

IN-PLACE PERFORMANCE OF POLYMER CONCRETE OVERLAYS



SP-169

EDITOR

STELLA L. MARUSIN

In-Place Performance of Polymer Concrete Overlays

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PREFACE

Two sessions on “Performance of Overlays of Polymer Concretes” sponsored by Committee 548 on Polymers in Concrete were held at the ACI Spring Convention in Denver, Colorado in March 1995. Five papers were presented at the first session titled: “Performance of Polymer Concrete Overlays Part I: Over 10 Years”, and six papers were presented at the second session titled: “Performance of Polymer Concrete Overlays Part II: Less than 10 Years Old”.

All eleven papers published in this volume are case studies. Since different types of overlays—including thin overlays, polymer, epoxy and sulfur concrete are successfully in service on bridge decks, highways and garages, these authors feel that it is important to share their knowledge with the readers of this publication.

These papers should be of interest to design, materials and research engineers, as well as to contractors and material producers.

I would like to thank all authors for their contributions, and all members (and non-members) of Committee 548 who reviewed the manuscripts.

Stella L. Marusin
Editor

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Experience with Epoxy Polymer Concrete Bridge Deck Thin Overlays in Service for Over 10 Years

by Shree Nabar and Peter Mendis

Synopsis: Repair and maintenance of aging bridge decks and parking decks has become increasingly important due to concrete and steel deterioration from exposure to deicing salts, acid rain, and other hostile elements. Rapid curing thin polymer concrete overlay offers a cost-effective option in protecting and extending the service life of the deck. The paper discusses the performance, physical properties and application techniques using a flexible epoxy polymer overlay. The low modulus epoxy binder is designed to achieve a balance between toughness and flexibility. With the use of gap graded aggregates, the flexible epoxy binder system provides low permeability, enhanced skid resistance while accommodating thermal and mechanical stresses. The outstanding performance and service life of flexible epoxy overlays has been documented in the SHRP study in 1991. The importance of proper surface preparation and quality control during application is critical to the success and durability of the overlay.

Keywords: Aggregates; bridge decks; epoxy resins; mixing; parking facilities; permeability; polymer concrete; protective coatings (polymers); skid resistance

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Peter Mendis, with degrees in chemistry and chemical engineering, has 39 years experience in research application and marketing of polymers and polymer concrete used in construction. He is chairman of ACI503 and member of ACI504, ACI548, ASTM C.03, ASTM C.09, and TRB A3C174.

One of the first bridge deck overlays, based on flexible low modulus epoxy polymer concrete, is celebrating its twentieth anniversary this year. Tests recently performed show that the overlay is still in good condition based on its retained bond strength and skid resistance. This paper discusses the experience, over the last twenty years, of flexible epoxy polymer concrete thin overlays as a protective and a wearing surface on bridge decks.

Concrete and steel are the main material components of a bridge deck. They share common properties of high strengths but this synergy is adversely affected by exposure to several factors. The porosity of concrete allows intrusion of deicing salts and chemicals contributing to the deterioration of concrete and corrosion of steel. Moisture intrusion through cracks in concrete followed by freezing and thawing, causes damage to both concrete and steel. Over time heavy traffic wears the surface away, leading to poor skid resistance and riding quality.

Escalating costs of deck replacement or rehabilitation especially due to downtime and traffic disruption restrictions, makes polymer concrete overlays a cost-effective and an attractive option to protect and extend the service life of the bridge deck.

What is a Polymer Concrete Overlay?

Polymer concrete is a composite material formed by physically blending an aggregate with a polymeric binder, formed by polymerizing monomers or reacting resins and hardeners. The polymer binds the aggregate together and imparts its own characteristic properties to the polymer concrete. It differs from latex-modified concrete in which water causes hydration of hydraulic cement. Commonly used polymeric binders are epoxies, polyesters, polyurethane and methyl methacrylate. These are two part systems with one component being the resin and the other being a hardener or a catalyst.

When to use Polymer Concrete Overlays?

Polymer concrete overlays are used commonly for repair, rehabilitation and preventive maintenance of decks if one or more of the following situations exist¹:

- High permeability in the concrete.
- Deck needing improvement in skid resistance properties.
- Extend the service life of a deck where steel and/or concrete is repaired and rehabilitation of the deck is planned.
- Preventive maintenance of new decks, generally or in specific cases where incorrect concrete placement led to lack of proper air entrainment and air void system.
- No increase in deadweight is allowed and/or where traffic shutdown on the bridge beyond off-peak periods is not permissible.

Epoxy Polymer Concrete Overlays

The first generation epoxy overlays used in the 1950's were based on high modulus, coal-tar modified epoxy. These did not perform well because they were too brittle to withstand the thermal and mechanical movements caused by exposure to traffic and thermal cycling. They were applied as one coat application, which created inherent porosity causing delaminations. The current technology evolved out of these experiences and the ensuing learning curve. The epoxy polymer system presented in this paper achieves a fine balance of flexibilizing the epoxy without losing its toughness and tensile strength. The flexibility maintains the low modulus required to accommodate thermal and mechanical movements, while the tensile and compressive strengths help the overlay withstand impact and shear loads from the traffic. Use of a gap graded aggregate, instead of a well graded aggregate, is vital to the success of the overlay.

Two part flexible epoxy polymer concrete overlays have achieved a sizable market share for rehabilitation or preventive maintenance of new or old decks. Epoxies develop an exceptional bond to concrete and steel, are unaffected by the presence of alkalinity, possess rapid strength development even at temperatures up to 35°F, all of which have contributed to its impressive performance history and popularity.

Advantages of Epoxy Polymer Concrete

- Epoxy polymers have excellent bond strength with concrete. The high tensile strength holds the aggregate in place when subjected to traffic, yet is flexible enough to accommodate thermal and mechanical movements.

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- Epoxies are not affected by alkalinity of concrete and have excellent chemical resistance to salts, oil, gasoline and chemicals.
- Have very little shrinkage and due to its low modulus properties any shrinkage stresses are relieved quickly.
- 100% solids, no volatiles, VOC compliant.
- Easy to work with because they are not flammable, have no strong odors, and are moisture insensitive during application and cure.
- Rapid curing permits installation during off-peak traffic periods. Lane closure, surface preparation, installation and curing all are accomplished during off-peak traffic period.
- High strength to weight ratio allows increased live load carrying capacity on the bridge. Typical epoxy polymer concrete overlay (0.375 " thick) weighs 6-8 lb./sq.ft. compared to latex modified concrete or asphalt (1.5" - 2.0 " thick) which weighs 16-20 lb./sq.ft.
- Epoxy polymer concrete has very high impermeability which prevents water and chloride intrusion into the deck. An Alberta Department of Transportation study² found that epoxy polymer concrete overlay extended the service life of the deck even where corrosion was active during installation.
- Depending on the type and gradation of the aggregate used, polymer concrete overlays improve pavement friction (skid resistance) and also improve riding quality. In one premiere installation of the epoxy polymer concrete overlay, reduction in noise level on the Brooklyn bridge³ was a targeted, additional benefit of the overlay.

Components of Epoxy Polymer Concrete System

Epoxy polymer concrete system consists of resin (base), curing agent (hardener) and the aggregate. Each component plays a critical role in the performance of the overlay.

The epoxy binder is a carefully formulated two component system designed to optimize adhesion, low viscosity for ease of application, high flexibility and toughness. The high flexibility results in a low modulus property capable of accommodating mechanical and thermal movements. When the binder is combined with the gap graded (near single size distribution) aggregate, it forms a matrix in which the resin is the continuous phase. The gap graded nature of the aggregate permits interstices between the aggregate to be filled with the flexible resin allowing the entire system to absorb thermal and mechanical stresses without disbonding from the bond line or the aggregate. This fundamental benefit of the low modulus binder has been proven with over twenty years of successful field experience with flexible epoxy polymer overlays. Table 1 lists the properties of uncured and cured epoxy binder.

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Aggregate--The aggregate used in this epoxy concrete overlay system is gap graded (uniform gradation) for reasons mentioned earlier. Although other types of aggregate have been used, testing and field experience has shown that aggregate containing high percentage of aluminum oxide offers the best performance for friction and skid resistance. The aggregate must have high compressive strength, be non friable, non expansive, and posses resistance to polishing. In both Multiple and Slurry methods of application mentioned in this paper, the aggregate is always broadcast in the final surface. Since this provides the traffic bearing surface, these properties are critical to the long term performance of the overlay. Table 2 and 3 show typical properties of such an aggregate .

Epoxy Polymer Concrete

The properties of the polymer concrete resulting after mixing of the epoxy binder and the aggregate and cure are described in Table 4.

Epoxy Polymer Concrete Overlays in Service at least Ten Years

Table 5 provides a list of key projects with flexible epoxy polymer concrete overlays on bridge decks. This partial listing, includes only overlays that have been in service for over 10 years.

Application of Overlays

Surface Preparation--Polymer concrete overlays should be applied to clean, dry and sound substrate. As simple as this sounds, the importance of proper surface preparation is often lost in the priorities of scheduling, conflicts in underestimating the costs required to do proper surface preparation, and in the past due to lack of quantitative standards. The overlay is subject to abrasion from traffic, snow plow blades, shear stresses from thermal cycling, attack from salt, moisture and deicing chemicals, and live load shear stresses caused by deceleration, acceleration or turning. It is therefore very important that the surface be clean and posses adequate profile so that a strong mechanical and chemical bond between the polymer and the substrate will be developed.

Surface preparation begins with a preliminary evaluation by trained personnel of the condition of the deck concrete and steel. Evaluating cracks, delaminations, extent of rebar/steel corrosion and other symptoms of distress should include finding the underlying causes.

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A plan to repair the cracks, repair full depth or partial depth spalls/delaminations, and replace corrosion induced areas of concrete or steel should be formulated. The choice of proper materials and techniques should take into account the cure requirements and compatibility with the overlay.

