# EXPERIENCES WITH SKID-RESISTANT EPOXY ASPHALT SURFACES ON CALIFORNIA TOLL BRIDGES

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Epoxy asphalt surfaces have been placed on 3 bridges to solve very special surfacing problems unique to each bridge. The surfaces fall into 3 general categories: pavements thicker than 1½ in. (3.8 cm) applied to orthotropic steel plate decks, pavements from ½ to 1 in. (1.3 to 2.5 cm) applied to old concrete decks that are structurally sound but have deteriorated as a riding surface, and chip seals ¼ in. (0.6 cm) or less in thickness also applied to old concrete decks that are structurally sound but need sealing and improved skid resistance. In addition to high skid resistance, each case has one other controlling factor. For the first case, the factor is flexure fatigue controls; hence, a pavement resistant to fatigue is required. For the latter 2 cases, the factor is superimposed weight on the existing bridge controls; hence, thin but durable surfaces are required. In all 3 cases, epoxy asphalt provided a thoroughly satisfactory solution.

•THE CALIFORNIA Department of Transportation manages 8 of the 9 toll bridges located within the State of California. The newest is the San Diego-Coronado Bay Bridge, opened in 1969. The list also includes 2 world-reknowned bridges: the San Francisco-Oakland Bay Bridge, opened in 1939, and the new San Mateo-Hayward Bridge, opened in 1967. This paper deals with these 3 bridges on which epoxy asphalt surfaces have been placed to solve very special surfacing problems unique to each bridge. These surfaces fall into 3 general categories:

1. Pavements thicker than 1½ in. (3.8 cm applied to orthotropic steel plate decks);
2. Pavements from ½ to 1 in. (1.3 to 2.5 cm) thick applied to old concrete decks that are structurally sound but have deteriorated as a riding surface; and
3. Chip seals ¼ in. (0.6 cm) or less in thickness also applied to old concrete decks that are structurally sound but need sealing and improved skid resistance.

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## EPOXY ASPHALT PAVEMENT

Epoxy asphalt pavement is similar to ordinary asphalt concrete pavement except that epoxy resin, hardeners, and other modifiers are added to the asphalt to produce a 2-component binder. It was originally developed for airfields to resist jet fuels and heat blasts (1, 2). It is mixed in the pug mill of a conventional hot plant, delivered in dump trucks, and placed and compacted by conventional equipment. A tack coat of the epoxy binder is applied to firmly bond the pavement to the substrate. After placement and rolling, the pavement has about the same properties as ordinary asphalt concrete; after cooling, it can be opened to traffic. The epoxy requires 30 to 60 days to become fully cured depending on the ambient temperature. When fully cured, epoxy asphalt is

Publication of this paper sponsored by Committee on Characteristics of Aggregates and Fillers for Bituminous Construction.

a thermoset plastic similar in strength to portland cement concrete but with the flexibility of asphalt concrete. Typical properties are given in Table 1 (3).

The conventional batch plant must be modified slightly to heat, meter, and inject the 2-component binder directly into the pug mill. To improve bond, the substrate is sprayed with a tack coat of the same epoxy binder as is used in the mix. Temperature of all ingredients is critical and must be carefully controlled before and after mixing. When the plant is producing epoxy asphalt it cannot be used to produce ordinary asphalt mixes.

The mix material in the truck must be placed within a specified time limit. Holding too long will not allow proper compaction or the mix may set in the paving machine. Placing the material too early will prevent full cure and cause some loss of strength. Rolling must begin immediately with both steel and pneumatic tire rollers. Although epoxy asphalt is more difficult to use than conventional asphalt, a paving contractor can control it after he or she learns the necessary skills.

## EPOXY ASPHALT CHIP SEAL

Epoxy asphalt chip seal is similar in form to ordinary asphalt chip seal except that an epoxy-modified asphalt binder is used. Typical properties are shown in Table 1 (4). The concrete deck is cleaned and sprayed with a flood coat of a 2-component epoxy asphalt. Then, stone chips are dropped into the binder. After a 2- to 4-hour cure period (depending on ambient temperatures), the area is swept to remove excess chips that have not bonded and the surface is ready for traffic (5).

The 2-component binder must be accurately heated, metered, mixed, and sprayed on the concrete deck in a uniform application. It is not the same binder as that used in epoxy asphalt pavement. A specially constructed 2-component distributer truck is used to spray the binder on the concrete deck. The aggregate is distributed by a side-dumping spreader. Temperature of the binder is critical, and the aggregate must be applied directly behind the sprayer. Epoxy asphalt chip seal must be applied by a skilled contractor with the proper equipment.

## SKID RESISTANCE OF EPOXY ASPHALT SURFACES

The thermosetting properties of epoxy asphalt surfaces provide the basis for high skid resistance if epoxy asphalt is used with a selected, tough, abrasion-resistant, and polish-resistant aggregate. The thermosetting epoxy asphalt binder will not flush to the surface or migrate within the pavement. Heat, oil, or gasoline has little effect on it. The epoxy asphalt binder holds the aggregate in a strong thermosetting grip that is durable under heavy traffic conditions. Traffic wear and ultraviolet chalking remove excess hardened binder from the valleys and crevices thus providing macrotexture and maximum exposure of the microtextured faces of the aggregate (6).

