Michigan Investigation of Soil-Aggregate Cushions and Reinforced Asphaltic Concrete for Preventing or Reducing Reflection Cracking of Resurfaced Pavements

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In an effort to reduce reflection cracking of bituminous resurfacing over rigid pavement, the Michigan Department of State Highways has investigated the use of both soil-aggregate cushions and continuous reinforcement in the bituminous-concrete resurfacing layer. Because of high traffic volumes, it is often important that any interruption of vehicle flow during resurfacing operations be for short durations.

During the past five years, Michigan has observed the performance of an old, distressed highway, resurfaced with soil-aggregate cushions of various materials as an insulator between the old portland cement concrete and the new bituminous-concrete mat. For comparison, some lengths of the project were resurfaced in the conventional manner, with the bituminous mat constructed directly on the old rigid pavement. Additional resurfacing projects incorporating soil-aggregate cushions have been constructed throughout the State during the past five years. No great construction problems were encountered and soil-aggregate cushions carried traffic well in the interim before bituminous-concrete mats were placed. Soil-aggregate cushions have proved effective in reducing reflection cracking, but additional research is suggested to determine the best cushion materials.

In 1955, the Department resurfaced a rigid pavement by placing wire-mesh fabric on the old surface and then applied the bituminous-concrete resurfacing. Control areas were also constructed, using bituminous-concrete resurfacing without reinforcement. After about six-years service, it was concluded that this method of reinforcement was unsatisfactory because (a) reflection cracking was not significantly reduced, (b) potholes occurred in reinforced areas but not in conventional areas, and (c) extensive corrosion of reinforcing steel occurred even in apparently sound areas of the pavement.

•AS THE mileage of bituminous resurfacing of rigid pavement has increased, reflection cracking has become an increasingly important problem in highway maintenance. The riding quality of the road is directly affected by the cracks, and foreign matter easily penetrates crack openings causing further damage to the pavement. Reflection cracks are apparently caused by horizontal and vertical movement of the resurfaced rigid pavement. The rigid slabs deflect and rock under heavy traffic and are subject to thermal expansion and contraction. Two methods investigated in Michigan for preventing or reducing reflection cracks are (a) the use of a soil-aggregate cushion between

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the old pavement and the new surface, and (b) the use of continuous reinforcement in the bituminous-concrete resurfacing layer. Michigan experience with these two methods is described in this report.

SOIL-AGGREGATE CUSHION

Soil-aggregate cushions placed between rigid pavement and the bituminous surface had been tried in several states, with varying degrees of success, on the assumption that the cushion would absorb most slab movement without transmitting detrimental effects to the resurfacing.

In August 1962, with the approval of the Bureau of Public Roads, the Research Laboratory Section established a research project with the following specific objectives:

1. To determine whether a soil-aggregate cushion would significantly reduce or eliminate reflection cracking when bituminous concrete is used to resurface rigid pavements.
2. To determine whether a soil-aggregate cushion would provide sufficient thermal insulation to prevent blow-ups in the original rigid pavement.
3. To investigate the relative effectiveness of various aggregates as cushion material.
4. To determine whether a soil-aggregate cushion may be stabilized economically by admixture or mechanical means, in order to carry traffic loads prior to the construction of the bituminous-concrete surface. This is a very important consideration in areas where traffic cannot conveniently be detoured during the construction period.

Description of the Test Area

A 3-mile section of rigid pavement on M 60, northeast of Leonidas in St. Joseph County, apparently constructed over an old gravel road which lay directly on soil classed pedologically as the B-horizon or zone of accumulation, was selected for the investigation. In areas of considerable frost heave, the old base material had been replaced with granular soil and surfaced with new concrete over the rebuilt areas. The pavement was in generally poor condition, showing a mean average of about 10 transverse cracks per 100-ft slab length, and had a history of blow-ups (Fig. 1). The old pavement was condition-surveyed and roughness measurements were taken using the Michigan Roughometer.

Figure 1. Original rigid pavement. Note transverse patch replacing blow-up.