Decks with new concrete should be cured for 28 days so that the moisture content is low enough so as to minimize excessive water vapor pressure which may cause failure of overlays.

The preferred method of surface preparation is by shot blasting. This closed system gives a clean, dust free surface with exposed aggregate which is ready to be overlaid immediately. In many larger projects, surface preparation and the application of the overlay are done in tandem.

Scarifiers, scabblers, and hydroblasting which are other commonly used methods for surface preparation are generally not suitable especially if rapid deck repairs is also a key objective. If, however, any of these methods are agreed upon initially, the time required for the surface to dry completely must be considered. In case of scabblers or scarifiers add the additional step of a light shot blast or high pressure water blast to remove any fractured concrete surface.

The all important question of knowing when the surface is clean enough is objectively determined by using the test method prescribed in ACI 503R, Appendix A, of the ACI Manual of Concrete Practice. The test method consists of bonding a steel disc to the cleaned surface using fast setting high strength adhesive. Using a hydraulic jack type fixture the steel disc is pulled by applying a vertical force. The tensile adhesive strength and the mode of failure is noted. If tensile adhesive strength is 1.7 MPa (250 psi) or greater, the surface preparation quality is acceptable. If the pullout value is less than 1.7 MPa and 90% failure occurs in concrete at a depth of 6 mm (1/4") or more, than the surface preparation quality is acceptable but the concrete quality may not be adequate.

Overlay Application--Epoxy overlays are applied by Multiple Layer Method or the Slurry Method.

Multiple layer overlays are constructed by applying the mixed binder to the surface using roller, notched squeegee, or brooms. While the binder is still wet, aggregate is broadcast to excess using mechanical or manual methods. The correct method of broadcasting is to let the aggregate fall vertically without violently disturbing the binder layer. Any wet spots appearing after the broadcast must be covered immediately with additional aggregate before the epoxy becomes tack-free. Saturation of the aggregate in the first broadcast should be avoided because the "wicking" action of the binder causes voids and reduced permeability in the overlay. After the binder is hard and cured, the excess unbonded aggregate is removed by vacuuming or brooming.

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The second and subsequent layers are constructed by repeating the process. To ensure proper coverage rates of the binder, it is recommended that sections be marked on the deck. Each section represents the spread rate to be achieved by the amount of binder mixed each time. The Multiple Layer Method is easy, does not need sophisticated equipment and no highly skilled labor is required to install the overlay. Since at least two layers are needed, cure time requirements dictate relatively longer downtime compared to the slurry method. Table 6 shows the typical application rates for the binder and the aggregate.

Slurry Method overlays are applied by mixing the binder and aggregate, in the correct proportions, in either continuous or batch mixing equipment. The mortar slurry is distributed on the deck using gage rakes, trowels, draw or beam boxes and then screeded to specified thickness using vibratory screeds. Guide rails are used to achieve the proper thickness using manual or self propelled vibratory screeds. Immediately after screeding, excess binder from the binder rich slurry "bleeds" to the surface. The excess binder eliminates the need for a separate step of priming the surface and also provides a binder film at the top surface into which aggregate can be broadcast to achieve skid resistance. Dry, gap graded aggregate is immediately broadcast uniformly to an excess and until no wet spots appear. After the binder cures, unbonded aggregate may be removed by vacuuming or sweeping.

Curing--Curing time for an epoxy overlay depends on the ambient and surface temperatures, overlay thickness and the resin, hardener and aggregate temperatures. Table 7 outlines a typical cure schedule for epoxy overlays applied by either methods of application.

Quality Assurance Procedures in the Field

A clean and sound concrete and steel surface is as critical as the proper binder system and the application method. The adequacy of the surface preparation and concrete quality is evaluated in the field by ACI 503R test method. Instead of relying visually to detect presence of moisture, follow ASTM D 4263 in which a plastic sheet (polyethylene) is taped on the surface and is observed for specified time for any condensed moisture under the surface of the sheet.

Binder / Aggregate--The first step is to ensure proper storage conditions of the binder and aggregate. The resin, aggregate and hardener, should be conditioned at about 70° F for at least 24 hours, prior to application especially in extreme temperature conditions. Utmost care should be taken to ensure that the resin and hardener are mixed in the correct proportion, for the proper duration and that the

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mixing should result in a homogenous mix without air entrapment. When automated dispensing equipment is used to meter and mix the binder, recalibration should be done every time the equipment is stopped and/or started and when ambient temperature changes by 10°F. The aggregate gradation should be certified by the manufacturer and the field quality assurance involves making sure that the aggregate is dry and that it does not contain excessive fines. The accuracy of the mix ratio and mixing procedures, for calibration or application, is judged in the field by a quick check of the gel time using about 100 gms of the mixed binder. At frequent intervals, samples of the mixed binder with the proportionate amount of aggregate are cast into 2" cube molds using plastic inserts. In order to be to avoid scatter of compressive strength results, prepare these field samples for consistency by tamping the cubes in accordance with ASTM C109 method. At low temperature, if the binder viscosity is high, the binder loses its penetrating, wetting and self priming abilities. On the other hand, at temperature of 90°F and above, the binder sets up quickly, which if the entire placement operation is not well coordinated, can cause poor bonding and aggregate wet out. It is strongly recommended to install an overlay test patch using the proposed methods of surface preparation, binder/aggregate mixing, and application methods that are to be used to place the overlay. Using ACI 503R test method, a tensile adhesion pull out test is done on the overlay sample which, if acceptable, sets the standards and procedures that will be used on the project.

Quality assurance for the completed overlay, if possible, should be based on non destructive test methods. Where core samples are needed to assure quality, the representative areas should be carefully chosen and repaired immediately after sampling.

Presence of cracks and porosity is evaluated by measuring electrical resistivity according to ASTM D3633 test method. Typically resistivity values greater than 500×10^3 indicate an impermeable membrane while values below 200×10^3 can note presence of cracks and/or porosity.

Another test which corroborates the permeability value is the rapid chloride permeability test according to AASHTO T277. This method gives the coulomb rating of the overlay as a measure of permeability. The epoxy overlay has a coulomb rating typically below 100 which denotes an impermeable membrane. The bond strength to concrete is evaluated by using ACI 503R test method. Failure in the concrete substrate is indicative of an acceptable bond. Skid resistance is measured by using ASTM E501 (treaded tire test), ASTM E303 (British Pendulum test) or ASTM E524 (bald tire skid) test method.

Service Life of Epoxy Polymer Concrete Overlays

An accurate service life prediction of the overlay is rendered difficult due to the fact that bridge surface deterioration mechanisms are different for every bridge. An exhaustive survey of the existing performance conditions of various deck protection, repair and rehabilitation systems was undertaken under the Strategic Highway Research Program (SHRP).⁵ The results of their evaluation on the flexible epoxy polymer overlays are found in Tables 8 and 9.

Trouble Shooting Overlay Problems

There are several variables that contribute to the success of an overlay and when more than one variable is suspected for causing the problem, it becomes extremely difficult to isolate the contribution of that variable and the interactive effects of other variables in contributing to the cause of the problem.

Overlay failures can be broadly classified into three categories -- Delamination / Debonding; Cracking / Increased Porosity; Loss of Skid resistance. The following briefly discusses how the Substrate, Binder/Aggregate, and Application methods can influence these failure modes.

Delamination / Debonding--Delamination/Debonding can be failure by itself or can be caused by the cumulative effects of other deficiencies in the overlay.

Improper or inadequate surface preparation is the single largest reason contributing to this mode of failure. The physical properties of the epoxy binder are achieved only when the resin and the hardener are mixed in the correct ratio and mixed intimately. Any deviation from the ratio or mixing can cause a myriad of problems which may not manifest immediately. In the Multiple layer method of application intercoat adhesion failures, in the form of surface delaminations may occur due to contamination between coats, waiting too long between the coats, or applying the binder to unbonded aggregate.

At overlay thickness greater than 1/2" (1.25 mm), the difference in the coefficient of thermal expansion between the epoxy overlay and concrete becomes significant. In an otherwise properly applied overlay, this aspect alone accounts for many delamination failures. Often overlooked is the need for proper details for termination of the overlay. Inadequate termination details at joints, drains, dividers and curbs cause water intrusion or edge delamination due to impact stresses.

Cracks in the Overlay--Though larger cracking may be evident visually, fine cracks or increased porosity can only be evaluated by tests mentioned earlier. Presence of large or moving cracks in the concrete, if untreated, will cause reflective cracking of the overlay. Excessive

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flexing of the sub-base, especially near joints, can induce fatigue stresses at the bond line leading to cracking and subsequent debonding.

Increased Porosity of the Overlay--Addition of solvents or thinners to the binder causes shrinkage and creation of voids after the solvent evaporates. Use of wet or damp aggregates prevents its bonding with the binder, eventually causing aggregate pop-outs and increased porosity. Application of the overlay over expansion joints is done by using either of these techniques--the joint is taped with a bond breaker tape, the overlay is applied over the entire surface including the taped areas, then the tape is pulled before the overlay has cured. The other method is to apply the overlay over the entire area and saw cut over the joints 24 hours after cure of the overlay. In both cases a flexible sealant is used to fill flush to the surface. Opening the overlay to traffic before sufficient cure and strength, may cause micro cracks which will grow with applied mechanical and thermal stresses.

Loss of Skid Resistance

The aggregate type and gradation is the major factor contributing to this property. Compromising any of these will reduce overlay's long term skid resistance proportionately.

Summary and Conclusions

Flexible epoxy polymer concrete overlays have established a long and successful track record. These applications have shown outstanding performance in protecting and extending the service life of bridge decks. Studies have shown that these rapid repair, rehabilitation and preventive maintenance systems retain skid resistance and permeability resistance for well over ten years.

