RELATIVE SKID RESISTANCE OF PAVEMENT SURFACES BASED ON MICHIGAN'S EXPERIENCE

E. A. Finney and M. G. Brown

US-23
G.R. INTERS
E.A.F.
7-26-63

A paper to be presented at the
First International Skid Prevention Conference
September 8-12, 1958
University of Virginia
Charlottesville, Virginia

Report No. 295
Research Laboratory Division
Office of Testing and Research
Research Project 54 G-74

Michigan State Highway Department
John C. Mackie, Commissioner
Lansing, August 1958

RELATIVE SKID RESISTANCE OF PAVEMENT SURFACES BASED ON MICHIGAN'S EXPERIENCE

E. A. Finney, Director, Research Laboratory Division
M. G. Brown, Chemical Research Engineer
Michigan State Highway Department

SYNOPSIS

This paper is essentially a progress report based on Michigan's experience in testing the skid resistance of various types of highway surfaces during the past 10 years.

Special consideration is first given to pavements constructed with stone sand as a fine aggregate.

The relative skid-resistance of basic highway surface types is briefly reviewed, and special consideration is given to the performance of bituminous concrete surfaces containing limestone aggregates from different sources.

Investigations on special surface types are discussed with reference to bleeding, slag aggregate, speed, and temperature.

The need for a standard test procedure and the necessity for establishing a minimum skid-resistance standard for all types of highway surfaces, at modern speeds and under wet conditions are stressed.

In conclusion, it is recommended that research be concentrated on design methods to develop high skid-resistant surfaces as well as non-skid surface treatments for correction of slippery surfaces in critical areas.

RELATIVE SKID RESISTANCE OF PAVEMENT SURFACES BASED ON MICHIGAN'S EXPERIENCE

The Michigan State Highway Department began its research on the skidding properties of pavement surfaces with an investigation in 1947-48. This study concerned a number of portland cement concrete projects constructed in the late 1930's and early 1940's, using stone sand as the fine aggregate material. (1) All skid tests during this study were made on wet surfaces by the stopping distance method at an initial speed of 20 mph.

More recently, in September 1954, a short cooperative skid testing program was undertaken at the request of the General Motors Proving Ground administration. The pavement projects selected for test were mainly of the bituminous concrete type including variations in aggregate type, traffic volume, and length of service. Several concrete pavement projects were also tested. The tests were performed on wet surfaces using a 1954 Buick Special sedan and a tow truck, operating at 40 mph. (2) The results of this cooperative venture indicated the need for the comprehensive skid-resistance survey of Michigan highways which was actually started in May 1957.

The 1957-58 investigation was initiated with three main objectives: 1) to determine the skid resistance level of all highway surface types now existing in Michigan;

2) from this information, to develop methods to ensure an increased, uniform, and permanent friction level on future pavement surfaces; and 3) to study means of de-slicking existing pavements found to be below a safe standard, or achieving skid resistance on new pavements which may not be built to some designated standard.

In order to carry out Part 1 of this comprehensive research program as rapidly as possible, a special two-wheel skid trailer was built to be towed by a truck at test speeds up to 40 mph. The truck also carried water and necessary electrical and mechanical devices to operate the equipment's component parts during the test cycle. Michigan's skid test equipment was designed and built concurrently with that of the General Motors Proving Ground, in close cooperation with Mr. Paul C. Skeels, Head of the Experimental Engineering Department. (3) Dynamic and static comparative tests of the two agencies' skid equipment show close agreement. (4)

Between June 1957 and August 1958, over 4000 skid tests have been performed with the Highway Department equipment representing coverage of some 2400 miles of state highways and including 183 portland cement projects, 193 bituminous aggregate and bituminous concrete, 44 bituminous surface treatments, 13 sheet asphalt, and several special skid-resistant test areas. Usually, about six tests were made on each project at representative locations selected according to the project's length. The average of these several test measurements constitutes the skid-resistance level of the specific project. Traffic conditions permitting, all tests were run on wet surfaces at 40 mph. The air temperature range during the course of the test program was between 40 and 90 degrees.

Michigan's investigation at this point is far from being completed. Therefore, it is possible in this report to deal in only the most general sense with the skid-resistance characteristics of certain types of pavement surfaces in relation to their material composition, and under conditions indigenous to Michigan.

Three general subjects will be covered: 1) the effect of stone sand on the slipperiness of concrete pavements; 2) a comparison of the skid-resistance properties of four common types of highway surfaces, namely: portland cement concrete, bituminous concrete, sheet asphalt, and bituminous surface treatments under equivalent wear conditions; also skid test results from several specially constructed areas in which certain material components have been included as test variables; and 3) miscellaneous considerations in skid resistance.

STONE SAND AS A FACTOR IN PAVEMENT SLIPPERINESS

Concrete pavements constructed with fine and coarse limestone aggregates from the same source can become dangerously slippery when wet, and to a lesser degree, when dry. Although no physical measurements of slipperiness of dry pavements were made during skidding studies, it was quite obvious upon inspection that the stone sand concrete pavements tested in Michigan were slippery under foot when dry and it was easily possible to skid tires during rapid acceleration of a vehicle under dry pavement conditions.

With the increase in postwar traffic in Michigan, a rash of skidding accidents developed on approximately 122 miles of concrete pavements at various locations, especially when wet, which had been constructed with stone sand as the fine aggregate. (1) During 1947-48, wet sliding coefficients of friction were measured on the individual projects involved, using the stopping distance method from an initial velocity of 20 mph. Results of this study are tabulated in Table 1. The projects tested had friction coefficients ranging from 0.20 to 0.42 with an overall average of 0.28. With reference to Figure 1, 63 percent of the projects tested had coefficient of friction values between 0.2 and 0.3, much below the minimum value of 0.4 recommended by the American Association of State Highway Officials for safe driving, under all speed conditions. (5) As a result of the investigation, use of stone sand in concrete pavement was banned in 1948, and these slippery projects have since been resurfaced with bituminous concrete.

