POLYESTER CONCRETE IN BRIDGE DECK OVERLAYS

Caltrans

District 4 Bay Toll Bridge Program

POLYESTER CONCRETE IN BRIDGE DECK OVERLAYS REPORT

SFOBB East Spans Safety Project Skyway Structure

O4-ALA/SF- 80-VAR

Ric Maggenti P.E.
Senior Materials & Research Engineer
Caltrans District 4 Bay Toll Bridge Program
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PREFACE

The "Skyway" portion of the new east spans of the San Francisco Oakland Bay Bridge (SFOBB) is to be a precast segmental constructed concrete structure. To achieve a smooth profile grade with the anticipated segmental construction either the finished product will need to be ground to a significant extent, or an overlay will be needed to smooth the profile. The designers chose the latter, though they had in mind a modified AC.

One reason polyester concrete overlay was later chosen was because it was developed as an engineered overlay for pcc decks. The system was engineered keeping in mind properties such as thermal coefficient of expansion, young's modulus, bonding properties, and toughness. These are reflected in our specifications. So actually from an engineering point of view, the end product of the deck is a composite of pcc and polyester concrete. Since the deck section becomes a composite material, the overlaid deck is still considered a 'bare deck'—a deck where signs of deterioration can be easily seen.

In addition to being used to rehabilitate old decks, it is now beginning to be used on new construction. Besides the anticipated use on the new SFOBB, one-inch overlays have been placed on newly constructed decks on I-80 near Truckee in the Sierra Nevada Mountains where bridge decks have a short life due to the heavy chain traffic and salt used for ice control.

The 20 year design life used for calculating life cycle cost for polyester concrete overlays is conservative and is subject to change as time and our data base increases. The first polyester concrete meeting substantially the present system was put down only in 1983 on Thomson

Keywords: Polymer concrete, aggregate, polyester resin, corrosion, bonding

Creek and Beaver Creek in District 2. There have not been any reports of any degradation of these very first systems, which are over 18 years old now.

Early laboratory tests indicated the superiority in terms of durability of polyester concrete. The California Test 550 for surface abrasion resistance and the ASHTTO Rapid Chloride Permeability tests were used for evaluation. Comparing the results of surface abrasion resistance per Test 550 shows that polyester concrete has a greater surface abrasion resistance than Portland cement concrete by a factor of 10. Typical abrasion loss per the test method for polyester concrete is around 2 or 3 grams while for high strength high performance concrete it is above 20 grams. A rapid chloride ion test was done in 1986 on a core taken from the Hayfork Creek Bridge that had polyester concrete placed on it in 1984. Less than 1 coulomb passed through the core. A high performance low permeability concrete is considered to have low permeability if it has less than 1000 coulombs passing per the test method.

Actual field tests done on polyester overlays have corroborated the lab tests. Field wear measurements on an overlay placed on pavement on I-80 subjected to chain wear etc. showed the surface was wearing less than .015 inches per year, substantially less then the pcc pavement in the area that is subject to rutting. Half-cell potential measurement done on the first bridges receiving this system indicated the steel was protected against corrosion. Therefore, all indications lead to concluding a polyester concrete wearing surface will far outlast a pcc while giving added corrosion protection to the deck reinforcing steel. Everything else aside, the polyester overlay should result in a superior riding surface and a superior deck.

Caltrans routinely uses premixed polyester concrete. Its success can be attributed in a large part to the Caltrans bridge construction engineers who oversaw the first projects large and small. Some of these engineers who first guided polyester projects still work for Structures Construction and are still available as sources of information. The list includes: Sonny Fereira, District 2, who was involved with some of the very first projects in District 2 such as Hayfork Creek Bridge on Rt. 36, and is still active in the continuing evolution of the specifications; Roberto Luena, District 4, who did the 250,000 sq. ft. Marina Viaduct during nighttime shifts opening the roadway to Marin County to San Francisco commuter traffic every morning without fail until the deck was completed; and Victor Maletic, District 4, who did Scofield Ave UC in 1988, the first bridge deck done with a continuous mixer.

The following report is a re-written version of document I wrote for a conference given by the International Congress of Polymers in Concrete. That document, presented at the conference, was edited by Leo Ferroni, a retired Caltrans engineer who had pioneered the polyester concrete system now used by Caltrans. Jerome L. DeVibiss formatted that article on a word processor, proofread it, and submitted it to the conference. Jerome L DeVibus also provided pictures for the Power Point presentation. Michel Sprinel did the Power Point presentation. Mr. Sprinkel, who has wide and lengthy experience in polymer concrete systems, is a Research Engineer for the Virginia DOT Research Council. Mr. Sprinkel had written SHRP reports on concrete overlays for bridge deck protection, which included a field and laboratory investigation of several of the 1st polyester concrete overlays done in California. A hard copy of the power point is included in an appendix. Also included in an appendix is a sample draft specification with commentary originally produced for AASHTO.

In addition to the "Skyway" polyester wearing surface on the traveled way and shoulders, the new SSOBB includes a pedestrian and bicycle path that will also receive a polyester wearing surface. This polymer concrete will have color requirements to distinguish pedestrian from the bicycle travel ways.

It is intended that this document be used as technical reference material by anybody involved in the SFOBB project.

Ric Maggenti Oct. 9, 2001

INTRODUCTION

The two main functions of polyester concrete overlays used on bridge decks are to establish a smooth riding surface profile grade, and protect the reinforcing steel in the deck. An overlay needs to be durable to traffic wear, petroleum products, weather condition, ultraviolet radiation and other environmental conditions. To protect bridge deck steel the overlays need to be impermeable to chloride ions and free of cracks that allows the intrusion of chloride ions. To meet the intended functions it must bond to the substrate. An unbonded overlay will eventually break up, while it can also result in salt solutions concentrating at the unbonded interface accelerating corrosion.

These main functions make a polyester concrete an ideal material for at least the skyway portion of the new east spans of the San Francisco Oakland Bay Bridge (SFOBB). This portion of the new spans is to use segmental construction methods. After the segments are completed, the riding profile grade will need to be addressed by either grinding to a smooth profile grade or by adding an overlay as the riding surface. A pre-mixed polyester system in addition to providing for a smooth riding surface will protect deck steel from corrosion as well as potentially outlasting even high strength high performance pcc.

The purpose of this report is to serve as a reference guide to those engineers that will be involved with the riding surfaces that are to receive polyester concrete on the SFOBB project. This report covers: 1) the historical development of pre-mixed polyester overlays used by Caltrans; 2) field evaluation of various overlaid bridge decks using pre-mixed polyester concrete; 3) placement techniques and physical properties affecting performance of bonded polyester overlays; 4) relationships between successful overlays and laboratory measurements; 5) theoretical analysis of overlay stresses; 6) field quality control testing procedures and standards; and 7) health and safety issues.

Polymer Concrete Overlay Principles

There are two placement methods for different overlay materials. The first consists of premixing all the components and placing the resulting concrete mixture to the desired grade and thickness using strike-offs and screed rails or a slipform operation. The second method, sometimes referred to as "broom and seed", is to apply resin to the substrate and broadcast, or scatter, the aggregate onto the resin. This is repeated until the desired thickness is achieved. If the final total thickness is less than 1/2-inch, it is considered a chip seal since this resembles asphalt chip seal technology. Its primary function is to add or restore skid resistance. The system discussed in this report and the planned system for SFOBB is the former, sometimes referred to as pre-mixed polymer concrete.