The polymer discussed in this paper is a flexibilized epoxy binder. The gap graded aggregate combined with the high elongation and low modulus properties imparted by the epoxy binder accommodate movements due to thermal and mechanical stresses. The physical and performance properties of the flexible epoxy binder, the aggregate and the polymer concrete have been characterized in the paper.

Various bridge deck overlay projects using the flexible epoxy system have been listed. Results of data evaluation during the SHRP study in 1991 confirm the excellent performance of this epoxy overlay system that had been in service for over 15 years. The success of the overlay application is closely dependent upon proper surface preparation, application methods and a rigid infield quality assurance program. Some basic tools and test methods for proper quality assurance and application techniques have been outlined.

Acknowledgments

Acknowledgment is extended to all our colleagues at Tamms Industries for their suggestions and help in preparing this paper. Special thanks to Ms Maryl Davis for her secretarial assistance.

References

- (1) AASHTO (American Association of State Highway and Transportation Officials); TRB (Transportation Research Board); ARTBA (American Road and Transportation Builders Association), Task Force 34, Guide Specifications for Polymer Concrete Bridge Deck Overlays, 1995.
- (2) James Skeet & Gary Kriviak, Service Life Prediction of Protective Systems for Concrete Bridge Decks In Alberta, Report No. ABTR/RD/RR-94/01, pp73-79.
- (3) New York State Department Of Transportation, Technical Report on Flexolith Epoxy Overlay, June 1987.
- (4) ACI 548.5 R-94, Guide to Polymer Concrete Overlays, American Concrete Institute, 1994.
- (5) Rapid Concrete Bridge Deck Protection, Repair and Rehabilitation, Strategic Highway Research Program, SHRP S-344, 1993.

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TABLE 1— PHYSICAL PROPERTIES OF EPOXY BINDER

Property	Value	Test Method
Viscosity	7-25 poise	ASTM D2393 Brookfield RVT spindle 3 @20 rpm
Gel Time	10-45 mins.	ASTM C881 paragraph 11.2 modified
Compressive Strength	>6.9 MPa (1000 psi) @ 3 hr. >34.4 MPa (5000 psi) @24 hr.	ASTM C579 modified (plastic insert)
Tensile Strength (neat)	> 13.8 MPa (2000 psi) @ 7 days	ASTM D638
Adhesive Strength- (mixed with aggregate @24 hr.)	> 1.7 MPa (250 psi) Appendix A,VTM 92	ACI 503R ⁴
Permeability to Chloride Ion	< 100 coulombs @ 28 days	AASHTO T277
Water Absorption (neat)	1% max. @ 24 hr.	ASTM D570
Thermal Compatibility (mixed with aggregate)	No delamination of overlay	ASTM C 884
Modulus of Elasticity	< 900 MPa (130,000 psi)	ASTM D695
Tensile Elongation	> 30%	ASTM D638
Bond Strength	>10 MPa (1500 psi)	ASTM C882

TABLE 2 — TYPICAL PHYSICAL AND CHEMICAL PROPERTIES OF THE AGGREGATE

PHYSICAL PROPERTIES		GRADATION	
<u>Property</u>	<u>Specification</u>	<u>US Sieve Size</u>	<u>%min.-max. retained</u>
Hardness	6-6 1/2 mohs	No. 5 (4-75 mm)	none
		No. 6 (3-35 mm)	0-3
Specific Gravity	2.99	No. 12 (1-70 mm)	70-97
		No. 20 (850 mm)	10-35
Burbank Abrasion Index	1.4119	>No. 20 (850 mm)	0-3
Fin Friability Index	78.0		
Loss of Ignition	0.24		

TABLE 3— TYPICAL CHEMICAL ANALYSIS OF THE AGGREGATE

<u>Ingredient</u>	<u>% Weight</u>	<u>Ingredient</u>	<u>% Weight</u>
Silicon Dioxide	52-53	Magnesium Oxide	8.10
Aluminum Oxide	13.85	Sodium Oxide	1.95
Iron Oxide	9.58	Titanium Oxide	0.89
Calcium Oxide	11.15		

TABLE 4 — PROPERTIES OF EPOXY POLYMER CONCRETE¹

<u>Property</u>	<u>Value</u>	<u>Test method</u>
Working Life	30-90 min.	AASHTO T 237
Cure Time	3 hr. @ 21°C	
Bond Strength	>10 MPa	ASTM C 882-91
	>1.7 MPa	ACI 503R Appendix A
Compressive Strength	>35 MPa	ASTM C 579-91
Modulus of Elasticity	0.6-1.0x10 ³ MPa	ASTM C 579-91
Flexural Strength	>14 MPa	ASTM C 580-93
Thermal Compatibility	must pass 5 cycles	ASTM C 884-92

14 Nabar and Mendis**TABLE 5 — CASE HISTORY OF EPOXY OVERLAYS IN SERVICE FOR OVER 10 YEARS**

Year	Project	Location	Owner	Method Application
1976	Rt. M-44, over the Grand River	Grand Rapids, MI	Michigan DOT	ML
1976	Rt. 106 & 107 Southbound Roadway	Hicksville, NY	New York DOT	ML
1979	Rt. LA572 Bayou Macon Bridge (Franklin Parish)	Chase, LA	Louisiana DOT	ML
1983	Brooklyn Bridge	Brooklyn, NY	New York DOT	S
1984	Queensboro (59th St.) Bridge	NY, NY	New York DOT	S
1984	Remington St. Bridge	Baltimore, MD	Baltimore, DPW	ML
1984	Clakamas River Bridge, Highway 99	Oregon City, Oregon	OregonDOT	ML
1984	Red Deer River Bridge	Sundrie, Alberta, Canada	Alberta DOT	ML
1985	Yakima River Bridge, Route 82	Ellensburg, WA	Washington DOT	S
1985	Thousand Islands Bridge	Thousand Islands, NY	Triboro Bridge Auth., NY	ML
1985	Crows Nest River Bridge	Hwy. No. 3, Frank, Alberta	Alberta DOT	ML
1986	Edgewood Ave., Rt. 17	Milwaukee, WI	Wisconsin DOT	ML
1986	Rt. 16 over Rt. 170	Columbus, OH	Ohio DOT	ML
1986	Jonesport River Bridge	Jonesport, ME	Maine DOT	ML
1986	Lackawanna/ Luzerne Counties L.R. 439, Rt. 52	Moosie, PA	Pennsylvania DOT	ML
1986	Strawberry Creek Bridge, Highway 2	Kinuso, Alberta	Alberta DOT	ML
1986	Dawson Bridge	Edmonton, Alberta, Canada	Alberta DOT	ML

Key: ML = Multiple Layer method
S = Slurry method
DOT = Department Of Transportation

TABLE 6—TYPICAL APPLICATION RATES IN MULTIPLE LAYER OVERLAYS

	Rate	lb./sq.ft.
Resin-1st layer	40 sq.ft./gal.	0.23
Aggregate-1st layer	1.1 lb./sq.ft.	1.1
Resin-2nd layer	20-25 sq.ft./gal.	0.41
Aggregate-2nd layer	1.4 lb./sq.ft.	1.4
Thickness	3/8"	
Total resin wt. %		21
Total aggregate %		79

TABLE 7— CURE SCHEDULE FOR OVERLAYS

Ambient Temperature in °F	Cure Time for 3/8" Thick Overlay, hr.			
	Binder Temperature 70°F		Binder Temperature 85°F	
	Multiple Layer	Slurry	Multiple Layer	Slurry
55	10-12	7-9	9-11	6-8
70	8-10	5-7	6-8	3-4
85	5-6	3-4	N/R	N/R

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TABLE 8— EVALUATION OF EPOXY OVERLAYS ON BRIDGE DECKS

State	Bridge History		Overlay Placement Date	Permeability Coulombs		Chloride Content at depth (lbs/cu yd.)		
	Year Built	Salt Rate 1990		2" from top	Base Concrete	@ 0.31"	@ 1.75 "	@ 4.25"
MI Rt 44 over Grand River	1963	H	1976	420 ('91)	2,885 ('91)	10.30 ('91)	3.23 ('91)	1.01 ('91)
OH Rt. 16 over I-270	1974	H	1986	77 ('87)	N/A	N/A	N/A	N/A
				151 ('91)	3,954 ('91)	13.71 ('91)	3.81 ('91)	1.07 ('91)
VA Rt. 617 over Rt. 644	1986	M	1986	74 ('86)	2,120 ('86)	0.77 ('86)	0.77 ('86)	0.77 ('86)
				37 ('89)	2,147 ('89)	N/A	N/A	N/A
				44 ('91)	1,668 ('91)	0.75 ('91)	0.60 ('91)	0.77 ('91)
WA Rt. 900 over I-5	1966	L	1986 - 1988			N/A	0.77 ('84)	N/A
				0 ('91)	1,457 ('91)	4.86 ('91)	0.96 ('91)	0.29 ('91)

SHRP Report '93
(SHRP-s-344)

Key: Salt Rates

H - > 5 tons/lane mile/yr.

M - 2.5 -5.0 tons/lane mile/yr.

L - < 2.5 tons/lane mile/yr.