It was determined that such construction factors as air-entraining materials, membrane curing compounds, and de-icing salts had no measurable effect on the

TABLE 1

COEFFICIENTS OF FRICTION ON CONCRETE PAVEMENTS BUILT WITH LIMESTONE COARSE AGGREGATE

	Project Number	Age at Time Of Test, Years	Avg. Coef. of Friction	
Natural Sand: 1957-58 Skid Test Survey, Trailer Method (40 mph)	64-22, C2	2	0.68	Average Coefficient: 0.51
	15- 2, C7	10	0.65	
	32-48, C2	5	0.60	
	40-15, C2	16	0.59	
	53- 4, C1	32	0.54	
	74-41, C2	9	0.54	
	74-39, C2	20	0.52	
	71-19, C12	12	0.52	
	77-42, C5	2	0.51	
	74-13, C2	28	0.50	
	32-41, C3	21	0.50	
	71-20, C7	12	0.49	
	74-40, C1	16	0.48	
	71-19, C4	17	0.48	
	32-42, C2	17	0.47	
	73-30, C2	20	0.46	
	32-13, C1	30	0.46	
	04-11, C4 & C5	19	0.46	
	77-32, C1	27	0.45	
	11-30, C1	26	0.45*	
	32-39, C2	20	0.44	
	74-27, C2	18	0.44	
	74-39, C1	25	0.43	
Stone Sand: 1947-48 Skid Test Survey, Stopping Distance Method (20 mph)	75-30, C7	11	0.42	Average Coefficient: 0.28
	75-30, C3	12	0.35	
	MANISTIQUE	9	0.35	
	49-28, C2	10	0.35	
	75-30, C3 & C5	12	0.32	
	77-66, C1	3	0.32	
	75-30, C3 & C5	12	0.31	
	51- 2, C3 & C5	3	0.29	
	75- 2, C6	4	0.29	
	51- 2, C3	3	0.27	
	75-31, C7	6	0.26	
	21-29, C7	10	0.25	
	51- 2, C3	3	0.24	
	75-30, C5	10	0.24	
	24-25, C1	8	0.24	
	21-29, C8	10	0.23	
	21-29, C7	10	0.23	
	75-31, C4	9	0.22	
	75-31, C3	14	0.20	

* Avg. of three tests; all others are avg. of six tests, three in each direction.

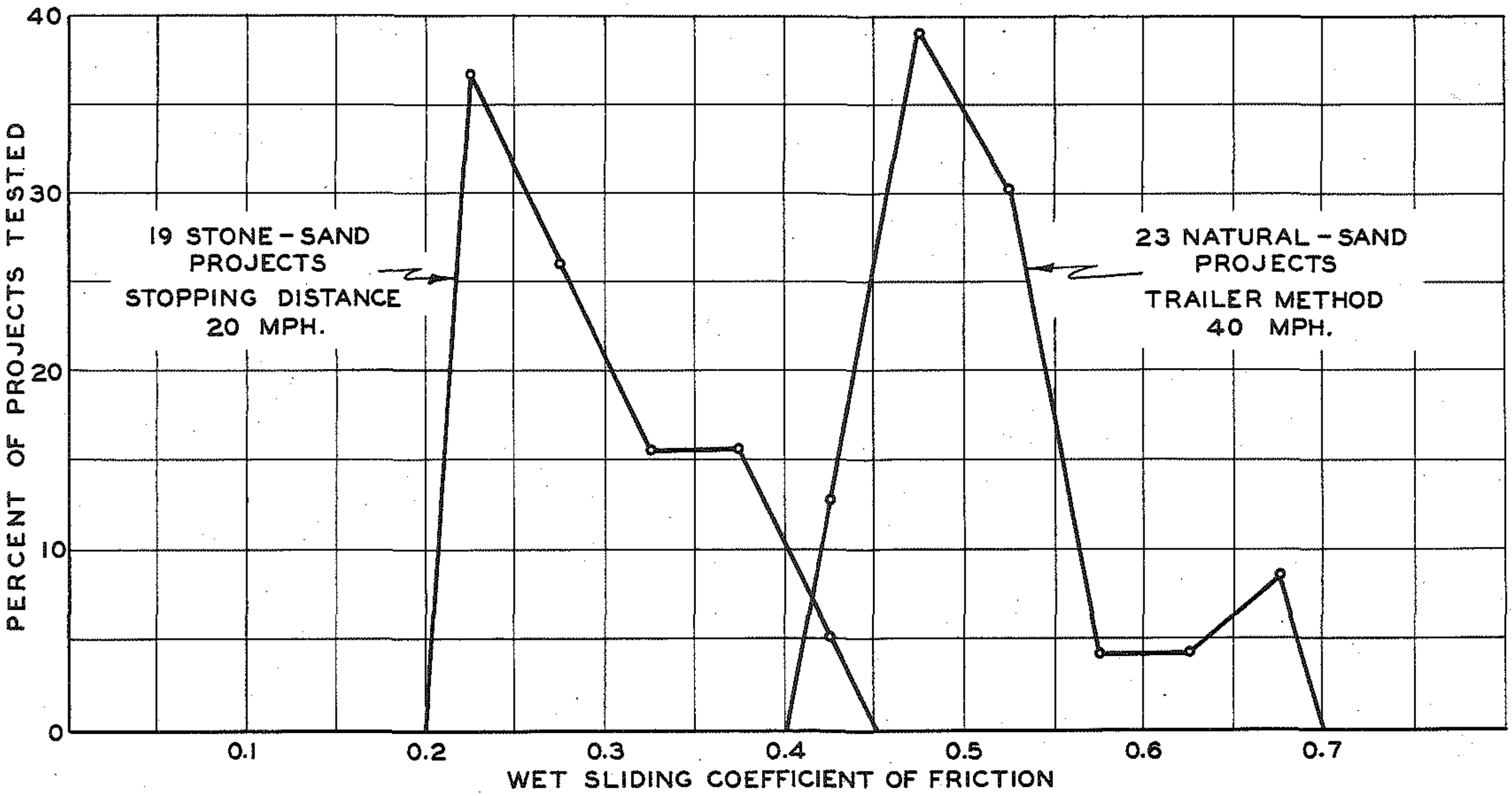


Figure 1. Coefficient frequency distribution for concrete surfaces containing stone sand and natural sand.

skid-resistant properties of the stone sand concrete surfaces. Further, skidding tests proved conclusively that once the surface mortar is removed, exposing the limestone coarse aggregate underneath, this aggregate also abrades and becomes exceedingly smooth, resulting in a surface with skidding characteristics not unlike those of the unscaled areas (Figure 2).