After a couple of decades of usage, the pre-mixed polyester concrete overlay system has been successful in restoring and protecting bridge decks. A bonded, premixed polyester bridge deck overlay provides many benefits. It provides chloride protection for bridge deck reinforcement steel while restoring roadway profiles and ride quality. Since the polyester system tends <u>not</u> to crack, the entire deck is protected, not just the portions between cracks. When placed as a thin overlay, typically 12 to 50 millimeters thick (1/2 to 2 inches), dead loads and modifications to approaches, barrier rails and overhead clearances are minimized. The overlays are easily placed with conventional PCC mixing and placement equipment. Using polyester (thermosetting) resin, set time can be controlled in the field by adjustments to initiators so that overlays can be placed under both the hot conditions of a desert and the cold night temperatures in coastal or mountainous area. As a result, two to four-hour cure times, which allow a rapid return to public traffic, are achievable under a wide variety of temperatures.

In the early opinion of engineering staff of the Caltrans Division of Structures, who were responsible for the evaluation of bridge deck overlays for the State of California, this system appeared to be universally superior to all other overlay systems in durability, crack resistance, chloride ion intrusion, bonding, ease of construction and lane closure time (Memo from Ed Dunn to Bridge Deck Protection Committee, 1984). Because premixed polyester polymer concrete has proven to be successful, it has been used routinely since its acceptance by the FHWA as a non-experimental overlay material in 1988.

History Polyester Concrete Overlay

The idea of using polyester for roadways occurred in the 1950s when Neil Estrada, then with the Reichhold Chemical Company, placed a number of small overlays, particularly, one on the Oakland-San Francisco Bay

Bridge in 1961. It was a "broom and seed" method.

Bonded, premixed polyester polymer concrete overlays were later developed in about 1978 using high viscosity polyester resin with silane couplers and a Fuller grading. They were first placed on a California Portland cement concrete pavement on I-80 at the 5,000-foot elevation in 1979. It proved to be very difficult to mix and to place, but still showed promise. This was also the first placement to use steel shot blasting for substrate preparation in California. [FHWA/CA/TL-85/16 "New Materials and Techniques for the Rehabilitation of Portland Cement Concrete", Ferroni, Krauss, Neal].

That system is an adaptation of the early polyester/styrene overlays described in a 1977 Oregon Department of Transportation Report for the Federal Highway Administration, (Jenkins, Beecroft and Quinn). Placement was by roller compaction, essentially an asphalt paving technique. The aggregate gradation was the Fuller's maximum density gradation, which is a mathematical straight line plot of retention vs. gradation, and the resin was a high viscosity resin (~1000 cps), incorporating silane couplers.

The main two differences between the Oregon DOT Report or the 1979 overlay on I-80 and the current system used in California are a change in the gradation of the aggregate, and the viscosity of the resin. By changing the aggregate gradation to the "banana" curve and adding styrene, a mixable resin with about the right physical properties was achieved. The resin now used has a specified viscosity of 100-200 cps and 1% silane coupler. Neil Estrada and Kiyoshi Sakakura, with Reichhold Chemicals at the time, reviewed the resulting resin and performed Izod Impact vs. Viscosity, Elongation & Tensile Strength vs. Viscosity, and, Styrene vs. viscosity tests with encouraging results. (Figures 1 & 2).

These modifications, the refinements to the gradation and resin viscosity, eased placement by allowing the use of pcc placement methods, techniques, and equipment. Since these refinements, polyester concrete has been successfully used in California since 1983 for restoring and preserving bridge decks from damage by road salts. The premixed, polyester concrete overlay system routinely used today in California is essentially the same as an experimental overlay placed on Beaver Creek Bridge deck on Rt. 96 in 1983.

The genaric specifications developed produced polymer concrete meeting material design expectations. Consistent engineering properties have been maintained by controlling the material properties of the resin and aggregate as well as the ratio of resin to aggregate. Polyester polymer concrete overlays have been placed on bridge decks and highways in California from the Oregon Border to Mexico and from the Pacific Ocean to the Nevada Border. They have been placed under a variety of conditions. Selected decks were evaluated every few years and performed well under all climates. These overlays were monitored for cracks, debonding, coefficient of friction, corrosion activity, and surface abrasion.

The first decks utilizing the polyester polymer concrete overlay design now in use were placed in 1983 on Route 96 in the Klamath National Forest, Siskiyou County (Beaver Creek (2-81, Sis-96- 52.5), and Thompson Creek 2-68, Sis-96- 88.3). Both bridges are in alpine environments on decks where travel is light. Two more bridges were overlaid in the summer of 1984 on rout 36--Hayfork Creek (5-7, Tri-36-38.4) in Trinity County, and Beegum Creek (6-57, Sha-36-11.9) in Shasta County. The overlays are still functioning well. Because traffic volume is low on these four bridges, only construction techniques and effects of environmental stresses, such as ultraviolet radiation, freeze/thaw cycling and weathering could be evaluated. To date, these stresses have not affected the performance of the overlays in any discernible way.

Beginning in the fall of 1984, the premixed polyester system began to be placed on roadways and bridge decks with heavy traffic volumes. The properly designed and constructed overlays held up well. A notable example is a 1985/86, 10-lane-mile placement on I-80 near Whitmore. It is at 5,000 feet (1,500 meters) elevation with high-volume truck traffic and subjected to chain wear and snowplowing in the winter. Though construction practices and material deficiencies (angular rock and insufficient resin content) encountered in the 1985 portion had affected its durability, the 1986 portion performed satisfactorily. The only distress was seen at the joints of the jointed plane concrete pavement substrate. The joints in the overlay were not properly located over the pavement joints causing some spalls to occur. The overlay was removed when the entire roadway section in the area was rehabilitated about 1997.

Before its removal, wear indicators placed in the wheel tracks showed an average annual wear of less than 0.38 millimeters (0.015 inches). This is in contrast to pcc pavement visibly rutting in this area of highway. To date, no traffic-induced failures have been noted on any properly designed and constructed overlay.