N/A - Not Available

TABLE 9—EVALUATION OF EPOXY OVERLAYS ON BRIDGE DECKS

State	Bald Tire Skid No. ASTM E-524	Deck Assessment Data, 1991		Spalls % > 0.35	Total Failed Area	Tensile Adhesion				
		Cracks (length)	Delamination			psi	Failure Area			
							Overlay	Bond	Base	Adhesive
MI Rt. 44 over Grand River	40('91)	0	1%	1%	2%	147('91)	0%	98%	0%	2%
OH Rt.16 over I-270	51('91)	0	3%	0%	3%	259('91)	12%	77%	11%	0%
VA Rt. 617 Over Rt. 644	56('86) 47('87) 52('89) 43('91)	0	0%	0%	0%	281('86) 149('87) 248('89) 113('91)	6%	85%	1%	8%
WA Rt. 900 over I-5	46('87) 37/59 ('88) 44('89) 47('90) 33('91)	0	0%	0%	0%	327('91)	20%	23%	57%	0%

SP 169-2

Performance of Thin Methyl- Methacrylate Polymer Concrete (mma) Overlay in a Post-Tensioned Parking Garage

by Donald F. Meinheit and Wilfried H. Riesterer

Synopsis: Methyl-methacrylate (mma) based polymer concretes have been used for thin overlays, patching repairs, and bearing pad applications since the late 1970's. These polymer concretes are moisture and wear resistive and have been used to protect embedded reinforcing steel from corrosion attack.

This paper reports on the condition of a post-tensioned parking garage that was repaired in 1983 using a thin mma polymer concrete overlay. An earlier paper reported on the garage condition, repair methods and materials (1). Comments will be made on the overlay wear, cracking, bonding to the substrate, continued corrosion of embedded reinforcing steel, and surface delaminations after 13 years of service. Comparisons of conditions in 1981 and 1995 are also made. Comments on the success of the application with respect to structural integrity and material durability are made at the end of the paper.

Keywords: Methyl methacrylate; parking facilities; polymer concrete; post-tensioning; serviceability

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INTRODUCTION

This paper is a case study of a methyl-methacrylate (mma) based polymer concrete overlay installed as a repair on the surface of a post-tensioned concrete parking garage in Nashville, Tennessee in 1983. This paper will review the conditions existing in 1981 when one of the authors did a condition assessment of the parking structure. As a result of that condition assessment, one repair approach was selected after considering several alternative repair methods.

After 13 years of service, the authors revisited the project, in the fall of 1995, to make preliminary assessments of how the repair system was functioning. Using the 1995 observations and information from the material supplier's inspection file, conclusions are drawn with respect the structural and material performance.

Description of Structure

Shown in Fig. 1 is a typical floor framing scheme for the eight story parking garage. This parking garage was built in 1975 and is constructed using unbonded post-tensioned concrete slabs and unbonded

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post-tensioned concrete girders. Each deck is a one-way post-tensioned slab, 5½ in. thick. The post-tensioning is at the top of the slab in the negative bending moment regions (on the column lines) and drapes to the positive bending moment regions at mid-span. Deformed mild steel reinforcing bars are also added at both of these locations. Post-tensioned girders are continuous over one support or frame into columns for partial end fixity. The sloping ramps on the south end of the garage serve as ingress and egress ramps. There is a cross-over slab between the two sloping ramps that allows cars to cross-over from an ingress to an egress ramp. On the east and west sides of the garage, there are inter-level ramps that permit the traffic to go from one level to the next higher or lower level. There is also one cross-over ramp on the west side of the garage which allows vehicles using the flat portion of the structure, between Column Lines 6 and 9, to exit that area without having to counterflow the traffic pattern.

This garage accommodates approximately 450 vehicles on a floor area of 197,000 sq ft. All of the structural concrete is normal weight aggregate concrete, and the typical span of the one-way slab is 20 ft. Post-tensioning was done with ½ in. 270 ksi tendons.

Descriptions of General Conditions in 1981

In 1981, the garage was only 6 years old and had already shown a number of deterioration signs. In the 1981 condition assessment, freeze-thaw damage was seen to exist at many locations on the floor slab concrete. One of the more heavily scaled areas at the roof level is shown in Fig. 2. The heavy scaling was attributed to a lack of air entrainment in the concrete.

Exposed corroding steel deformed reinforcing bars and post-tensioning tendons were also frequently found. The exposed reinforcement resulted either because the reinforcement was never covered with concrete or the shallow cover over the deformed bars had spalled because the bar had corroded. A frequently identified condition is shown in Fig. 3 where the post-tensioning tendon sheathing is shown to be torn and the post-tensioning tendon lies directly adjacent to a reinforcing bar. The tendon typically was exposed because of the corroding deformed bar, although none of the post-tensioning tendons had fractured at the time of the 1981 condition survey.

Deck cracking was minimal for this post-tensioned structure although some through-thickness cracks existed due to shrinkage.

Portions of this structure, the cross-over and inter-level ramps, are not post-tensioned concrete but reinforced concrete. Hence, both types of construction showed shrinkage cracking as well as flexural cracking in negative bending moment regions of the cross-over and inter-level ramps.

At the entrance level of the garage, the post-tensioned deck slab was covered with an elastomeric membrane. In the 1981 condition survey, the membrane had several areas where it had worn through. There were also consistent complaints of water leakage through the structure into the occupied space below the entrance slab. Apparently breeches occurred in the membrane at the through-thickness cracks causing leakage into the occupied space.

Concrete Properties

The 1981 condition survey studied various characteristics of the concrete primarily because of extensive freeze-thaw deterioration. Core samples were removed for compression testing, air-void testing and chloride ion content evaluation. Table 1 summarizes the properties of the concrete measured in 1981. Core compressive strength results indicated that the concrete had a compressive strength of at least 6000 psi. Petrographic analysis and air void counts on cores from various locations in the structure showed that the heavily scaled regions of the deck slab had at best 3.8 percent air. In those areas with no scaling, the air void content was about 8.6 percent. Chloride ion contents $\frac{1}{2}$ in. below the top surface of the deck ranged from 0.10 to 0.30 percent by weight of concrete. Chloride testing results from mid-depth of the slab implied that the concrete did not use a chloride admixture to accelerate the set. The high chloride ion concentration appears to be the result of the salt being carried in by the parking vehicles or having the sloping deck surfaces salted to reduce the risk of formation of ice. The chloride ion contents at a $\frac{1}{2}$ in. level are at least 3 times the threshold value required for corrosion of embedded reinforcing steel. Considering that some of the reinforcing steel was placed high in the deck slab, the deformed bar reinforcing should have corroded.

Condition Survey Results in 1981

Visual observation and delamination surveys of two of the deck slabs are shown in Figs. 4 and 5. Figure 4 shows a deck slab where an extensive number of delaminations and exposed tendons and deformed

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reinforcing bars were found in the negative bending moment regions of the sloping slab surfaces. In Fig. 5, considerable freeze-thaw damage exists in the concrete on the flat portion of the level and primarily on the west side of the structure. Delaminations and exposed reinforcing bars in both of these figures were predominantly on the sloping surface of the garage floor. The flat portion of the structure was relatively free of corrosion deteriorated concrete but was found to be more influenced by water that ponded on poorly air-entrained concrete causing freeze-thaw deterioration.

REPAIR APPROACH

Repair Philosophy

After completing the condition assessment work in 1981, recommendations were made for repair to enhance the service life. In 1981, the following objectives were selected as being important: a) there was an immediate need to protect both the deformed reinforcing bars and the post-tensioning steel near the surface from being abraded, b) there was a need to enhance the corrosion resistance of the reinforcing steel, c) there was a need to minimize moisture and chloride absorption into the concrete and d) most important, there was a need to protect the post-tensioning tendons from fracturing. Aside from the structural integrity issues, a final objective was to minimize the future overall maintenance for this structure.

Repair Alternatives

Various repair alternatives from a leave as-is to demolition and rebuilding were considered for various parts of this project. The alternatives for restoration repair are listed in Table 2.

Reasons for eliminating some of these restoration or repair methods are as follows. Cementitious or polymer-modified concrete patching has been used in a great number of parking garage repair projects. Because minimizing future maintenance was our objective, this alternative was rejected because patching repairs have not always been durable. The waterproof membrane alternative with a heavy duty traffic bearing wearing coat was seriously considered at the time; however, the then owner was not enthusiastic about this alternative because of the

poor performance of a 6 year old membrane on the entrance slab. Concrete overlays were considered briefly; however, it was soon realized that the overlay must be at least 2 in. thick and would reduce the existing tight headroom of the garage. Cathodic protection, in 1981, was not a proven repair alternative for a post-tensioned concrete structure and therefore was not attempted. The final repair alternative considered was a thin bonded overlay of polymer concrete. Polymer concrete is lightweight and caused no reduction in the live load or reduction in the height limitation for the garage.

Laboratory testing of mma polymer concrete materials had shown, in 1981, that this material was water and chloride resistance (1). Hence it was considered to be a good material to minimize moisture and chloride ingress into the concrete. The mma polymer concrete is also a dielectric material.

Selected Alternative

Mma polymer concrete repairs when kept to about $\frac{1}{4}$ in. thick were found to be cost competitive with membrane solutions as well as other polymer modified concrete patching solutions. However, the advantage mma polymer concrete had over other solutions was its ability to be installed over a broader temperature range than an elastomeric membrane or a cementitious concrete. One other attribute was that the polymer concrete did not require an extended cure time so the garage could be kept open at all times. Ingress and egress access for this garage was exclusively on the sloping ramps; therefore, these ramps had to be kept open. The mma polymer concrete offered the flexibility to open an area to traffic within hours after the material had been placed. Since the structural system had relatively few cracks, the polymer concrete overlay offered a very viable option to the owner, engineer and the contractor.

Repair Construction

Repair work on this garage was done in both summer and winter months. The mma based polymer material had the ability to be placed and cured under a wide range of temperature conditions, as high as 100°F and as low as 20°F. Mma polymer concrete was placed in a) deep cavities around reinforcing bars that had corroded, b) to cover freeze-thaw damaged concrete, c) in beam stressing pockets, and d) to cover

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both reinforced concrete and post-tensioned concrete areas in the negative bending moment regions. The repair construction work in 1983 attacked the areas where the deck was most significantly affected by the corroding deformed reinforcing and freeze-thaw deterioration. The entire deck did not receive an overlay. Each of the cross-hatched areas in Fig. 6 is an area where the surface was overlaid with a thin mma polymer concrete, that is, the overlay was placed in strips.