Figure 3 illustrates the typical appearance of a slippery, stone sand concrete pavement surface under reflected light.

Stone Sand Versus Natural Sand

Skid tests made during the course of this early investigation, as well as during the 1957-58 test program, definitely indicate that concrete pavements made with limestone coarse aggregate and natural sand have skid-resistance properties when wet superior to stone sand (Table 1). In these tests, the average friction value for the 23 projects tested was 0.51, as compared to 0.28 for the 19 concrete projects constructed with stone sand. Referring again to Figure 1, 100 percent of the natural sand projects were above 0.4; 70 percent of these projects had friction values between 0.45 and 0.55 as determined by the trailer method at 40 mph.

Friction frequency curves in Figure 1 clearly demonstrate the advantages of natural sand over stone sand as a fine aggregate material for concrete pavements. Although the difference in test methods for the two materials limits this comparison, from comparable test data for similar aggregate types reported by Whitehurst and Goodwin (6) it can be assumed that the friction values for the stone sand projects would be even lower by approximately 50 percent if determined by the trailer method at 40 mph.

Figure 2. Typical appearance of a scaled stone sand concrete surface.

Figure 3. Typical appearance of slippery stone sand concrete surface under reflected light.

Physical Characteristics of Stone Sand Concrete Surfaces

Photomicrographs in Figure 4 illustrate typical surface conditions found on several stone sand concrete pavement projects during the 1947-48 survey. From these photos it may be observed that in some cases, the stone sand particles extend slightly above the cement mortar but are well rounded and polished. In other instances, the aggregate and matrix have become equally polished to a smooth, glossy surface, which offers practically no mechanical interlocking for the tires or openings for quick water egress from between the tire and the surface.

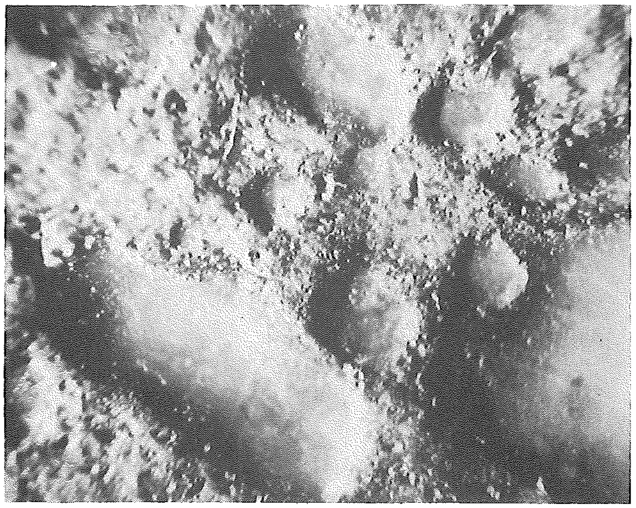
Since gravel aggregate results from disintegration of various rocks, the individual particles, both coarse and fine, are by nature heterogeneous and thus may vary considerably in physical properties. The quartz particles predominating in natural sand have a hardness factor of 7. Limestone, on the other hand, is a sedimentary rock generally having a hardness of 3 in Moh's hardness scale. Thus, it is only reasonable to suspect that under traffic the small limestone particles comprising stone sand will become smooth more rapidly. Furthermore, since the coarse and fine limestone aggregates are from the same material source, the resulting concrete is fairly homogeneous in character.

Conversely, the small quartz grains and other hard stone particles found in natural sand apparently remain intact and firmly embedded in the mortar, resisting abrasion sufficiently to remain jutting above the mortar, thus offering a high mechanical resistance to skidding as well as a release for surface water (Figure 5).

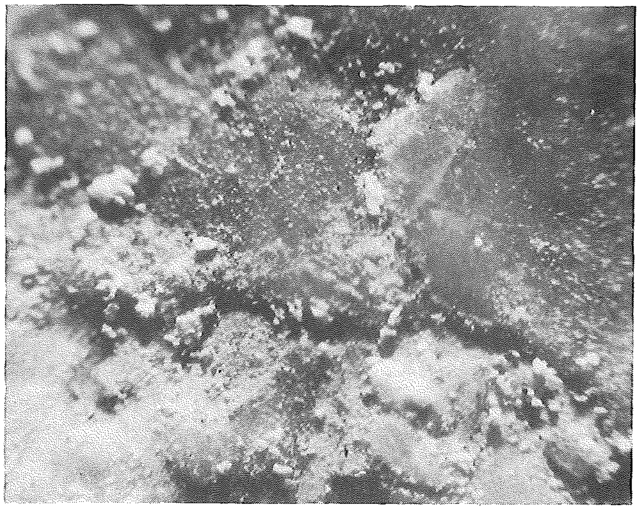
In addition, limestone aggregates are coated with a fine dust which it is practically impossible to remove by repeated washings. This dust material, when com-