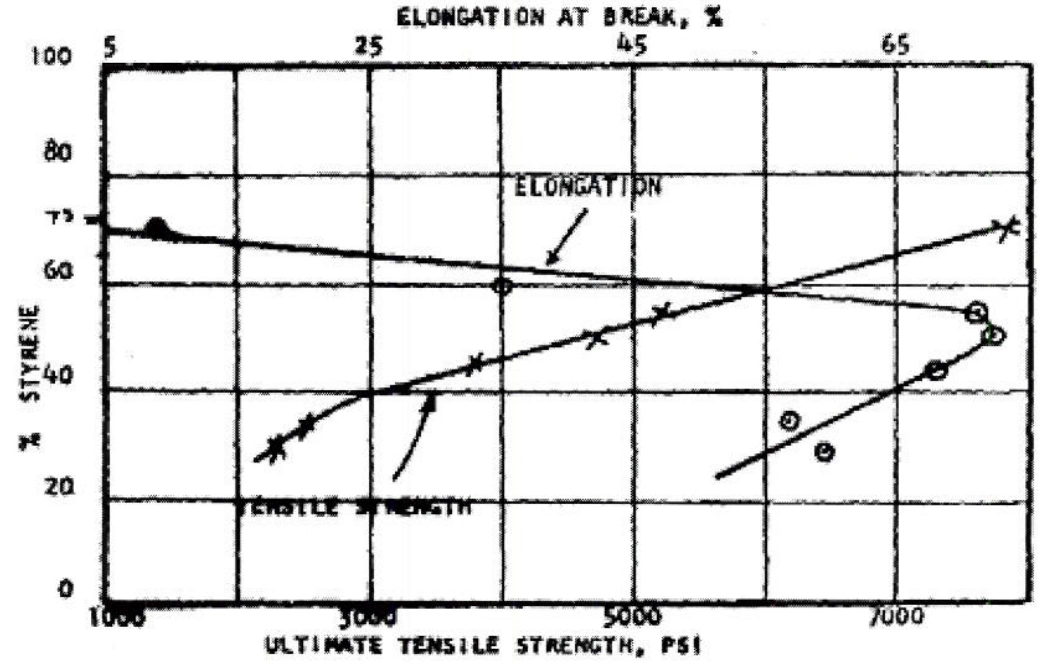
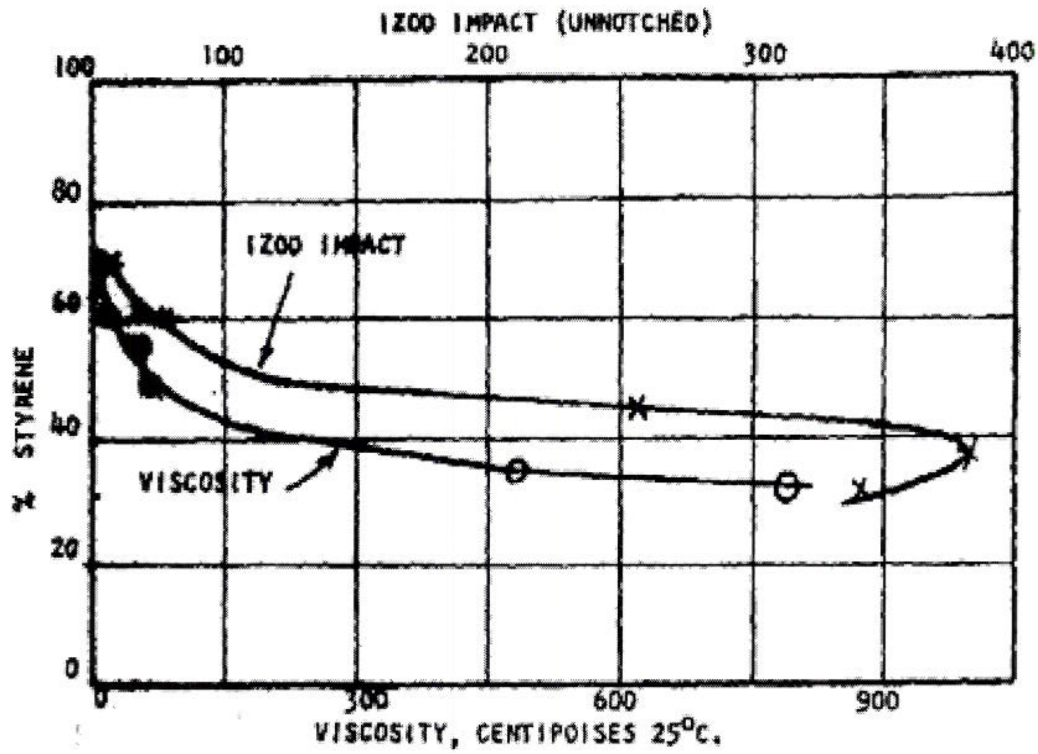


FIGURE 1

FIGURE 2



Polyester overlays were constructed under a variety of environmental conditions. A polyester concrete overlay on the Marina Viaduct (the San Francisco approach structure to the Golden Gate Bridge), was completed in July 1992. Traffic flow would have to be interrupted when a quarter million square feet (23,000-sq. m) of deck was overlaid. All placement and preparation, such as surface cleaning and installing grade control string lines, were done at night. All lanes were reopened to traffic each morning. This meant having the overlay ready to support traffic a maximum of two hours after placement, even when temperatures fell below 45°F (7°C). Fog and mist were issues that needed to be dealt with. At about the same time, approximately 150,000 square feet (14,000 m^2) of bridge deck were placed on I-15 near Victorville in Southern California's high desert with ambient temperatures as high as 100°F (38°C). Both of these jobs utilized continuous mixers and paving machines.

History has shown that two important factors determine a successful overlay: construction materials and construction practices. The design and specification engineers control the materials, while the construction engineers control practices and techniques.

Theoretical Analysis of Overlay Bond

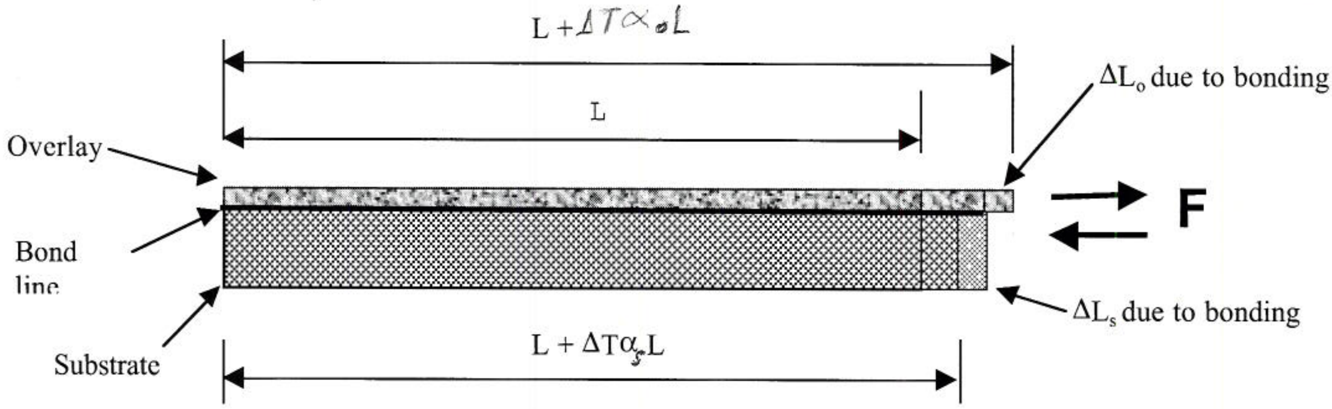
In the process of evaluating model overlays 3.7 by 0.3 meters (12-feet long by 1-foot-wide) of varying thickness, three observations were noted: (1) in some overlays that were very well bonded, stresses were produced that failed the PCC substrate in shear; (2) in other bonded overlays that did not fail in the substrate, this shear stress appeared to be relieved by the cracking of the overlay; and (3) thermal cycling brought on both these types of a failures if they did not appear initially.

These observations show that differential movement of the overlay relative to the substrate creates stress if the bond does not allow independent movement. If the overlay has a different thermal coefficient of expansion than the substrate, temperature changes create a potential energy that is resisted by the force transmitted by the bond. A simplified model of this stress on the bond line is illustrated in Figure 3.

This model neglects: plastic flow or creep, that the overlay is unrestrained above the bond line, heat capacity, and thermal gradients. These first two factors could be accounted for by multiplying the whole equation by a constant, probably less than 1, the value depending on the material. If the heat capacity is sufficiently higher in the substrate than in the overlay, or if for any other reason the overlay changes temperature significantly faster that the substrate, then the alpha of the substrate can be ignored. But the result would be a higher stress since mathematically this is the same as assuming it has an alpha of 0. Solar heating of an overlay can cause a thermal gradient such that the overlay, receiving direct sun, might be significantly warmer than the substrate, which has a greater mass and, therefore, a larger heat capacity. Similarly, ice or snow can produce the same thermal shock.

The theory led to examination of four parameters. The four parameters considered were bonding strength, modulus of elasticity, thermal coefficient of expansion and cross sectional area. The data collected on the four parameters mentioned above may prove useful for future analytical work.