The repair construction followed standard repair techniques of cleaning the surface delaminations, chipping to expose corroded reinforcing bars, sandblasting to remove corrosion by-products and sandblasting to removing small chips from the surface chipping step. After the surface had been sandblasted, it was primed with mma liquid including all of the exposed reinforcing bars. After the primer cured, deep areas of the repair region were filled with mma polymer concrete extended by pea gravel. After curing the deep areas, that is, for a period of 3-4 hours, the entire negative bending moment region was surfaced with a ¼ in. thin overlay of mma polymer concrete. Figures 7 and 8 show pictorially the preparation and overlaying steps. Further details of the repair construction can be found in Ref. 1. Mix designs for the mma polymer concrete and patching mortar followed the material suppliers' recommendations.

CONDITION REVIEWS

Earlier Site Visits

The authors worked closely in 1982 on the repair specifications for the mma materials and surface preparation. The material manufacturer had previously developed good long-term performance records for their mma based polymer concrete on conventionally reinforced concrete parking structures and bridge structures. This project, however, was the first large-scale installation of mma polymer concrete to a post-tensioned structure. Therefore, because of the nature of this project, the material manufacturer had a vested long-term interest the performance. Consequently, the mma material supplier made a number of post-construction visits to the deck. The following descriptions review observations made prior to the authors' visit in August 1995.

After approximately 1½ years of service, the entire overlay appeared to be in excellent condition. Some minor surface crazing was found throughout particularly around the perimeter where the overlay was

exposed to more direct sunlight. This was expected since other outdoor overlays on grade and on bridge decks also had exhibited crazing. Core samples were subsequently taken and found that the crazing crack was about 0.012 in. deep. Approximately 7 years after the initial installation, the overlay again appeared virtually identical as it did after 1½ years of service. Surface crazing may have appeared slightly more pronounced around the perimeter of the structure or were exposed to direct sunlight. After 10 years of service the garage was walked from top to bottom, and notes indicate the presence of surface crazing around the perimeter of the structure. The overlay did not show any additional cracks, spalls or delaminations, nor was there any visibly detectable wear of the surface, particularly in the acceleration/deceleration areas of the garage.

Site Visit 1995

In August 1995, the authors made an unsolicited visit to the structure to inspect the general condition of the overlay. During the 13 years of service, neither of the authors had received any calls from the owners of the structure concerning a lack of performance. It does not appear that the owners of this garage have invested any money into maintenance repairs during the 13 years of service.

Observations of Conditions at 13 Years -- The heavy traffic at the entrance level, which originally had an elastomeric membrane and was completely overlaid, had not experienced any significant wear. To the authors' knowledge, leaks through that level existing before the overlay was installed have not reappeared after the level was overlaid. Above the entrance level, to the authors disappointment, the overlay areas, particularly in the sloping ramp portion of the garage and in some of the flat areas, contained overlay delaminations. In Fig. 9 is shown a portion of one of the overlay areas with the delaminations highlighted.

Most of the delaminations were associated with cracking of the polymer concrete surface. Frequently those cracks contained corrosion staining, implying that there was an embedded reinforcing bar that was continuing to corrode and cause the delamination. Figure 10 shows one of these long linear cracks above a deformed reinforcing bar exhibiting corrosion staining. In some cases, these long cracks extended almost the entire 10 ft width of the overlay region. These later cracks were associated with a post-tensioning tendon rather than a corroding deformed reinforcing bar.

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In addition to these long linear cracks, the authors saw conditions that are typically depicted in Fig. 11. These cracked areas look like small mounds and when sounded with a chain or tapped with a hammer they were delaminated. One of these mounds was opened and a corroding deformed reinforcing bar was found causing the deterioration. Figure 12 shows the conditions observed. The authors noted that this cracking typically occurred near the cutoff end of the deformed reinforcing steel. Cracking and delamination of this nature could also represent a very local corrosion area of a deformed reinforcing bar.

The top deck of this garage was found to be severely freeze-thaw damaged in 1981. Therefore, the entire roof deck was overlaid with mma polymer concrete. The roof deck and many other areas adjacent to the exterior were found to contain crazed mma polymer concrete as shown in Fig. 13. Crazing occurred predominately where it was exposed to ultraviolet radiation.

In areas where the mma polymer concrete was used to overlay freeze-thaw deteriorated concrete the overlay was still bonded although the surface was frequently crazed. In no areas had the polymer concrete overlay debonded. In the freeze-thaw deteriorated areas of the parking deck, some delaminations were found, but they were attributed to corrosion of deformed reinforcing steel. None of the mma polymer concrete placed on previously freeze-thaw damaged concrete, even though crazed, was found to have debonded in large sheet type fashion.

Comments on Serviceability Performance -- The objectives of the selected repair have been previously reviewed. In Table 3, preliminary conclusions are drawn based upon the authors' one-day visit in 1995.

The primary observation from the site visit was that corrosion of the deformed reinforcing bars is still continuing. Cracking of the surface of the mma polymer concrete along post-tensioning tendons and deformed reinforcing bars most likely lets additional water into the area permitting the reinforcing steel to corrode. Up until the time of the 1995 site visit there have been no reported post-tensioning tendon fractures in this structure. Likewise, the authors found the overlay covering freeze-thaw damaged concrete to be well bonded and the overlay appears to be protecting the substrate concrete from additional freeze-thaw damage.

In terms of the original project objectives, the structural performance after 13 years of service is poorer than that anticipated. Since the objective was to protect the embedded reinforcing steel, be it deformed reinforcing steel or post-tensioning steel, the thin overlay at this point is not performing that function. This means that moisture and

chloride intrusion has not been arrested in the negative bending regions of the structure where reinforcing steel is most susceptible to the effects of chloride. Closely coupled with keeping the deformed and post-tensioning steel from corroding is the objective that the post-tensioning tendons should not fracture. There is an elevated concern for the structural integrity if tendons in the slab system fracture. None of the post-tensioning tendons have fractured during the last 13 years of service. The last objective was to minimize overall long-term maintenance. The conditions observed in August 1995 require that additional maintenance now be done.

POSSIBLE CAUSES FOR CONDITIONS OBSERVED AFTER 13 YEARS OF SERVICE

Delaminations

By superimposing the 1981 condition survey maps onto condition survey maps from the 1995 site visit, the authors find that the existing delaminations are concentrated near the edges of the strip overlay regions near the ends of the deformed bar reinforcement or the delaminations are directly superimposed on delaminations that existed in the 1981 survey. It is likely that the overlay deterioration found at the edge of the strip overlay is the result of moisture migrating under the edge of the strip overlay and continuing to provide sufficient electrolyte for the corrosion process to continue on deformed bars near that edge. Consequently, the edges of the overlay have probably never dried out. Likewise, the chloride contamination in the concrete was not removed to any significant depth, hence any moisture that can migrate underneath the edge of the strip overlay would still permit reinforcing steel to continue to corrode. From earlier reported site visits, corrosion of reinforcing steel in the strip overlay region may have been proceeding at a relatively slow pace for a number of years and only began to accelerate.

Crazing

The reason for the surface crazing is primarily due to a combination of the thermal plastic nature of the mma based polymer concrete and the application technique. Considering that the specific gravity of the monomeric liquid component of mma-based polymer concrete is only about 0.93 and its viscosity is around 1 centipoise, the

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liquid concentration on and close to the finished surface is slightly higher than in the body of the material. This in turn creates higher stresses (shrinkage) on the surface of the material upon complete curing. Over a very short period of time, generally within a few weeks, these stresses relieve themselves through surface crazing. Since mma-based polymer concrete is a thermoplastic material, the rate at which this crazing phenomenon occurs is influenced by surface temperature, which is higher around the perimeter of the structure where it is exposed to direct sunlight.

Using different finishing techniques and/or minimizing over-troweling during application will generally reduce/eliminate surface crazing.

Chloride Contaminated Concrete

Serious corrosion problems were initially induced into this garage by chloride ion concentrations from 3 to 10 times the accepted threshold limit. Ample amounts of water on the surface of the water exist because water can be carried in by vehicles as well as driven in through the open walls in the garage. Therefore, it is likely that the corrosion process was never completely stopped by the relatively impermeable overlay. The corrosion process appeared to be dormant for a certain number of years, that is, for the first 10 years of its service life no visible problems appeared. Had conductivity tests been conducted immediately after the initial installation, it may have been discovered that latent corrosion existed from the initial overlay installation. It appears that it may have taken 10+ years before the essentially impervious acrylic reactive primer and mma polymer concrete lost their protective capabilities and "oxidation pressures" opened up conduits to the moisture from the surface. The exposure to surface moisture subsequently accelerated the corrosion process so that in relatively few number of years numerous delaminations could occur.

SUMMARY

After 13 years of service, a thin ($\frac{1}{4}$ in.) mma polymer concrete overlay was found with continuing corrosion deterioration of the reinforcing steel. Inspections made during the service period, however, did not show conditions as they appeared in August 1995. The useful life of this parking structure has been significantly increased by the 1980's repair work without intervening additional investment expenses. For

about 10 years after the initial repair installation, the repairs appear to have met all of the design engineers criteria for performance. In areas where the concrete had been found in 1981 to be freeze-thaw deteriorated, the mma polymer overlay has performed well in protecting the surface from additional freeze-thaw deterioration. No large sheets of overlay material were delaminated in areas previously exhibiting extensive freeze-thaw deterioration. The entry level overlay experiences all the inbound and exiting traffic in the garage. No signs of wear to the overlay exist nor has leaking into occupied space below persisted.