**Table 1. Typical properties.**

| Properties | Epoxy Asphalt Binder for Concrete | Epoxy Asphalt Binder for Chip Seal | Epoxy Asphalt Concrete | Asphalt Concrete | Portland Cement Concrete |
|---|---|---|---|---|---|
| Tensile strength at 73 F, psi | 190 | 2,000 | 600 | 130 | 350 |
| Tensile elongation at break at 73 F, percent | 215 | 50 | 3 | 1.2 | 0.3 |
| Flexural strength at 77 F, psi | | | 640 | 80 | 600 |
| Flexural modulus at 77 F, psi × $10^3$ | | | 380 | 200 | 3,000 |
| Marshall stability at 140 F, pounds | | | 14,400 | 2,685 | |
| Tensile bond strength to steel, psi | | | 220 | 30 | |
| Tensile bond strength to PCC, psi | | 400 | 240 | 50 | |
| Marshall stability after immersion in JP-4 jet fuel for 24 hours at 140 F, pounds | | | 13,200 | Disintegrated | |
| Stability at 400 F after 2 hours at 400 F, pounds | | | 4,200 | Nil | |
| Hveem stabilometer value at 140 F | | | 73 | 25 | |

Note: 1 F = 1.8 (1 C) + 32. 1 psi = 6.89 kPa. 1 pound = 4.4 N. 1 mil = 25.4 μm.

## TEST AREAS

### Open-Graded Epoxy Asphalt Pavement

The San Francisco-Oakland Bay Bridge (SF-OBB) was modified and strengthened from 1958 to 1963 to carry 5 lanes of automobile and truck traffic on both its upper and lower decks. In 1963 the upper deck was surfaced with an epoxy coal-tar chip seal. The lower deck was surfaced the next year with the same system.

In 1968 specimens taken from the deck showed that particles had been picked out, polished, or sheared off to the level of the resin matrix. This loss of aggregate was attributed to the rounded shape of the grains, low adhesion of the epoxy coal-tar binder to the slick silica surface, and low particle toughness. The deck was structurally sound but had deteriorated as a riding surface. In late 1969, 2 large test areas on horizontal curves were paved with an open-graded epoxy asphalt ½ in. (1.3 cm) thick (7). Two different types of aggregate were used: an air-cooled blast furnace slag and a granite. As expected, wet weather accidents at these 2 locations were reduced dramatically.

Average daily traffic in these test areas is approximately 17,000 vehicles per lane, about 10 percent of which is heavy trucks. Both types of aggregate have raveled a little but are still performing satisfactorily as a pavement.

### Dense-Graded Epoxy Asphalt Pavement

In a search to find a surface for the remainder of the SF-OBB, 16 test areas were placed on the upper deck of the bridge in the summer of 1971 to test a variety of pavements and chip seals. Six of these areas are dense-graded epoxy asphalt pavements, 1 is epoxy asphalt chip seal, and the remaining 9 are chip seals using polyester, urethane, or epoxy resins as binders. Each test area is a full lane-width wide and approximately 200 ft long.

For the 6 areas of dense-graded epoxy asphalt, 3 different types of aggregate were used in ½-in. (1.3-cm) and 1-in. (2.5-cm) thicknesses. Surfaces had to be thin to keep down the weight added to the bridge. Test patches 1 and 2 contain an expanded shale, lightweight aggregate conforming to ASTM C 330-69 with the surface sealed by firing after crushing. Test patches 3 and 4 used a blast furnace slag, and test patches 5 and 6 used a granite aggregate. The latter 2 were the same as those used for the open-graded pavement areas placed in 1969. Average daily traffic is the same as that for the open-graded pavement test areas.

The San Mateo-Hayward Bridge (SM-HB), paved with a dense-graded epoxy asphalt in 1967 (8, 9), and the San Diego-Coronado Bay Bridge (SD-CBB), also paved with a dense-graded epoxy asphalt in 1969, provided several older test areas for skid-resistance monitoring. Both bridges have orthotropic steel deck spans for which dense-graded epoxy asphalt pavement is an ideal paving material because of its proven resistance to flexure fatigue (10, 11). Pavement thickness for both bridges varies from 1½ to 2 in. (2.5 to 5.0 cm).

The orthotropic portion of the SM-HB is paved with a calera limestone and is designated test patch G. Average daily traffic is approximately 4,400 vehicles per lane, over 900 of which are heavy trucks.

The orthotropic portion of the SD-CBB is paved with a rhyolite aggregate. The outer lanes are designated as test patch O. The center lane of the 5-lane bridge is a switch lane that is opened to traffic only a few hours a day. This lane is designated as test patch D. Thus, 2 areas of different traffic exposure were available for skid resistance monitoring. Average daily traffic on the outer lanes is approximately 5,900 vehicles per lane, about 3 percent of which is trucks.

### Epoxy Asphalt Chip Seal

The epoxy asphalt chip seals placed on the SF-OBB designated as test patch 14 used a calcined bauxite aggregate. This type of aggregate is manufactured from bauxite mined in British Guiana, South America, by calcining at 1 600 C. The resulting particle is about 85 percent aluminum oxide and has a minimum Mohs' scale hardness of 8. Traffic exposure is the same as that for the other test areas placed on the upper deck.

