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16. ABSTRACT

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During the later part of the course of our investigations, a comprehensive review of the state of the art of paving orthotropic steel bridges was prepared and published by the Battelle Institute for the American Iron and Steel Institute.

Other recent orthotropic steel bridge decks either have been paved or are planned to be paved with systems different from that recommended for the San Mateo-Hayward Bridge.

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RESULTS OF STUDIES OF MATERIALS FOR STEEL ORTHOTROPIC DECK PAVEMENT

SAN MATEO-HAYWARD BRIDGE

December 1966

BEN BALALA
Construction Engineer

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1. INTRODUCTION

The problem of paving orthotropic steel decks has never been satisfactorily solved. Even before bids were received for the San Mateo-Hayward Bridge orthotropic spans, studies were begun to find a suitable paving system. European practice was studied which only confirmed that existing paving systems were somewhat less than satisfactory. In addition, the most satisfactory system in use in Europe was the mastic type which is not used in this country and consequently no acceptable techniques, workmen, or equipment for this material are available. Due to the hand methods used in application, the finished surface is far from acceptable freeway standards.

During the later part of the course of our investigations, a comprehensive review of the state of the art of paving orthotropic steel bridges was prepared and published by the Battelle Institute for the American Iron and Steel Institute[1].

Other recent orthotropic steel bridge decks either have been paved or are planned to be paved with systems different from that recommended for the San Mateo-Hayward Bridge.

1. The Port Mann Bridge in British Columbia is paved with asphaltic concrete overlaying a slip-resistant epoxy coal-tar grit coating which in turn is placed over a polyamide cured epoxy red-lead corrosion protective paint coating. The floor beams, however, are closely spaced by comparison with those on the San Mateo-Hayward Bridge. Two years after construction this pavement appears to be entirely satisfactory.

2. The Severn River Bridge in England has an asphaltic mastic type pavement similar to that used on the German bridges.

3. The pavement chosen for the Poplar Street Bridge across the Mississippi River at St. Louis is asphaltic concrete containing a rubber additive placed over a slip-resistant epoxy coal-tar and grit layer. Indications are that some cracking has occurred in the pavement placed on the prototype test bridge at Troy, Illinois.

4. The State of California, Division of Highways, has paved a test orthotropic bridge where Dublin Canyon emerges into Livermore Valley on U.S. 50. A thin type epoxy, coal-tar, grit-filled wearing surface placed over sprayed metallic zinc is showing lack of adhesion. A similar type placed on bare steel is performing much better. An asphaltic concrete pavement placed over an epoxy, coal-tar, grit-filled, slip-resistant coat shows signs of cracking.

Thin type surfacings were not considered for the San Mateo-Hayward Bridge for two reasons: first, they are not adaptable to covering the bolted steel plate splices, and second, they can only reflect the riding surfaces built into the steel plate.

With due regard to the flexibility of the San Mateo-Hayward Bridge deck and the results of our preliminary laboratory tests, ordinary asphaltic concrete was not considered as a suitable pavement and is represented in the field applications only as a control.

In reviewing the general performance of the various layered types of construction, it was thought that a single layer of material with an adequate binder would be the most desirable from the standpoint of both costs and performance. Also from our previous experience in searching for an overlay for the concrete decks of the San Francisco-Oakland Bay Bridge, we had reason to believe that satisfactory materials were available[2,3].

The goal set was to develop a system that would incorporate a protective coating for the steel and a prime coat over the protective coating of the same resin to be used to bind the mineral aggregate in the paving material used.

[1] Current Paving Practices on Orthotropic Bridge Decks, Battelle Memorial Institute, Bulletin No. 1, October 1965

[2] Resident Engineer's Report, Test Overlays-Steel Deck, Contract No. 5026

[3] Report of Tests on Resurfacing Materials for Concrete Roadways, Bay Toll Crossings, 1962

2. TEST RESULTS

a. Preliminary

Drawing No. M-5023-1, approved on November 14, 1963, titled Laboratory Tests for Steel Deck Overlay, was the basis for the preliminary test program. See Figure 1. Forty test specimens were prepared.

Specimens were 1-1/2" thick pavement applied to 4" x 5/8" x 1'-6" steel plates conforming to the A-36 specification (the same quality as the steel decking on the bridge). The treated surface was sandblasted and on 20 specimens sprayed metallic zinc was applied to a five-mil minimum thickness and on the other 20 plates self-curing inorganic zinc primer (Carbozinc 11) was applied to a 3.5 mil minimum thickness. The Carbozinc was considered to be representative of the corrosion protection planned for the bridge structure.