PROJECT 75-30, C3, CORE 635

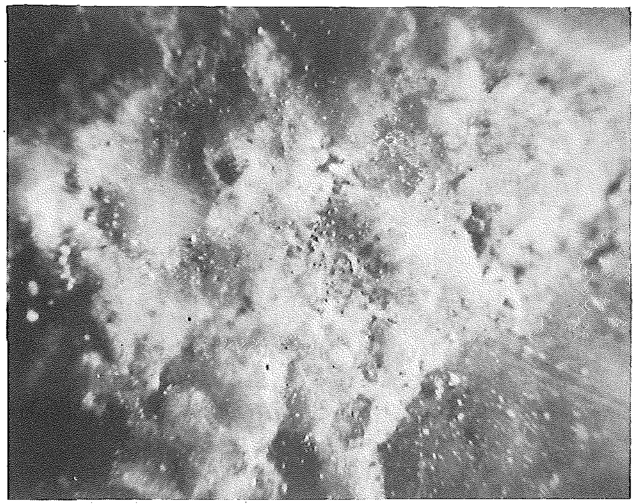
PROJECT 21-29, C7, CORE 633



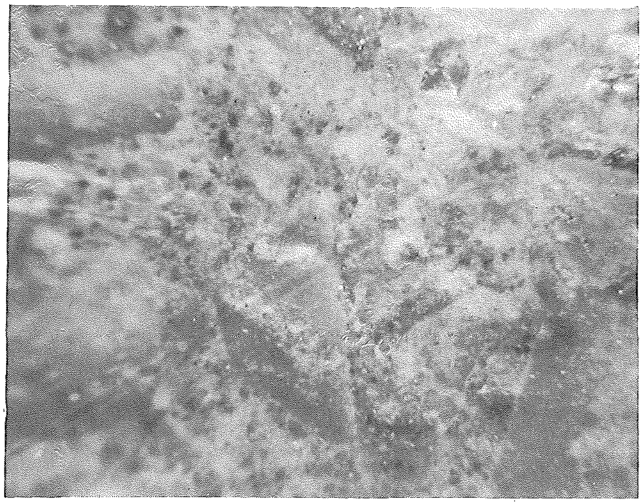
PROJECT 75-31, C4, CORE 668



PROJECT 25-30, C3, CORE 634



PROJECT 21-29, C7, CORE 630



IN THE CITY OF MANISTIQUE, CORE 636

Figure 4. Examples of surface texture on stone sand concrete projects. (enlarged 24 times)

bined with water, forms a greasy film on the aggregates. Under traffic, a similar surface condition probably would develop as fine limestone abrasion products accumulate.

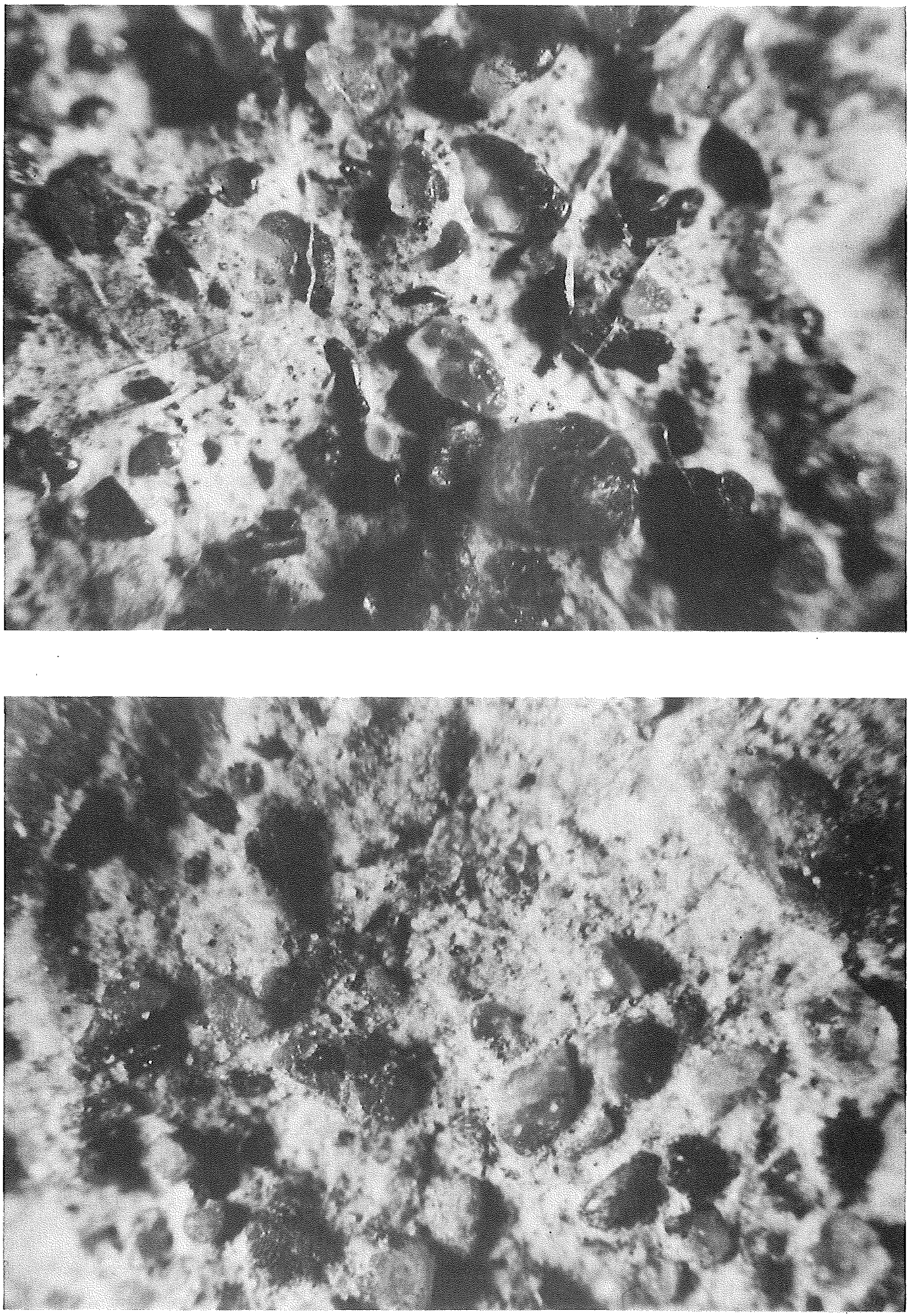


Figure 5. Typical surface texture of natural sand concrete surfaces (enlarged 24 times)

EFFECT OF PAVEMENT TYPE ON SLIPPERINESS

Results of Michigan's 1957-58 skid tests verify data from earlier Michigan tests (2) to the effect that definite differences exist in surface friction-wear patterns for the following basic types of highway surface: portland cement concrete, bituminous concrete, sheet asphalt, and bituminous surface treatments. Similar conclusions have been published for skid tests in Louisiana (7).