What appears important is that the thermal movement and the stress strain characteristic of the material account for immediate stress at the bond plane.



So, the force at the bond line would be a function of the equation:

$$F = \Delta T(\alpha_o - \alpha_s)\left(\frac{1}{E_o A_o} + \frac{1}{E_s A_s}\right)^{-1}$$

Where: F is the force developed

ΔT is change in temperature

α_o and α_s are the thermal coefficients for overlay and substrate

E_o and E_s are Young's Moduli for overlay and substrate

A_s and A_o are cross sectional areas for overlay and substrate

L is length before temperature change

FIGURE 3

Laboratory Measurements

Moduli of elasticity were measured in compression. Bonding strengths were measured by casting the concrete against the vertical face of a PCC sample and loading the resultant beam in flexure. Young's modulus and bond were measured per California Test 551. A device was fabricated to measure thermal coefficients of expansion. (More details of this equipment can be found in a March 17, 1987, memorandum to R. N. Doty from P. Krauss and G. Yowell, Minor Research Project, Determination of Expansion of Proprietary and Generic Concrete, File EA 631140-30017). The device held a 3 by 3 by 10-inch concrete specimen in a horizontal position inside a muffle that served as a heat exchanger. The measuring apparatus consisted of two vertical steel bars pivoting on an invar actuator rod on the bottom and attached to the pins embedded into the ends of the sample. An invar actuator rod was fastened to a linear variable differential transducer (LVDT) between the top and bottom of the vertical bars. Changes in length could be read over a temperature range of 10-degree C to 70 degree C. Results for some of the samples are shown in Table 1.

Concrete Material	Thermal Coefficient of Expansion	Modulus of Elasticity	Flexural Bond Strength
Magnesium Phosphate	15.9 x 10 -6 /°C	5.5 x 10 -6 psi	400 psi
High Molecular Weight Methacrylate	31.3 x 10 -6/°C	5.5 x 10 -6 psi	+1,000 psi
Type II Polyester	14.6 x 10-6/ °C	2.0 x 10 -6 psi	+1,000 psi
Conductive Polyester	28.6 x 10-6/°C	1.2 x 10 -6 psi	+1,000 psi

TABLE 1

Thermal Coefficient of Expansion Testing

The moduli of elasticity and bond strengths are typical values. The high molecular weight methacrylate (HMWM) shown in the table had a viscosity of less then 10-cps. The polyester was an isophthalic meeting current specification for Type II resin and the conductive polyester was the same used for the cathodic protection system placed on the O'Brien Undercrossing (Bridge 6-148L, 02-SHA-5-32) in 1988.

The Type II polyester polymer concrete thermal coefficient of expansion is similar to PCC, but its modulus of elasticity is less than half. The conductive polyester polymer concrete has about double the coefficient of expansion, but only about half the modulus of elasticity. Both of these systems perform well as bonded overlays. The high molecular weight methacrylate concrete performed poorly as an overlay; it tended to crack severely and shear the PCC substrate. It has a relatively high thermal coefficient of expansion as well as a high modulus of elasticity. The magnesium phosphate with its high modulus of elasticity has not performed well as an overlay. Bond strength is high for all four materials. The 400 psi for the magnesium phosphate, though lower than the other three materials, is still a very good bond value considering the severity of the test method. These results tend to confirm that modulus of elasticity is an important factor.

In addition to the physical characteristics outlined above, an overlay material should be workable enough to allow compaction with the equipment and techniques being used, but also have the ability to hold the desired grade lines. Properties that effect handling, such as set times, are factors that need to be considered

Material Control

The first priorities of a bonded overlay are to remain bonded and not contribute to the deterioration of the PCC substrate or the overlay. In addition to having good adhesion properties to PCC, it must not induce destructive stresses at or near the bond line. Temperature change creates a potential energy that is resisted by the force transmitted by the bond, which was previously discussed and illustrated in Figure 3.

It is important to control the thermal coefficient of expansion and Young's Modulus. Plastic flow or creep, heat capacity, heat transfer and polymerization shrinkage are factors that can affect stress values. Though these are not directly controlled, they are assumed to be indirectly controlled by specifying aggregate characteristic, styrene to isophthalic polyester resin ratio, viscosity range and specific gravity of the resin.*

The composite's thermal coefficient of expansion and Young's Modulus can be influenced significantly by resin and aggregate characteristics. The ratio of a given resin to a given aggregate determines the coefficient of expansion and Young's Modulus. As the aggregate fraction increases, the coefficient of thermal expansion approaches that of the PCC substrate reducing potential bond stresses due to temperature changes. However, as the resin fraction increases, Young's Modulus decreases, also reducing bond stresses caused by thermal movement. Precisely how much the thermal coefficient of expansion and Young's Modulus vary because of changes in the aggregate-resin ration has not been determined. Resin content is typically about 10% by weight, though contents as high as 14% have resulted in successful overlays. However, since resin is by far the most costly component, it has been kept at about 10%, primarily by controlling the aggregate characteristics. Recently, more efficient aggregates have been used resulting in resin contents below 8%.

The resin content required to fill the volume between aggregate particles and to achieve an adequately workable mix are directly related to the angularity, absorption and gradation of the aggregate, as well as the viscosity and wetting characteristics of the resin. Angularity is controlled by specifying only natural sand having a fractured face limitation of 25% of the aggregate retained on the Number 8 sieve. (However, with very efficient fine aggregate, the angularity of the courser aggregate becomes less important). Absorption is limited to 1%, which usually indicates a dense, sound rock as well. Dryness is limited to one-half of the actual absorption value of the rock. Gradation (or performance) parameters are specified and, though there is no check on resin wetting characteristics, viscosity is specified to be between 75 and 200 centipoise.

Young's Modulus is controlled by engineering the material properties and proportion of the resin. Adequate elongation and toughness are ensured by specifying 1/4-inch (6 millimeters) thick tensile specimens to have an

* PCC on PCC should work well and some states, notably Iowa, reported success. However, for bridge decks, a lack of cracks is important to success and since concrete shrinks there is a tendency for PCC bonded overlays to crack, at least on those observed in California. Pioneer overhead in District 2 (Bridge 2-36R/L, 02-SIS-5-9) is an example of a successfully bonded PCC overlay, but it has cracks every 1 to 4 feet. Latex admixtures, though easing stresses since they lower Young's modulus, still shrink thus crack

elongation of 35% or greater and tensile strength of at least 2,500 psi (17.25 Mpa).

Specific gravity and silane coupling agent requirements were derived empirically. Styrene content, as shown above in figures 1 and 2, effects toughness and elongation. These requirements for the resin were specified in the successful early overlays; therefore, they are still a part of the current specifications. This guards against unwanted surprises.

Control During Construction

Polyester overlays have been placed by a variety of contractors throughout the State. At the start of each contract, the contractor is required to place a trial slab. This demonstrates his ability to meet the intent of the specifications before placement on the deck or highway begins. Additionally, the trial slab gives the contractor an opportunity to gain experience or to try new equipment.

Proper surface preparation is essential to the success of an overlay. It is important that unsound concrete is removed and the deck is clean before placement of the overlay. Steel shotblasting of the PCC surface to a uniformly gray-white color has been the practice. Visible streaks where passes overlap indicates the surface is not clean. Cleanliness is as important for overlays on new decks as it is for old decks receiving overlays.

The prime coat is placed immediately after cleaning. It may be applied by pouring and spreading with brooms, squeegees, paint rollers or by hand spraying or spray bar. The coverage rate is determined by the roughness and absorbency of the PCC surface. Puddling should be avoided.

