EPOXY-ASPHALT OPEN-GRADED PAVEMENT AS A SKID-RESISTANT TREATMENT ON THE SAN FRANCISCO-OAKLAND BAY BRIDGE

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In late 1969, the Division of Bay Toll Crossings applied ½-in. thick expoxy-asphalt, open-graded pavement to 2 large test areas on the heavily traveled San Francisco-Oakland Bay Bridge. Two types of aggregate, air-cooled iron slag and granite, were used with ¼-in. California standard open grading. This report describes the selection of epoxy asphalt as the skid-resistant treatment, its application, and its performance to date. In the 11 months since its application, the pavement has been tested for skid resistance and core pullout strength. In spite of minor localized raveling attributed to inadequate compaction in isolated areas due to cold temperatures at the time of placing and to other factors, the pavement promises fulfillment of the purpose for which it was selected: to provide increased skid and hydroplaning resistance, low increase in dead load, and superior structural properties. The accident history has improved substantially in the resurfaced areas.

The 7-mile-long San Francisco-Oakland Bay Bridge is one of the most heavily traveled roadways in the United States. Its 5 lanes in each direction carry about 5 million vehicles per month. On days of maximum flow, there have been more than 200,000 vehicle passages. It is indeed a heavily burdened facility. Considering this intensive use, it is essential that a high-quality riding surface be provided for the safety of the bridge users.

In 1963 and 1964, surfacing of epoxy coal tar and sand was placed on the reinforced concrete decks. This surfacing, having a thickness of about ³⁄₁₆ in., sealed the concrete and provided a good riding surface for several years. There was, however, a gradual loss of aggregate, which led to the selection of 2 critical areas for testing and remedial work.

One of these areas is on the upper deck where westbound traffic nears the San Francisco ramp turnoffs. Much weaving and braking is done there as drivers decide between alternative routes and maneuver on a downhill grade to get into their proper lanes. The other critical area is on the lower deck where traffic emerges from the Yerba Buena Island tunnel. Here there are gusty winds and the roadway enters a curve with minimal superelevation. These two areas, totaling about 155,000 sq ft, comprise about 5 percent of the bridge area.

The operating agency, the Division of Bay Toll Crossings, initiated a program with 3 objectives: to select the best method to improve the skid resistance; to apply that

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method to the 2 areas; and to use the application as a standard by which to judge other methods that might be proposed for the future treatment of the remaining 95 percent of the bridge. The alternatives considered for increasing the skid resistance are described following a brief review of the conditions as they existed.

EXISTING CONDITIONS

The existing surfacing had been applied by spraying on the epoxy coal tar binder and dropping sand on it to excess by shoveling from a truck. After the epoxy cured, the excess sand was swept off.

In 1968, 30 core samples were taken from the deck. The samples showed a high percentage of craters from which sand had been removed. The sand particles still remaining had been polished or sheared off to the level of the epoxy coal tar matrix or below. It was also found that the epoxy coal tar surfacing varied in thickness from $\frac{1}{4}$ to $\frac{1}{16}$ in. This variation did not appear to be primarily due to wear because some of the thinnest areas were in locations where there was the least traffic wear. It seemed to result from the flow of the liquid binder after it was applied to the deck. There was little evidence that the thickness of the surfacing had been significantly reduced by traffic wear.

The aggregate was a subangular silica natural sand. The loss of aggregate was attributed to the adhesion of the binder being less on the natural-grained aggregate than it would have been with a crushed aggregate; the adhesion of the binder being less with the slick silica surface than it would have been with most other minerals; the grains not being tough enough; and the method of application, which precluded compaction after placement so that there was little intergranular friction due to close proximity of grains.

Over the surfacing was a layer of dirt, oil, and rubber up to a thickness of $\frac{1}{8}$ in. A major question was the degree of cleaning required to obtain bond of the new pavement to the old surfacing. Bond to the reinforced concrete deck was very good, exceeding 150 psi on the average.

POSSIBLE METHODS OF INCREASING SKID RESISTANCE

The means by which the skid resistance could be increased fell into 2 categories: methods that do not require the addition of new material and methods that do. The first category included sandblasting, diamond-saw grooving, diamond-cylinder texturing, and flail grooving. The second category included spray-on surfacings with aggregate sprinkled on, overlays placed by screeding without compaction, and pavements placed by asphalt concrete (AC) paving machine and compacted with rollers.

