Studies Leading to Choice of Epoxy Asphalt for Pavement on Steel Orthotropic Bridge Deck of San Mateo-Hayward Bridge

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Long-span bridges with orthotropic steel decks have created the need for a lightweight, durable surfacing to act as both a leveling course and pavement. The pavements used by the originators of orthotropic steel deck plate girders in Europe are not feasible for use in this country. Developments in synthetic resin pavements show promise. The problem, insofar as available materials are concerned, is related to overlays used to repair damaged portland cement concrete bridge decks.

The experiences of the California Division of Bay Toll Crossings on major toll bridges in the San Francisco Bay Area are related. These include choice of a thin epoxy coal tar overlay, 1/8 in. to 3/16 in. thick on the San Francisco-Oakland Bay Bridge concrete decks, and choice of an epoxy asphalt concrete pavement, 1 1/2 in. to 2 1/2 in. thick on the steel orthotropic deck of the San Mateo-Hayward Bridge. The first epoxy coal tar was experimentally applied to the San Francisco-Oakland Bay Bridge in 1958. Subsequent studies progressively testing over 20 materials are still in progress.

The author believes that when numerical criteria have been established various resins may be satisfactory if acceptable application methods can be developed. A clearinghouse for accumulation of experience on the subject is required. Experimental applications are needed. The methods for measuring adhesion in direct tension on a diamond-drill cut core and fatigue in bending are mentioned as a start on the problem of establishing numerical criteria.

•LONG-SPAN bridges with orthotropic steel decks have created the need for a lightweight, durable surfacing to act as both leveling course and pavement. A variety of solutions to this problem by the originators of this type of construction in Europe are either not feasible or not permanent enough for recently projected uses. Developments in synthetic resins show promise in solving this problem. Earlier studies for concrete bridge deck overlays gave some insight into the area of resinous pavements.

The qualitative criteria developed for the intended use were investigated for various materials and choice made for the San Mateo-Hayward Bridge. Continuing developments and the results obtained in both testing laboratories and actual installations will probably lead to innovations in the use of synthetic resins for this purpose.

The history of construction of orthotropic steel deck bridges and the history of research into pavements for orthotropic steel decks in general are well covered (4, 6, 9).

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The technical data from actual tests and other relevant data appear in the references at the end of this article. The information on completed work has also been covered (1, 11).

This paper will be confined mainly to the reasons for the tests, the interpretations made from the data obtained, and the reason for the choice made for this particular installation. Of necessity, the materials were all proprietary compounds and because of their nature exact formulations are not available. This made the evaluation procedure by actual field tests unavoidable.

THE PROBLEM

The steel girder with orthotropic steel deck developed in Germany after World War II has found wide acceptance for long-span bridges primarily because of its attractive appearance. On the San Mateo-Hayward Bridge the steel box girder was chosen because of its unobtrusive silhouette as compared with a steel truss bridge. This choice led to studies which found substantially what subsequent investigations have confirmed, that the problem of paving steel plate decks is not yet completely or satisfactorily solved.

The European bridges have been paved by a number of methods which were not considered feasible under conditions prevailing in the paving industry in this country. The pavements used in Germany were mainly mastics which were subject to rutting and shoving particularly in hot weather. Stabilization of these mixtures is achieved by rolling rock into the surface and resistance to shoving by welding attachments to the steel deck to produce physical anchors. The practice in continental Europe is to use a multilayered construction; and with the long guarantees which are prevalent in the construction industry there, this type is generally acceptable.

The first and best-known pavement studies made in this country for steel orthotropic decks were made for the Poplar Street Bridge on a prototype at Troy, Illinois. This was an asphaltic concrete with various additives including neoprene, rubber, asbestos fiber and a bond or prime coat of epoxy coal tar. Shortly after the Troy experiments came the actual paving, in 1964, of the Port Mann Bridge, a steel arch with an orthotropic steel deck, with asphaltic concrete over an epoxy red lead corrosion protective coat and an epoxy coal tar bond coat containing embedded grit. The Port Mann pavement is regarded as completely successful. The Troy Bridge developed cracks in the surfacing during its 2-yr test period. These were the North American predecessors of the pavement chosen for the San Mateo-Hayward Bridge.

