MICHIGAN'S EXPERIENCE WITH DIFFERENT MATERIALS AND DESIGNS ON THE SKID RESISTANCE OF BITUMINOUS PAVEMENTS

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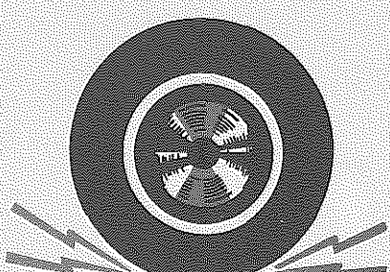

MICHIGAN DEPARTMENT OF STATE HIGHWAYS

MICHIGAN'S EXPERIENCE WITH DIFFERENT MATERIALS AND DESIGNS ON THE SKID RESISTANCE OF BITUMINOUS PAVEMENTS

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MICHIGAN'S EXPERIENCE WITH DIFFERENT MATERIALS AND DESIGNS ON THE SKID RESISTANCE OF BITUMINOUS PAVEMENTS

With the rapidly rising number of vehicles on the road it is not surprising that there is a corresponding rise in the number of vehicular accidents. Factors contributing to this include human behavior, vehicle mechanical failure, environmental conditions, road layout, and pavement surface. To tackle all these problems is a task for people of diversified interests. This report intends to isolate one of these factors, pavement surface, and taking advantage of the research and experience of others, to report on the work performed during the past four years by the Michigan Department of State Highways in improving skid resistance of pavements.

Accumulations of deposits on the road surface such as rubber particles from tires, mud film, oil and grease drippings from auto crankcases, are among the factors that contribute to slippery pavements especially at the beginning of a rain after a long, dry spell. Excess surface bitumen and polishing of the coarse aggregate particles also contribute measureably in causing slippery pavement conditions.

An example of a slippery pavement caused by polished coarse aggregate is shown in Figure 1. Note the reflection of light from the pavement surface which is a good indication that it may be slippery. A close-up of a sawed pavement core taken from this surface is shown in Figure 2. Note that the coarse aggregate particles have become oriented in such a way that their flat faces are exposed to the surface and subject to subsequent polishing by traffic. Turning this same specimen at an angle, as illustrated in Figure 3 shows the oily bitumen absorbed into the surface of the coarse aggregate particles which adds to the problem under wet condition.

Although all coarse aggregate particles will eventually polish and exhibit the above characteristics, experience indicates that some carbonate aggregates such as limestone, particularly the softer type, will polish at a faster rate than the harder or non-carbonate aggregates. On the other hand experience indicates that fine aggregate particles produce a sandpaper surface texture that offer skid resistance. As the fine particles are gradually lost through wear, the surface rejuvenates itself and sandpaper texture continues.

Figure 1. Polished limestone-slippery pavement surface.

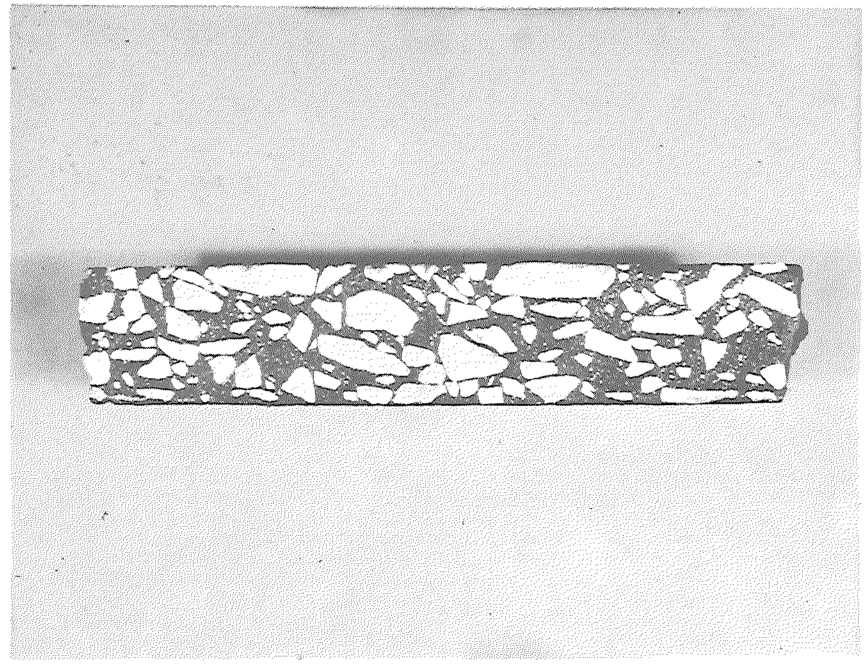

Figure 2. Pavement cross section showing oriented flat particles.

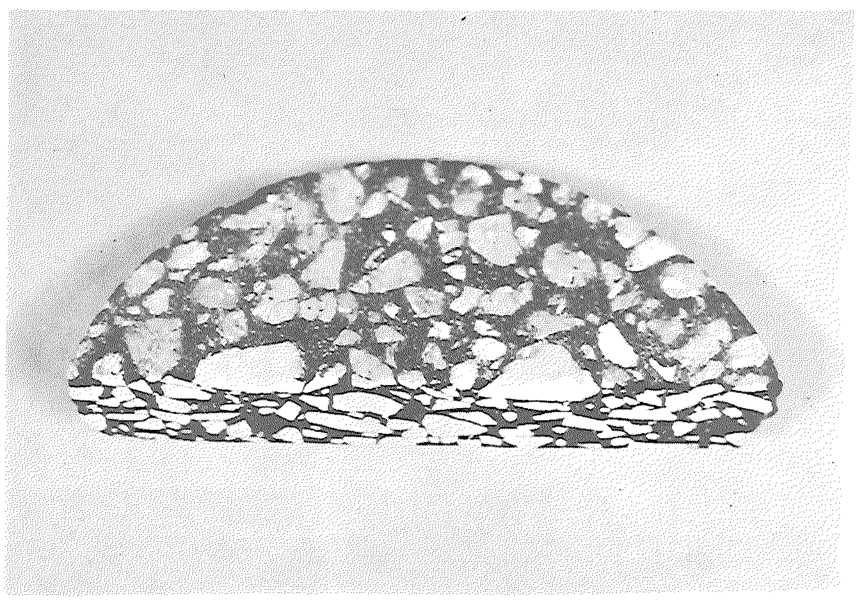

Figure 3. Pavement core showing oily polished surface aggregate particles.

Although a sandpaper surface texture offers a skid resistant surface, as vehicle speeds increase, particularly when the pavement is wet, the effect of this sandpaper texture becomes minimized. Some engineers explain this as being due to hydroplaning of the tire on a water film. To nullify this one might consider constructing a surface having sharp aggregate particles that protrude through the water film to make contact with the tire at higher speeds.

Most accidents occur in heavy traffic approaching intersections or other critical areas that may cause drivers to brake. Normal maximum speeds in these areas are below 40 miles per hour. Therefore, in the interest of confining ourselves to a specific type of condition, let me further isolate this problem to surfaces that will be subjected to speeds under 40 miles per hour.

Correcting these critical conditions usually involves resurfacing, commonly performed by placing a bituminous mat on the old surface. So let us further narrow the scope of this study to fine textured bituminous skid resistant surfaces.

