 bridges
S. Dakota	Not used		
Texas	Experimental	Polyester	1 installation
Vermont	Experimental	Epoxy	3 installations
Virginia	Standard	Polyester	Used extensively
Washington	Experimental Feature	Epoxy	Since 1984
		Polyester	Since 1989
Wisconsin	Not used		2 experimental deck failures
Wyoming	Experimental	MMA	2 installations

Results of the surface adhesion tests (*9*) on the epoxy overlays are summarized in Table 3. In addition the 2790-m^2 (30,000-ft^2) Flexolith test section on the Brooklyn Bridge has been in service for 8 years and averaged 1420 kPa (206 lb/in^2) for nine tests. Similarly the Flexolith test patch on the Manhattan Bridge has been in place for 8 years and averaged 945 kPa (137 lb/in^2) for six tests. The minimum desired bond strength for this particular adhesion test is 1725 kPa (250 lb/in^2). None of the installations with more than 3 years of service attained this value, nor did the University Heights bridge, which was not open to traffic. These low values are not reflected in the distresses reported in Table 2, but may indicate more rapid deterioration in the future.

CONCLUSIONS AND RECOMMENDATIONS

The objectives of the study reported here were to outline what is already known about PC bridge deck overlays and to document their performance in New York State and elsewhere:

1. Earlier generations of PC overlays had a poor performance record. Testing to date supports optimism for the suitability and durability of newer polymer systems, although there is no way to predict their long-term performance accurately at this time.

2. The performance of these systems is limited by the surface on which they are placed. Successful use depends on proper surface preparation. The deck to which the overlay is applied must be sound. The substrate as well as the coarse aggregate used to extend the mix must be dry and clean.

4. New York, Virginia, and California have the most experience with these materials, with generally favorable results. The e-mail survey documented mixed results from other states, which had only limited experience.

4. PC overlays in New York appear to meet expectations, showing good performance during their first 5 to 7 years. The principal long-term concerns to be resolved are whether they will retain an adequate bond to concrete and resist wear where traffic volumes remain high. Because of the variability of field conditions, lab screening tests may be poor indicators of performance when the

TABLE 2 Surface Overlay Condition

	Structure and % of Surface Failed				
	Queensboro				
Distress	North Upper Roadway	South Upper Roadway	Brooklyn	Yaphank	Main St.
Peeled	0.19	0.09	0.00	1.55	0.20
Patched	1.21	0.00	0.13	0.00	0.00
Worn	0.48	0.25	0.32	0.00	0.00
Total	1.88	0.34	0.45	1.55	0.20

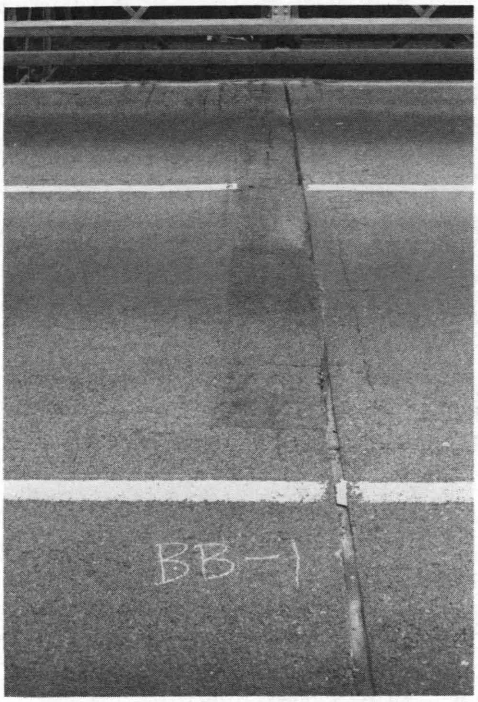


FIGURE 3 Cracking at relief joint has been patched.

overlays are installed in the field. Continued monitoring and expansion of the test patch program thus seem necessary.

On the basis of this review of the past performance of PC overlays and the types of distress noted on bridge decks, it seems advisable that these systems be considered only in two special cases: (a) for bridges where the weight of the overlay is critical, such as movable spans, or (b) where extended traffic disruptions are intolerable, such as in urban areas.

Use of PC overlays with high-strength, fast-curing characteristics and reasonable durabilities can result in minimal traffic delays and improved safety, and in some cases may eliminate the need for expensive detours. These desirable characteristics must be weighed against the need for continuing maintenance patching of the overlay to prevent possible failures because of the loss of adhesion. There is no apparent difference in the effectiveness of the various materials used in New York. Long-term studies should continue to investigate the nature of deterioration of the polymer after application and of polymer-deck concrete interactions. This could lead to the development of life cycle models for the various polymer products. Continued testing is also necessary to identify changes in deck conditions and to monitor the performances of existing overlays.

Further investigation of polyester overlays seems warranted on the basis of the results for the overlays placed on Long Island and the positive experiences of other states.

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FIGURE 4 "Washboard" deterioration on Crown Point Bridge.

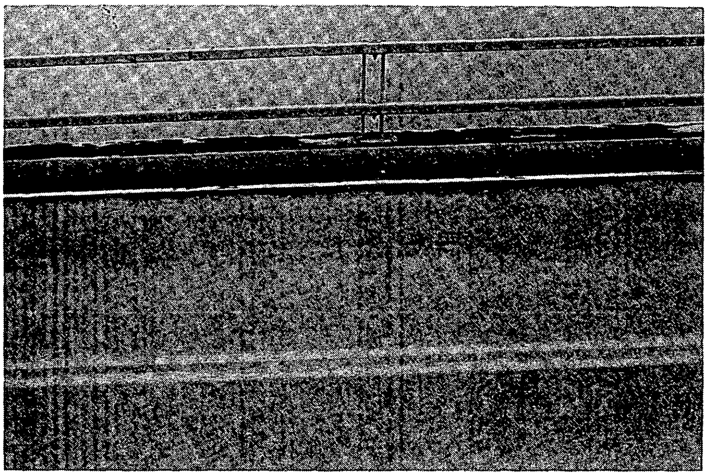

FIGURE 5 Cracking possibly resulting from deck flexure.

TABLE 3 Adhesion Test Results (psi = lb/in² = 6.89 kPa)

Location	Age, years	Overlay Material	Total Tests	Avg Bond Strength, psi
Queensboro Bridge				
South Upper Roadway	7	Flexolith	6	239
South Upper Roadway	7	Flexolith	8	99
North Upper Roadway	3	Flexolith	7	336
Brooklyn	6	Flexolith	9	224
Crown Point	1	Transpo T17X	9	267
Crown Point	0	Transpo T17X	9	324
University Heights	0	Flexolith	8	221

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