From a strictly rational standpoint, even neglecting the experience of others, it appeared that several criteria for a pavement could be established:

1. Satisfactory bond to steel.
2. Sufficient ductility and elasticity to expand and contract with temperature changes in the steel substrate and to accommodate flexure under load without cracking or disbonding.
3. Sufficient stability to resist shoving and rutting.
4. A construction process permitting placement at a reasonable cost over large areas to tolerances acceptable to high-speed vehicular traffic.

The actual limiting numerical values for these criteria must be determined by future experience for the various paving methods and materials used. We did compare the materials available and used 200 psi in tension for bond and a million repetitions for flexure as the numerical values for criteria to choose materials for experimental installation and study.

EARLY STUDIES

The Division of Bay Toll Crossings first became involved with resinous paving materials when the problem of surfacing the 25-year-old concrete decks of the San Francisco-Oakland Bay Bridge was encountered in 1962. This surface was a 59-ft 4-in. wide lightweight concrete deck surfaced with ordinary sand cement topping and divided into six lanes by ceramic tile markers embedded in the mortar topping. The deck was in

good condition but it was necessary to obliterate the tile markers, which were slightly raised above the surface of the concrete in order to change the traffic pattern.

Studies at this time evaluated moduli of elasticity, coefficient of expansion, and adhesion for a number of aggregate-filled resins as well as for latex modified portland cement concrete.

The subject of resins had been broached to the Division of Bay Toll Crossings in 1958 by a test application of Guardkote 140 on the San Francisco-Oakland Bay Bridge upper deck with the cooperation of the Shell Chemical Company. Guardkote 140 was an epoxy coal tar formulation derived from basic patents held by the Pittsburgh Coke and Chemical Company.

At about this same time we were approached by the California Chemical Company, Oronite Division of Standard Oil Company of California, regarding use of a polyester resin for this purpose. The possibility of a polyester performing the same function as an epoxy at about half the cost sounded attractive. A further attraction was the fact that although the epoxies were truly two component materials requiring intimate mixing and precise proportioning, the polyesters were catalyzed only and less critical mixing would still produce the required end product.

Test installations of five materials each about 20 ft long and about 12 ft wide were placed on the lower deck of the San Francisco-Oakland Bay Bridge in 1962. There were two latex-modified concretes, three polyester resins, an epoxy asphalt, and a proprietary concrete floor system without an adhesive (2). The epoxy asphalt formulation used in this application never seemed to set up, and abraded quickly under the heavy traffic. The proprietary concrete floor system and the latex-modified concretes showed under hand hammer soundings, extensive rattly areas indicating general lack of bond. The three polyester resins were excellent. The only apparent difficulty or obvious drawback to the polyester resin applications was lack of a commerical method producing an acceptable riding surface.

It became necessary to terminate the test when the lower deck paving contract was awarded in 1964. All test areas other than the polyester resins were readily cleaned down to the original concrete deck which was the new unsurfaced lightweight concrete over the former interurban trackway. It was practically impossible to remove the polyesters without removing part of the concrete substrate, and they were covered by the new surfacing.

The surfacing chosen for the upper deck paving contract in 1963 and the lower deck in 1964 on the basis of cost, commercial quality of application equipment and material, convenience to traffic, and current availability of contractors and equipment was Shell Guardkote 140 (basically a flood coat of epoxy coal tar filled with clean, hard sand passing a number 10 screen), at that time under the control of Shell Chemical Company. This was not a perfect solution but with the state of knowledge at that time it fulfilled most requirements. It obliterated the tile markers satisfactorily, renewed the surface, obliterated the difference in texture between the new and old concrete slabs on the lower deck, and provided a construction method that was compatible with the complicated lane-scheduling procedure required to switch traffic from mixed bidirectional traffic on each deck to unidirectional mixed traffic on each deck. It did not, however, provide a new screedable surface since the placing procedure is somewhat similar to that for a seal coat in that it repeats to some degree the imperfections of the underlying pavement.