A statewide search was conducted to obtain different types of hard aggregates which could be crushed and used to produce fine textured bituminous surfaces. Also, preliminary laboratory studies were made to consider maximum particle size, gradations, bitumen content, mineral filler content, air void, stability, etc. To further supplement this investigation a contract was entered into with the American Oil Company to allow preliminary skid studies to be conducted on their laboratory-type circular test track over short sections using different mixes.

Based on information obtained from all of these sources, a number of different types of materials and designs were used to produce skid resistant surfaces at selected critical areas in the southern part of Michigan. The following are some of the materials used in these installations with a brief description of each.

Sandstone

This aggregate was a sandstone from the Grindstone City area of Michigan's "Thumb" region; geologically identified as the lower Marshall Sandstone Formation, Pointe Aux Barques Members. Large broken pieces of old, seasoned, discarded grindstones, which were processed years ago, were used as raw material for this project. Pieces containing excessive amounts of the finer-grained brownish layers were generally not used. Freshly quarried sandstone from this source is reported to be somewhat "friable," and may require seasoning in the open air to harden the cementing material that holds the sandstone grains together.

The material was put through a crusher and that portion still exceeding 3/8 in. was passed through the crusher a second time. These two crushings were combined which resulted in the following average gradation.

	Percent
Passing 3/8-in. sieve	100
Passing No. 4 sieve	64
Passing No. 8 sieve	44
Passing No. 30 sieve	35
Passing No. 100 sieve	24
Passing No. 200 sieve	8.0

Physical characteristics of the material tested in the central laboratory were as follows:

Soundness, percent loss	57
Los Angeles "A" Abrasion, percent wear	59
Specific Gravity, dry basis	2.2
Absorption, percent	7.2

Since the crusher-run material appeared to contain sufficient fines, no additional sand was added to the initial mix design. Several bitumen contents, varying from 8 to 10 percent, were tried but the resulting mixture was tough to handle and produced a non-uniform, open-textured mat. After some experimentation, the mix design was changed by adding one part fine sand to five parts crusher-run sandstone, and 9.5 percent 60-70 asphalt. Commercial mineral filler was not added to this mixture. This mixture produced a uniform textured, skid-resistant surface and was used on three intersections in the Bay City area. Normally, a gradation of this type would use about 6.5 percent asphalt; however, because of this material's high absorption (7.2 percent), it was necessary to raise the bitumen to about 9.5 percent in order to produce a serviceable pavement. Figure 4 shows a typical intersection after four years of service using this sandstone mixture and Figure 5 is a close-up showing the sandpaper surface texture. After several months of wear the larger sandstone particles began to show a dishing effect as illustrated in Figure 6. This has not detracted from the excellent service performance of this surface after four years of service under moderately heavy traffic, rather it is felt it has improved its skid resistance characteristics.

Quartzite

The aggregate used is identified as Ajibik Quartzite and was obtained from the Upper Peninsula. The crusher-run material contained about 17 percent passing the 200 mesh sieve which was considered somewhat high for a proper mix design. Consideration was

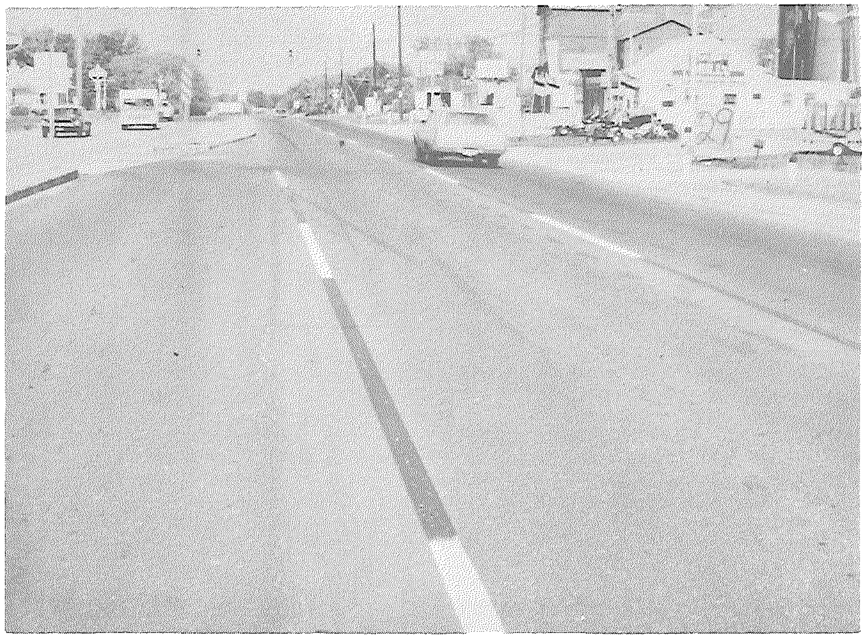

Figure 4. Crushed sandstone surface, 4 years after construction.

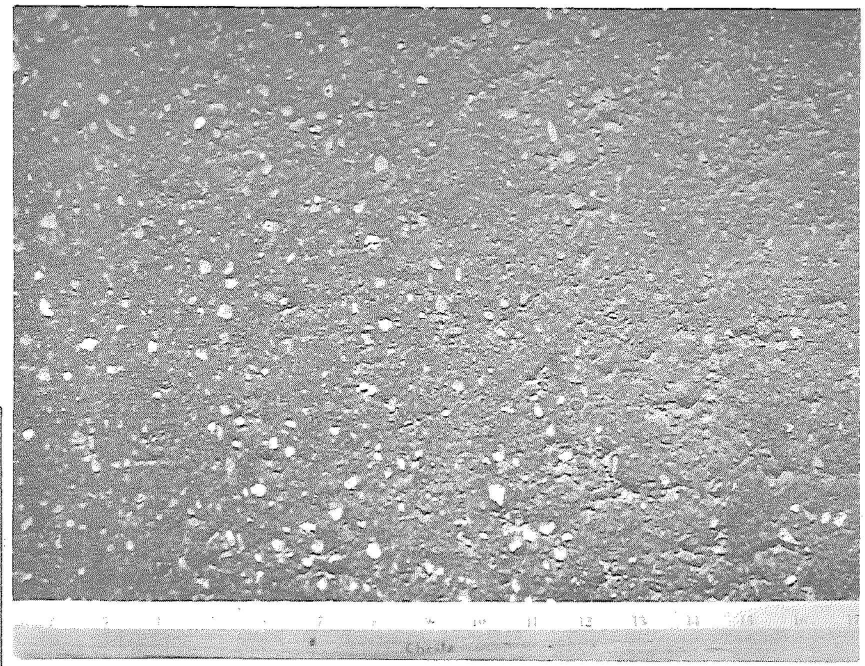

Figure 5. Close-up of sandstone surface, 4 years after construction.