## EVALUATION OF TEST SURFACES

A total of 12 test areas that used epoxy asphalt with different types of aggregate and different traffic exposures were available for evaluation. Although over 35 test areas were included in the study, only the test areas containing epoxy asphalt are reported here. The following 6 evaluation factors were used to judge the surfaces:

1. Visual inspection to determine obvious wear, raveling, or structural deterioration;
2. Pull-out force on 1-in. (2.5-cm) and 2-in. (5.0-cm) round cores to determine bond strength;
3. Macrophotographs of the surface to determine wear, polish, and aggregate loss;
4. Polish values of the aggregate as determined by the British wheel test to determine relative polishing values;
5. Los Angeles Rattler values to obtain aggregate toughness; and
6. Towed trailer skid tests to determine skid resistance of the surfaces.

Visual inspection in the fall of 1973 indicated all epoxy asphalt pavements and chip seals were performing satisfactorily. Raveling was continuing at a very slow rate in the open-graded mixes. Some rutting was evident in the dense-graded mixes placed on the concrete deck particularly in the lightweight aggregate test areas. The rutting was believed to be caused by the wheel rims of flat tires. Some aggregate loss was evident on the epoxy asphalt chip seal.

Pull-out values varied quite markedly, ranging from a low of a few pounds per square inch to well over 200 psi (1 378 kPa). The highest values were obtained for pavement placed on steel decks. The low values are associated with the old epoxy coal tar layer that was not removed in all areas because of the additional cost of removal.

Magnified photographs of the surface show some aggregate loss and some points of wear or polish on certain types of aggregates.

Los Angeles Rattler values were obtained from the California Department of Transportation laboratory. All aggregates met the requirements for class A aggregates.

Polish values of various aggregates were determined by the Texas Highway Department, which had one of the few British wheel testers in the United States in 1973. The Texas laboratory used a modified method to determine polish values, so the values reported here may not be directly comparable to values obtained from other laboratories (12). However, the values are useful because they are relative and can be used to rank the aggregates according to their polishing susceptibility. Table 2 summarizes the Los Angeles Rattler values and the polish values for the aggregates used in these epoxy asphalt test areas.

## TOWED TRAILER SKID RESISTANCE STUDIES

Despite its limitation the most practical device for monitoring skid resistance of surfaces in the field is the towed trailer tester (ASTM E 274-70). The California Department of Transportation's 2 trailers were used to evaluate more than 35 test areas

**Table 2. British wheel polish and Los Angeles Rattler values.**

| | | British Wheel Polish | | Los Angeles Rattler | |
|---|---|---|---|---|---|
| Aggregate | Classification | Value | Expected Range | 100 Revolutions | 500 Revolutions |
| Air-cooled slag | Blast furnace slag, moderately vesicular | 38 | 38 to 44 | 6 | 29 |
| Granite | Hornblend granite | 39 | 34 to 40 | 4 | 20 |
| Lightweight | Lightweight synthetic expanded shale | 47 | 40 to 53 | 5 | 25 |
| Limestone | Dolomite limestone and chert | 32 | 25 to 40 | 5 | 23 |
| Rhyolite | Rhyolite/andesite, weathered | 42 | 33 to 42 | 4 | 17 |
| Calcined bauxite | Synthetic | 44 | — | 6 | 27 |

**Table 3. Comparison of composite SNs.**

| Bridge | Surface | Aggregate | Date Placed | Wear Factor 9/72 | Wear Factor 10/73 | Composite $SN_{40/55}$ 9/72 | Composite $SN_{40/55}$ 10/73 |
|---|---|---|---|---|---|---|---|
| SF-OBB | ½ in., open graded | Air-cooled slag | 11/69 | 57 | 74 | (38 + 36) + (34 + 32) = 140 | (40 + 34) + (36 + 31) = 141 |
| | ½ in., open graded | Granite | 11/69 | 57 | 74 | (44 + 41) + (42 + 39) = 166 | (44 + 45) + (43 + 34) = 166 |
| | ½ in., dense graded | Lightweight | 9/71 | 19 | 41 | (44 + 34) + (23 + 23) = 124 | (47 + 40) + (27 + 22) = 136 |
| | 1 in., dense graded | Lightweight | 9/71 | 19 | 41 | (44 + 34) + (29 + 17) = 124 | |
| | ½ in., dense graded | Air-cooled slag | 9/71 | 19 | 41 | (42 + 38) + (33 + 30) = 143 | (47 + 35) + (29 + 24) = 135 |
| | 1 in., dense graded | Air-cooled slag | 9/71 | 19 | 41 | (44 + 39) + (36 + 32) = 151 | (45 + 46) + (40 + 38) = 169 |
| | ½ in., dense graded | Granite | 9/71 | 19 | 41 | (36 + 28) + (20 + 14) = 98 | (34 + 28) + (25 + 17) = 104 |
| | 1 in., dense graded | Granite | 9/71 | 19 | 41 | (36 + 28) + (17 + 20) = 101 | (43 + 31) + (23 + 18) = 115 |
| | Chip seal | Calcined bauxite | 9/71 | 19 | 41 | (62 + 56) + (51 + 51) = 220 | (62 + 58) + (57 + 48) = 225 |
| SM-HB | 1½ in., dense graded | Limestone | 10/67 | 25 | 32 | (52 + 48) + (37 + 33) = 170 | (56 + 47) + (41 + 23) = 167 |
| SD-CBB | 1½ in., dense graded | Rhyolite | 7/69 | | 20 | | (54 + 46) + (42 + 31) = 173 |
| | 1½ in., dense graded[a] | Rhyolite | 7/69 | | 8 | | (59 + 56) + (48 + 40) = 203 |

Note: 1 mile = 1.6 km. 1 in. = 2.5 cm.