A bond coat of tar modified epoxy resin, Carbomastic, 10 to 12 mils thick filled with fine sand was applied to 20 plates. Ten of these had been sprayed with metallic zinc and the other ten were coated with inorganic zinc primer.

Two paving materials were used; one was the State's standard 1-1/2" asphalt concrete mix using 95-100 penetration grade asphalt, and the other a 1-1/2" Epon asphalt concrete. The tack coat for standard asphaltic concrete was liquid asphalt, SS-1 b, applied at the rate of 0.05 gal./sq. yd. The tack coat for the Epon asphalt concrete was Epon asphalt.

Preparation and application of material to the specimens were accomplished by the material supplier, Shell Oil Company[4]. Sprayed zinc was applied by Metallizing Company, Inc. of America. Self-curing inorganic zinc and the tar modified epoxy resin bond coat were applied by Carboline Company.

Four different tests were made on each variation of material and application.

1. Flexure Test. A testing rate of five cycles per second and an applied loading of 700 pounds was used. This was continued until failure or 1,000,000 cycles, whichever occurred first. The composite action of the different materials with the steel plate varied the actual stress obtained in the steel plate.

2. Fast Shear Test. Performed at a speed to cause failure within two seconds.

3. Slow Shear Test. Performed at a maximum rate of travel speed for the testing machine of 0.0002 inch/second.

4. Adhesion Test. Pulling on a cored specimen until failure with an applied load rate of 20 pounds/second.

All tests were conducted at a temperature of 72 degrees F., plus or minus four degrees.

Results are shown in TABLE 1, Nos. 1 to 40 inclusive except that shear test results are not shown.

Results of these tests indicated that asphaltic concrete applied in accordance with customary highway practices would not be satisfactory for a pavement on a steel deck. The average life in flexure was 7,000 cycles, the slow shear average was 3 p.s.i., the fast shear average was 68 p.s.i. and the adhesion average was 78 p.s.i.

In comparison the Epon asphalt had an average life in flexure of 721,400 cycles with four specimens reaching approximately one million cycles. Three of the specimens showed no cracking at one million cycles. The average value for slow shear was 38 p.s.i. for fast shear 82 p.s.i., and for adhesion 118 p.s.i. It is possible that the Epon asphalt did not have its full cure at the time these early values were obtained as later results for adhesion are much higher.

The tests also indicated the following:

1. Either inorganic zinc primer or sprayed zinc had an adhesion to steel stronger than the tensile strengths of the asphalts.

2. Tar modified epoxy bond coats were not an advantage and did not increase the adhesion value of asphaltic concrete or Epon asphalt.

3. Good adhesion to the steel was required to provide good flexural resistance.

One of the asphalt specimens that developed separation at the bond line to the steel plate was placed in a salt fog chamber for 1,600 hours and then examined for the effect on the corrosion inhibitor. The inhibitor was sprayed zinc in this case and was almost all sacrificed after the exposure, showing that this protection is effective.

b. Second Series

Based on the experience of the tests noted above, other materials were investigated and tested for only flexure and adhesion. Adhesion to steel plate is considered a prime requisite for a satisfactory surfacing. In general, a pair of specimen plates, sandblasted and coated with inorganic zinc primer were provided to suppliers of materials to be tested. The suppliers applied their paving materials to these test plates in accordance with their own specifications.

Results of this second series of tests appear as Nos. 41 to 50 inclusive in TABLE 2.

Following the tests on the first 50 plates a group of five materials were chosen for field test installations.

[4]Flexural Tests of Paving Materials for Orthotropic Steel Plates by C. T. Metcalf, Shell Development Company Paper P-1420

3. FIELD TESTS

Two test installations were made of five materials on steel decks:

1. Asphaltic concrete (control section).
2. Shell Epon asphalt.
3. Shell Guardkote 250.
4. Fuller Resiweld R7122.
5. Adhesives Engineering Concresive 1064.

One test installation was in one traffic lane of the Ulatis Creek Bridge, on Interstate 80, north of the S.P. Overhead at Vacaville. This installation in the Sacramento bound lane closest to the shoulder is subject to heavy high speed truck traffic.

The other test location, decked with a prototype simulating the San Mateo-Hayward Bridge orthotropic construction, is on an old scale pit on the traveled way of the existing detour at the west end of the San Mateo-Hayward Bridge.

The asphalt concrete section on the Ulatis Creek Bridge has failed by slip or shoving on the steel deck and has been replaced twice since the original installation about a year ago. All other test patches are in good condition.