It is demonstrated throughout this report that a properly developed wear factor for each project under study can be a useful tool for evaluating certain pavement variables in relation to skid resistance. The wear factor used throughout this report is a modification of an earlier Michigan method (2), with the wear effect of commercial vehicles reduced to that of an equivalent number of passenger cars. It is believed that this gives a more realistic value for denoting pavement wear.

The new wear factor is computed as the product of the average daily volume per traffic lane since construction, weighted for percent of commercial traffic, divided by 1000 and multiplied by the age of the project in years. The percent of commercial traffic for each project is converted to an equivalent number of automobiles, so that total traffic may be considered as entirely composed of passenger cars. This equivalent number of cars is considered to be the product of the average truck-to-car tire contact area ratio, and the truck-to-car, weight per unit-area ratio. This product reduces to a direct ratio of average truck weight (loaded and empty) to average car weight. In general, this ratio has been increasing over the years and has become quite significant, especially on older projects.

Portland Cement Concrete

Average friction results from 162 concrete pavement projects, with no distinction as to coarse aggregate types, are presented as a friction frequency curve in Figure 6. This curve shows that friction values range from 0.35 to 0.67, with about 54 percent of the projects having friction values between 0.45 and 0.55. Eventually, when sufficient skid test data have been assembled representing many more concrete pavement projects, a more definitive study may be made of the effect of material components on skid resistance in relation to wear. Concrete components are listed in Appendix A.

In Figure 7, average skid test values for the 162 concrete projects have been plotted in relation to wear. By statistical methods, a curve was established indicating the relation between friction and wear to be practically linear. Average friction for concrete pavement at zero wear would be 0.53.

An attempt was made to compare the skid-resistance data for surfaces including gravel or limestone coarse aggregates, but no significant trend was detected. It seems unlikely, however, that a notable difference would appear until wear had progressed sufficiently to expose the coarse aggregate beneath the surface mortar layer.

Bituminous Concrete

In the case of bituminous concrete pavements, it was possible to separate the individual projects by the type of coarse aggregate used, such as crushed limestone or crushed gravel. Numerous projects were included in the survey, on which two or more different types of coarse aggregate had been used in construc-

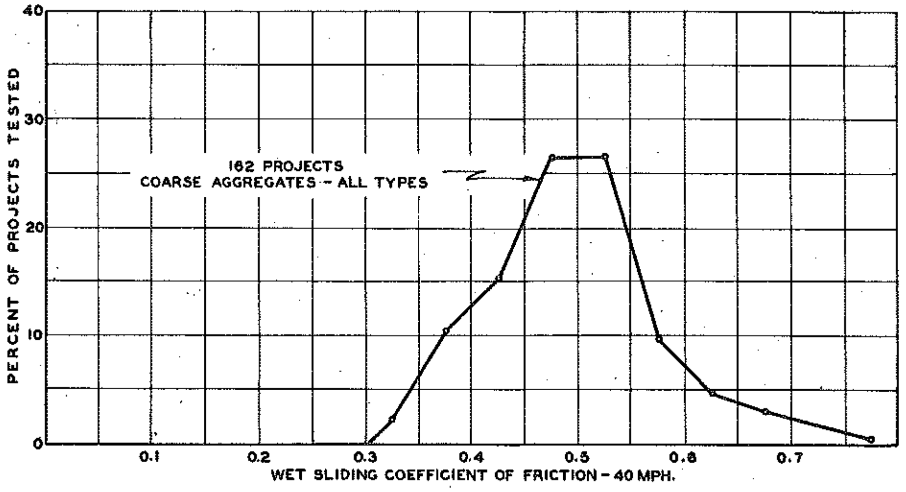


Figure 6. Coefficient frequency distribution: Portland cement concrete pavement.

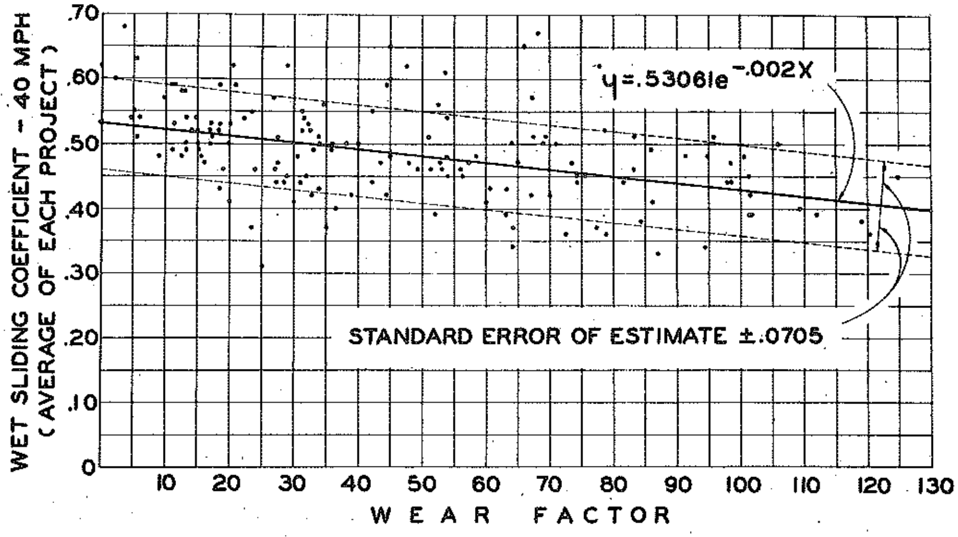


Figure 7. Friction in relation to wear: Portland cement concrete pavement.