[a]Center lane.

included in our studies although only 12 test areas containing epoxy asphalt are reported here.

The drop in skid number (SN) with increasing speed is well known. One measure of a superior surface would be only a slight drop, or, better, a constant SN with increasing speed. This suggests that an SN reading at a higher speed could be added to the standard 40-mph (64-km/h) reading as a means of comparing one surface with another.

A smooth tire braking on a wet surface depends on the pavement macrotexture for the escape of water. Thus, an SN produced by a smooth tire on the towed trailer tester can be used in a general way to compare the macrotexture of surfaces and tendency toward hydroplaning. The surface with the highest smooth-tire SN should have the greatest macrotexture and raise the speed at which hydroplaning will occur.

Similarly, an SN reading for a smooth tire at a higher speed could be added to the aforementioned readings as a further means of comparing surfaces.

If the SNs for 40 and 55 mph (64 and 88 km/h) for ribbed and smooth tires are added together, the resulting composite SN can be used to rate surfaces. The equation used for calculating the composite skid number in this report is: $SN_{40/55} = SN_{40} + SN_{55} + SN_{40S} + SN_{55S}$. The subscript number indicates speed in miles per hour; subscript S denotes a value obtained with a smooth tire.

The high speed value of 55 mph (88 km/h) is about the speed range on most California toll bridges. The 40-mph (64-km/h) value is used because it is currently the standard of comparison. The composite SN can be divided by 4 to lower it to a more familiar range although reporting it as a series of 4 numbers allows a more detailed comparison of surfaces.

Skid numbers were also taken at 20 mph (32 km/h) for both ribbed and smooth tires for the SF-OBB upper deck test areas. This was possible because the area could be coned off from traffic and the slow speed of the towed trailer was not a traffic hazard. Under some traffic conditions, the high speed reading had to be taken at 50 mph (80 km/h).

Table 3 compares the composite SNs for the epoxy asphalt test areas for a 12-month interval. Most of the pavements showed a small gain in the composite SN. Increases in skid resistance are expected during the early life of epoxy asphalt pavements. As excess binder is worn from the faces of particles and removed from crevices, the skid resistance increases to the maximum value possible with the aggregate used.

## WEAR FACTOR

The average daily traffic per lane on each bridge varies. The SF-OBB carries approximately 17,000 vehicles per lane (vpl), about 10 percent of which is trucks. The SM-HB is approximately 4,400 vpl, about 20 percent of which is trucks. The SD-CBB count is 5,900 vpl, about 3 percent of which is trucks.

To compare surfaces with different traffic counts, a wear factor was calculated (13). Wear factor is vpl multiplied by pavement age, in years, at the time of testing, divided by 1,000.

## DISCUSSION

Graphs of SN as a function of speed for the 12 test patches of epoxy asphalt are shown in Figures 1 to 12. Test patches 1 to 6, 14, and A and B are on the SF-OBB. Test patches A and B (Figs. 1 and 2) are for open-graded pavements with granite and steel slag aggregates. The superior performance of open-graded pavement to dispel water from the tire tracks is indicated by the fact that the smooth tire line is very close to the ribbed tire line and that the speed gradient is flat. Skid resistance is still increasing slightly for both types of aggregates. The composite SN is high.

Test patches 1 and 2 (Figs. 3 and 4) are for a dense-graded pavement with a lightweight aggregate. The speed gradient is quite steep indicating poorer high speed performance. The smooth tire line is well below the ribbed tire line. Both of these observations suggest low macrotexture. Close observation of the pavement and magnified photographs confirm this. This type of pavement apparently tends to wear to a flat plane with little macrotexture. High SNs at slow speeds indicate good microtexture. The composite SN is low.

Test patches 3 and 4 (Figs. 5 and 6) are for a dense-graded pavement with a steel slag aggregate. The speed gradient is flat and the smooth tire line is fairly close to the ribbed tire line. Many other states have had excellent experience with this type of aggregate. The composite SN indicates good overall performance.

Test patches 5 and 6 (Figs. 7 and 8) are for a dense-graded pavement with a granite aggregate. This test section is not performing well. It has the lowest composite SN of all the test sections. The SN at 40 mph (64 km/h) is too low, and the smooth tire speed gradient line is well below the ribbed tire line. This poor performance probably is due to excess binder in the pavement at first placement. The initial skid-resistance values were so low that the surface was sandblasted to remove excess binder. This improved the skid resistance, and improvement should be shown in the future as the binder is removed by wear and oxidation.

Test patch 14 (Fig. 9) is for a chip seal with calcined bauxite synthetic aggregate. The speed gradients are almost ideal—high and very flat—and the smooth tire line is quite close to the ribbed tire. The composite SN is the highest for all the test areas. Calcined bauxite has been used in Great Britain for about 6 years and is just beginning to be used in the United States. It is still quite expensive and can be used only in chip seals. The short life of chip seals compared to that of pavements has been one of their limitations.

Test patch G (Fig. 10) is for a dense-graded pavement with a limestone aggregate for the SM-HB orthotropic steel deck. The speed gradients are fairly flat, although, as expected in a very dense pavement, the smooth tire line is well below the ribbed tire line. The skid resistance still is increasing slightly, which is unusual for limestone aggregate. This pavement is performing very well and showing no signs of distress after nearly 6 years of heavy truck traffic. The composite SN is high.