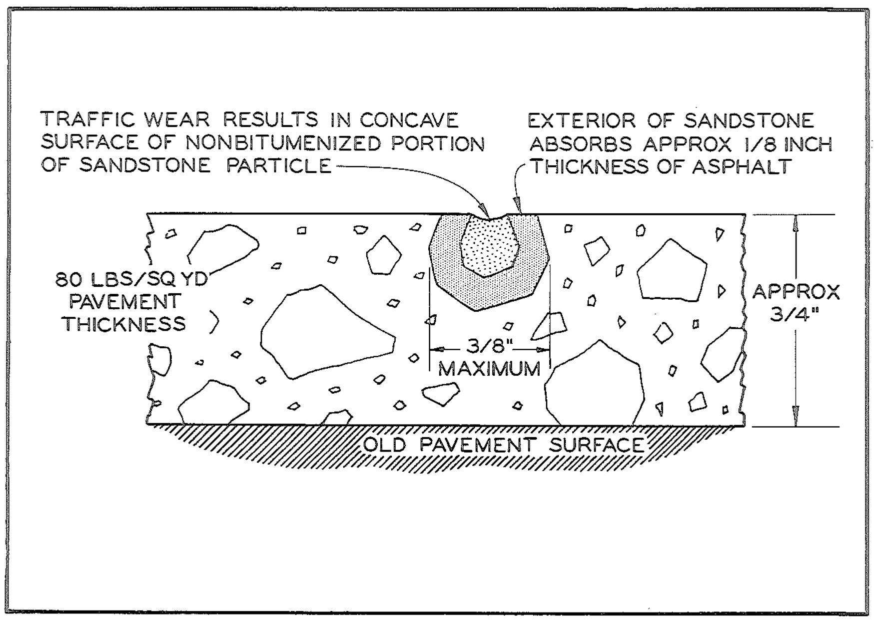

Figure 6. Result of traffic wear on larger particles of crushed sandstone.

given to washing a portion of the crushed material and blending the washed and unwashed stockpiles in proportions that would produce about 7.5 to 10 percent passing the 200. Inadvertently, the producer washed all the crushed material produced, resulting in the following gradation:

	Percent
Passing No. 8 sieve	100
Passing No. 16 sieve	72
Passing No. 30 sieve	43
Passing No. 50 sieve	25
Passing No. 100 sieve	11
Passing No. 200 sieve	4.5

Based on laboratory-prepared Marshall specimens and the appearance of a trial pavement surface, the mix design for the major portion of the project was set at 6.5 percent 60-70 asphalt and 4.0 percent fly ash added as mineral filler to make up for the fines lost through washing, with the balance being the quartzite crushings. No other aggregate was added for this mix design. Figure 7 shows a typical surface after three years of service in the Flint area. Note that some loss was experienced where traffic entered from a side gravel road causing considerable localized abrasion, however the balance of the surface is in good condition. Figure 8 shows a close-up of this excellent skid resistant surface.

Stripping tests performed on quartzite have usually indicated poor adhesion of the asphalt to the quartzite surface in the presence of water. The amount of stripping may vary, depending on the sources of the materials used. For this reason, on one additional project a heat-resistant anti-stripping additive was added to the asphalt cement before incorporation in the mixture. An intersection north of Flint was selected for this application to determine by actual service whether any differences show up after service between the quartzite mixtures containing asphalt with and without the additive. One percent of heat-resistant anti-stripping additive was added to the 60-70 asphalt cement. A stripping test was performed in the laboratory on a mixture prepared with this quartzite (P8-R16) and 4.5 percent asphalt cement containing the additive. After curing, the mixture was subjected to a boiling test. Eighty percent of the asphalt containing the additive was retained on the quartzite, as compared to only 20 percent of the asphalt without the additive on a similar mixture. After four years, the surface containing the additive appears to show somewhat less wear than the surfaces constructed with untreated asphalt. However, both areas exhibit satisfactory durability and excellent skid resistance.

Crushed Beach Pebbles

The aggregates used were crushed pebbles obtained from beach deposits on the Lake Superior shore at the east end of Michigan's

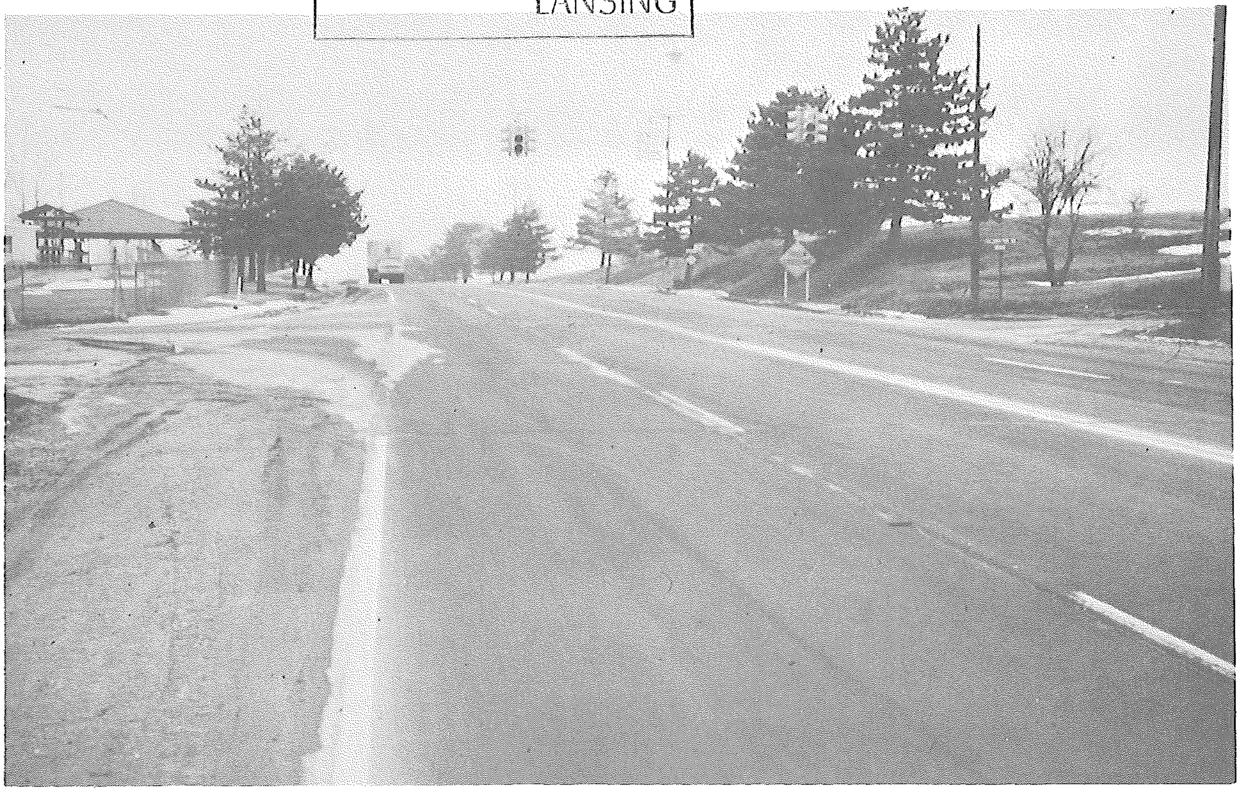

Figure 7. Crushed quartzite surface, 3 years after construction.