The state-of-the-art in rehabilitating structures exhibiting distress, as this one did in 1981, has advanced. The crazing phenomena appears to be a function of bringing too much liquid up to the surface by using a steel trowel, other finishing techniques now exist and can reduce this situation. The application of an active corrosion inhibitor capable of scavenging free electrons (such as a zinc-containing primer), on the originally corroded reinforcing steel prior to patching/overlaying, could possibly have prevented the continuing corrosion observed in 1995. Possibly the selection of a wider overlay strip would have also permitted the substrate concrete to dry out beneath the thin overlay in the region where the deformed bars are terminated, thus eliminating the moisture which promoted the corrosion of embedded steel in chloride contaminated concrete.

While all of the engineering objectives stated earlier in this paper were not met at the 13-year service life, some of the objectives have been and the project should not be considered a failure. Considering all the circumstances prior to and since the rehabilitation project, the materials used did perform the function of extending the useful service life of this structure by more than 13 years. Regardless of how repairs to post-tensioned or reinforced parking garages are carried out, or whichever materials are employed, owners must realize that preventive maintenance is part of an equation that is part of extending the service life of structures susceptible to environments that can cause deterioration.

Reference

- (1) Meinheit, Donald F. and Monson, Jack F., "Parking Garage Repaired Using Thin Polymer Concrete Overlay," *Concrete International, Design and Construction*, V. 6, No. 7, July 1984, pp. 7-13.

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TABLE 1 — CONCRETE CHARACTERISTICS IN 1981

• Average core compressive strength:	6000 psi+
• Air-void characteristics	
- Heavily scaled:	3.8%
- Moderately to lightly scaled:	4.9%
- No scaling:	8.6%
• Chloride ion content	0.10 to 0.30 percent
- Measured ½ in. below top surface	(by weight of concrete)

TABLE 2 — RESTORATION ALTERNATIVES

- Cementitious or polymer modified concrete patching
- Waterproof membrane with heavy duty traffic bearing wearing coat
- Concrete overlay
- Cathodic protection
- Thin polymer concrete overlay

TABLE 3 — PRELIMINARY PERFORMANCE CONCLUSIONS

- Corrosion is continuing on deformed reinforcing steel.
- Nonstructural cracking has occurred along both deformed bars and post-tensioning tendons.
- The overlay on freeze-thaw damaged concrete is well bonded although crazed.
- No signs of mma polymer concrete wear were found.
- None of the post-tensioning tendons have been reported to have fractured.
- Application technique and direct sunlight has some influence on the crazing of mma polymer concrete.

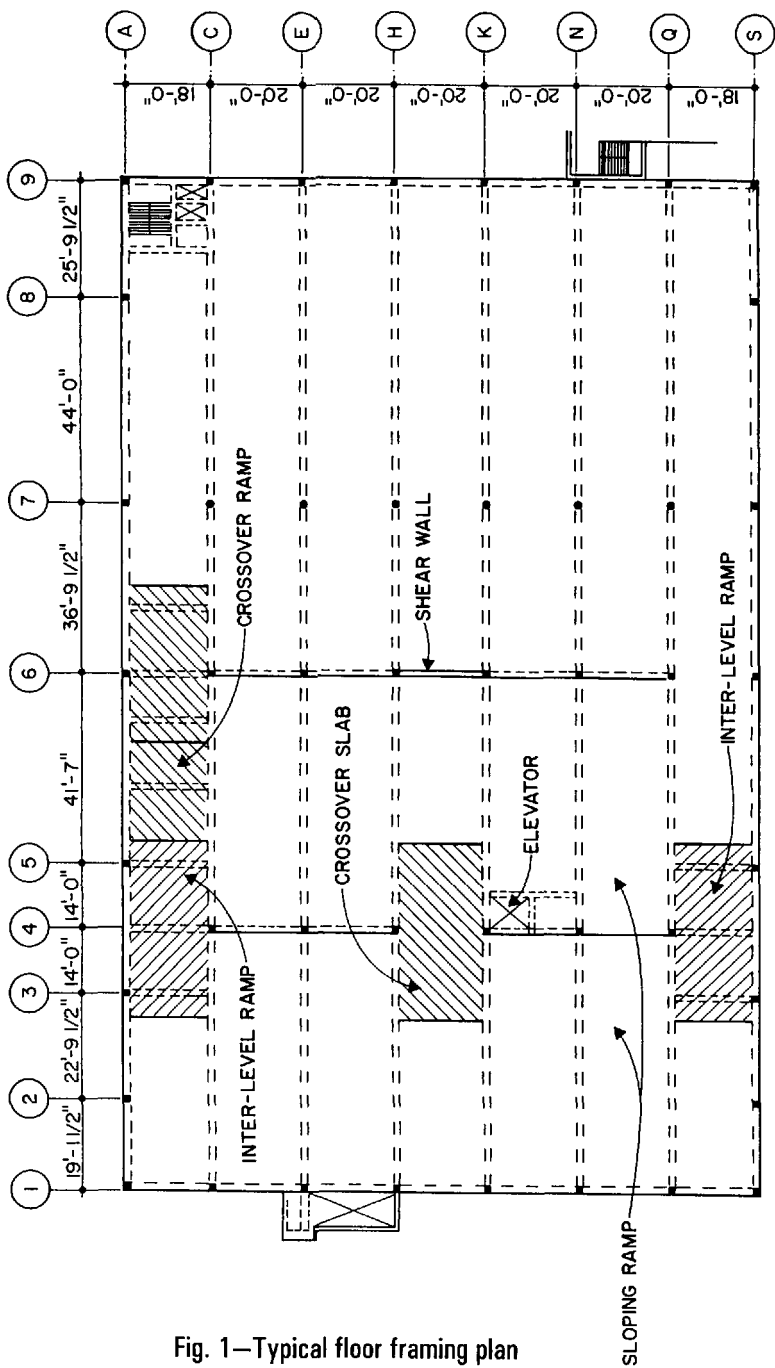


Fig. 1—Typical floor framing plan

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Fig. 2—Freeze thaw damaged concrete