Test patches O and P (Figs. 11 and 12) are for a dense-graded pavement with a rhyolite aggregate for the SD-CBB orthotropic steel deck. The speed gradients are fairly flat and the smooth tire line is well below the ribbed tire line. The composite SN for the center lane is very high and is high for the other lanes.

## SUMMARY

Some of the experiences with skid-resistant epoxy asphalt surfaces on California toll bridges have been presented. A composite SN has been developed that considers the speed gradient between 2 selected speeds for both a ribbed and smooth tire.

Epoxy asphalt with properly selected aggregate can provide satisfactory skid-resistant surfaces to solve special problems and will continue to maintain good skid resistance under heavy traffic.

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Figure 1. Test patch A, SF-OBB lower deck, open-graded epoxy asphalt concrete with granite aggregate.

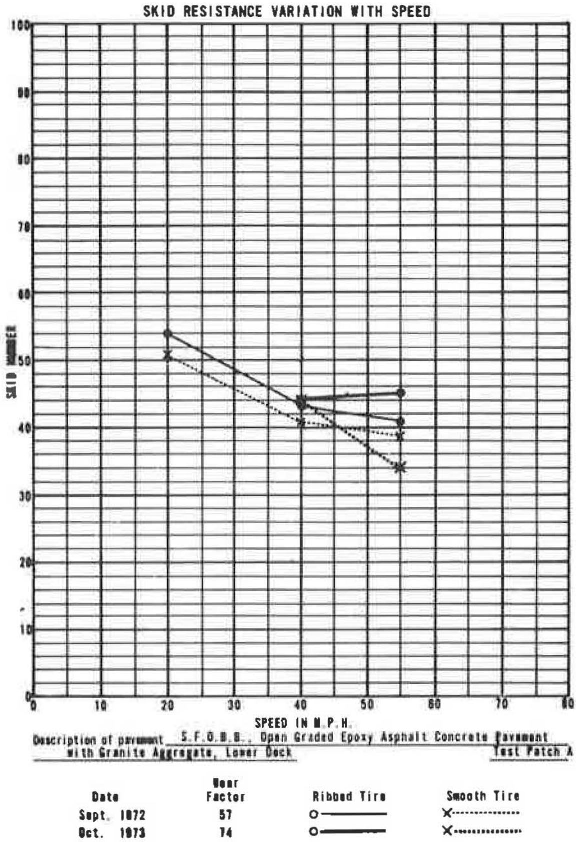



Figure 2. Test patch B, SF-OBB lower deck, open-graded epoxy asphalt concrete with steel slag aggregate.

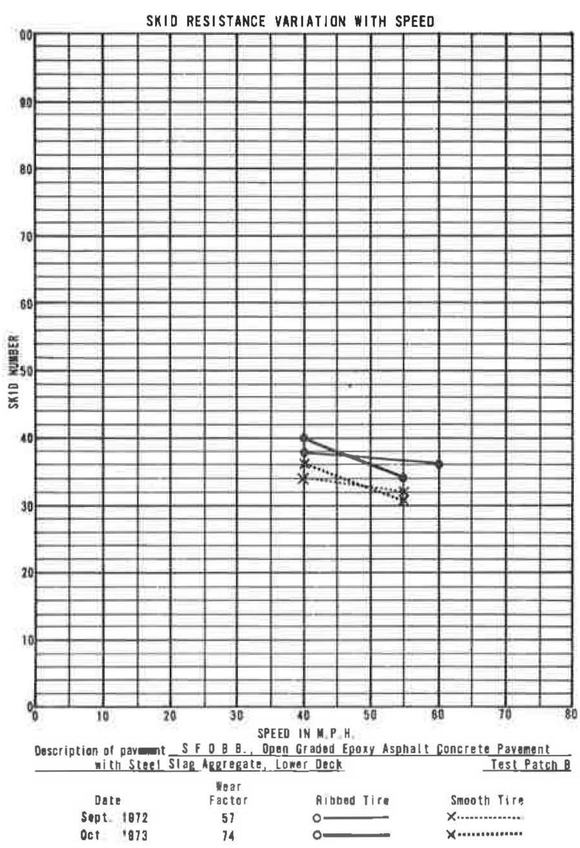


Figure 5. Test patch 3, SF-OBB, 1-in. (2.5-cm) epoxy asphalt concrete with steel slag aggregate.

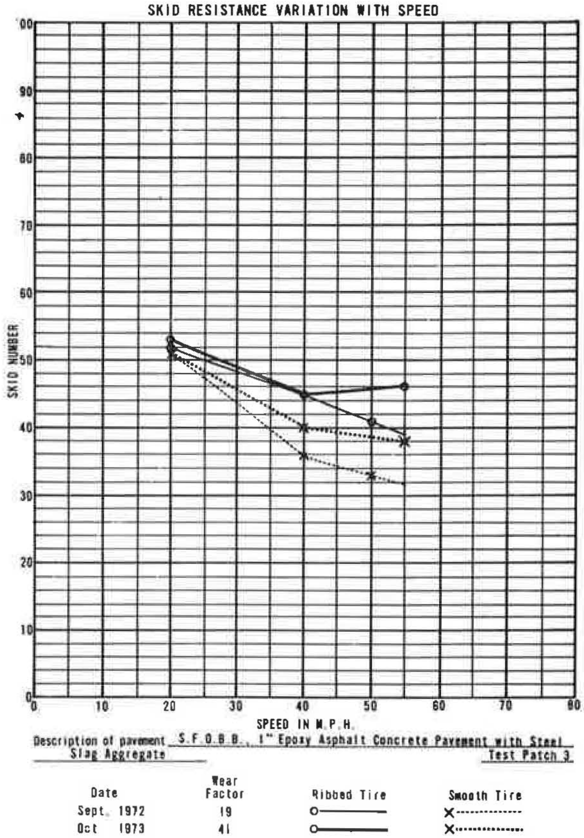



Figure 6. Test patch 4, SF-OBB, ½-in. (1.3-cm) epoxy asphalt concrete with steel slag aggregate.