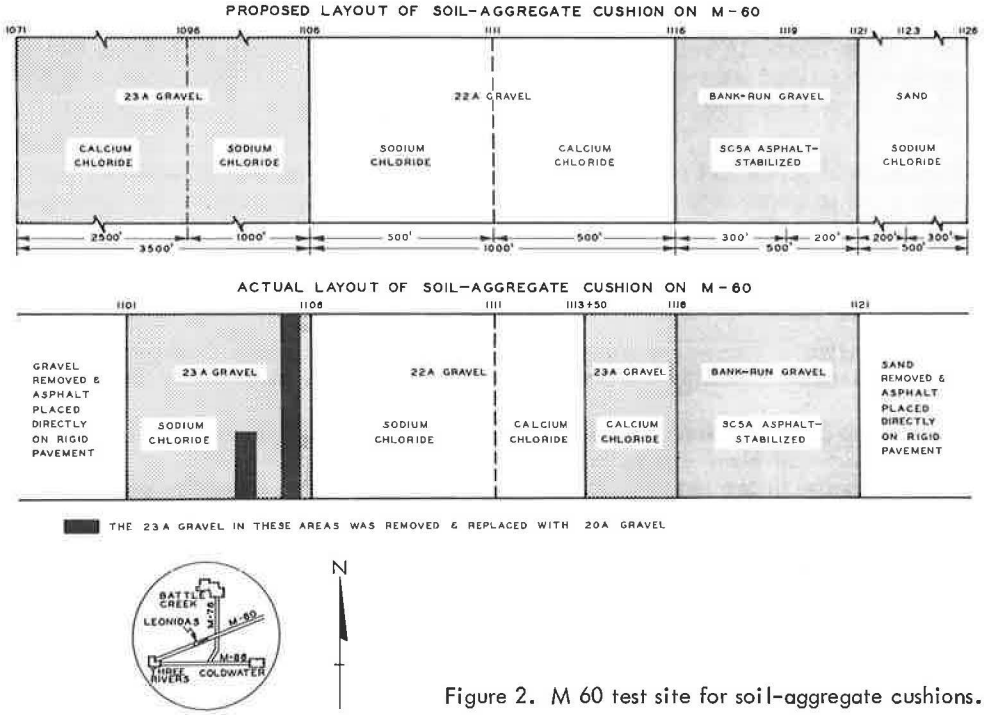


Figure 2. M 60 test site for soil-aggregate cushions.

Soil-aggregate cushions were placed over the rigid pavement for 5500 ft of its total length. The remaining length of pavement, used as a standard of comparison, was resurfaced conventionally by placing bituminous concrete directly on the rigid pavement. The entire 3-mile length of rigid pavement including the soil-aggregate cushion was covered with 250 lb per sq yd of bituminous concrete. All sections of soil-aggregate cushion were constructed to a uniform compacted depth of 4 in.

Construction procedures were in accordance with 1960 Michigan Department of State Highways Standard Specifications for Road and Bridge Construction. Six different materials were used for the cushion: 22A and 23A gravel with calcium chloride admixture, 22A and 23A gravel with sodium chloride admixture, "bank-run" gravel with SC-5A asphalt admixture, and sodium chloride-treated "bank-run" sand (Fig. 2). Michigan Department of State Highways grain-size specifications (1960) for 22A and 23A soil aggregates are given in Table 1. The bank-run gravel used in the M60 soil-aggregate cushion has a grain-size distribution according to the AASHO classification as follows: gravel, 28.4 percent; coarse sand 32.8 percent; fine sand 27.8 percent; silt 6.2 percent; and clay 4.8 percent. The grain-size distribution indicates that this bank-run gravel would be unstable if no admixture were used.

TABLE 1

TOTAL PERCENT PASSING STANDARD SIEVE SIZES

Class	1 In.	¾ In.	⅜ In.	No. 10	No. 40	Loss by Washing Through No. 200 sieve
22A	100	90-100	65-85	30-45		3-7
23A	100		60-85	25-50		7-15
20A*		100	60-80	40-50	15-30	0-7

*Used for replacing distressed cushion material.

All the 22A and 23A processed gravel had been mixed with 6 lb of Type 1 calcium chloride per ton of gravel in the stockpiles. Because it was believed that some of the admixture had leached out, an additional 4 lb of Type 1 calcium chloride were added to each ton of gravel.

Construction of the Cushion

1. Calcium chloride-treated 23A gravel. Some trouble was experienced in eliminating moist spongy areas in the cushion. Traffic was easily maintained during construction, and on completion of the cushion the roadway appeared smooth and stable.
2. Calcium chloride-treated 22A gravel. The material was compacted easily and traffic was maintained over the cushion without difficulty. No spongy areas developed.
3. Sodium chloride-treated 23A gravel. Approximately 4 lb of sodium chloride were added to each ton of gravel as it was hauled to the job site. Density was readily obtained with a rubber-tired roller. Traffic was easily maintained over the cushion during construction.
4. Sodium chloride-treated 22A gravel. Approximately 6 lb of sodium chloride were added to each ton of gravel as it was hauled to the site. The material was compacted very readily with a rubber-tired roller and traffic was easily maintained over the cushion.
5. Asphalt-treated bank-run gravel. The asphalt and gravel were combined at an asphalt mixing plant and hauled about 20 miles to the construction area. The bitumen content of the mixture was 4 percent by weight, the temperature of the mix was 250 F. The material was easily compacted with a steel-wheeled roller. About six hours after compaction traffic was permitted to travel over the cushion. The cushion held up very well under traffic, especially in view of the heavy trucks traveling over it after the short curing period. The compacted cushion appeared to be somewhat "rich" in bituminous material and even better results might possibly be obtained by a slight reduction of the bitumen content of the gravel. The unit cost of this asphalt-stabilized gravel was about four times that of the 22A gravel.
6. Sodium chloride-treated bank-run sand. This material was produced specifically for use in this section and contained about 8 percent silt, which was ineffective as a binder material. Each ton received about 8 lb of sodium chloride. Despite the addition of water and considerable rolling, the sand could not be stabilized and would not carry traffic. As a result, the sand was taken away to be used elsewhere and the bituminous concrete placed directly on the old rigid pavement.