In addition, we became acquainted with the capabilities of resin producers and their statements, which we have no reason to doubt, that if we could tell them the physical characteristics of the material required for our use, they could produce it. Numerical criteria developed by future tests may yet produce an opportunity for the resin producers to fulfill their promises.

Shell representatives in 1962 also described their Epon asphalt system, but the half-inch average thickness proposed for the San Francisco-Oakland Bay Bridge due to weight limitations was not considered feasible for Epon asphalt, basically a ⅜-in. maximum asphalt-concrete aggregate mixture bound with an epoxy-asphalt compound.

There were countless products investigated that did not receive complete study due to lack of proper financial or technical backing by the vendor. A definite factor in deciding on a coal tar epoxy for the San Francisco-Oakland Bay Bridge was the furnishing of a bonded written guarantee for three years.

LATER STUDIES

When the problem of paving the San Mateo-Hayward Bridge was faced in 1964, it was soon apparent from studies of European pavements that the problem of paving steel plate decks needed further study.

The best pavement based on long-time use was the so-called German Gussasphalt, a job-cooked mastic that had been developed through local usage and perpetuated with patented procedures and formulations and kept acceptable by guarantees. As far as our application was concerned, there were two reasons why Gussasphalt was not considered seriously. First, as with all mastic type mixtures that retain their plasticity, we expected that the performance under heavy traffic in hot weather would be unacceptable, and second, it seemed impossible under the existing construction industry framework to import such a patented controlled process involving not only material and equipment but also very exacting and demanding labor and construction procedures.

We were also aware of the Troy prototype paving experiments and there were again two basic reasons for not following that pattern. First, we had never found confirmation in the paving industry that rubber additives would improve asphaltic mixtures to the degree that we required for paving on steel decks, and second, the epoxy coal tar bond coat increased costs to the point where solid instead of layered construction could be considered. Later cracking problems at the Troy bridge terminated our interest in that system.

The Port Mann Bridge was apparently proceeding satisfactorily with a different multilayered system: a red lead epoxy polyamide paint overlaid with epoxy coal tar with grit embedded to act as a "tooth" for the overlaying asphalt concrete. There were again several reasons for not following this method. The floor system of the Port Mann Bridge with floor beams at about 5-ft 6-in. intervals was much stiffer than that proposed for San Mateo-Hayward with a minimum floorbeam spacing of 10 ft 6 in. Also it seemed by this time that a simpler system involving only one type material should be sought.

In 1964, a series of tests was designed to investigate a one-material system—a prime or bond layer on the steel deck of the same material used to cement together the aggregates in the overlying pavement. This would eliminate investigation of additional possible reactions between a variety of materials and also eliminate the cost of additional equipment and operations required for differing materials. The type of inorganic zinc protection system required by the designers had already been chosen. The contract specified inorganic zinc as a second line of defense from corrosion in addition to the pavement. The contractor chose Enjay Chemical Company's Rust-Ban 191. This same Rust-Ban was used on all laboratory test specimens.

Two fundamental tests were used as criteria for choosing materials for a field test. Pavement specimens were prepared on ½-in. thick, 4-in. by 18-in. steel plates coated with inorganic zinc and 1½ in. of compacted paving material. Diamond drill cores (2-in. diameter) were cut through this pavement to the steel and pulled off in direct tension to measure adhesion. Other specimens were placed between supports at 15-in. centers and deflected with a 700-lb load applied repeatedly so as to produce tension on the exposed face of the paving material to establish a fatigue strength (3).