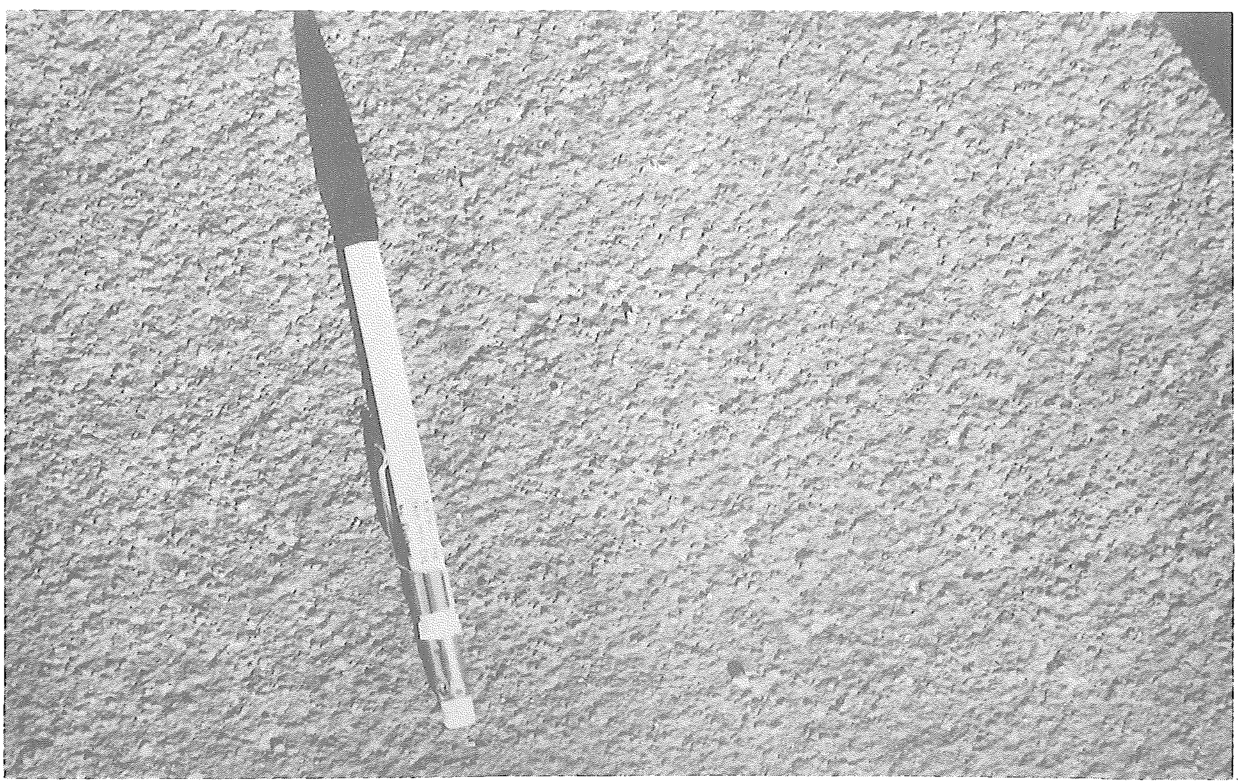

Figure 8. Close-up of quartzite surface, 4 years after construction.

Upper Peninsula. After many years of grinding wave action on the aggregate particles, only the hard pebbles remain. The deposit is quite extensive along the lakeshore in this vicinity and is used as a source of pebbles for polishing, for use in decorative panels, and other applications.

It was desired to crush the pebbles, 1/2 inch or larger, to 100-percent passing the No. 8 sieve; however, difficulties were experienced with the small crusher used for this purpose therefore it was decided to accept the material as produced with the following average gradation:

	Percent
Passing 3/8-in. sieve	100
Passing No. 4 sieve	97
Passing No. 8 sieve	70
Passing No. 16 sieve	47
Passing No. 30 sieve	30
Passing No. 50 sieve	19
Passing No. 100 sieve	11
Passing No. 200 sieve	5.5

The mix design used was 5.7 percent 60-70 asphalt and 2.0 percent fly ash mineral filler, with the balance as crusher-run beach pebbles. No other aggregate was added to this mixture. Figure 9 shows a typical surface three years after construction at an intersection south of Flint. Figure 10 shows a close-up of the surface after four years of service. This surface is in fair condition; however, due to relocation of the roads in this area, part of this project was resurfaced last year.

Trap Rock

The aggregate used was predominately of basic igneous origin and was obtained from Michigan's Upper Peninsula. Because of the high amount of stone dust, the crushed material was washed, resulting in the following gradation.

	Percent
Passing No. 8 sieve	100
Passing No. 16 sieve	76
Passing No. 30 sieve	44
Passing No. 50 sieve	22
Passing No. 100 sieve	10
Passing No. 200 sieve	6.6

The mix design called for 6.1 percent 60-70 asphalt plus 3.5-percent added fly ash mineral filler, with the balance being crushed trap rock. No other aggregate was added to this mixture, which was used at an intersection south of Flint. Figure 11

Figure 9. Crushed beach pebbles, 3 years after construction.

Figure 10. Close-up of beach pebble surface, 4 years after construction.

shows the surface after three years of service. Note that considerable areas of the surface were worn completely through to the old pavement. No detour provisions were made and heavy traffic was permitted to traverse the uncured, warm mat, resulting in premature wear that was evident within a few days after construction. I believe this mix would have proved more durable if traffic had not been permitted on the warm surface during construction.

Synthetic Bitumen and Natural Sand

Previous experience indicated that when certain synthetic bitumens were mixed with sand, they exhibited promising skid resistance due to what appeared to be a noticeable rejuvenation of the sandpaper texture. This mixture was placed at a rate of 80 lb/sq yd on a section of I 96 about 50 miles west of Detroit. During the start of the first winter, sections of the pavement peeled off as noted in Figure 12. The balance of this surface was later bladed off. It was determined that considerable hardening of the bitumen occurred within a few months resulting in penetrations approaching zero. It is believed this contributed to the loss of adhesion between the thin bituminous mat and the underlying concrete pavement.

Hot Asphalt Emulsion and Sand

In recent years the Asphalt Emulsion Industry has promoted the use of hot emulsion sand mixtures for skid proofing purposes and other states have reported satisfactory service with these mixtures. A mixing grade emulsion was used for this purpose with the producer claiming that the bitumen residue has certain thixotropic characteristics, thus permitting higher bitumen contents to be used in the mixture without danger of flushing. A fine aggregate passing the No. 8 sieve was mixed with about 10.8 percent emulsion resulting in about 7.5 percent residue. The temperature of the mixture delivered to the street ranged between 245 and 270 F. Figure 13 shows a typical pavement section after four years of service while Figure 14 shows a close-up of the fine sandpaper texture. This road is in good condition and offers a skid resistant surface.

Sand Asphalt

Although most of the previous materials and designs exhibited excellent skid resistant properties, they were costly to construct primarily because of special handling of materials which are not normally used for paving purposes. On the other hand it has been determined that ordinary sand-asphalt mixtures produce satisfactory although not high skid resistance surfaces. Because sand-asphalt mixtures are less costly, it was decided to use them for much of the balance of the skid proofing program during the next several years.

Figure 11. Crushed trap rock, 3 years after construction.

Figure 12. Synthetic bitumen and sand, 1 year after construction.

Figure 13. Sand-emulsion surface, 4 years after construction.