Methods Not Required the Addition of New Material

If the skid resistance could be increased satisfactorily without the addition of new material, the cost would be much less and the dead load on the structure would not be increased.

Sandblasting seemed to be a possible method. Six areas were, therefore, sandblasted by bridge maintenance painting crews, and 3 grades of sand were used in each area. In one area thorough-blast techniques were used, and in one area whipblast techniques were used. Thorough-blasting with the heaviest grading, No. 12, was most effective but gave only a slight increase in skid resistance, which was soon nullified by further wear.

To test diamond-saw grooving and diamond-cylinder texturing, a contract was awarded to Industrial Diamond Services, Inc., for grooving 2 test areas and texturing 2 test areas. Each area was about 3 ft wide and 100 ft long. Grooving was defined as sawing grooves with saw blades, in one case spaced at $\frac{3}{4}$-in. centers and in the other case spaced at 1-in. centers. The grooves were $\frac{1}{8}$ in. in width and depth. Texturing was defined as grinding the entire surface with diamond-studded cylinders mounted on a rotating arbor. Although both grooving patterns and one of the texturing patterns were effective in increasing skid resistance, these methods were both discarded because the depth of cut could not be controlled sufficiently to prevent their penetrating the epoxy coal tar, destroying the seal of the concrete.

Five test areas were also textured by flail grooving, three with lightweight cutting discs and two with heavy cutting discs. The lighter discs left a texture similar to thorough-blasting with No. 12 sand. The heavier discs were much more aggressive than the lighter discs and were quite effective in removing the entire epoxy coal tar surfacing. Three of the patterns showed minor increases in skid resistance; the other 2 patterns showed a significant increase, but were not considered satisfactory as they destroyed the seal.

Methods Requiring the Addition of New Material

The structural capacity of the bridge was reviewed, and it was decided that the maximum permissible increase in dead load would be approached through the addition of a ½-in. pavement. Only materials that could be applied in thicknesses of ½ in. or less were therefore considered. Fullest encouragement was given to manufacturers of epoxies, polyester, elastomers, and any other synthetic or natural materials that might be used in a satisfactory surfacing. The only stipulations were that the material proposed must demonstrate all of the following characteristics:

1. Applicability by a means that would pave large areas in a short time so that no part of the bridge would be obstructed during peak traffic periods and by a means that would not obstruct more than 2 traffic lanes at any time;
2. Safety for adjacent traffic and the structure;
3. Good bond to the substrate;
4. Good riding qualities;
5. Excellent skid resistance;
6. Seal of the concrete deck or preservation of the existing seal;
7. Good stability; and
8. Good wear resistance.

Sprayed-On Surfacings—The use of another layer of thin sprayed-on binder with sand or abrasive aggregate sprinkled on by shovel or spreader was rejected because it appeared that skid resistance would again fall off because of removal of aggregate by wear.

Overlays Placed by Screeding—Portland cement concrete or grout is not successful in this thickness because of its rigidity and lack of tensile strength and bond, but considerable effort was given to developing a polyester, epoxy, or epoxy admixed in portland cement grout that would be suitable. Several manufacturers of ingredients for such systems became involved to some extent, but economically feasible products have not yet been found. It is hoped that continued development will eventually lead to additional competitive products.

Pavement Placed by AC Paving Machine and Compacted With Rollers—The Division of Bay Toll Crossings began the investigation of epoxy-asphalt pavement in 1963 when this material was proposed as a dense-graded surfacing for the steel deck of the San Mateo-Hayward Bridge, which was then being designed by the Division. In 1965, test patches were placed on the Ulatis Creek Bridge near Vacaville on Highway 80 and at other locations.

On the basis of these successful tests and a long and arduous program of evaluation, dense-graded epoxy asphalt was used on the steel deck of the San Mateo-Hayward Bridge in 1967 and on the San Diego-Coronado Bay Bridge in 1969. These coatings, applied in a minimum thickness of 1⅝ in., have performed admirably. Their skid resistances were good from the start and improved with age.