The prime coat provides adhesion by wetting out the PCC surface for immediate bonding and acting as a barrier to limit the possibility of debonding by saponification (alkali attack on the isophthalic resin) for long term bonding. The first two bridges, Beaver and Thompson, used isophthalic polyester as the prime coat. High-molecular-weight methacrylate (HMWM) and fumarate polyester have been used on all projects since then. Although in situ pull-off strengths for all three prime coats are similar, HMWM and fumarate perform better in laboratory tests and have superior alkali resistance. Of these two, HMWM has been preferred because it appears to reinforce the PCC surface. Pull-off tests show failure occurring deeper in the PCC deck with HMWM than with the fumarate, and it penetrates further into any existing cracks.

Following the application of the prime coat, the aggregate and resin binder are proportioned, mixed and placed. The overlay can be placed either before or after hardening of the prime coat, though caution should be taken to prevent damage to the prime coat by construction equipment. The prime coat may be most vulnerable when in a "tacky" state, when it may be peeled off the deck by construction traffic.

There are several items to inspect during placement. Both the aggregate and deck must be dry. Polyester polymer concrete will tolerate limited moisture shortly after it is placed, but moisture from the aggregate or deck is detrimental, because it becomes trapped within the polyester matrix and adversely affects polymerization. Another detail that needs close attention is the proportioning and thorough mixing of the initiator. Reduction of initiator will cause the polyester polymer concrete to cure either slowly or not at all. Soft spots that result may not be discovered until after the overlay has been opened to traffic, and even if discovered prior to opening, will delay opening to traffic.

When stationary mixers are used, current specifications require the concrete to be mixed for at least two minutes. Capabilities of continuous mixers are demonstrated before the trial slab placement. The regulating devices for metering the material components need to be calibrated so if adjustments to the mix proportions are made they are accurate and deliberate and not by trial and error. Once mixed, the polyester polymer concrete is placed on the deck, vibrated and struck off using conventional concrete placement tools and techniques. Texture and skid resistance have been achieved by using embossing rollers, tining tools, sand or chip broadcasting or by a combination of sanding and either embossing or tining. The SFOBB will require longitudinal tining.

The mix should have a 4-inch to 10-inch slump so that adequate compaction and strike-off can be achieved. On the earlier jobs, too much emphasis was put on minimizing resin content at the job site. This has resulted in premature deterioration of some overlays. Part of the deterioration of the 1985 Whitmore placement resulted from compaction caused by deficient resin content. Minimization of the resin content should be achieved by addressing the aggregate properties previously discussed.

Safety and Health

Environmental and worker safety is always a concern. Unpolymerized resin, peroxides, cleaning solvents and containers may be considered hazardous waste materials. There should be a plan for proper cleanup and disposal. Material Safety Data Sheets (MSDS) should be posted, read and understood by all personnel who will be working with or around the materials. Air monitoring, checking for styrene emissions, has been performed on numerous jobs in California. Emission levels have been lowered by adding BYK™740 to the resin, a special paraffin wax from BYK-Chemie Inc. California requires its workers to use respirators.

In 1985, air sampling done during application of the polyester polymer concrete overlay on the Whitmore grade showed styrene exposures to be below the Permissible Exposure Level (PEL) of 100 part per million (ppm) as an 8-hour, time-weighted average (TWA). Air samples taken on other projects also indicated the PEL of 100 was never in danger of being exceeded. However, the odor of styrene was always very strong both at and near the job sites. Increasingly, literature indicated a PEL of 100 ppm was too high. In 1988, Finland and West Germany limited the PEL to 20 ppm.

It was clear after the 1987-construction season that something needed to be done about styrene emissions. An Assistant Resident Engineer surveyed eleven workers on a project overlaying decks located in a mountainous area above 3,000-ft. elevation. The survey indicated that those workers not wearing respirators felt nausea, dizziness and headaches. Following the survey and with input from the Resident Engineer, all the workers voluntarily wore respirators and follow up surveys indicated there was no longer any ill effects experienced by the crew. Also that year the California South Coast Air Quality Management District (SCAQMD) proposed a new regulation that became effective July 1, 1988. The regulation, Rule 1162, required a reduction in volatile organic compound emissions from the fabrication or repair of products using polyester resin. The industry complied by adding a wax compound to the resin. The wax, BYK-S740, was specifically manufactured for this purpose and contained an additive that did not effect bonding characteristics of the polymerized resin. Translab began testing this additive early in 1988.

Polyester polymer concrete was fabricated with 0.0%, 0.5% and 1% BYK-S740 by weight of the resin. The BYK-S 740 did not significantly alter the physical characteristics of the concrete. These first test results are shown in Table 2. It was concluded that the differences were only a result of statistical scatter. Tests were per California Test Method 551.

	Compression, psi		24-Hour Flexural	24-Hours Wet Bond
	24-hour	7-day	psi	psi
Control	7000	7190	1760	460
0.05% BYK-S740	6640	7060	1825	450
1.9% BYK-S740	5750	6140	1680	500

Bonding Using Styrene Suppressant Wax

TABLE 2

A wind tunnel was used to check the effectiveness of the additive for preventing evaporation of volatiles—in this case, styrene. Testing was done on initiated and uninitiated resin mixed with aggregate and on initiated and uninitiated resin only. The resin included 0.0%, 0.5%, or 1% by weight BYK-S 740. The material was weighed into a (6-inch) 152 mm-diameter can lid. The lids were placed in a wind tunnel calibrated to have airflow of 3.35 meters per second (11 feet per second). The samples were weighed at specific time intervals. The wax significantly lowered mass loss to both initiated and uninitiated resin.

The laboratory test warranted a field trial. Two more bridges, on the same contract from which the survey was taken, were scheduled to receive polyester polymer concrete overlay in 1988. The BYK-S 740 was tested at 0.0%, 0.5%, and 1% by weight of resin.

Polyester polymer concrete containing BYK-S 740 at 0.5% by weight of resin was placed September 23, 1988 on the southbound lane of Deer Creek Bridge, 8-71, Route 32 in Tehema County PM 21.5.

Air samples were taken at the breathing zones of several workers. No clear trend was found between the quadrants. The results are shown in Table 3.

Location/Duty	Quadrant 1 0% BYK	Quadrant 2 _% BYK	Quadrant 3 1% BYK	Quadrant 4 0% BYK
		Parts Per Million (ppm)		
At Mixer	24	21	15	10
Strike-Off/Raker	0.2	6	4	3
Strike-off/Opp	3	10	18	11
Strike-off/Trowel	16	23	39	40
Wheelbarrow	10	6	8	4

Presence of Volatiles – Southbound – Deer Creek Bridge 8-72

TABLE 3

The time interval between each quadrant was only about 25 minutes. This may have been too short a period to detect trends. The laboratory test and the subjective evaluation were enough to warrant further use.

During 1990, air monitoring was done on several polyester overlay jobs

The Benicia Bridge deck overlay was monitored for styrene volatile emissions September 27, October 1,5 & 22, 1990 by a certified hygiene testing firm. On September 27, air samples were taken during production. The results were as high as 22 ppm to as low as 0.1 ppm. Air samples taken from back of the mobile mixer at the control panel, which was on the up wind side that day, had results ranging from 0.44 – 0.75 ppm. On October 5 the control panel was down wind and the air at that location measurements were as high as 24 ppm. Samples at the strike-off at deck elevation ranged from 12- 67 ppm. At 1M above the deck the measured volatile emissions was much lower. Sample beyond 30M (100feet)) of the paving operation ranged from 2ppm - 4ppm.