At this time we were surprised to find that we were unable to produce a satisfactory specimen with the epoxy coal tar Guardkote 140 as the resin. It has since been stated by various chemists that the curing agent in this formulation reacts with zinc and thus affects the bond between the epoxy coal tar and the zinc-coated steel. On the other hand, we are informed that epoxy asphalt employing a curing system different from epoxy coal tar has no effect on the zinc coating. This may account for some of the failures of the epoxy coal tar paving attempted on zinc-sprayed orthotropic decks. Apparently, the bond between clean bare steel and epoxy coal tar is satisfactory.

Again Shell was approached concerning the epoxy asphalt discussed earlier during the San Francisco-Oakland Bay Bridge tests. However, that company had had some discouraging experience and was not interested at first. Sometime later, after internal changes of responsibility, Shell returned to us with a revised formulation which the company was willing to subject to our test procedures. This Type III Epon asphalt had been reformulated and reevaluated on the basis of field experience especially with re-

TABLE 1

PARTIAL LIST OF MATERIALS INVESTIGATED

Binder Material	Supplier
Epon asphalt	Shell Oil Company
Guardkote 250	Shell Oil Company
Guardkote 140	Shell Chemical Company
Polyester resin	California Chemical Company, Oronite Division
Polyester resin	Reichhold Chemicals, Inc.
Polyester resin	Cook Paint and Varnish Company
Latex	B. F. Goodrich Company, Chemical Division
Latex	Dewey and Almy Chemical Corporation
Epoxy asphalt	Protex-A-Cote, Inc.
Asphalt concrete	California Highway Specifications
Miradon	Humble Oil and Refining Company
Humbleweld 7502	Humble Oil and Refining Company
Resiweld R7122	H. B. Fuller Company
Resiweld 7122M	H. B. Fuller Company
Resiweld 7121	H. B. Fuller Company
Resiweld R7123	H. B. Fuller Company
Concresive 1112	Adhesive Engineering
Concresive 1113	Adhesive Engineering
Ductron	Standard Oil Company of Ohio
Epoxy IR413A	California Division of Highways, Materials and Research Department Formulation
CDC	Mitchell, Pianta and Pfenning, Inc., San Antonio

gard to curing time and flexibility or ductility of the resultant pavement.

TEST RESULTS

As a result of laboratory tests (5, 8), two field applications were made with five materials in each test in the fall of 1965. One test area was made available by the State Division of Highways at the Ulatis Creek Bridge near Vacaville on an Interstate Highway in one of the eastbound lanes. This bridge is an orthotropic steel deck that is structurally stiff but, due to its short span, very light. The second area was a prototype section of the San Mateo-Hayward Bridge orthotropic section erected over an abandoned scale pit on the site of the former toll plaza at the west end of the San Mateo-Hayward Bridge. The five materials (Table 1) were as follows:

1. Ordinary asphaltic concrete, ⅜-in. maximum aggregate;
2. Shell's Epon asphalt, Type III, graded aggregate ⅜-in. maximum;
3. Fuller's Resiweld R7122, sand resin mortar;
4. Shell's Guardkote 250, sand resin mortar; and
5. Adhesive Engineering's Concresive 1113, sand resin mortar.

The immediate and early result of these field applications was a prompt failure of the asphalt concrete at Ulatis Creek by slipping. This was repaired by the State Highway Maintenance Department. The repaired section performed much better than the original installation. All of the resin pavements were applied according to the recommendations and with the assistance of their sponsors although the actual work was done under contract. At the San Mateo-Hayward Bridge even the ordinary asphaltic concrete remained intact through the entire test period. The Ulatis Creek materials are still in place. The test area over the scale pit had to be removed to complete the San Mateo Bridge for public traffic.

Traffic is unusually heavy and fast at Ulatis Creek, whereas at the scale pit location it was light by comparison and of limited duration due to construction exigencies.