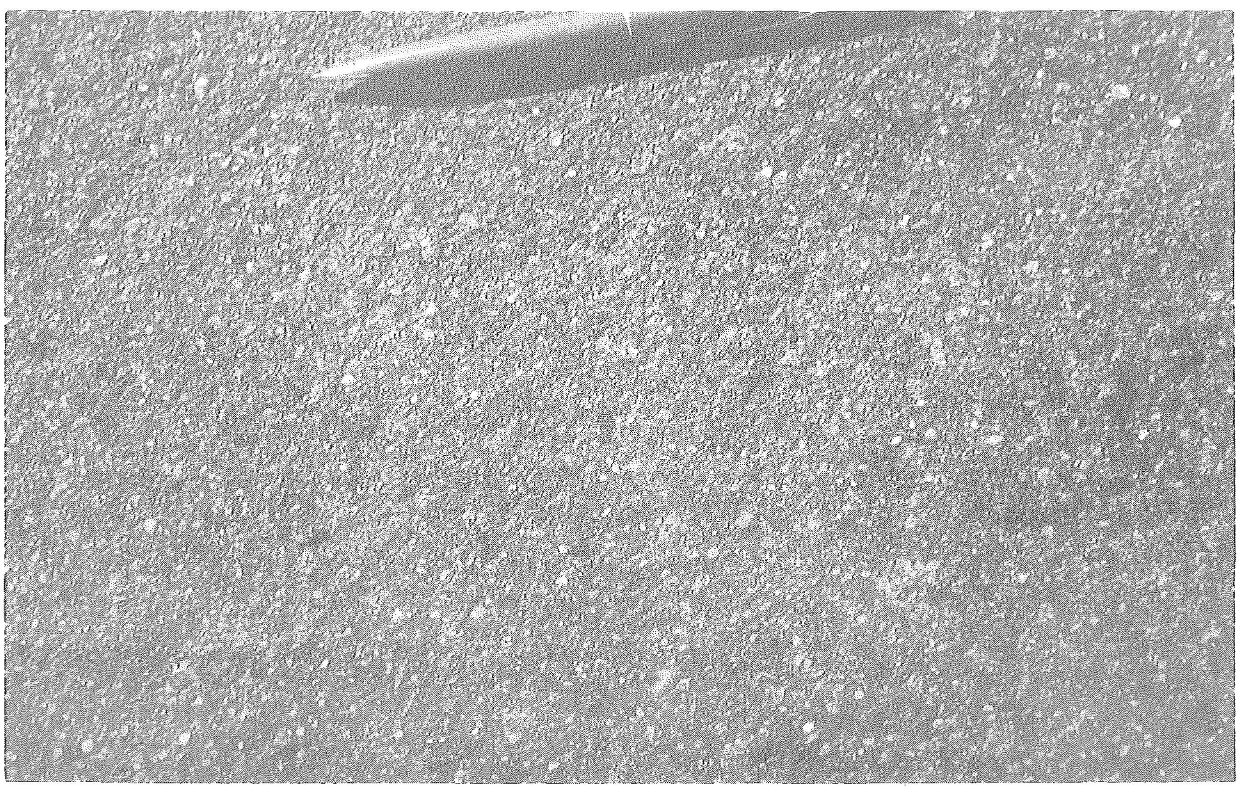

Figure 14. Close-up of sand-emulsion surface, 4 years after construction.

At the beginning of the first winter season, some sand-asphalt surfaces showed delamination in the wheel tracks. That is, about 1/8-inch layers would separate from the balance of the mat. Figure 15 shows a typical example of such a road and Figure 16 illustrates a detail of this phenomenon.

Although some theories have been proposed as to the cause of this, the writer has reservations about these explanations. Of more importance is the fact that solutions have been found to reduce this type of failures. After several years of observation it was noted that bituminous mixtures with sands which are predominantly one size "belly type" often exhibit this delamination while uniformly graded sands very seldom show any delamination.

Stone Filled Sand Asphalt

Another solution to the delamination problem is to tie the 1/8-inch top layer to the lower main portion of the mat by introducing coarse aggregate (3/8-inch top size) into the sand asphalt mix. Figure 17 illustrates this technique of tieing the upper and lower layers together. Satisfactory performance has been observed using this technique with the coarse aggregate content ranging from 10 to 25 percent. Figure 18 shows a pavement in Detroit with a stone filled sand asphalt mixture after four years of service. Figure 19 is a close-up showing the stone particles sticking up above the sand asphalt mortar. Since there are very few exposed stone particles, softer type aggregates such as limestones may be used without concern regarding the polishing effect.

Asbestos Fiber and Sand Asphalt

Experience indicates that, within certain limits, leaner mixes exhibit better skid resistance than bituminous pavements designed at their optimum bitumen and mineral filler content. However these leaner mixtures may show faster wear than corresponding surfaces having optimum designs. In an attempt to improve the durability of these mixtures, short fiber asbestos was added as filler which, because of higher absorption, are able to hold more asphalt in the mix. Three intersections were constructed with this material, all on Telegraph Rd in the Detroit area.

A typical design used is as follows:

	Percent
Sand	87.5
Asbestos	2.0
Fly Ash	2.0
Asphalt	8.5

Figure 15. Sand-asphalt surface, 1 year after construction showing delamination.

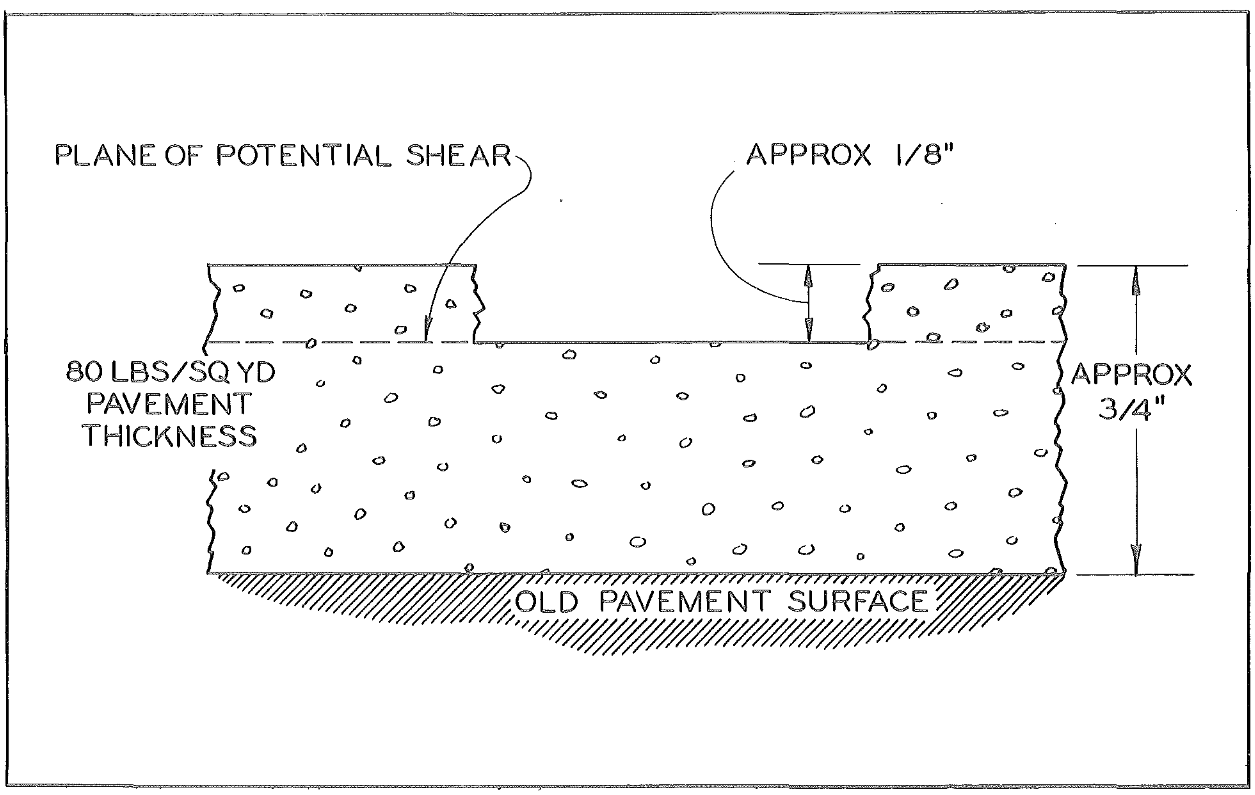

Figure 16. Cross-section of sand-asphalt surface showing delamination.