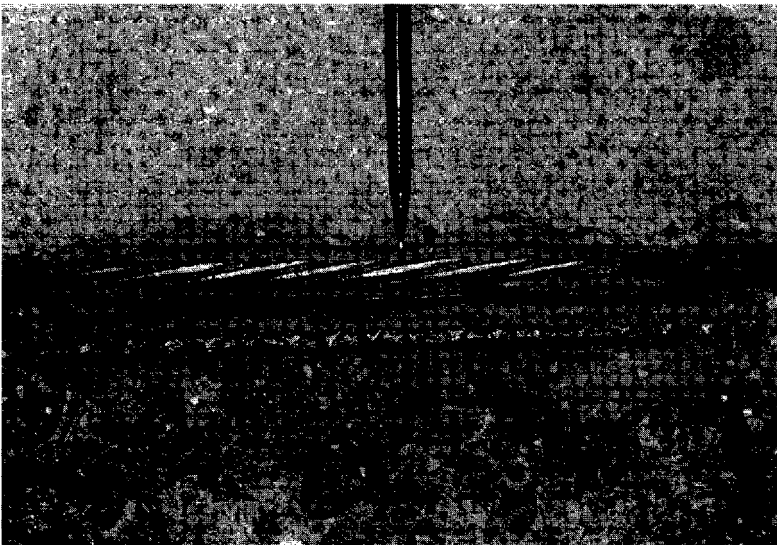


Fig. 3—Corroding, deformed bar and exposed, corroding post-tensioning tendon

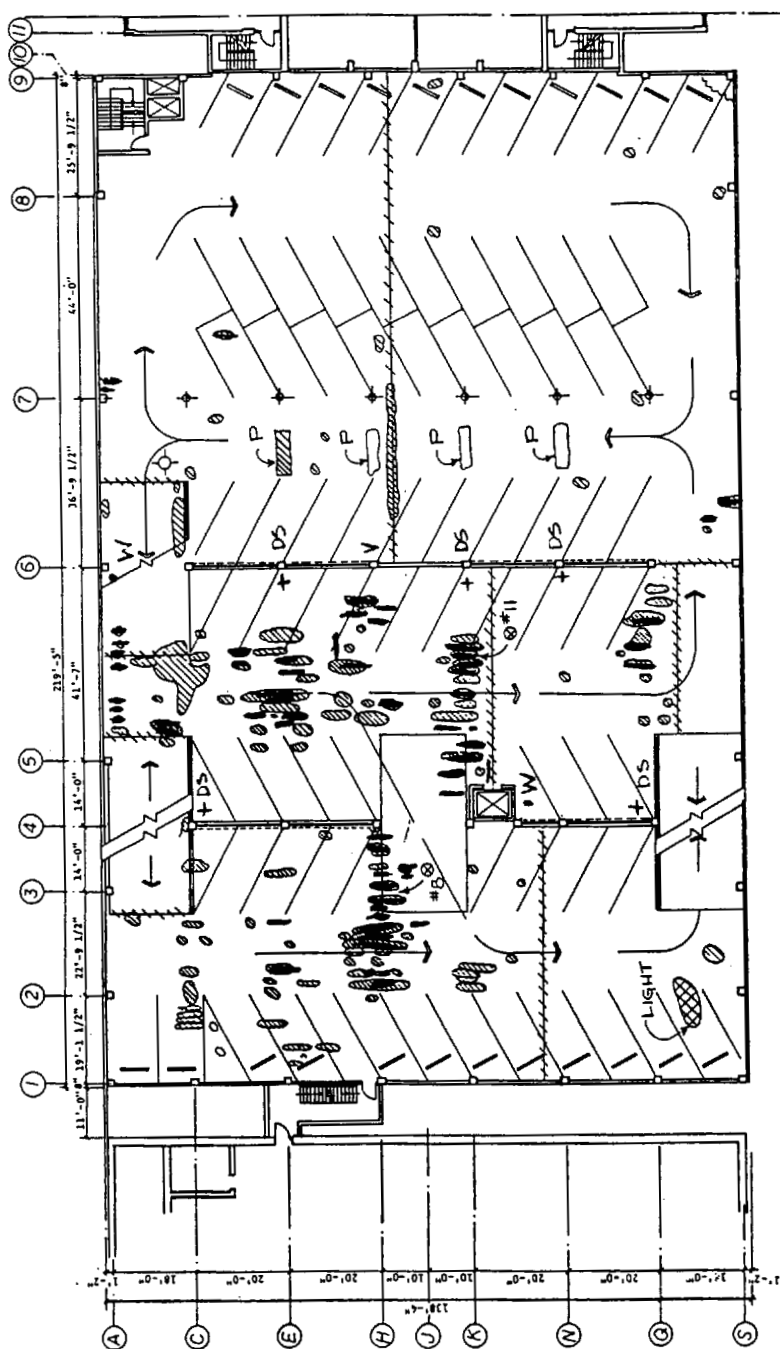


Fig. 4—Deck slab with numeruos delaminations and exposed reinforcements

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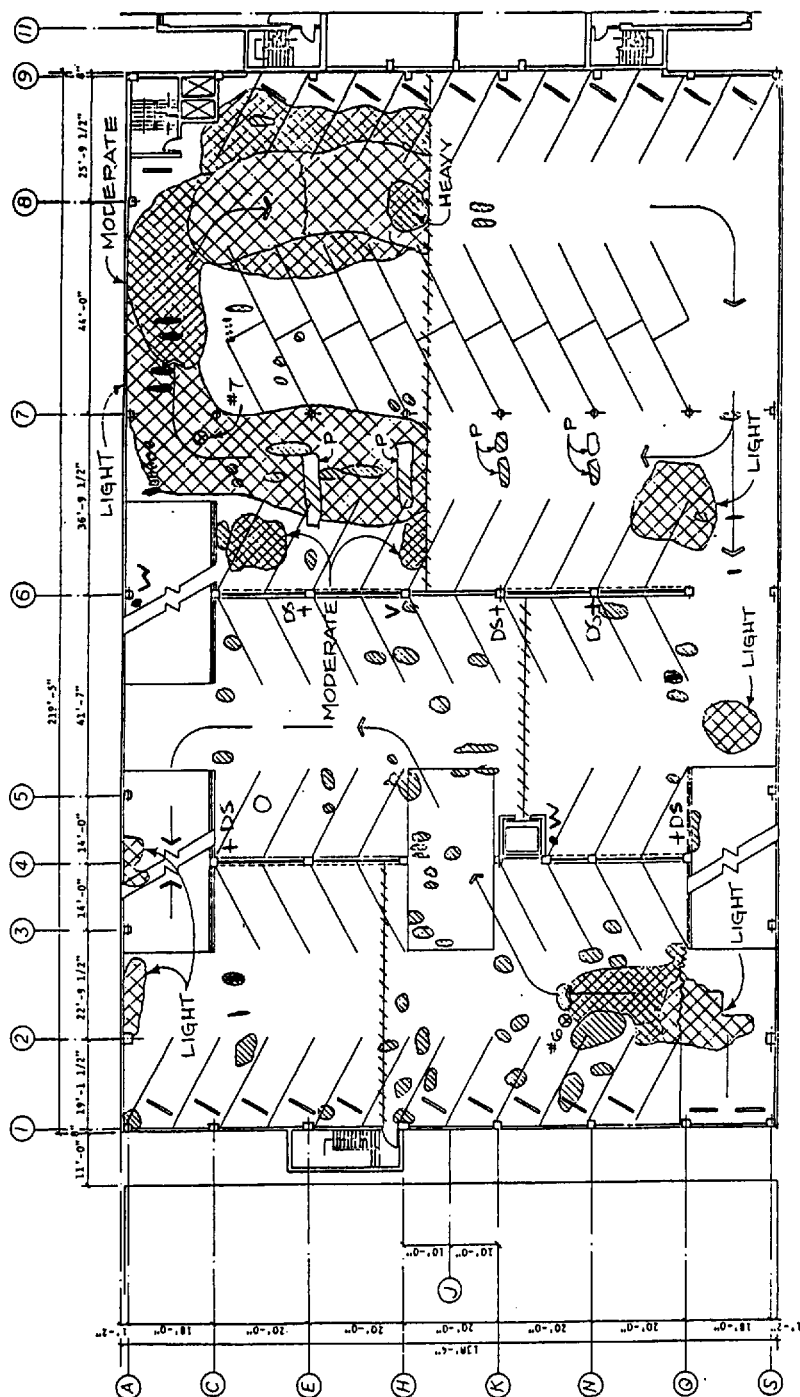


Fig. 5—Deck slab with surface scaling

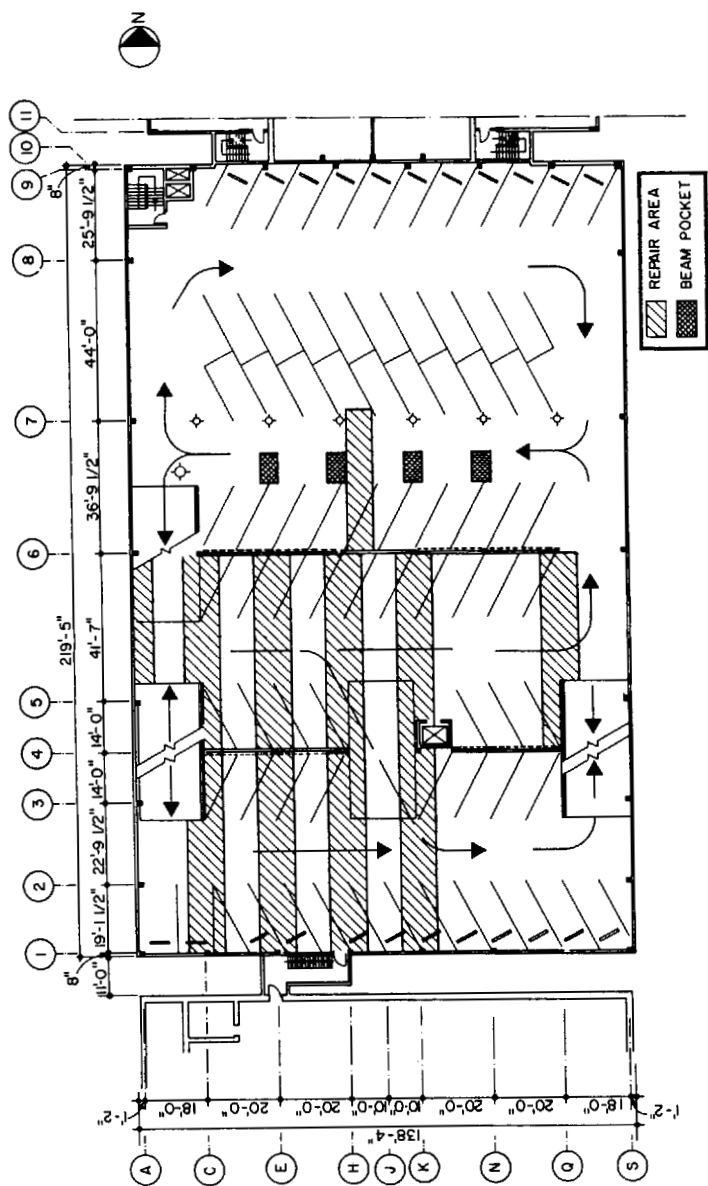


Fig. 6—Plan view of typical repair scheme

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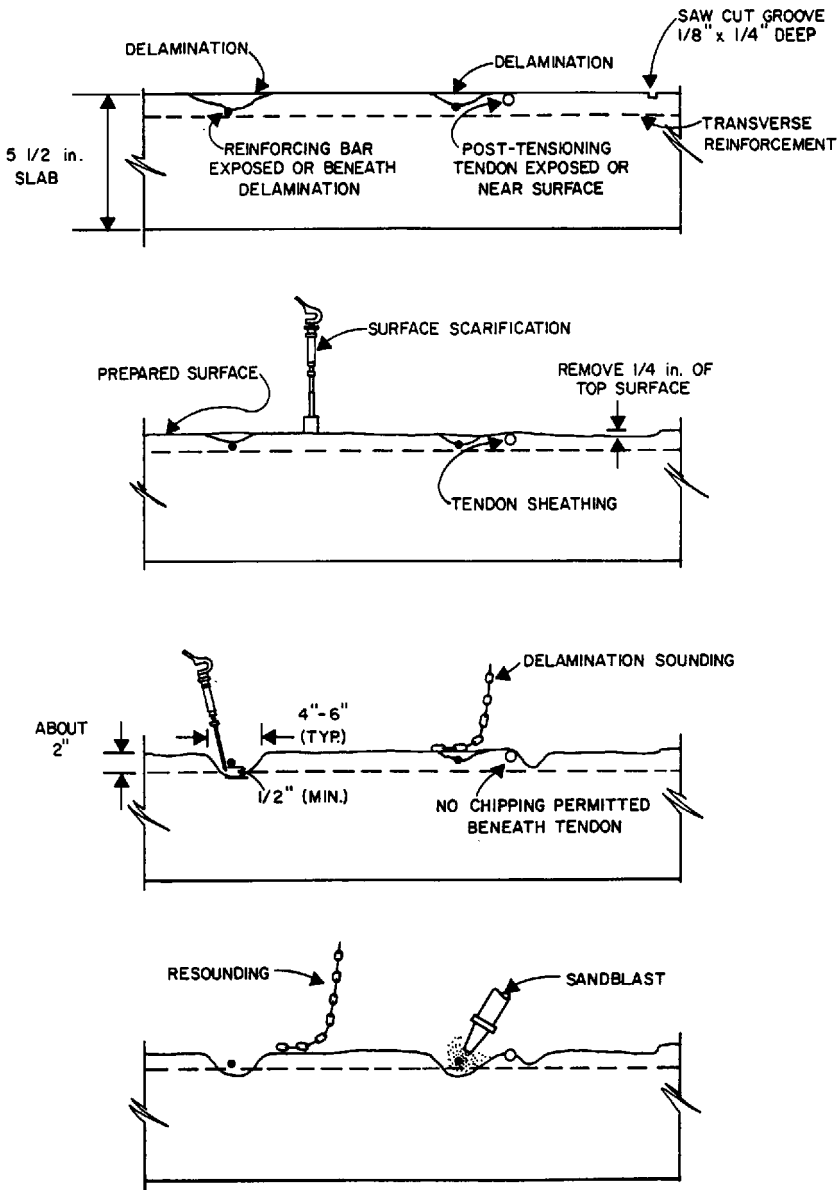