The epoxy materials when placed on Ulatis Creek were of substandard surface finish, with a very rough surface. Concrete sawing (cutting closely spaced parallel grooves with diamond saws) the surface to acceptable tolerances was accomplished on January 28, 1966.

4. RECOMMENDATIONS

The goal of all the investigations was to find a paving material with satisfactory adhesive and flexural fatigue qualities, and a material that could be placed to the high surface finish standards of modern freeway construction with currently available construction equipment. The methods used by the material suppliers in constructing the test patches indicated that methods for placing the epoxy mixtures to obtain good riding qualities were not yet systematized. The Epon asphalt and the asphaltic concrete were placed with paving machines.

On the basis of the above, it appears the only material tested in the first 50 plates, meeting the design goals is Epon asphalt. It is the only available choice for a paving material based on the test results on the sample plates and also on observation of the test patches. It can be mixed in existing hot plants and placed and finished with available standard paving equipment.

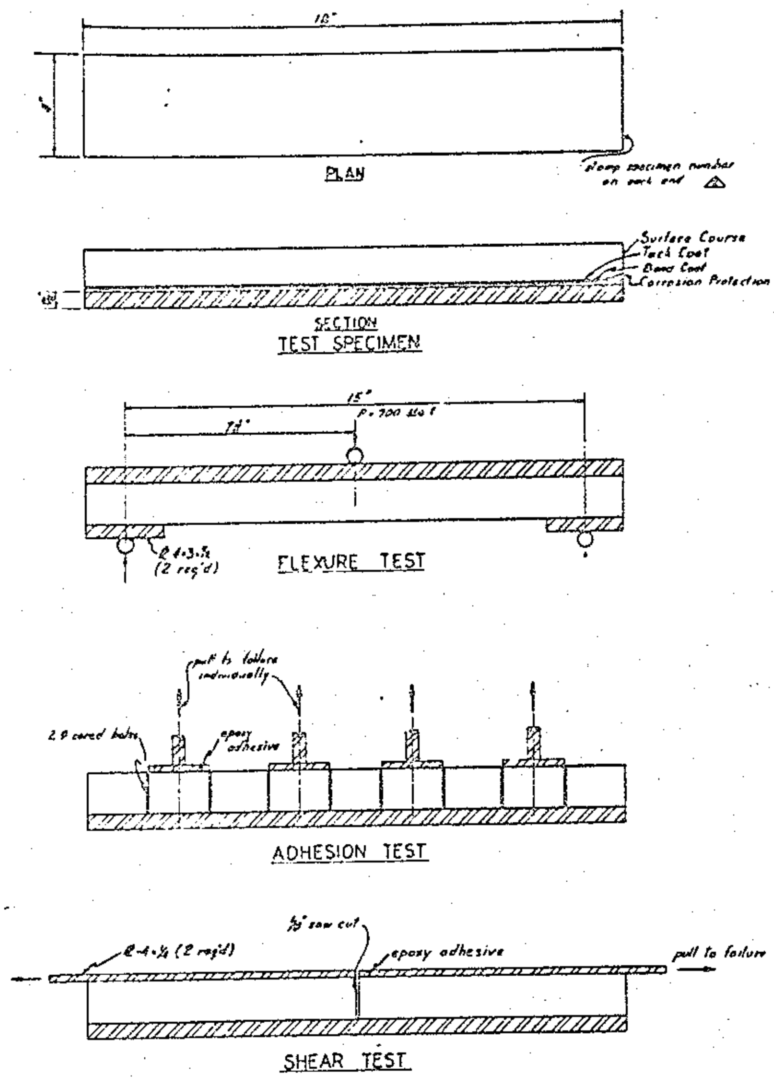
By no means the least consideration in the recommendation of Epon asphalt is the anticipated difference in cost between Epon asphalt and the other epoxy mixtures tested. After the cost of preparation, aggregate, placing, etc. which are comparable for all materials, the predominant variable factor in the cost is the epoxy content. About one tenth as much epoxy is required for Epon asphalt as for the other epoxy mixtures. This coupled with the hope of using a normal hot plant for mixing and a normal paving machine for placement makes Epon asphalt virtually the only logical choice.

In comparing the cost of Epon asphalt with the layered types used elsewhere it can be considered that the epoxy resin used for the slip-resistant coating has been added to the asphalt concrete mixture. Accordingly Epon asphalt may cost even less than the layered type of construction.

5. CONTINUING LABORATORY TESTS

Many of the materials tested, after the contract for the placement of the test patches had been completed, performed admirably in the laboratory tests. However, lacking field data extrapolation of laboratory tests to predict field performance was not attempted. Attention is directed to the exceptional laboratory results of Concrete Development Corporation specially modified polyester resins. The composite action of this material was very evident in the fatigue testing. However, preliminary results by Battelle Institute indicate that polyesters may lose their superior qualities at elevated temperatures as low as 140° F.