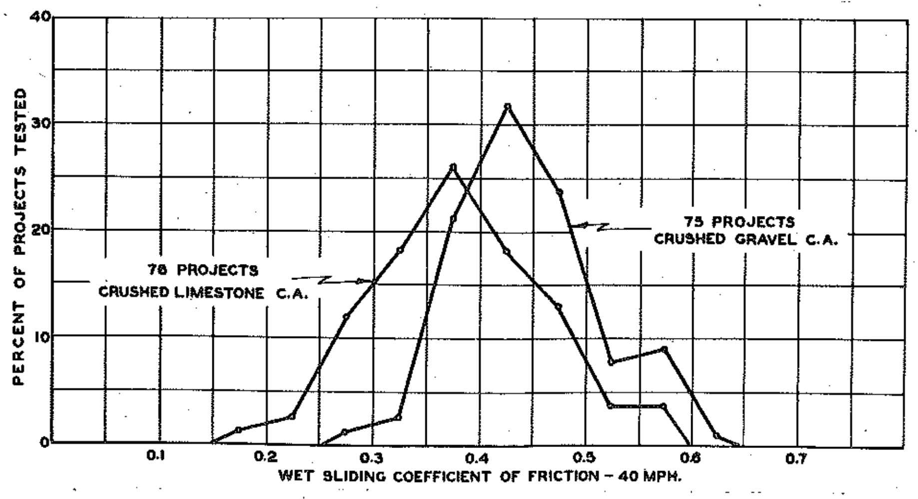


Figure 8. Coefficient frequency distribution: Bituminous concrete containing limestone and gravel aggregate.

tion. Skid test data from such projects have been excluded from this report, but will be a subject for individual study later in this investigation.

Gravel Versus Limestone Coarse Aggregates: Figure 8 shows the results for 151 bituminous concrete projects, of which 76 contained crushed limestone and 75 crushed gravel coarse aggregates. The graphic material in Figure 8 indicates that limestone aggregates generally produce a less skid-resistant surface than gravel aggregates, at least in bituminous concrete surface course construction of the type employed in Michigan (details of which are outlined in Appendix B). This has been verified by tests in Tennessee (6) and Virginia (8).

In Figures 9 and 10, average friction values for 75 gravel and 76 limestone aggregate bituminous concrete projects, respectively, have been plotted in relation to wear. Here, as in the case of portland cement concrete, it has been possible to establish a statistical relationship between bituminous surface type and wear, which may be considered linear in nature.

Friction-wear curves have been plotted in Figure 11 for portland cement concrete and for bituminous concrete with gravel and limestone aggregates, showing how these three basic surface types compare with one another, especially at wear factors less than 100. These curves also indicate it would be possible for the three surface types to reach approximately equal friction factors, but at different ages or under abnormal traffic conditions. The curves will be modified as more data becomes available from the current skid test program.

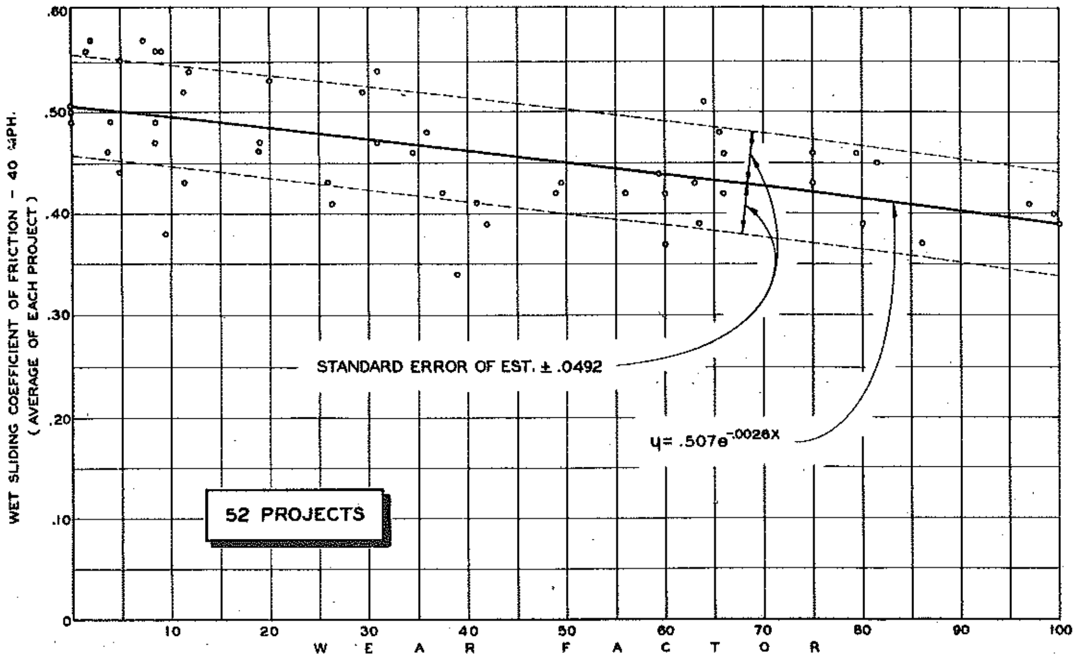


Figure 9. Friction in relation to wear: Bituminous concrete with gravel coarse aggregate.