Bond to the inorganic zinc-coated steel deck plates was outstanding (over 200 psi), and epoxy asphalt withstood the flexural demands of the very limber deck. Furthermore, epoxy asphalt can be applied by AC paving machines with electronic screeds and compacted with standard rolling equipment so that large areas can be surfaced in a very short time.

From this past experience with epoxy asphalt pavements, the Division was assured that this type of surfacing was feasible on the San Francisco-Oakland Bridge, at least as a dense-graded pavement. Also, epoxy asphalt offered the potential advantage of applicability as an open-graded durable pavement that might provide higher skid and hydroplaning resistance.

Asphalt concrete reinforced with latex or asbestos fiber would be inadequate in bond strength and long-term skid resistance. If the bond strength were to be increased through the use of an epoxy asphalt bond coat, the cost would not be enough lower to justify the sacrifice in tensile strength, flexibility, and other qualities that could be obtained with epoxy asphalt.

Because the other possibilities had been eliminated, it was concluded that only epoxy asphalt met all of the requirements.

APPLICATION OF METHOD

Selection of Aggregate

Many types of aggregates were considered on the basis of their hardness, durability, friability, angularity, nonpolishing qualities, availability, and cost. Some of the candidate materials were nickel slag, copper slag, Sinopal (a synthetic aggregate manufactured by Martin Marietta Corporation from limestone and silica sand fused and crushed), air-cooled iron blast-furnace slag, and granite. The comparison resulted in a standoff between the last two, so it was decided to include both in the test.

The nearest source from which slag possessing sufficient strength to resist crushing under the rollers and meeting all requirements for California grade A aggregates could be obtained was the U.S. Steel Corporation in Geneva, Utah. This slag had been used by the state of Utah as a skid-resistant aggregate in bituminous pavements with excellent results and has been in use for many years in other parts of the country. The cost at the site was about $9.25 per ton.

Watsonville granite also has a good record of use in skid-resistant bituminous surfacings on California highways. This aggregate was available from the Granite Rock Company, Watsonville, California, for a cost at the site of about $2.40 a ton.

Testing of an Open-Graded Mix

As the choice of treatments narrowed to epoxy asphalt, the desirability of open-graded aggregate became more compelling as a means of obtaining higher skid and hydroplaning resistance. In order to determine the feasibility of this improvement, the vendor had 6 test slabs made up of the paving material ½ in. thick on 18- by 4- by ⅜-in. steel plates, three with air-cooled blast furnace slag and three with granite aggregate, all using ¼-in. California standard open grading. The paving material was made up and applied to the slabs in the laboratory by using methods that would approximate as closely as possible the field conditions of application and compaction. Skid tests were then made on the slabs and, to simulate the effect of wear, the slabs were lightly sandblasted and then retested. The average skid resistances as determined by California test method 342-C were as follows:

Type of Aggregate	Before Sandblasting	After Sandblasting
Slag	0.45	0.45
Granite	0.36	0.38

With this evidence and with evidence of average laboratory pullout values in the vicinity of 300 psi, it was decided to use open grading.

Determination of the Amount of Surface Preparation Required

A lucky development in the investigation was the discovery that the primer develops a bond to the epoxy coal tar substrate through the oil, rubber, and dirt film. This eliminated the need to sandblast the surface before placing the surfacing material. Core specimens were taken from the deck with the dirt film intact, epoxy asphalt was applied in the laboratory, and bond tests were made. There was no significant difference in bond strength between sandblasted and uncleaned surfaces. These tests also confirmed that the adhesion of the old epoxy coal tar overlay to the concrete was more than 150 psi.

Placing the Materials

A purchase agreement was made with the Adhesive Engineering Company for furnishing and placing the surfacing material. This company is the only company licensed to manufacture epoxy asphalt under patents held by Shell Oil Company. The agreement also included removing raised pavement markers, providing traffic controls, furnishing and welding ½-in. square steel bars on each side of expansion joints, furnishing and placing thermoplastic stripe and raised pavement markers, and performing other work incidental to the resurfacing.

The work was done in 10 working days not including 3 working days that were spent in applying and then removing the first loads of material that had not been properly mixed. The total amount of material permanently placed on the deck was about 425 tons of epoxy-asphalt surfacing and about 2,000 gal of epoxy-asphalt bond coat.