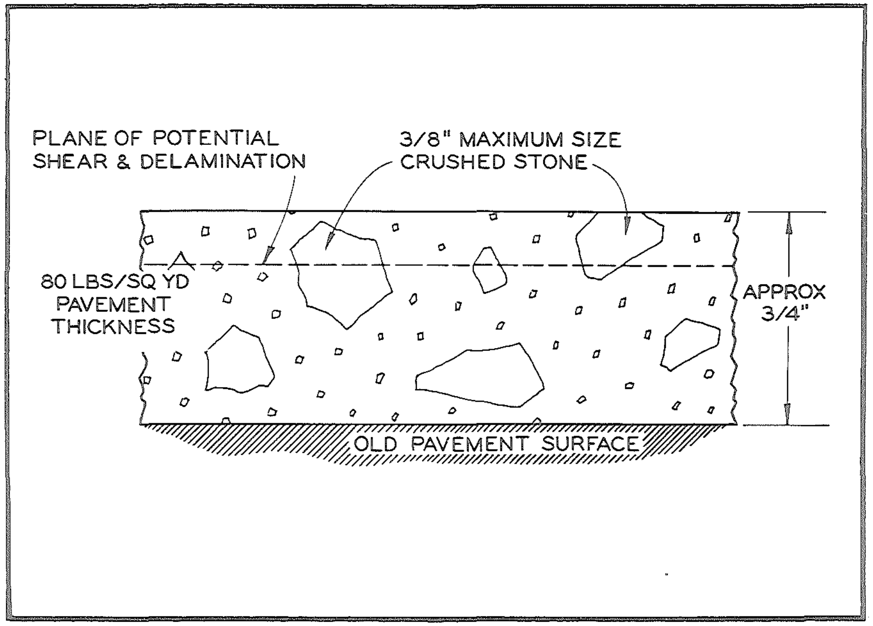

Figure 17. Cross-section of stone-filled sand-asphalt surface.

Figure 18. Stone-filled sand-asphalt surface, 4 years after construction.

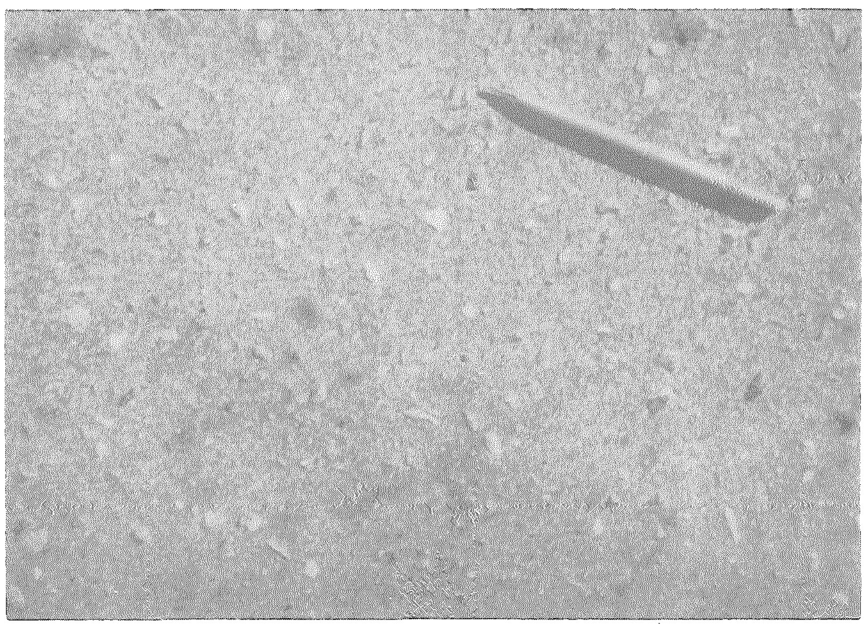

Figure 19. Close-up of stone-filled sand-asphalt showing stones sticking out.

Figure 20 shows a typical area in Detroit after four years of service. It is generally in good condition except for the fillet areas which were manually placed and cooled before they were properly compacted resulting in some ravelling. Figure 21 is a close up of the sand asbestos asphalt surface texture which exhibits satisfactory skid resistance.

Synopal Sand Asphalt Mixture

During the period of placing the other experimental skid resistant surfaces, a synthetic aggregate which is a product of fluxed Silica and Dolomite, was shipped in from Europe. This is a white aggregate having a hardness about 6 on the Mohs scale of hardness. One part of the synthetic aggregate was mixed with two parts of natural sand, to which was added 2.5 percent limestone filler and 6.5 percent 60-70 asphalt. This was laid between 1/2 to 3/4-inch in thickness in the Benton Harbor area.

Figure 22 shows this surface after four years of service. The lighter colored areas shown in the right two lanes have the Synopal added while the darker areas in the left two lanes are mixtures of sand asphalt without Synopal. Figure 23 is a close up of the Synopal surface, note the white particles of Synopal exposed at the surface. This surface, in general, is in good condition and exhibits good skid resistance.

Construction Notes

Motorists are sometimes warned of freshly laid bituminous surfaces with a sign indicating "Slippery When Wet". Figure 24 shows a freshly laid bituminous mat constructed with MC-3000 liquid asphalt. The left foreground surface was laid the day before while the balance of the surface which appears spotted has just been completed when it was rained on. After one day of curing and weathering, water wets the pavement. However, as indicated on Figure 25, a close-up of the fresh surface shows water globules formed on the mat. This non-wetting phenomenon of a fresh bituminous surface may contribute to slippery pavements when wet.

Psychologically, when a driver observes a smooth wet newly constructed bituminous surface he may be inclined to apply brakes to slow down. Because of the non-wetting phenomenon, and because the sandpaper texture has not yet developed the driver may lose control of his vehicle on the slippery pavement. Therefore it was felt something had to be done to improve the initial skid resistance of pavements that ultimately should offer good skid resistance.

After considerable experimentation, a procedure was developed to produce an initial skid resistant bituminous surface by applying hot sand, precoated with about one percent asphalt cement, on

Figure 20. Sand-asbestos surface, 4 years after construction showing raveled fillets.

Figure 21. Close-up of sand-asbestos surface, 4 years after construction.

Figure 22. Synopal-sand surface, 4 years after construction.