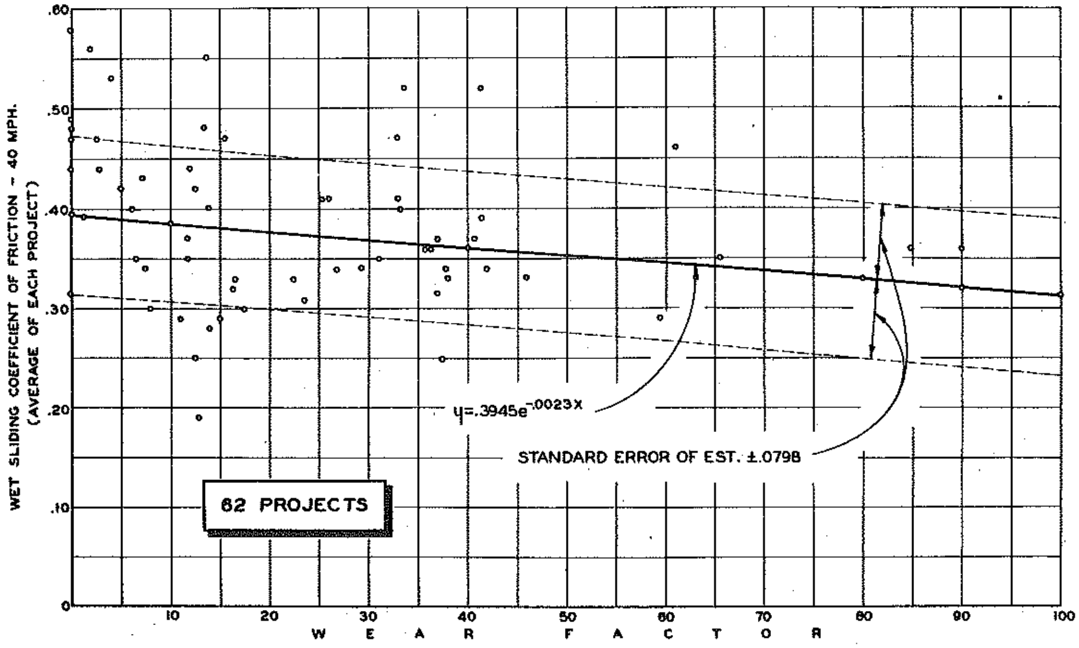


Figure 10. Friction in relation to wear: Bituminous concrete with limestone coarse aggregate.

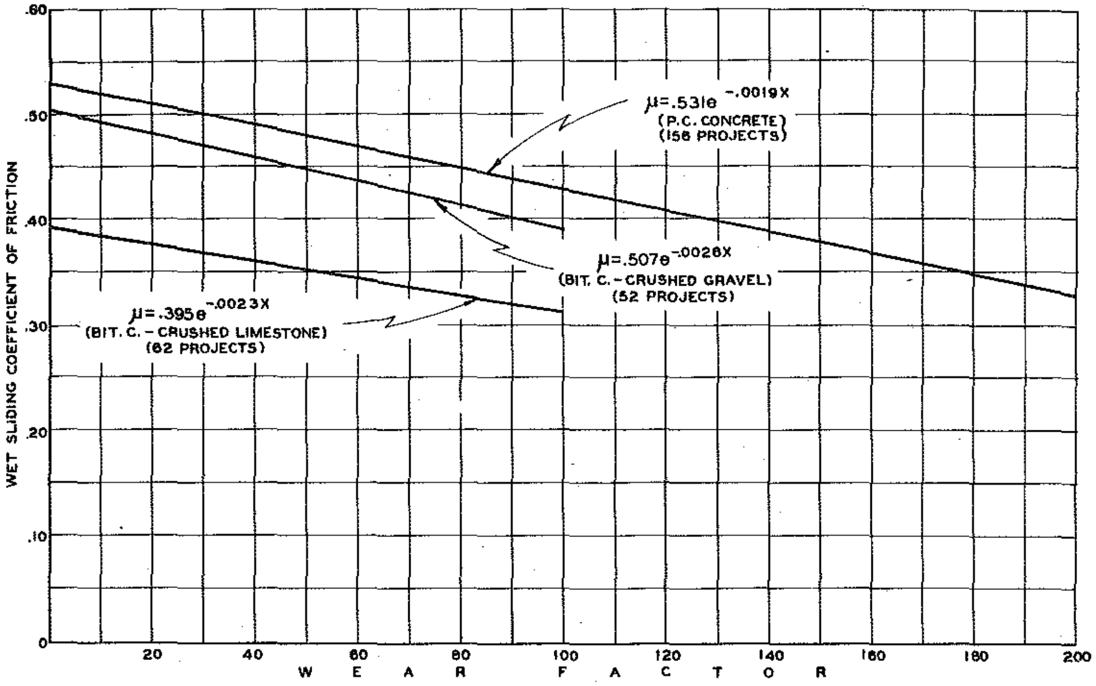


Figure 11. Comparison of friction - wear relationship: Portland cement concrete, bituminous concrete with gravel and limestone aggregates.

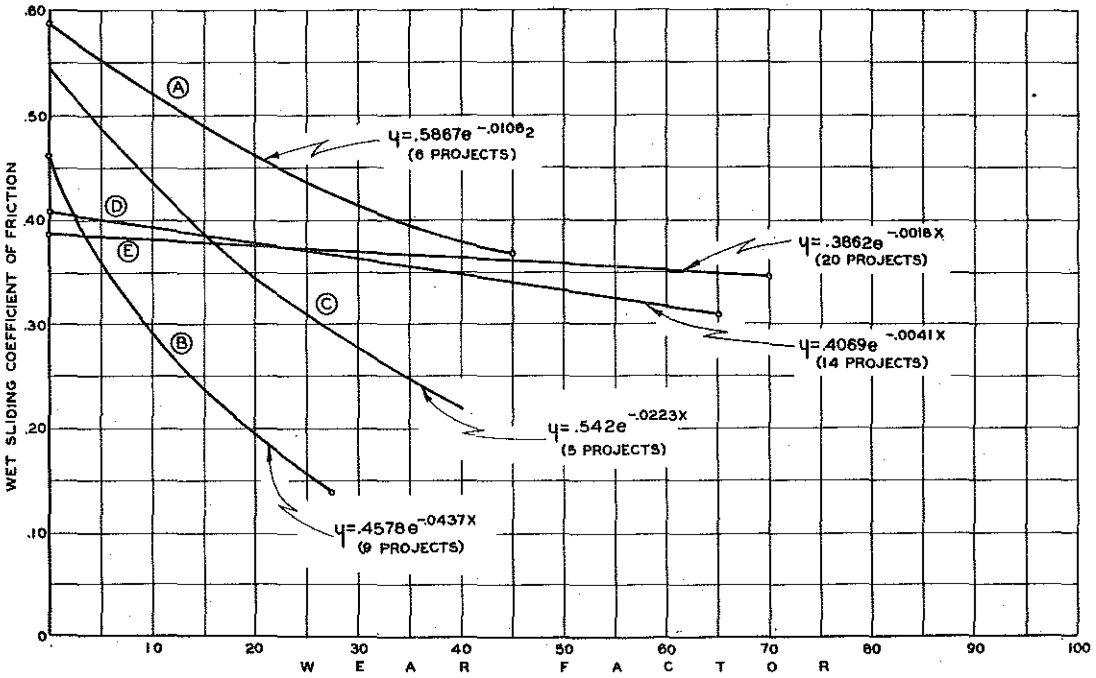


Figure 12. Friction - wear relationship: Bituminous concrete with limestone coarse aggregate from Michigan, Indiana and Ohio.