. By 1991, all polyester jobs required air monitoring and a Lab test for volatile emission.. Contract change orders were written in 1990 to add BYK-S 7840 to polyester resin at the rate of 0.5% by weight.

The Lab test consists of pouring 100 grams of uninitiated resin into an approximately 155-millimeter diameter lid and determining the mass loss after evaporation for 30 minutes at a temperature of 25°C and relative humidity of 50%. The loss was limited to 60 grams per square meter. However, it was not specified how the resin was to be made to meet the emission standard. Suppliers typically added approximately 3% by weight of resin of BYK-S 740 to meet the requirements.

In 1991, the South Coast Air Quality Management District's Standard Method for Static Volatile Emissions Test was incorporated into Polyester Concrete Overlay Specifications. Mandatory air monitoring on all projects has been discontinued, but safety plans are required form the Contractor.

Polyester Concrete Overlay Applications

After several years of usage, the premixed polyester polymer concrete overlay system was by far the most successful compared to the other overlay systems. Consequently, polyester concrete overlays were changed from "experimental feature" to "alternative rehabilitation feature" and routine use began for rehabilitation and protection of bridge decks (See W.J. Jurkovich). Two decades of experience have justified this conclusion.

Overlays were placed throughout the State, some of them monitored. Placement procedures were evaluated, and specifications evolved as experience was gained. Some specifications were changed to adapt to the special needs of particular projects.

The overlay placed on the Marina Viaduct is a foremost example of adapting specifications for special needs. Benicia Bridge is an example of a large-scale project that has performed well over the years while the Klamath River Bridge and the Scofield Ave were projects that had marginal success though there was valuable experience gained. Simms Road is still performing well despite aggregate deficiencies.

Five projects are reviewed below. The sample projects illustrate some of the lessons learned over the years.

Simms Road Undercrossing I-5,6-111,02 Sha-5-57

The Simms Road overlay was placed in the summer of 1986. The bridge is a four-lane, conventionally reinforced concrete structure on a major highway where tire chains, snowplows and salt are used in winter. Though polyester overlays had been placed on PCCP having heavy traffic, this is the first bridge deck on which a polyester overlay was subjected to heavy traffic. The ADT is approximately 13,000 with 32 percent trucks. Two problems were encountered during construction: (1) some areas were left deficient in resin and exposed rocks, (2) other areas had too much resin at the surface that caused slick-looking areas. This left the deck surface looking irregular.

The first problem was the use of a coarse aggregate that was out of specification. The aggregate had an excess of crushed particles that led to a difficult-to-compact, harsh mix. The second problem was high air temperature that was not compensated for with the initiator. The high air temperature caused: (1) faster set times, (2) a necessary increase in placement speed, and (3) hindered efforts to roughen the slick spots before final set. According to the original construction reports, the air temperature reached 110° F. In spite of the poor appearance of the deck surface, the useful life of the overlay has not been lessened.

An evaluation in March 1987 reported small areas of unsound concrete detected by chain dragging. The locations were in the same areas where unsound concrete was found in the deck shortly after completion. Another survey was done in May 1990; no appreciable change in the deck condition was observed. There was no rutting or potholing.

In September 1993, the deck was again evaluated. No rutting or potholing had occurred and chloride impermeability had been maintained since there was no cracks in the overlay. As a comparison, the asphalt placed on the roadway at the same time as the overlay was being repaved during the 1993 survey of the deck. The overlay was a success, despite the poor appearance of the deck surface. The wear and integrity of the overlay was not affected by the problems encountered during construction.

The overlay is still performing Okay.

Klamath River Bridge – 2-117, 02-SIS-96

The Klamath River Bridge deck overlay was also placed in 1986. The same aggregate source that was found to be out of specification on the Simms Road Undercrossing job was used again on the westbound lane of this project. The aggregate was also used for the eastbound lane, but modified to meet the specification by blending beach sand with the aggregate until it met the limitations on crushed particles. In 1992, this bridge was evaluated and found to be marginally successful. Many cracks and areas of unsound concrete were found, though they were noted to be on a small percentage of the deck. A larger number of cracks and unsound areas were documented in the westbound lanes than in the eastbound lanes. It should be noted that one important purpose of the overlay is undermined when cracks permit salt water to enter the deck, such as in those areas.

Scofield Avenue Undercrossing – Bridge 28-14R/L, 04-CC-580-6

The Scoffield Avenue Undercrossing bridges are steel I-girder with lightweight concrete decks constructed in the early 1950s. In 1988, the bridges were widened, strengthened and the riding surfaces rehabilitated. The deck was rehabilitated by removing the sand-cement grout riding surface and replacing it with a polyester polymer concrete overlay. This overlay was placed in 1988 utilizing a continuous mixer made by Haus Equipment Company of Oklahoma and a T650S Power Box asphalt paving machine built by Puckett Brothers Manufacturing of Lithonia, Georgia. Approximately 72,000 square feet (6,700 meters*)* of polyester polymer concrete was placed. This was the first time that polyester polymer concrete was placed on a lightweight concrete deck. At the time, one concern was the potential for problems caused by excess moisture in the lightweight aggregate. Thus far, this appears to have been a nonissue.

The continuous mixer was a modified auger type mobile mixer. It was one of the mixers used on the I-80 pavement project mentioned above. Its capacity was about 30,000 lbs. of aggregate stored in two bins (one for coarse and one for fine), 400 gallons of resin and 15 to 20 gallons of initiator. The aggregate was belt-fed to the mixing trough. Adjusting the belt speed and the height of the gate acting as an orifice controlled the amount or rate of aggregate. The resin was stored in what was initially the cement hopper and was delivered via a positive displacement Binks pump that provided one quart per stoke. Adjusting the number of strokes per unit time by varying the hydraulic feed that powered the pump controlled the flow rate. A smaller slave pump attached directly to the same lever arm that drove the piston of the resin pump fed the initiator. Adjusting the stroke length of the initiator pump controlled the amount of initiator per stroke of resin pump. Thus, the desired composition could be achieved by controlling the delivery rate of the aggregate, the stroke rate of the resin pump and the stroke length of the initiator pump.

Before paving began, polyester polymer concrete mixed in the continuous mixer was compared to polyester polymer concrete batch mixed in a stationary plaster type mixer. The plaster type mixer was run for two minutes while mixing time in the trough of the continuous mixer averaged about 17 seconds. Samples were taken and tested using California Test Method 551. Samples were taken before and after the concrete passed through the paving machine. The results suggest the action of the paving machine aided in mixing the polyester polymer concrete. Flexural and compressive strengths were higher for both stationary-mixed and continuous-mixed concrete after it was worked by the paving machine. Moreover, though the stationary mixer produced concrete with higher strengths, the gap was closed if the concrete was worked by the paver. Test results are shown in Table 4.

	Stationary Mixer				Continuous Mixer			
	After	Before	After	Before	After	Before	After	Before
Compressive @ 24 hours, psi	6490	6460	6710	6750	5160	5265	6220	6435
Average	6480		6730		5210		6330	
					80% of Stationary		94% of Stationary	
Flexural @ 24 hours, psi	1480	1430	1570	1560	1400	1370	1540	1550
Average	1455		1565		1385		1545	
					95% of Stationary		99% of stationary	

Comparisons of Mechanical Properties By Mixer Type

TABLE 4

Based on test results, the continuous mixer was approved for the project. The mixer was calibrated and paving began after the grout cap had been removed and the deck surface was sandblasted. Typically, one lane of the bridge was placed during each work shift. The continuous mixer dispensed the polyester polymer concrete into the paving machine. The paving machine vibrated and struck off the polyester polymer concrete to grade. At the start of the operation much time was lost loading the aggregate into the continuous mixer. This was later resolved by loading aggregate during the paving operation. Stoppages to refill the resin tank were kept to once per bridge lane.