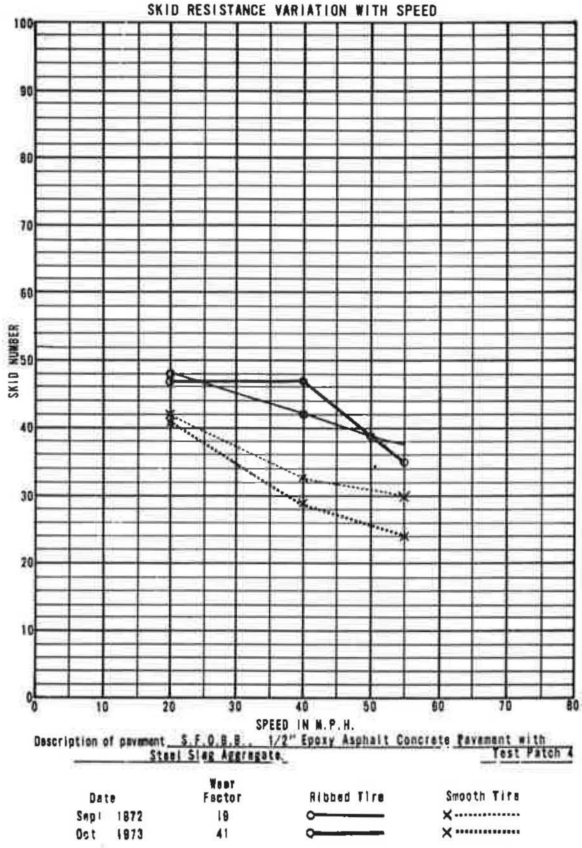


Figure 3. Test patch 1, SF-OBB, ½-in. (1.3-cm) epoxy asphalt concrete with lightweight aggregate.

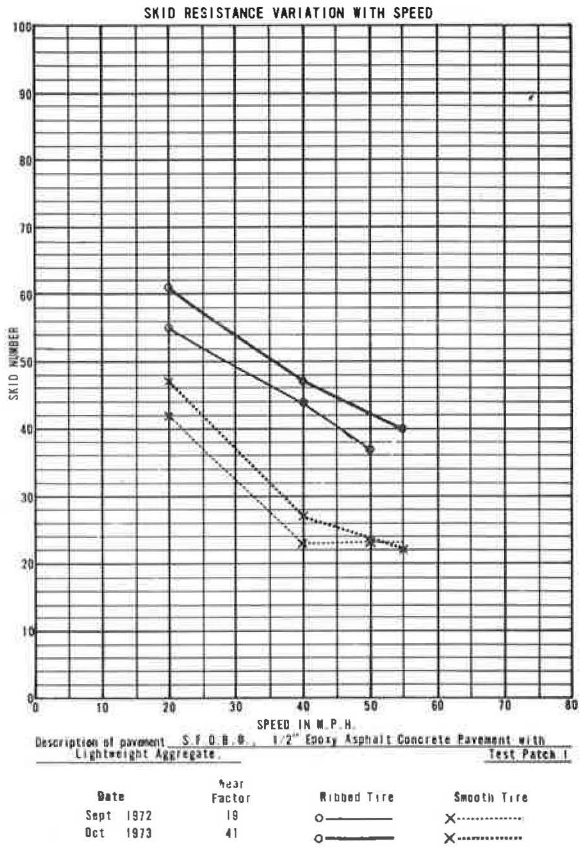



Figure 4. Test patch 2, SF-OBB, 1-in. (2.5-cm) epoxy asphalt concrete with lightweight aggregate.