In spite of the fact that the resin pavements, with the exception of the epoxy asphalt, were very rough and despite the fact that all of the joints between the various materials were square, whereas the pavement continued across the skewed joints in the steel on the Ulatis Creek Bridge, the Ulatis Creek resin pavements are all in good condition. The pavements have cracked over the skewed joints but only minor spalling is evident. The roughness produced violent impacts and vibration without producing visible damage. This roughness was overcome later—not to diminish abuse of the pavement but for the relief of the traffic which tended to avoid the rough area. An abrasive grinding operation was used for corrective work such as is used on portland cement concrete pavement that is out of specification for roughness.

At Ulatis Creek all materials except the ordinary asphaltic concrete performed very well, although the riding surface of the three light-colored epoxies was very rough because of construction procedures.

At the scale pit installation, there was no surface evidence of unsatisfactory performance in any of the materials. The most interesting results were observed during removal of the pavement from the steel bridge deck prototype.

Various methods of removal were tried including a demolition ball and a bulldozer. The asphaltic concrete came off rather readily as expected, and at the fracture faces, it separated from the aggregate particles and also cleanly from the inorganic zinc covering the deck.

The epoxy asphalt at fractures broke cleanly through the aggregate particles and in places came up with the inorganic zinc film attached. The three light-colored epoxies also brought up inorganic zinc. They did not include any aggregate particles larger than sand in the mixture.

A 200-ft length of steel bridge one lane in width was paved in the summer of 1968 just before the paving contract to observe and study the effect of the construction procedure on the transverse and longitudinal bolted splice plates and the two-course construction in general. Results were good.

THE CHOICE

The choice of the Epon asphalt (7) was based on four factors:

1. Cost is between ordinary asphaltic concrete and the light-colored epoxies. The final contract cost was about one dollar per square foot in place including the deck preparation but not the inorganic zinc coating.
2. Surface tolerance and riding characteristics are as good as asphaltic concrete and better than the light-colored epoxies.
3. Construction procedure was feasible by modification of existing construction equipment.
4. Physical characteristics were far superior to ordinary asphaltic concrete and approached those of the more expensive epoxies.

CONSTRUCTION

The contractor engineered and purchased the special equipment required to mix and proportion the epoxy asphalt components and installed it at a paving plant rented for the duration of the work which took about three weeks. The spreading equipment had a detention tank to hold the mixed components at an elevated temperature to speed the curing.

Epoxy asphalt has an extended curing time which varies with the ambient temperature. This can be accelerated by holding at an elevated temperature. The problem in the field is to keep it at an elevated temperature long enough so that it does not take unduly long for the material to reach its ultimate properties but not so long that workability and compressibility are affected to a degree that is detrimental to the construction procedure (11). In contrast to earlier formulations, the present Type III epoxy asphalt formulation is not critically sensitive in this regard.

The pavement has a typical Marshall stability of 14,400 lb at 140 F and 4,200 lb at 400 F. By contrast, ordinary asphalt concrete has a Marshall stability of 2,600 lb at 140 F and has virtually no stability at 400 F.

THE FUTURE

Following completion of work leading to the choice of material for this project, other material suitable for use were submitted to us. We have continued laboratory tests, and at least two additional materials should be considered in future investigations. One of these is Cybond produced by American Cyanamid Company, a polyester resin mortar primed with polyester resin and the other CDC, a polyester resin (10) primed and bonded with epoxy resin. These should be field tested and appraised for determination of the cost of installation.

It is encouraging that the American Iron and Steel Institute has retained the Battelle Institute and, under the direction of Fred Fondriest, has published several reports on the state of the art. This could turn out to be a necessary clearinghouse for findings on orthotropic paving procedures. However, field tests are required for a variety of materials and procedures to ascertain whether laboratory criteria can be established to determine probable field performance.

Additional work should be done on commercial applications of resin materials to bridge decks with surface tolerances meeting the riding requirements of high-speed traffic. It is believed that costs can be clearly assessed when the procedure and choice of material have been determined. The science of resin formulation has been developed so that with sufficient flexibility a number of resins should be acceptable and costs would then be the determining variable.

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