Tests for adhesion and fatigue in tensile flexure are also being continued on promising materials submitted to our attention from time to time. These later tests are still continuing and results are those from 51 on in TABLE 3.



MATERIALS

Corrosion Protection

A. Sprayed metallic zinc by Metallizing Company of America or equal (5 mils minimum)
B. Zinc-filled self-curing inorganic coating, Carbo-Zinc 11 or equal (3.5 mils minimum)

Bond Coat △

a. For modified epoxy resin, Carbomastic 12 or equal (10 mils minimum). While the epoxy resin is still liquid a fine sand, with the following gradation, shall be dropped into the resin.

Sizes	Sand Gradation % Retained	% Passing
No 30	0	100
No 30	30-50	50-70
No 40	40-80	20-60
No 50	97 min.	3 max.

Tack Coat

△ I. Liquid asphalt SS 1h at the rate of 0.05 to 0.10 gallons per square yard
II. Epon asphalt, applied hot, Shell or equal

Surface Course

△ a. 1½" asphalt concrete
b. 1½" Epon-asphalt concrete, applied hot, Shell or equal

GENERAL NOTES

1. The purpose of these laboratory tests is to evaluate representative samples of deck overlay materials for use in surfacing orthotropic steel plate deck.
2. All test specimens shall be prepared in accordance with the approved manufacturers detailed specifications and procedures for the formulation, application, and curing of materials, or in accordance with the Division's Standard Specifications.
3. All test specimens shall be returned to the Division for inspection after testing.
4. The results of all tests shall be carefully recorded and compiled into a final report.

TABULATION OF TEST SPECIMENS △

Specimen Number	Preparation: Corrosion Protection	Bond Coat	Tack Coat	Surface Course	Testing: Flexure test	Shear test: fast	Shear test: slow	Adhesion test
1	A	a	I	a	X	o		
2					X		o	
3						X		
4							X	
5				a				X
6			II	b	X	o		
7					X		o	
8						X		
9							X	
10		a	II	b				X
11		none		a	X	o		
12					X		o	
13						X		
14							X	
15				a				X
16			II	b	X	o		
17					X		o	
18						X		
19							X	
20	A	none	II	b				X
21	B	a		a	X	o		
22					X		o	
23						X		
24							X	
25								X
26			II	b	X	o		
27					X		o	
28						X		
29							X	
30			II	b				X
31		none		a	X	o		
32					X		o	
33						X		
34							X	
35				a				X
36			II	b	X	o		
37					X		o	
38						X		
39							X	
40	B	none	II	b				X

x Indicates primary test

o Indicates secondary test to be performed if specimen was not failed during primary test.

PREPARATION OF TEST SPECIMENS

1. Steel plates for test specimens shall be ASTM-A36 structural steel. (Total 40 plates)
2. Five test specimens of each combination of materials shall be prepared and tested as tabulated hereon.

TESTING PROCEDURE

1. Flexure Test:
   The cyclic load for flexure test shall be sufficient to produce a stress of 10,000 p.s.i. in the extreme fiber of the steel plate in contact with the overlay material. The cyclic flexure load shall be applied at a rate between 5 and 50 cycles per second. The test shall be continued until the overlay material shows signs of severe cracking at which time the total number of cycles shall be recorded. Flexure test shall be stopped after 1,000,000 cycles.
2. Shear Test:
   Shear test shall be conducted at two different load rates as shown below and tabulated hereon.
   Fast - sufficient to cause failure within 2 seconds.
   △ Slow - maximum of 0.0002 inch per second ± 20%
   Record failure load in p.s.i. and location of failure plane.
3. Adhesion test:
   △ Adhesion test shall be conducted at a load rate of 50 pounds per second ± 10%.
   Record failure load in p.s.i. and location of failure plane.
4. All tests shall be conducted at 72°F ± 4°F.
5. Determine density of the surface course of each specimen.