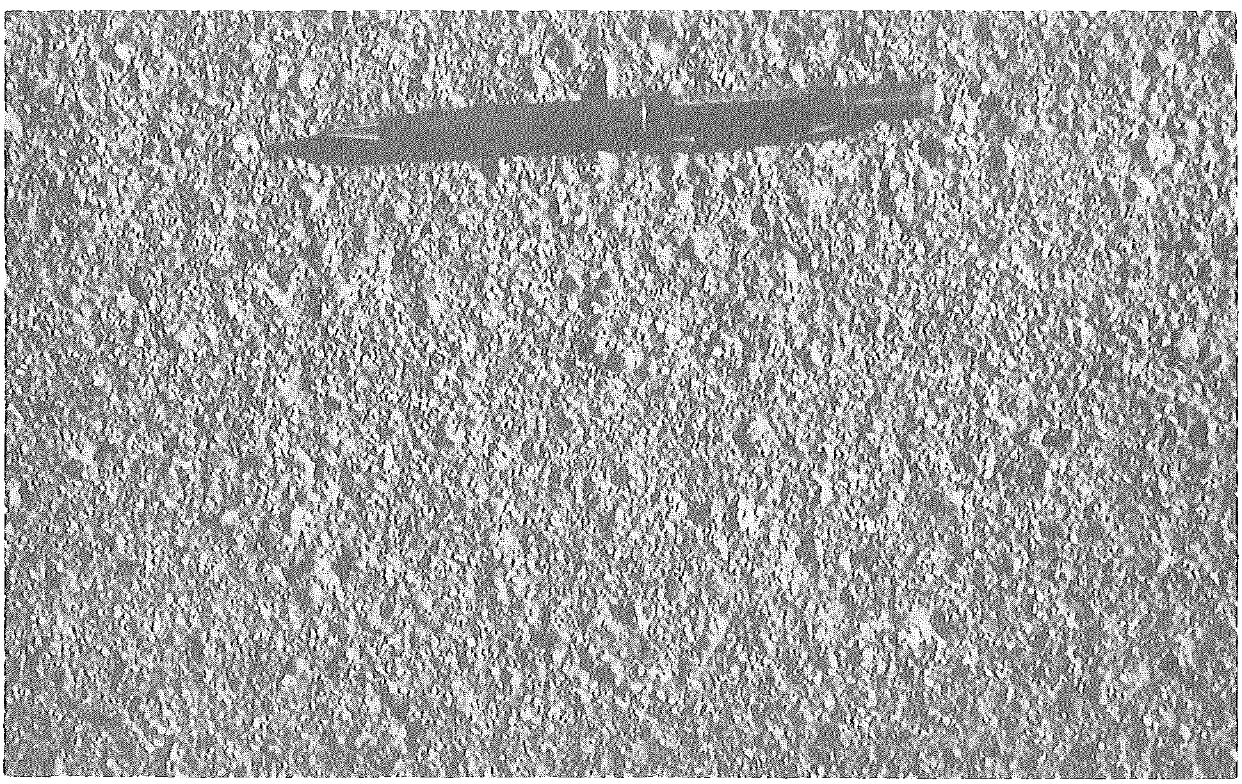

Figure 23. Close-up of synopal-sand surface, 4 years after construction - note white synopal particles.

Figure 24. Freshly laid bituminous surface after rain.

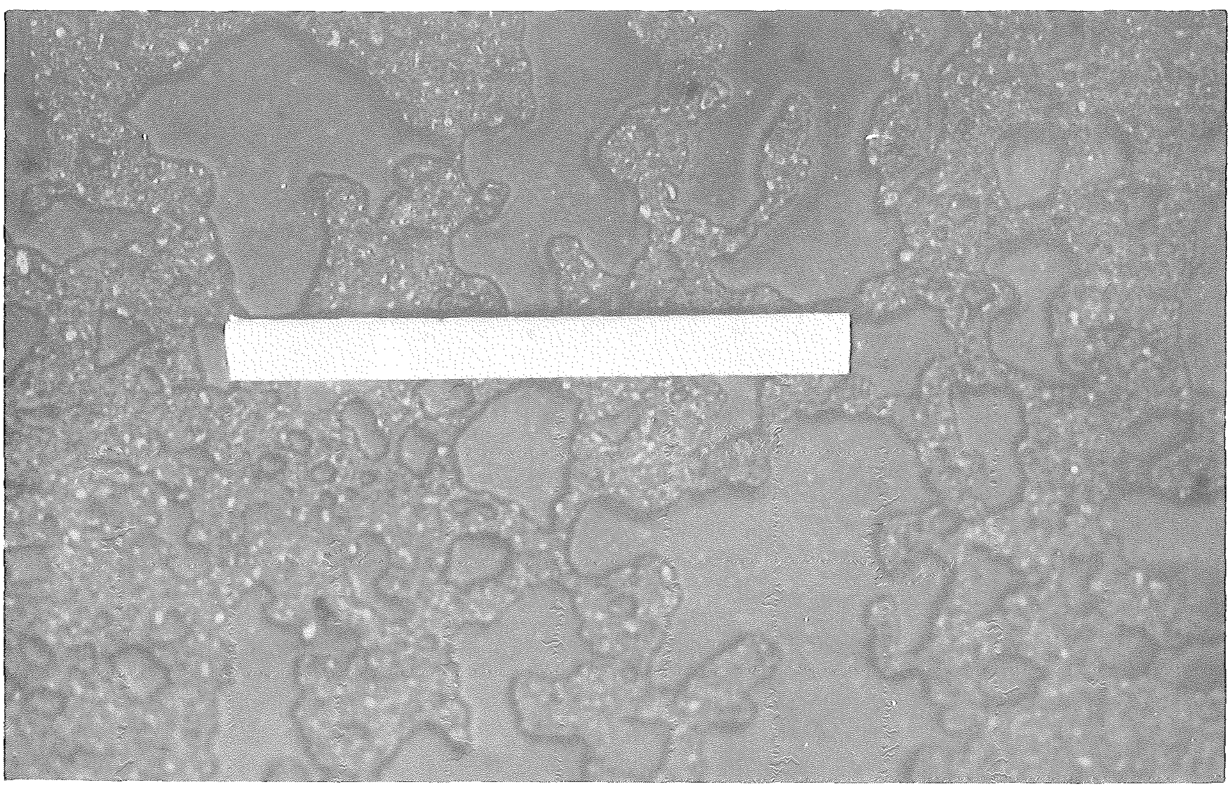

Figure 25. Close-up of fresh oily non-wetting bituminous surface after rain.

the unrolled mat behind the paver. This is then rolled into the surface which reduces the initial slickness. About 2 to 5 pounds per square yard of this precoated sand is sufficient; an excess may produce a ball bearing effect which also can be dangerous and also may mar the pavement surface when bunched up sand is rolled into the mat.

Figures 26 through 30 show some typical equipment used in this technique. Note that the spreader in Figure 27 is not equipped with a deflector, thus allowing about 2/3 of the precoated sand to be wasted on the shoulder. Using a seeder, as in Figure 28, sometimes leaves ridges that subsequently mark the pavement.

CONCLUSION

In conclusion let us examine the figures and curves shown in Figures 31 and 32.

All the experimental surfaces start out with an initial average skid resistance coefficient of friction of over .45. The sandstone surface had an initial coefficient of .74 followed by the quartzite surface of .71, crushed beach pebbles .63, etc. There is a dip in all the curves after one year of service followed by an increase and leveling off of the coefficients. After four years of service again the sandstone and quartzite surfaces with coefficient of .57 and .58 are higher than the rest of the materials used in this study.

Considering that a satisfactory coefficient of friction should be over .35 or .40, it is indicated that excellent skid resistance can be obtained using special hard aggregates in the bituminous surfaces. However, to obtain the most for the money the uniformly graded sand-asphalt mixtures offer a satisfactory skid resistance and have proven through service to be durable. Therefore currently many of the critical areas on Michigan trunklines are being resurfaced with the more economical sand-asphalt mixtures.

After observing these bituminous skid resistant surfaces for four years, it is felt the following ten items are worthy of consideration.

1. Soft coarse aggregates such as the carbonate types may polish faster than the harder aggregates. However all coarse aggregates will eventually polish under traffic.