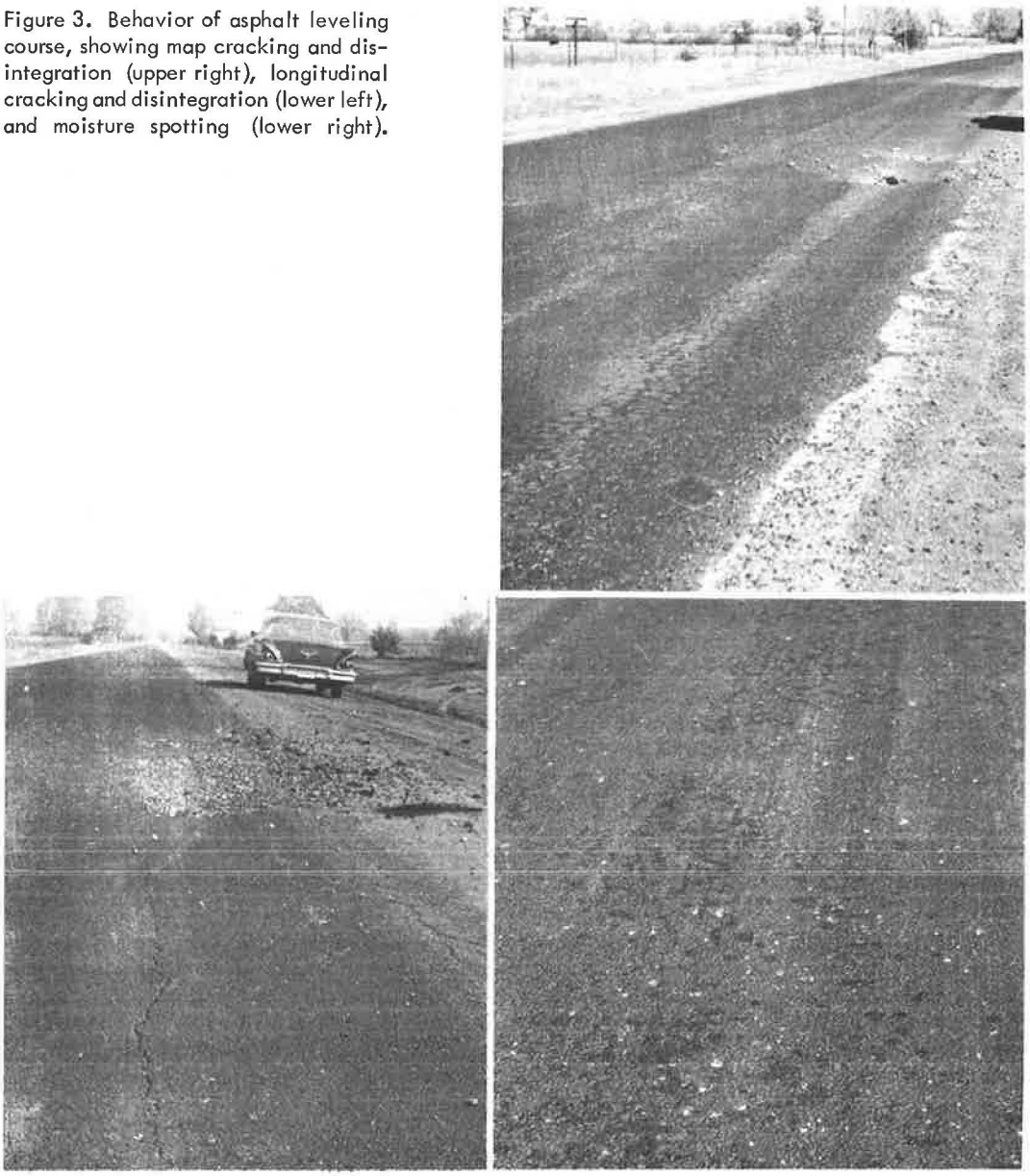
Porous aggregate shoulders were placed to a compacted depth of 4 in., constructed to provide adequate drainage for the cushions. Because of the impermeable appearance of the cushion, it was decided to omit the prime coat under the leveling course. A leveling course of 130 lb of bituminous concrete per sq yd of area was placed over the entire 3 miles of test pavement, followed by a 120 lb per sq yd bituminous-concrete wearing course.

PERIODIC PERFORMANCE REPORTS

Early Performance of the Test Sections

After carrying traffic for about one day, signs of failure began to appear in the bituminous leveling surface over the 23A gravel cushion. Two types of early failure were noted, both influenced by high moisture content. With the first type of failure the asphalt surface was spotted with moisture, giving the appearance of water migrating up from the base, and areas of map cracking or longitudinal cracks appeared. The second type appeared to be a shear failure resulting in rutting of the cushion and asphalt mat. Then the asphalt appeared to disintegrate with damage spreading into large broken areas (Figs. 3 and 4). However, these failures were confined to areas where asphalt had been placed over the 23A gravel and did not appear to be as frequent or as serious in those areas in which the 23A gravel contained sodium chloride admixture. There was considerable rainy weather during placement of the 23A gravel cushion on the west end of the project where calcium chloride admixture was used. Since both calcium chloride and sodium chloride are hygroscopic, the use of these admixtures probably made the problem worse. Attempts were made to patch the distressed areas but the

Figure 3. Behavior of asphalt leveling course, showing map cracking and disintegration (upper right), longitudinal cracking and disintegration (lower left), and moisture spotting (lower right).



failure became so widespread that it was necessary to remove large areas. These were replaced by asphalt applied directly on the rigid pavement surface.