Fig. 7—Surface preparation sequence

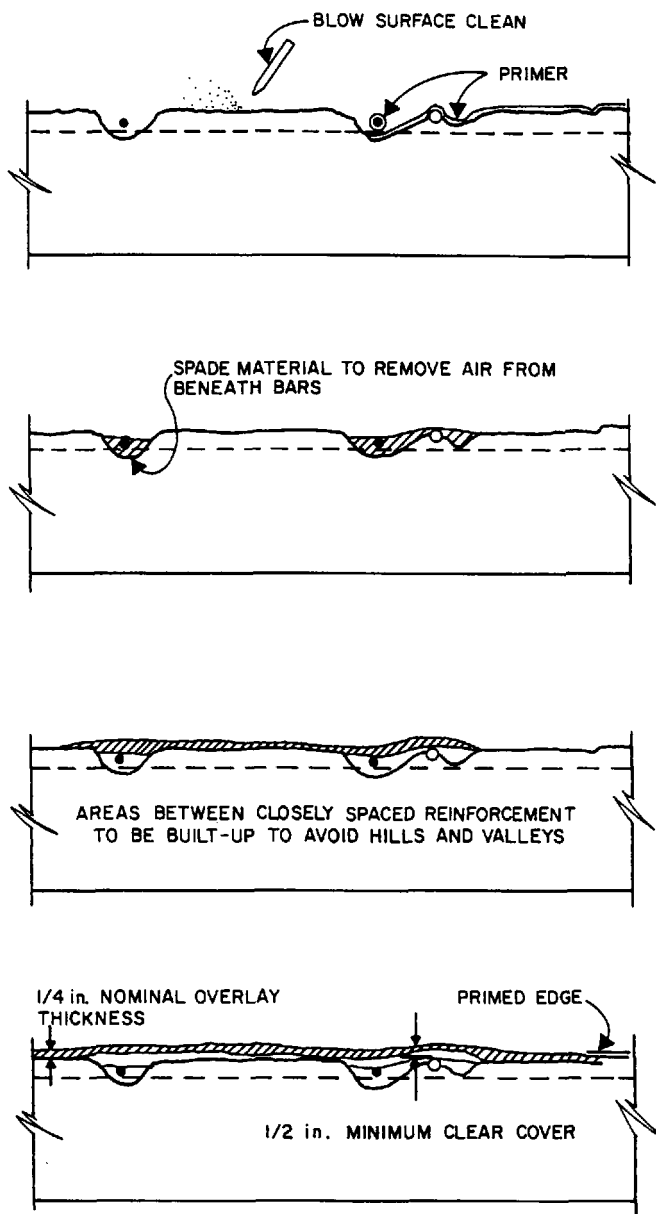


Fig. 8—Polymer concrete overlay repair sequence



Fig. 9—Delaminations in mma polymer concrete overlay

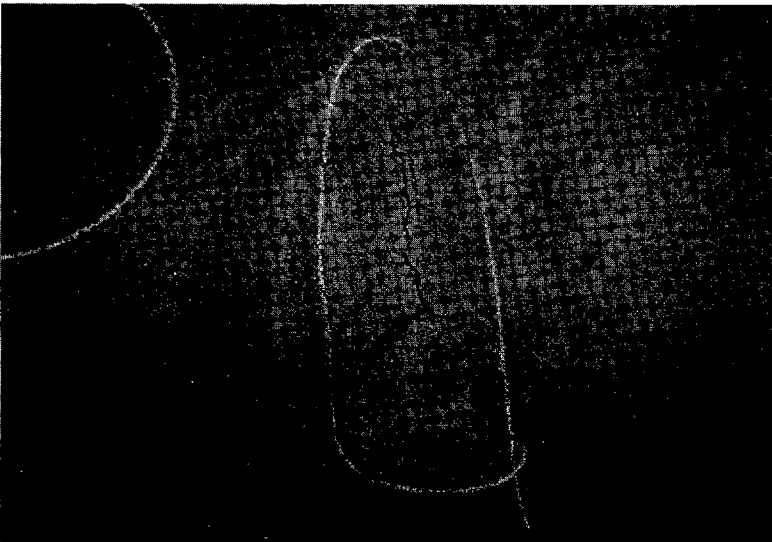


Fig. 10—Long cracks with corrosion staining



Fig. 11—Local cracking and delamination



Fig. 12—Corroding reinforcing bar below local mound-type cracking and delamination

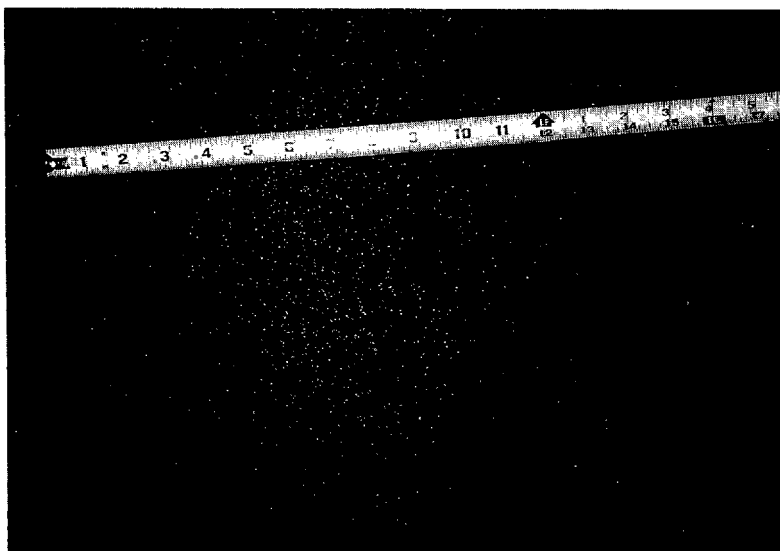


Fig. 13—Surface crazing of mma polymer concrete

SP 169-3

Nineteen Year Performance of Polymer Concrete Bridge

by Michael Sprinkel

ABSTRACT

The performance of polymer concrete bridge deck overlays ranging in age from 6 to 19 years is presented. The performance is based on tests for tensile bond strength, permeability to chloride ion, thickness and skid number. The physical and mechanical properties of the concretes used, the types of uses, the application methods, and the economics, are also described. It is shown that multiple-layer epoxy, multiple-layer epoxy urethane, and premixed polyester styrene polymer concrete overlays can provide skid resistance and protection against intrusion by chloride ions for 20 years or more and are an economical technique for extending the life of concrete decks reinforced with black steel, particularly when overlays must be constructed during off-peak traffic periods to minimize inconvenience to motorists. Also, multiple-layer polyester overlays have a life of ten years.

Keywords: Bridge decks; epoxy resins; permeability; polymer concrete; skid resistance

INTRODUCTION

Polymer concrete overlays similar to those currently in use have been installed on portland cement concrete bridge decks in many states during the past 20 years. The overlays are usually placed on decks to reduce the infiltration of water and chloride ions into the concrete and improve skid resistance, ride quality, and surface appearance (1,2).

Three types of overlays are typically used:

- Multiple layer: two or more layers of unfilled polymer binder and broadcasted gap-graded, clean, dry, angular-grained aggregate;
- Slurry: a polymer aggregate slurry struck off with gauge rakes and covered with broadcasted aggregate; and
- Premixed: a polymer concrete mixture consolidated and struck off with a vibratory screed.

The objective of this paper is to describe the performance of polymer concrete overlays used on concrete decks. The evaluation is based on background data obtained from Strategic Highway Research Program (SHRP) Project C103 in which decks were evaluated in 1991, and tests of cores from the decks and skid numbers obtained from Department of transportations (DOT) in 1995 (3,4). The economics of polymer concrete overlays constructed in accordance with currently accepted practice are also described.

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POLYMER CONCRETES AND MORTARS

The most frequently used binders for polymer concretes and mortars are epoxy, epoxy urethane, polyester styrene, and methacrylate (4, 5,6). The binders are usually two-component systems: one component contains the resin and the second contains the curing agent or initiator. The aggregates are usually silica and basalt. Fillers, such as coke breeze, are used to impart conductivity when the overlays are used as part of a cathodic protection system (7). Typically, uniformly graded aggregates are used with slurry and premixed overlays, and gap-graded aggregates are used with multiple-layer overlays and are broadcast on the top of slurry and some premixed overlays (Table 1).

Monomers and Resins

Binders for polymer concretes and mortars are usually classified on the basis of the properties of the uncured and cured binder and the cured polymer concrete or mortar (Table 2) (4-6, 8-13). Epoxy urethane binders have properties that are similar to those shown for epoxy with the exception that the viscosity is typically higher (35-70 poises).

Table 2 shows a typical range of values for viscosity and gel time (4-6, 8-9). The viscosity of the individual or mixed components affects the coating of the aggregates and the surface on which the polymer is placed. Binder resins with a low viscosity are specified for highly filled premixed and slurry mixtures and prime coats. Resins with a higher viscosity are usually specified for multiple-layer overlays to allow for proper coating and filling of the space between the