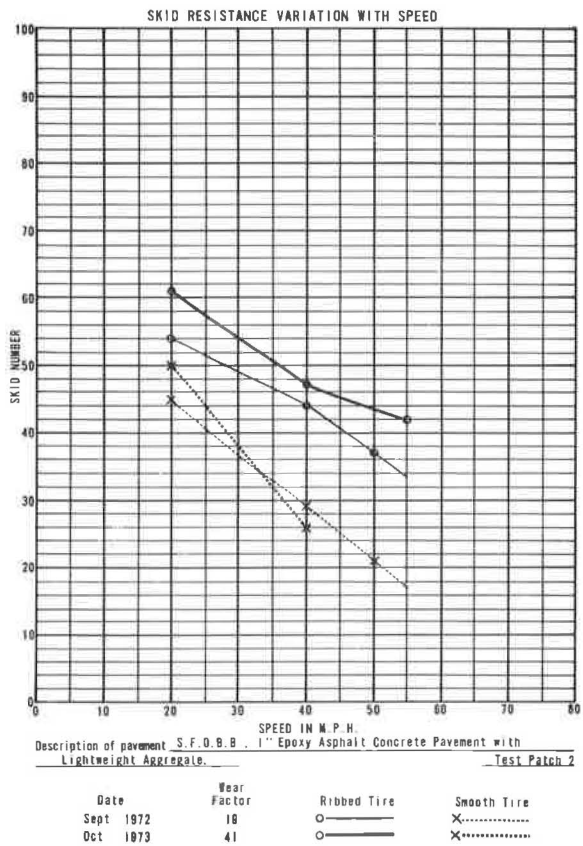


**Figure 7. Test patch 5, SF-OBB, ½-in. (1.3-cm) epoxy asphalt concrete with granite aggregate.**

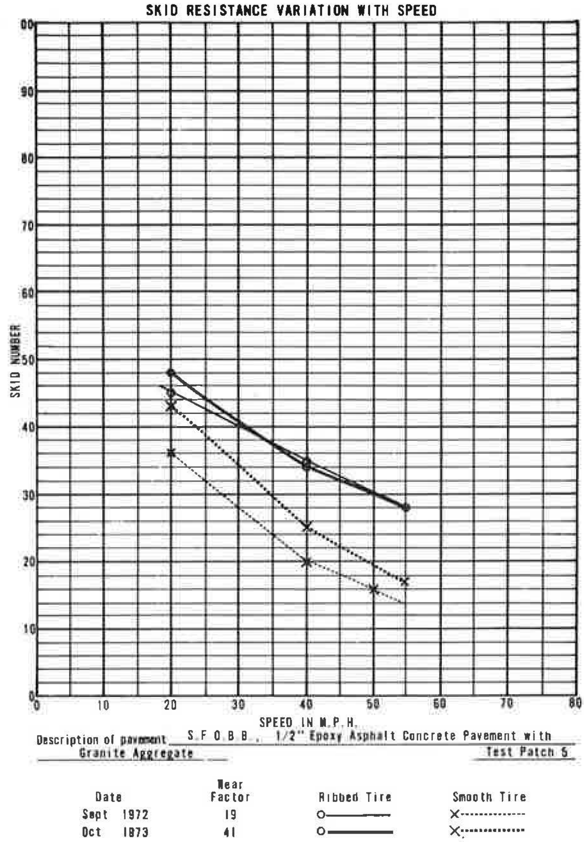



**Figure 8. Test patch 6, SF-OBB, 1-in. (2.5-cm) epoxy asphalt concrete with granite aggregate.**

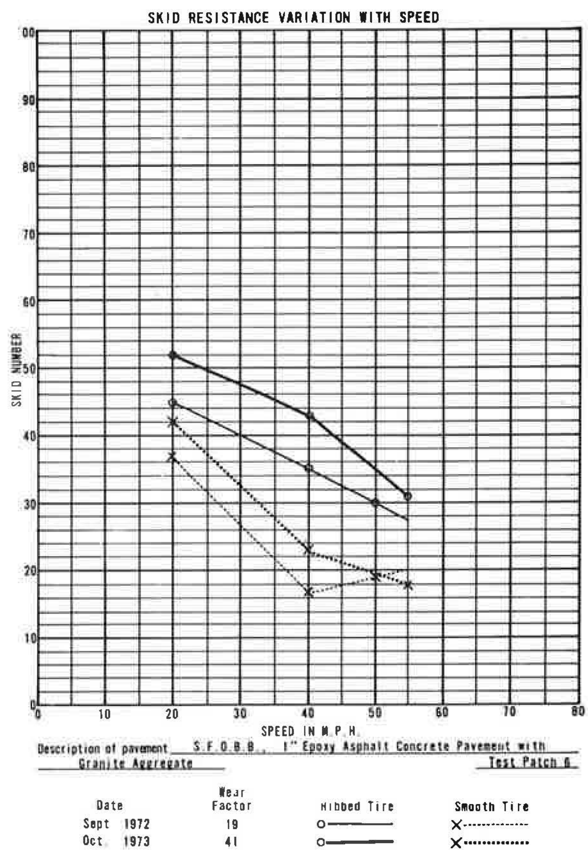


**Figure 9. Test patch 14, SF-OBB, epoxy asphalt chip seal with calcined bauxite aggregate.**

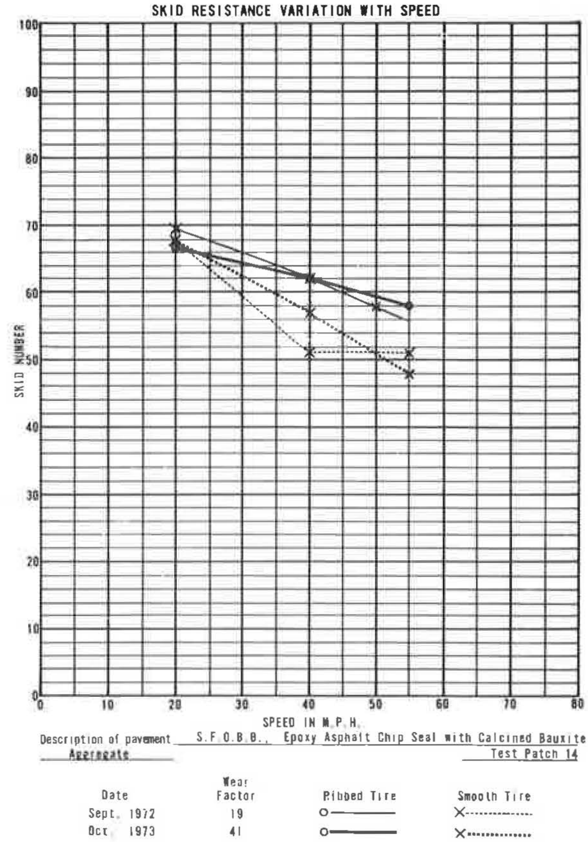