Inspection of the distressed areas revealed that no bond existed between the asphalt and the 23A gravel. A thin film of moisture existed between the asphalt and gravel which appeared to act as a lubricant. Tests indicated a moisture content of 10 to 12 percent in the top ½ in. of cushion but only 4 to 5 percent below this.

After a month, severe map cracking was noted in wearing surface areas which covered the remaining 23A gravel. Again, the 23A gravel which contained sodium chloride admixture exhibited fewer distressed areas than the 23A gravel which contained only calcium chloride. In retrospect, it appears that the surface failures just discussed might have been prevented by reducing the hygroscopic soil admixture quantities.

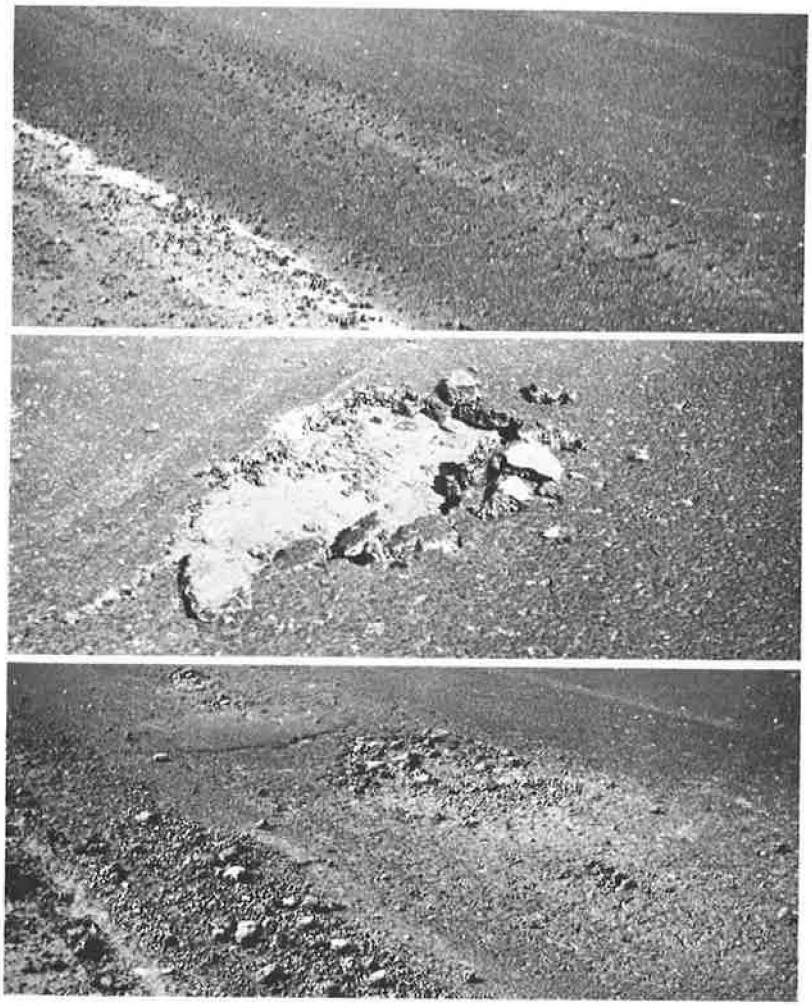


Figure 4. Behavior of asphalt leveling course, showing severe alligator cracking (top) and localized distress (center and bottom).

Performance of the Test Section After Five Years

Five annual surveys of the project have been made and progress reports surveying the condition of the pavement were published by the Department after two and four years of service. Because only slight differences appeared between pavements over the two gradations of processed gravel and since the test sections involved are so short, no significant difference could be proven, and the four 22A-23A cushions will be considered as a single unit in comparisons with the asphalt-stabilized bank-run gravel and sections where resurfacing was applied directly over old pavement.

Figure 5 shows how transverse reflection cracking increases as a function of time. After five winters, about 54 percent of the transverse cracks had reflected through the bituminous surface where no cushion was used, about 26 percent through the 22A-23A gravel cushion area, and about 20 percent in the asphalt-stabilized bank-run gravel cushion area. It is interesting to note that most transverse reflection cracking occurred during the first year of service.