On a typical working day, the working area was closed at about 9:00 a.m. and coned by 9:30. Between 9:30 a.m. and 1:00 p.m. the bond coat was applied and allowed to cool. Between 1:00 and 2:00 p.m. epoxy AC was applied. Between 3:30 and 4:00 p.m. traffic was allowed onto the resurfaced area. The pavement was intended to withstand full exposure to traffic after cooling although the cure of the epoxy was not yet complete.

Equipment provided at the plant consisted of a 4,000-lb hot plant owned by the Pacific Paving Company and rented and modified by the Adhesive Engineering Company with special equipment for metering, mixing, and dispensing epoxy-asphalt binder into the pug mill.

Equipment used at the site consisted of a Barber Green SA40 electronically controlled AC paving machine, two 8-ton tandem steel-wheeled rollers, and an Adhesive Engineering Company chemical reactor-distributor for application of the bond coat. The material was delivered in 7-ton batches. Mechanical brooming was the only surface preparation used.

The plans and specifications called for placement of epoxy-asphalt, open-graded, slag-aggregate pavement on the upper deck area, which was 5 lanes wide and about 1,150 ft long, and granite-aggregate pavement on the lower deck area, which was 5 lanes wide and about 1,400 ft long. However, most of the slag aggregate was lost in shipment because of leaks in the gondola cars, so the slag aggregate overlay was placed only on the outside lanes of the lower deck.

The bond coat ingredients were the same as the binder ingredients, consisting of component A, an epoxy resin, and component B, asphalts mixed with epoxy resin hardeners. When used as a bond coat, the components were heated, mixed, and applied at the site by a special reactor-distributor. When used as a binder, the components were mixed at the plant with special mixing equipment and sprayed on the heated aggregate.

The slag aggregate, being more porous on the surface, required more binder, about 7.5 percent by weight, than the granite aggregate pavement, in which 6 percent was used. The initial application of the slag aggregate mix with only 6 percent binder failed and had to be removed. The binder ratio was then increased to 7½ percent and no further raveling was noted.

EVALUATION

The pavement has been observed for more than 8 months at the time of this report, and has been tested for skid resistance and core pullout strength.

The appearance of the slag-aggregate pavement and of the granite-aggregate pavement on the lower deck is indistinguishable from that of sound open-graded asphalt concrete. In the granite-aggregate pavement on the upper deck, however, there is raveling in certain local areas, oddly enough, mostly between wheel tracks. There are several factors that could have contributed to these local failures, including inadequate compaction resulting from having to open the work area to traffic before compaction was completed, and low temperatures (around 50 F, which is low for any kind of open-graded AC) at the time of placement.

Three series of skid resistance tests have been made with a towed-trailer test unit in accordance with ASTM E 274 at a speed of 40 mph. Results are given in Table 1. Although not as high as was hoped for on the basis of earlier laboratory tests, the skid resistance is considered to be satisfactory.

Bond to the deck, determined by pull-out tests on 40 cores removed from the deck, was 249 psi in the slag-aggregate pavement and 111 psi in the granite-aggregate pavement on the average.

The accident history has improved substantially in the test areas since the surfacing was placed.

In summary, the surfacing generally appears to promise fulfillment of the purpose for which it was developed, providing increased skid resistance and hydroplaning resistance, low increase in dead load, and superior structural properties with good prospects for long-lasting satisfactory performance. When the application is scheduled at times when the temperature of the deck is higher and when time is allowed for complete compaction of the material, raveling should be completely prevented and the promise should be fully realized.

TABLE 1

RESULTS OF SKID-RESISTANCE TESTS

Location, Number, and Date of Test Series	Epoxy Coal Tar Pavement	Slag Aggregate Pavement	Granite Aggregate Pavement
In wheel tracks			
Series 1, 1-70	30.6	37.5	40.5
Series 2, 4-70	33.7	38.2	44.0
Series 3, 8-70	31.8	35.4	40.4
Between wheel tracks			
Series 1, 1-70	31.8	36.0	36.3
Series 2, 4-70	35.9	35.0	41.5
Series 3, 8-70	27.4	35.0	37.5

Note: Values are skid numbers (SN 40).

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