On one occasion, blistering occurred because the polyester polymer concrete did not set up properly. Whether this was caused by water in the aggregate or a problem with the initiator system was not determined. The rock was sent back to the quarry for drying and instruments were installed that indicated when the initiator was dispensing. The problem did not appear to arise again. The uncured polyester polymer concrete that was noted was removed and replaced.

The profile grade was established by string lines that were followed by sensors on the paving machine. On the first pass, string lines were used on either side of the paver. On subsequent passes, one side of the paver followed a string line while the other side rode on the previously applied overlay. This was satisfactory for most of the deck. However, three profile control deficiencies required correction by grinding. There was one deficiency when the edge of the overlay ran very close to the K-rail and made the use of a string line impossible. Grade control was attempted by eyeballing, which resulted in an unsatisfactory profile and the K-rail was moved. The second control deficiency occurred whenever the paving operation was stopped and started in the same lane. Since the paver glides on the polyester polymer concrete that it is placing, it tends to sink slightly when it stops and rise again when it resumes paving. An undulation results when this occurs. The third deficiency was an occasional transverse swale that occurred near longitudinal construction joints. About 80% of the left bridge and 25% of the right bridge required grinding.

Another problem was debonding at the expansion joints. If these joints are not maintained in the overlay, movement at the joints can cause the overlay to debond. The problem can be avoided if the joints are preformed with sheet packing or some other suitable material before paving. However, in this case, the joints were reestablished by sawcutting after the polyester polymer concrete hardened. If the deck warmed before sawcutting, debonding was sometimes followed by spalling; these areas were removed and replaced where the problem was detected.

Engineering staff of the Caltrans Division of Structures evaluated the deck in 1992 and gave it an overall success rating. Because of heavy traffic, part of the traffic lane, most of the shoulder, the ramp extension and the construction joint adjacent to the shoulder were chained for unsound concrete. Unsound concrete was found on the last 20 feet of the ramp extension and generally along the construction joints. Two cracks in the overlay were noted, both on the right structure. The surface texture on part of the overlay suggested adequate compaction was not always achieved or the resin content was lower then it needed to be. This may explain the unsound concrete found along the construction joints.

Overall, the deficiencies encountered during production have lowered the expected life of this overlay. The overlay is showing signs of wear. It now requires some additional maintenance.

Benicia-Martinez Bridge-28-153, 04-CC,SOL-680

The Benicia-Martinez Bridge was the largest bridge deck overlayed before 1991. The bridge was widened, strengthened and the deck was rehabilitated by removing the grout cap and placing a 3/4-inch polyester overlay. As in the Scofield job, the overlay was placed using continuous mixer equipment and a modified asphalt paver. Two continuous mixers were used. One was the same unit used on Scofield, and the other was a sister model. Both of these mixers were used to pave 10-lane-miles of polyester overlay on I-80 in the Sierra Nevada Mountains in 1985-86. Some slight modifications were made. More meters were added to better control the mix proportions and a seat was added near the control and dispensing area for a full-time operator. Nearly 500,000 square feet (44,000m^2) of polyester polymer concrete was placed.

The strike-off was a modified asphalt paver by Allen Engineering. It could pave six or 12-feet wide. A 1 1/2-feet wide vibrating strike-off plate driven by two, rotating vibrators at each end consolidated the polyester polymer concrete. Preplaced metal tube rails on which the paver rode controlled profile grade. The tubing rested on screw jacks that adjusted the rail to the desired grade.

The resin was delivered to the job in tankers. The aggregate was delivered in 3,000-pound, moisture-tight bags. Before the contract was completed, the overlay near the expansion joints debonded frequently. The contractor elected to form the joint by sawcutting the overlay after polymerization. This method proved inadequate.

This deficiency was compounded by the discovery that polyester polymer concrete will not adhere to magnesium phosphate concrete that is less than three-day old. Magnesium phosphate concrete was used to patch the deck before the overlay was placed. It is now the practice, where possible, to patch a deck with polyester polymer concrete during placement. Where magnesium phosphate is used for patching, a three-day cure time must be allowed before placing a polyester overlay.

Prime coat for a full day’s run was placed at one time. Consequently, the overlay was placed on fresh HMWM at the beginning of the day, tacky HMWM in some areas in the middle of the day, and hardened HMWM at the end of the day. Tensile pull-off tests were later performed to determine whether the condition of the prime coat had produced any measurable effect on bond strength. Table 5 shows that it did not have any measurable effect on bond strength.

Location	HMWM	psi	Type of Failure
Bent 2	Uncured	260	Top 0.125 inch of polyester overlay
Bent 6	Cured	300	Bond between HMWM and polyester
Bent 7	Uncured	390	Top 0.25 inch of polyester overlay
Bent 9	Cured	350	Light weight concrete deck
Bent 10	Uncured	410	Light weight concrete deck
Bent 11	Cured	210	HMWM bond directly over exposed rebar
Bent 11	Cured	410	Light weight concrete deck
Bent 12	Uncured	480	Bond between HMWM and polyester
Abutment 19	Cured	260	Top 0.125 inch of polyester overlay{ "}

Pullout Strength of Benicia Bridge Overlay

<u>TABLE 5</u>

Lab tests indicated that polyester concrete could be placed on fully cured HMWM or fresh HMWM with no difference in bond strength to pcc. (Bond testing to aluminum plates showed higher bond values when the polyester concrete was placed on fresh HMWM) Placement of the polyester polymer concrete on this deck allowed for field-testing.

Another feature of this project was the attempt to reduce styrene emissions. By a contract change order, BYK-S 740 was added to the resin to reduce the volatilization of styrene into the air. BYK-S 740 is a wax that floats to the surface and seals styrene in the system that would otherwise escape into the atmosphere. The cost, including markups, was about $0.60 per square foot. The air around the area was monitored to determine the effectiveness of the inhibitor. The results showed that styrene concentrations in the air were well below acceptable limits. The overlay appears to be holding up well with the exception of a few spalls in the southbound direction.

The overlay is performing well. There are a half a dozen spalls in the southbound direction, but the deck was patched before placement and it is probable it is the patch pulling from the deck. Also, when viewed from underneath the bridge, it was observed that in a couple of locations the lightweight deck failing from below at expansion joints caused a few spalls. Other then these isolated spots, the deck is showing no signs of wear.

Marina Viaduct Bridge – 34-14,04-SF-480,

The Marina Viaduct Bridge is located on Route 480 along the Presidio in the Marina District of San Francisco. It is the main feeder to the Golden Gate Bridge connecting Marin County to San Francisco. The deck had high steel that was corroding and spalling the concrete. The steel needed to be protected to extend the life of the structure. Without corrective maintenance, vehicle weight limits would have been reduced. A protective overlay would prevent further damage to deck steel and avoid lowering the limit on vehicle weight.

A polyester concrete overlay using a bisphenol fumarate based resin for the prime coat was chosen to extend the life of the bridge. Though there was no doubt that HMWM could have been used as the prime coat; it was felt, at the time that the fumarate could be easily manipulated to achieve an adequate bond strength at the high rate needed for this project. Another reason for using the fumerate was that the same initiator/promoter/accelerator systems could be used in both binder and primer resin to ensure no delay in polymerization of prime coat.