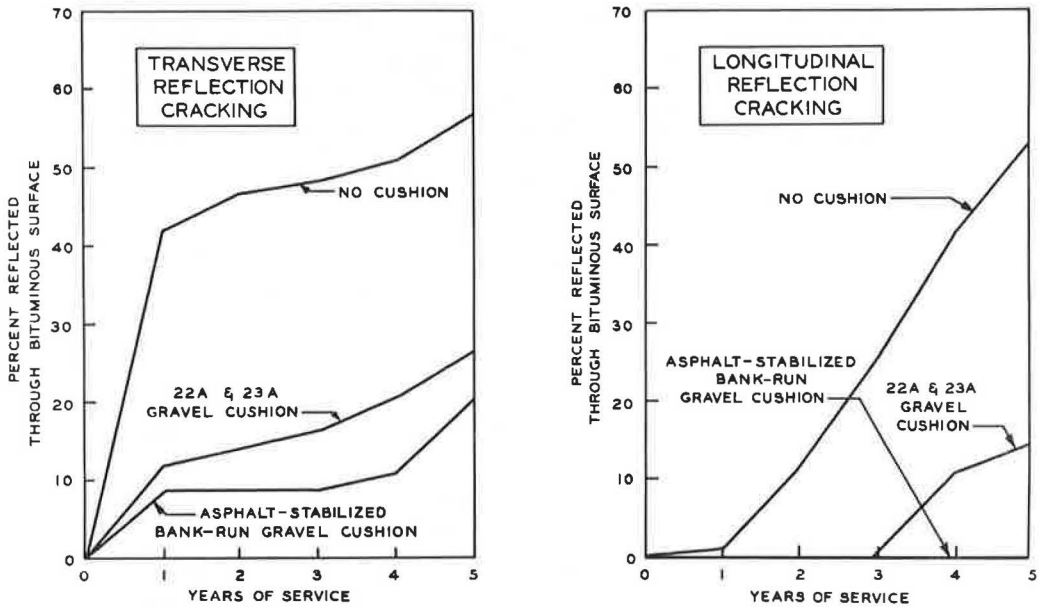


Figure 5. Transverse and longitudinal reflection cracking as influenced by aggregate cushion.

Figure 5 also shows how longitudinal reflection cracking increases as a function of time. In areas where the asphalt-stabilized cushion was used, no longitudinal reflection cracking was present. No longitudinal cracking had been noted in the 22A-23A gravel cushion for the first three winters, but after the fourth about 10 percent of the length of widening strip had reflected through the pavement. Statistical tests of the data indicate that the effect of the gravel cushions in reducing longitudinal reflection cracks was highly significant. Further, the test indicated the asphalt-stabilized cushion to be significantly better than the 22A-23A in reducing longitudinal reflection cracks.

Although a few joint blow-ups were observed in areas of conventional resurfacing, none were apparent in any of the cushioned areas. Map cracking extended about 8 in. in from the edge of the pavement in the 22A-23A gravel cushion areas. None was observed in the asphalt-stabilized gravel cushion area.

SUMMARY OF M 60 INVESTIGATION

After nearly five years of service, the soil-aggregate cushions used in these tests have been of significant value in reducing reflection cracking of the bituminous overlay. Of the cushion materials, asphalt-stabilized soil aggregate appears to be more effective in reducing reflection cracking and in preventing map cracking at the edge of the pavement than the 22A-23A gravel.

All cushion materials except the sand proved satisfactory for carrying traffic in the interim before the bituminous overlay was constructed.

Bank-run sand, similar in gradation to that used in this test, should not be used as a soil-aggregate cushion where traffic must be maintained unless an acceptable means of stabilizing it can be found.

Slow-curing (SC-5A) asphalt-stabilized bank-run gravel costs more initially and must be allowed to cure for about six hours before traffic can be permitted to travel over it.

A reason for the effectiveness of the asphalt-stabilized cushion may be that the relatively unstable bank-run gravel particles are able to shift and absorb movements of the underlying rigid pavement.

DETROIT INDUSTRIAL EXPRESSWAY (I-94) PROJECT

Subsequent to the M 60 experimental project, Michigan resurfaced a number of rigid pavements with asphaltic concrete underlain with soil-aggregate cushions. The most important soil-aggregate cushion project is being constructed over a length of about 14 miles on I-94, the Detroit Industrial Expressway (DIE), located west of Detroit. Much of the DIE was constructed of portland cement concrete during World War II and contained no load transfer dowels or reinforcing steel. Although the original divided four-lane rigid pavement had been resurfaced with a 3-in. thickness of asphaltic concrete, the surface, a two-lane roadway for each direction, had deteriorated and riding quality was poor. Further, because of the high average daily traffic volume of 45,000 vehicles, about 17.5 percent of which were commercial, it was determined that both the existing two-lane roadways were of insufficient capacity. After considering relocation of the highway, it was decided to widen each two-lane pavement with an additional 12-ft width of portland cement concrete, 9 in. thick, and to construct an asphalt-stabilized 22A soil-aggregate cushion approximately 8 in. in depth over all three lanes of each roadway. The highway would then be resurfaced with a 3-in. thickness of asphaltic concrete.

The full length of the project has not been completed. After two years of service, however, the first section to be completed (a three-lane pavement about one mile in length) showed no transverse cracks and about 277 linear feet of longitudinal cracking per lane-mile. Longitudinal cracking occurred at joints between lanes where the bituminous mats were joined and therefore the cracking may not have been due to reflection. A lane-mile is defined as a one-mile length of pavement 12 ft or one lane in width. Areas of the project approaching bridges where no soil-aggregate cushion was used showed about 232 transverse cracks per lane-mile and 2538 linear feet of longitudinal cracking per lane-mile. Thus, at this stage the soil-aggregate cushion has been very effective in reducing reflection cracking.