△

Mark	Date	Description	By	Chk
△	3-4-65	Notes changed	DLS	CS
△	2-1-65	Revised tabulation of test specimens; bond coat and added Tack Coat	DLS	CS

SAN MATEO-HAYWARD BRIDGE IMPROVEMENT
SURFACE STEEL DECK
LABORATORY TESTS FOR STEEL DECK OVERLAY

FIGURE 1

TABLE 1

SUMMARY OF TEST RESULTS - SURFACING STEEL DECK

Test No.	Material	Adhesion Test-PSI	Flexure Test - Cycles Start of Crack	Bond Failure
1 C Z	Asphalt Concrete	--	3,800	5,300
2 C Z	Asphalt Concrete	--	3,000	4,500
5 C Z	Asphalt Concrete	67	--	--
6 C Z	Epon Asphalt Concrete	--	(No cracks at 1,000,000)	
7 C Z	Epon Asphalt Concrete	--	167,000	586,000
10 C Z	Epon Asphalt Concrete	95	--	--
11 Z	Asphalt Concrete	--	2,100	2,100
12 Z	Asphalt Concrete	--	11,000	61,000
15 Z	Asphalt Concrete	152	--	--
16 Z	Epon Asphalt Concrete	--	505,000	(No cracks at 638,000)
17 Z	Epon Asphalt Concrete	--	213,000	1,055,000
20 Z	Epon Asphalt Concrete	218	--	--
21 C IZ	Asphalt Concrete	--	4,100	6,400
22 C IZ	Asphalt Concrete	--	10,000	17,000
25 C IZ	Asphalt Concrete	21	--	--
26 C IZ	Epon Asphalt Concrete	--	992,000	(No cracks at 1,000,000)
27 C IZ	Epon Asphalt Concrete	--	(No visible cracks at 1,000,000)	
30 C IZ	Epon Asphalt Concrete	74	--	--
31 IZ	Asphalt Concrete	--	13,811	13,811
32 IZ	Asphalt Concrete	--	8,000	61,000
35 IZ	Asphalt Concrete	71	--	--
36 IZ	Epon Asphalt Concrete	--	794,000	(No cracks at 1,154,000)
37 IZ	Epon Asphalt Concrete	--	(No visible cracks at 1,007,200)	
40 IZ	Epon Asphalt Concrete	86	--	--

C Carbomastic 12 and sand granules
Z Sprayed metallic zinc
IZ Inorganic zinc primer

TABLE 2

SUMMARY OF TEST RESULTS - SURFACING STEEL DECK

Test No.	Material	Adhesion Test-PSI	Flexure Test - Cycles Start of Crack	Bond Failure
41	Miradon-Plate #3	94	64,000	410,000
42	Miradon-Plate #5	154	390,000	1,014,000
43	Guardkote 140-1/2" Mix	89	107,000	144,000
44	Guardkote 250	579	(No cracks at 1,057,000)	
45	Ductron	67	3,200	120,000
46	Concresive 1064-3	228	47,000	300,000
47	Guardkote 140	302	(No cracks at 1,000,000)	
48	Resiweld R7122	815	(No cracks at 1,000,000)	
49	Concresive 1112	522	41,000	346,000
50	Concresive 1113	958	(No cracks at 1,122,000)	

Note: All plates coated with inorganic zinc primer Rust-Ban 191.

TABLE 3

SUMMARY OF TEST RESULTS TO DATE - SURFACING STEEL DECK

Test No.	Material	Adhesion Test-PSI	Flexure Test - Cycles Start of Crack	Flexure Test - Cycles Bond Failure
*	Epon Asphalt	210	--	--
*	AC Paving	71	--	--
*	Resiweld R7122	473	--	--
*	Guardkote 250	432	--	--
*	Concresive 1113	453	--	--
**	Epon Asphalt	206	--	--
**	AC Paving	0*+	--	--
**	Resiweld R7122	448	--	--
**	Guardkote 250	256	--	--
**	Concresive 1113	423	--	--
51	Epoxy IR413A State Lab	375	182,670	427,000
52	CDC-On Zinc Coated Steel	224	(No cracks at 1,072,000)	
53	CDC-On Sandblasted Steel	656	(No cracks at 1,077,000)	
54	Humbleweld 7502, Aggregate + Cement	--	(No cracks at 1,000,000)	
55	Humbleweld 7502, Aggregate + Cement + Fibreglass	--	(No cracks at 1,000,000)	
56	Humbleweld 7502, Aggregate + Carbon Black	--	(No cracks at 1,000,000)	
57	Humbleweld 7502, Aggregate + Carbon Black	--	(No cracks at 1,000,000)	
58	Humbleweld 7502, Sand + Cement	--	(No cracks at 1,000,000)	
59	Fuller 7122-M	892	797,000	--
60	Fuller 7121	656	(No cracks at 1,200,000)	
61	Fuller R-7123	736	(No cracks at 1,054,000)	

*Ulatis Creek Bridge
**San Mateo Scale Pit
*+Tack Coat Failure

Note: All plates coated with inorganic zinc primer Rust-Ban 191.