Because of traffic, work on the bridge deck would typically be done between the hours of 9 P.M. and 6 A.M. The contract specified the use of mobile mixers only. After allowing for preparation of the deck and cure time for the polyester polymer concrete, the actual paving time on a productive night was about four hours. On some shifts, placement time, which necessitated mechanizing techniques, was less than two hours.

The area was subject to fog rolling in from the ocean and the dew point was often reached, thus there was a greater potential for moisture contamination than in other locations. Dry weather generally coincided with colder temperatures was another problem. Low temperatures, potential moisture and the restrictions on working shifts necessitated increased polymerization rates and reduced moisture sensitivity.

Laboratory tests were performed to verify whether polyester polymer concrete could be ready for traffic after curing two hours at 50°F. For the laboratory test, the resin polymerization rate for both the prime coat and the binder was increased by the addition of demethyl-p-toluidine (DMPT) to the resins. After aging the samples for two hours at 45°F, bond and compression tests were run using California Test Method 551. The results supported the possibility of success on the project. (The contract did not specify the use of DMPT, but left the method to the contractor's discretion subject to approval by the Engineer.) To reduce chances of failure caused by moisture, the percentage of silane, specified for fumarate prime coats on past jobs, was increased four times from 0.5 percent to 2 percent.

In September 1991, small test pads were placed to evaluate initiators proposed by the contractor. The test pads were 0.3 by 1.0 meters (1 by 3 feet), fabricated and placed by the contractor on a closed portion of the Embarcadero Freeway. These were placed at night to simulate as closely as possible environmental conditions expected during actual placement. Five test pads were placed using three initiators and two combinations of the three initiators. The initiators were: DDM9, a methyl ethyl ketone peroxide (MEKP); Delta-X, a blend of MEKP and hydrogen peroxide; and 224 pentane dione peroxide. The two combinations were a 1:1 mixture of 224 and DDM-9 and a 1:1 mixture of 224 and Delta-X. The 224 was the strongest initiator, while the MEKP was the weakest.

The deck area was steel shotblasted. Each pad was painted with the fumarate prime coat 10 to 15 minutes before the overlay placement. Both primer and overlay resin had the same initiator. After casting a pad, 2-inch-diameter cylinder molds with the bottom cut out were inserted into the overlay leaving between 1 and 2 inches of the molds above the surface of the overlay. A 2-inch-diameter bobbin was inserted into the molds. These bobbins were later used for pull-off tests to determine bond strength at early ages. Also 2 by 4-inch cylinders were cast to determine compressive strength and modulus of elasticity. The results are shown in Table 6.

The one and seven-day modulus of elasticity measurements showed the initiators did not detrimentally effect the polyester polymer concrete. However, the early compression tests showed that only the 224 was sufficient to polymerize the concrete enough to support traffic in the time allotted for the expected conditions. The pull-out tests were inconclusive for Test Pads Three and Four, but indicated adequate bond strength for

Test Pad Five. However at 3:45 A.M., Tests Pads Three, Four and Five withstood prying and chiseling efforts at or near the bond line. The ages of Pads Three, Four and Five were: two hours, 15 minutes; one hour, 50 minutes; and one hour, 20 minutes, respectively. This indicates adequate bond strength could be developed

Test Pad	Initiator	Pull-Out Strength/Age (psi/hours)	Compressive Strength/Age (psi/hours)	14-Day Compressive Strength (psi)	1-Day Modulus of Elasticity (psi)	7-Day Modulus of Elasticity (psi)
1	DD M-9	50/3.75 75/5:40	290/3:15	5,250	320,000	390,000
2	**Delta-X**	**100/3:45 50/4:55**	**110/---**	**2,830**	**360,000**	**250,000**
3	**224**	**75/2:20 75\5:40**	**>1,590/3:45**	**4,310**	**290,000**	**400,000**
4	**224 + DDM-9**	**115/2:35**	**>1,800/3:40**	**4,800**	**290,000**	**390,000**
5	**224 + Delta X**	**260/3:20**	**1,200/3:10**	**5,330**	**330,000**	**450,000**

Test Pad Results for Evaluating Proposed Initiators

TABLE 6

Additional pre-testing and trial runs were performed to decrease the possibility of traffic delays. Several 50 by 10 foot (15.2 by 3 meters) wide trial overlays were required before proceeding to the deck. As an added precaution, placement the first night (after the successful trial overlay) was limited to 100 feet (30 meters) and the ramps were paved before proceeding to the main line.

Grade control and surface texturing were worked out during these trials. After the acceptance trial, paving on the deck began in early November 1991. Though paving was successful even when temperatures approached 4.5°C (40°F); dew, fog and rain delayed the paving and added the risk of moisture contamination. In mid-December, the project was suspended for the remainder of the winter.

Many unforeseen details emerged during the first few weeks of paving. One was the importance of ensuring that the aggregate remained dry. During December, moisture was detected in some of the "super sacks" in which the aggregate was shipped and stored. Each of these sacks contained about a cubic meter of aggregate. A major concern was that this moisture could retard set time as well as affect the strength of the polyester polymer concrete. Whether the moisture was due to inadequate drying, contamination at the time of bagging or inadequate sealing was not determined. To remedy this potential hazard, a plastic inner liner was added to the sacks and better shelter was provided for on-site storage. The aggregate was thoroughly inspected, both visually and with a moisture probe, before it was loaded in the mobile mixer bins.

Quantity determinations used for payment were improved. Samples of the polyester polymer concrete were taken from the paving machine and weighted immediately. This sample was then washed with acetone and dried over a gas flame to remove the polyester resin. The percentage of resin in the concrete could then be measured. By measuring the unit weight and knowing the percentage of resin in the polyester polymer concrete, the quantity of concrete can be determined by the quantity of resin used. Estimating the thickness of the overlay and multiplying by the area placed provided a check.

In April 1992, the paving resumed after a winter suspension, and continued without major problems until completion in August. In addition to the quality assurance testing required by the contract, pull-off and compression test were performed to ensure the overlay was performing as planned. On one occasion, the overlay was below the desired grade and weeks later a second lift was placed as a remedy. Since the first layer had been placed on a prime coat contaminated with moisture, this was of particular interest. However, pull-off values indicated the bond to the PCC substrate to be acceptable and the fresh polyester polymer concrete bonded to the fully cured polyester concrete.

Methacrylate was used as a prime coat in a portion of Lane Three near Abutment 11 to compare it with the fumarate prime coat. The contractor proposed this at no cost. No significant difference was observed when comparing pull-off test results.

No signs of wear have been observed to date on any portion of this overlay.

Summary

After two decades of usage, the polyester concrete overlay has been successful. It has proved to be very effective in terms of durability, crack resistance, chloride ion intrusion, bonding, ease of construction and lane closure time. It is now being used on new decks constructed in areas where the life of pcc decks has been limited due to being subjected the harsh conditions of heavy traffic requiring chains, salt used for ice control, and snowplows.

There are many advantages to a premixed polyester concrete overlay being used to produce the profile grade on the segmental portion of the new SFOBB. It is an engineered material with consistent properties, providing chloride protection, establishment of a smooth roadway profile, high-durability, ease-of-placement and a short cure time under a wide range of temperatures. The premixed nature of the material enables it to be placed by contractors who have ordinary highway construction experience.

The keys to a successful overlay are a sound design that will resist the stresses it will be subjected to and control of materials and construction. Materials can be controlled through specifications and by quality control during construction. Construction should utilize proven practices and techniques. These principles have been employed routinely in the successful rehabilitation of bridge decks throughout California. Considerable expertise and continued success has been achieved among Caltrans design, construction, maintenance and materials engineers.

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