**Figure 10. Test patch G, SM-HB, dense-graded epoxy asphalt with calera limestone aggregate on steel bridge.**

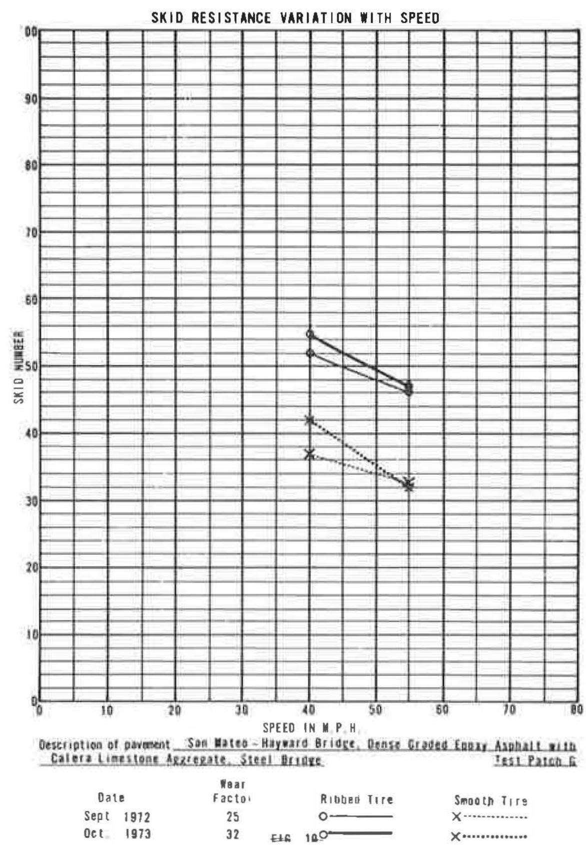


Figure 11. Test patch O, SD-CBB, dense-graded epoxy asphalt with rhyolite aggregate on steel bridge.

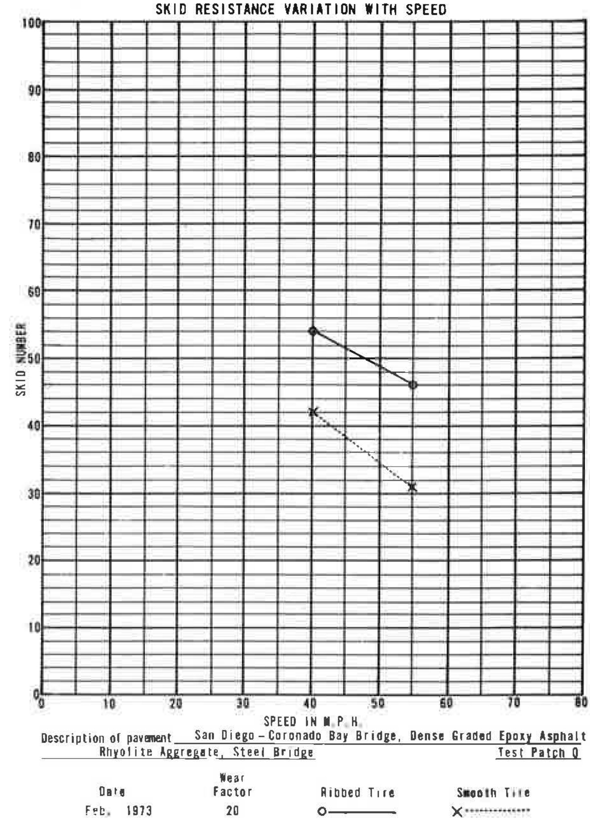
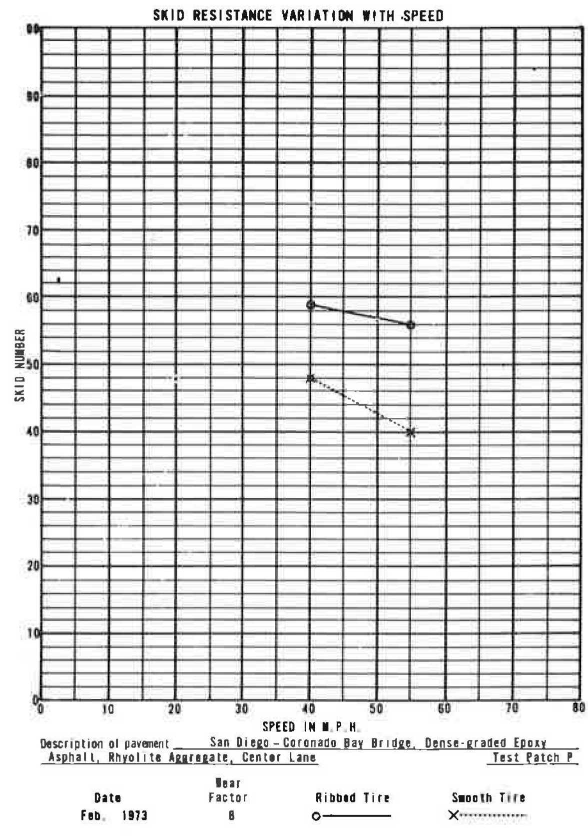



Figure 12. Test patch P, SD-CBB center lane, dense-graded epoxy asphalt with rhyolite aggregate on steel bridge.



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