M 15 PROJECT, NORTH AND SOUTH OF MILLINGTON

Route M 15 north of Millington in Tuscola County (Mich. Proj. No. F679031C, C4) is another area where an asphalt-stabilized soil-aggregate cushion was used. Also an adjacent area of M 15 south of Millington (Mich. Proj. No. Fb79031C, C3) was resurfaced at about the same time without a soil-aggregate cushion. Both projects are two-lane roadways which were resurfaced with asphaltic concrete about 1½ in. in depth. The cushioned project north of Millington was about 3½ miles long, with a 4-in. thick asphalt-stabilized 22A soil-aggregate cushion. After 3-years service, this area showed 70 transverse cracks per lane-mile and 36 ft of longitudinal cracking per lane-mile. The project south of Millington, where the asphaltic concrete overlay was placed directly on the old pavement, was 3.6 miles in length and showed 94 transverse cracks per lane-mile and 2614 ft of longitudinal cracking per lane-mile. Longitudinal cracking occurred over both the old pavement centerline joint and concrete widening strip joints.

Other Michigan resurfacing projects were constructed over a length of about 24 miles of US 23 north of Tawas and on a 30-mile length of M 53 south of Port Austin. With these latter two jobs, there were no conventional resurfacing projects in the area to use as standards of comparison.

CONTINUOUSLY REINFORCED BITUMINOUS RESURFACING

Another method of preventing reflection cracking was tried in Michigan in 1955 where two sections of continuously reinforced bituminous-concrete resurfacing were placed over widened portland cement concrete on a 1½-mile length of Detroit Industrial Expressway west of Ypsilanti (now I-94). Control sections of non-reinforced resurfacing of similar lengths (totaling 1¼ miles) were placed at the same time. The portland cement concrete pavement to be resurfaced was constructed in 1943 under wartime specifications, where load transfer and reinforcing steel were omitted. Expansion joints were spaced at 120 ft with weakened plane contraction joints at 20-ft intervals.

The project carried heavy commercial and passenger traffic continuously since completion. By 1955 this pavement had severe transverse cracking and faulting of joints and cracks. Prior to resurfacing, the old pavement was widened from 22 to 24 ft. This 2-ft concrete base course widening was added to the outer edge of the traffic lane, reinforced longitudinally with deformed bars but not tied to the old pavement. The widening and the old pavement was 9-in. uniform thickness.

The Wire Reinforcing Institute advised the Department of various aspects of design and construction. At about the same time, crack control in bituminous resurfacing by means of reinforcement was attempted in research-oriented projects in California, Minnesota, Ohio, Texas, Indiana, New Jersey, Illinois, District of Columbia and in England. Welded wire-mesh fabric (3 × 6-10/10) was installed as continuous reinforcement. The cleaned pavement surface was sprayed with a bond coat of asphalt emulsion without elaborate patching or resealing of deteriorated joints, cracks, or rough slab surfaces. The reinforcement was then laid directly on the pavement followed by a binder course of 190 lb per sq yd (about 2 in. thick) and a surface course of 130 lb per sq yd (slightly over 1 in. thick). The mesh was supplied in 7.5 by 15-ft flat sheets which were lapped one transverse wire spacing (6 in.) at the leading edge. Hog rings were used to tie the lapped sheets. A "hold-down sled device" was used beneath the paver to ride along and depress the wire-mesh wires under the spreader. The "hold-down sled" was only partially effective and problems arose with buckling of the wire-mesh sheets ahead of and behind the paver. Some replacement of entire sheets was necessary but in other cases, where smaller areas were involved, the buckled reinforcement was cut out and not replaced.

The performance of reinforced and non-reinforced sections was observed for six years. During this period, the average daily traffic increased from 10,600 with 19

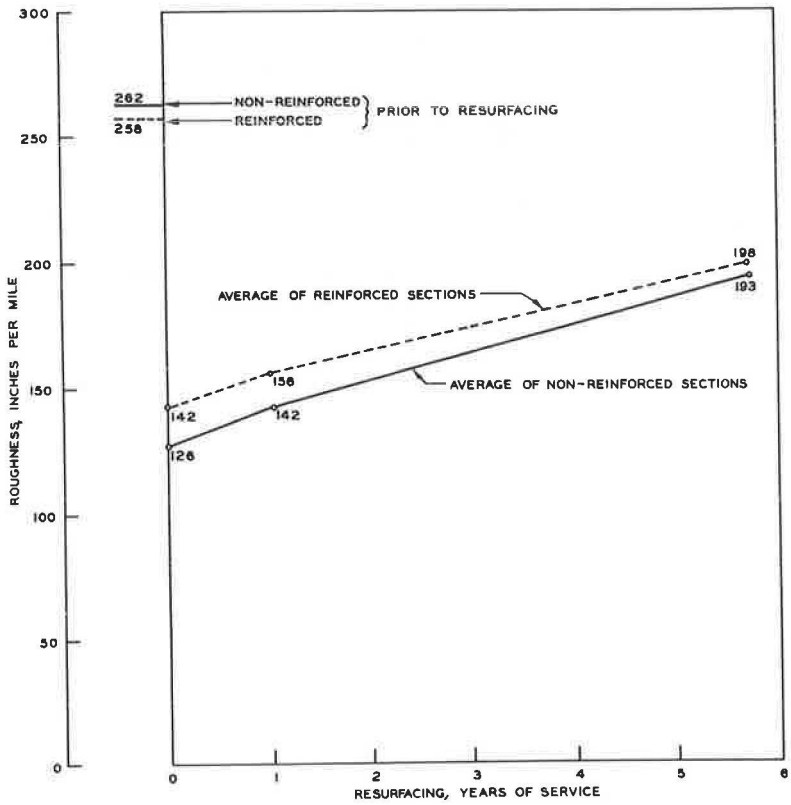


Figure 6. Increase in roughness with service for reinforced and non-reinforced sections.