2. Fine aggregates (Passing #8) usually wear away exposing new ones before they become polished therefore they offer skid resistance at lower speeds (below 40 mph).

3. Uniformly graded fine aggregates resist wear better than non-uniformly graded ones and are not prone to surface delamination.

4. Angular fine aggregate particles offer slightly better skid resistance than rounded sands.

5. Natural sand, well graded, containing predominantly hard particles (5.5 plus Mohs Scale), offer satisfactory skid coefficient (0.40 - 0.50) and may be considered over the special aggregates for economic reasons.

6. Fresh bituminous surfaces are oily and non-water-wetting and are initially slippery when wet. This may be corrected by the application of sand, precoated with one percent asphalt, to a mat before rolling.

7. 80 lb/sq yd mats appear to be the desired application rate for skid proofing purposes. Lesser thickness may wear prematurely and may peel off. Greater thickness may rut or shove.

8. Addition of mineral filler and asphalt should be kept slightly below optimum to obtain satisfactory skid resistance.

9. Thin mats are best applied at 60+F air temperatures to obtain satisfactory compaction before chilling.

10. Existing surfaces must be thoroughly cleaned and with light application of tack coat before placing thin bituminous skid resistant mats.

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Figure 26. Spreading precoated sand on unrolled bituminous mat.

Figure 27. Spreading precoated sand - showing sand being wasted on shoulder.

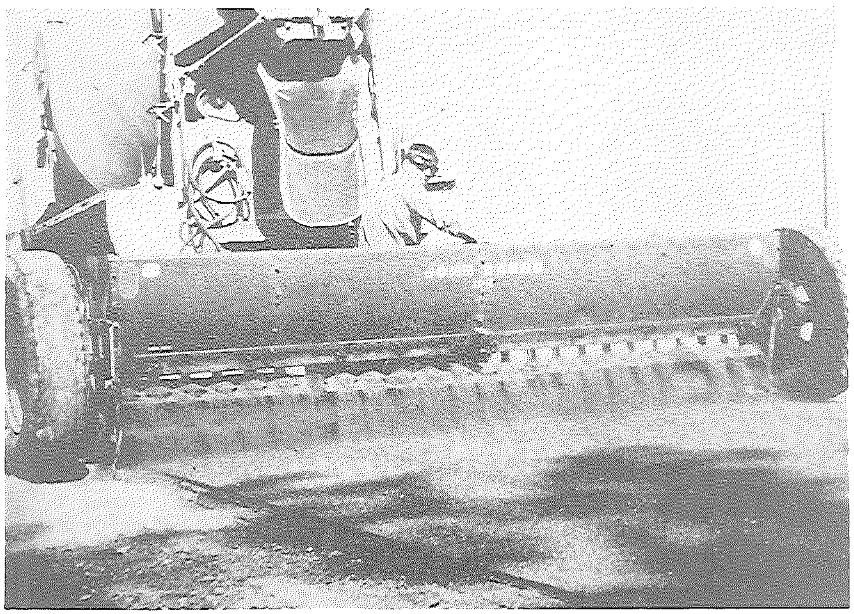

Figure 28. Seeder being used for spreading precoated sand.

Figure 29. Rolling pavement after sand application.

Figure 30. Partly rolled surface showing precoated sand on mat.

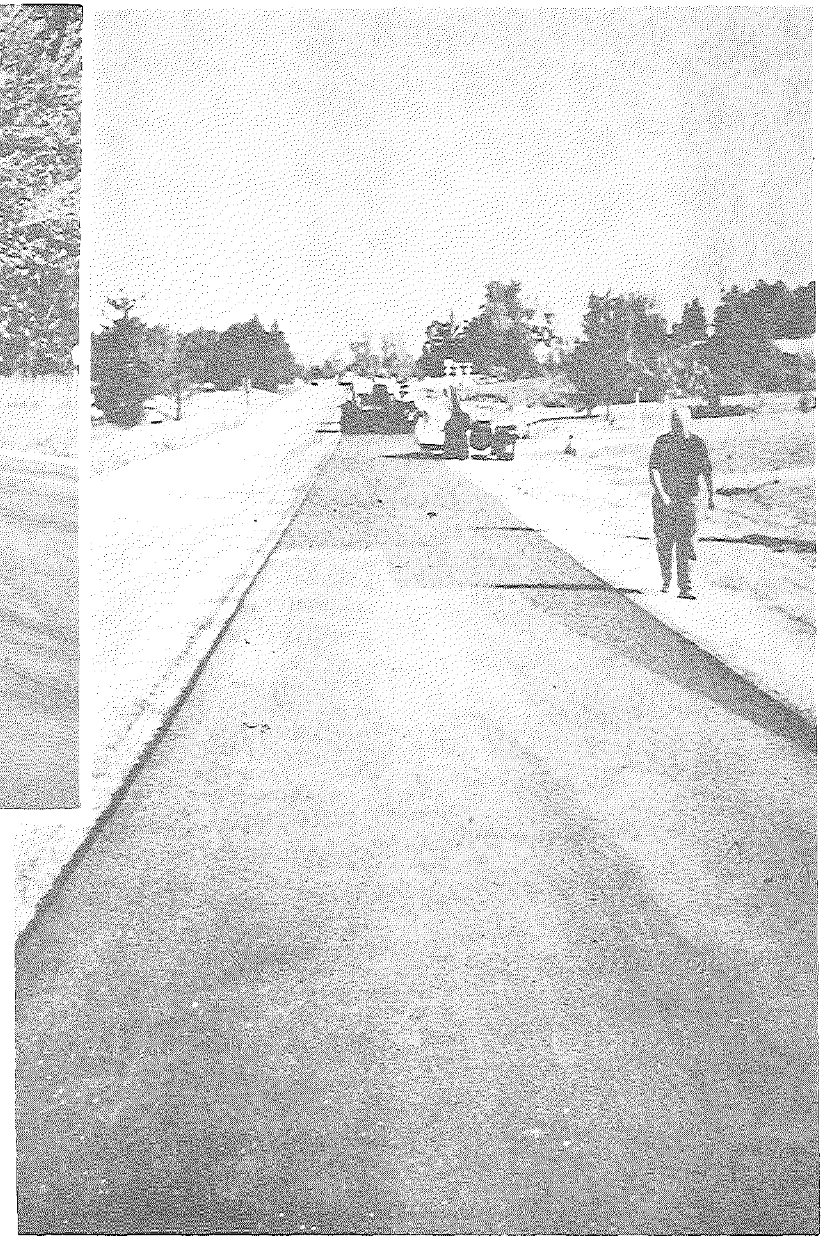

Figure 31. Tabulation of pavement skid-resistance coefficients of different materials vs. years of service.

	0	1/2	1	2	3	4
	1965	1966 SPRING	1966 FALL	1967	1968	1969
QUARTZITE	71	52	50	57	54	58
SANDSTONE	74	54	48	53	57	57
SAND-EMULSION	59	48	46	54	54	56
CRUSHED BEACH PEBBLES	63	47	46	44	47	52
SYNOPAL-SAND	47	41	39	54	47	49
STONE-FILLED SAND	52	41	37	45	45	48
ASBESTOS-SAND	62	39	36	43	44	46
SAND-ASPHALT	47	41	41	52	47	50

Figure 32. Curves of pavement skid resistance coefficients of different materials vs. years of service.