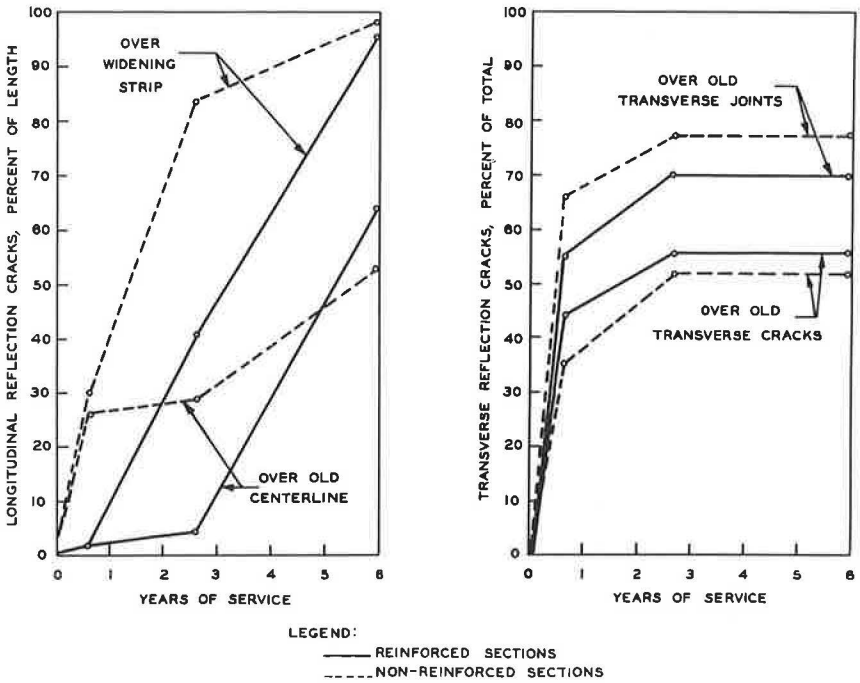


Figure 7. Average reflection cracking for reinforced and non-reinforced sections.

percent commercial, to 19,750 with 22.5 percent commercial. The difference in roughness with service was insignificant for reinforced and non-reinforced sections (Fig. 6). However, the first reinforced section was initially rougher than the other sections, probably due to construction problems incident to buckling and deforming of wire-mesh mats which was most prevalent in the first two days of constructing the first reinforced section.

During the first eight months of service, transverse and longitudinal cracks developed both in reinforced and non-reinforced sections (Fig. 7). Survey procedures included specific detailed mapping of the entire project length.

The reinforcement seems to have controlled longitudinal cracks over the centerline and the widening strip quite effectively for a while but showed reduced effectiveness by 2½ years and was completely ineffective by the end of 6 years.

The ineffectiveness of reinforcement in crack control over transverse joints and cracks even for a short time can be seen in Figure 7. No significant reduction of transverse reflection cracking was noted. In addition, transverse reflection cracks also developed over lapped mat edges on the reinforced sections with 13 percent reflected through the resurfacing by the end of 8 months and 17 percent by the end of 32 months.

The reinforced sections were also prone to an additional problem which did not occur in the non-reinforced sections. At the intersection of transverse and longitudinal reflection cracks over the widening strip, the reinforced sections developed alligator cracking which produced potholes requiring patching in 15 cases for a total of 127 sq ft (Fig. 8).

During final inspections, bituminous concrete was removed from potholes at other locations to expose the reinforcement. The wires were fractured and severely rusted in potholes over intersections of transverse and longitudinal joints in the old pavement, indicating extensive infiltration of moisture to the steel. However, steel exposed at other locations, where no surface deterioration had occurred, suggested that the reinforcement after 6 years had been reduced throughout the overlay to disconnected networks of broken and corroded wire fragments (Fig. 9).

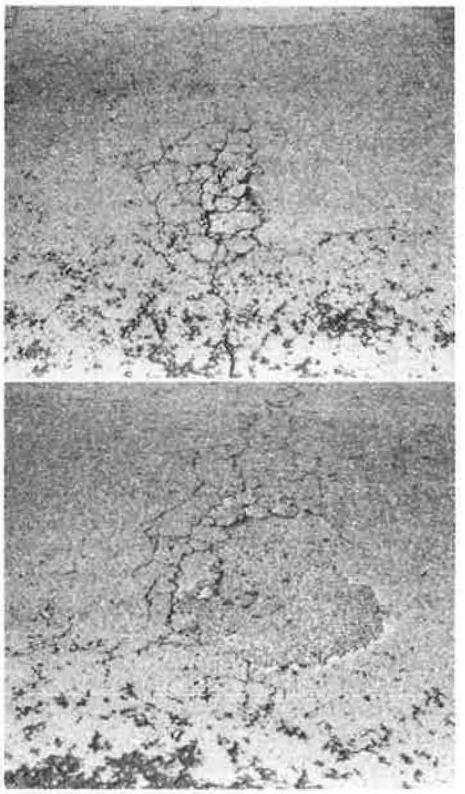


Figure 8. Alligator cracking leading to pothole patching of resurfacing in reinforced sections.

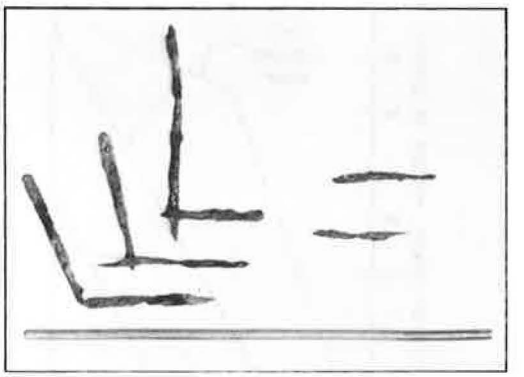


Figure 9. Reinforcement specimens removed from sound and unsound resurfacing areas. Sample of new No. 10 gage wire at bottom.

Of all the steel examined, the best preserved after 6 years was a lightly rusted short length of wire that had never been covered during resurfacing, but had been left exposed to the weather at the pavement edge. This exposed wire was in better condition than parts of the same sheet that had been covered with bituminous concrete (Fig. 10). It would seem that any bituminous-concrete reinforcement lacking specific treatment for corrosion prevention would be liable to rust and

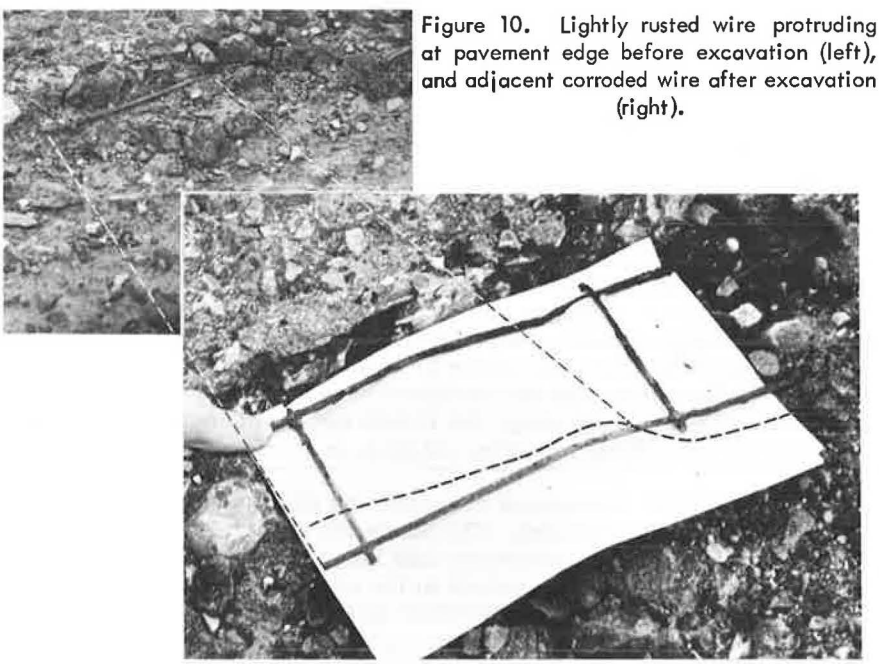


Figure 10. Lightly rusted wire protruding at pavement edge before excavation (left), and adjacent corroded wire after excavation (right).

fracture after about 5 years, wherever winter maintenance chemicals were used extensively.

SUMMARY

Soil-Aggregate Cushion

Wherever comparisons between resurfaced projects with and without soil-aggregate cushions could be made, soil-aggregate cushions proved capable of reducing reflection cracking. However, with the 4 to 8-in. thicknesses used in Michigan, soil-aggregate cushions have not completely eliminated reflection cracking. The Detroit Industrial Expressway, I-94, project has indicated that heavily traveled highways can be rehabilitated without reflection crack problems by using a soil-aggregate cushion. The cushions have proved satisfactory for carrying traffic during construction periods, and thus time can be minimized when a project is closed to vehicles.

In conclusion, it appears that soil-aggregate cushions significantly reduce reflection cracking. However, the preceding discussion shows the performance of cushions is variable and further research is required to minimize variability and maximize efficiency.

Reinforced Asphaltic Concrete

The Michigan experiment with welded wire-mesh continuous reinforcement placed directly on a widened portland cement concrete base and then covered with two-course bituminous-concrete resurfacing indicates:

1. Reinforcement offers no significant advantage in control of transverse or longitudinal reflection cracking or in preserving a smooth riding resurfacing.
2. Alligator cracking at intersections of transverse and longitudinal joints leading to potholes requiring patching was a performance problem unique with only the reinforced resurfacing sections.
3. Extensive corrosion and fragmentation of reinforcing steel, a performance factor not mentioned in the literature, was encountered even where the overlay surface was in good condition.

On the basis of other experimental studies, the Wire Reinforcing Institute and state agencies active in this research area now advise against installation of reinforcement directly on the base pavement. Notably successful experiments have been reported in other states by placing a leveling or binder course over the concrete base, then laying reinforcement, and completing the resurfacing with a wearing course, for a "sandwiched" type cross section. In some cases, the sandwiched reinforcement is placed over a leveling course or binder course and then covered with a separate binder and surfacing courses for a three-layer cross section.