Effect of Limestone Source: Figure 12 shows the friction-wear relationship for limestone coarse aggregates from three States. Curves A, B, and C represent three Michigan quarries; Curve D, an Indiana quarry; and Curve E, an average of three Ohio sources. Chemical composition of these materials is shown in Table 2.

In Figure 12 it has been possible to demonstrate, with limited data at hand, a marked difference in the effect geological formation of limestone aggregate has on pavement slipperiness; this fact has been reported by others (6, 8). Similar comparisons are planned for gravel aggregates when sufficient data are available.

It is of interest to note that the limestone coarse aggregate material represented by Curve B in Figure 12 is from the same source which manufactured the stone sand used in the slippery portland cement concrete projects discussed previously.

Effect of Aggregate Degradation: Possible differences in weathering of asphalt-sand mortars and in their subsequent abrasion by traffic, as well as the manner in which the coarse aggregate particles polish or disintegrate with age and traffic, are considered important factors and are to be included for study in the Michigan investigation.

Figure 13 shows the traffic lane surface of a bituminous gravel project built before 1948. Note the preponderance of coarse aggregate particles in various stages of disintegration. This gradual aggregate disintegration process has evidently caused a continual exposure of new, sharp-edged projections, imparting high skid-resistant properties to the surface, regardless of age and traffic load.

TABLE 2

MINERAL CONTENT OF LIMESTONE AGGREGATES ENCOUNTERED IN MICHIGAN SKIDDING INVESTIGATION

Source	Geologic Description	$CaCO_3$	$MgCO_3$	SiO_2	Rock Terminology
A[1]	Mississippian - Bay Port and Michigan Formation	81.62	6.82	7.69	Sandy Magnesian Limestone
B[1]	Silurian - Niagaran (Manistique)	90.45	8.01	0.97	Fine-Grained Magnesian Limestone, buff colored
C[1]	Silurian - Engadine Dolomite	57.75	39.97	1.28	Dolomite, hard, bluish colored with granular texture
D[2]	Silurian dolomite Niagaran Series - Huntington formation (Reef)	55.6	43.2	0.75	Dolomite, dense, whitish & fine grained
E[3]	Silurian dolomite, Monroe and Niagaran Series	53.5	40.2	5.0	Dolomite, dense, blue-gray & fine grained

Source of Chemical Data:

[1] MSHD Research Laboratory 1948-1949 tests

[2] Patton, J. B., "Crushed Stone in Indiana." Division of Geology, State of Indiana, Progress Report No. 3, April 1949.

[3] Ohio Geological Map, and France Stone Co. Handbook, Toledo, Ohio, 1954.

Figure 13. Bituminous concrete gravel aggregate, traffic lane, age 13 years, showing various stages of aggregate disintegration; coef. 0.55.

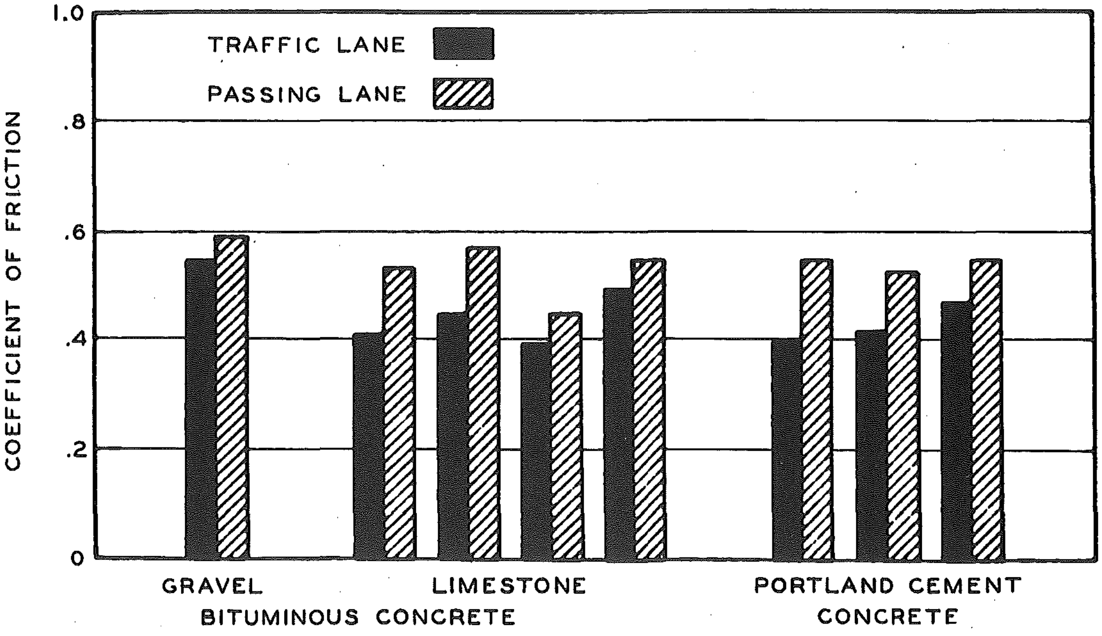


Figure 14. Comparison of coefficients for passing and traffic lanes in eight projects of various surface types.

The matter of aggregate heterogeneity as a desirable and essential property of paving materials in producing skid-resistant highway surfaces has been recognized and very adequately discussed by Breyer.(9)

Traffic Effect: The effect of traffic on the skid resistance of pavement surfaces can be readily understood by comparing the results of skidding tests made in adjacent passing and traffic lanes, where all factors may be assumed reasonably constant except for traffic volume. Figure 14 shows comparative results for eight projects, including one bituminous surface with gravel aggregate, four surfaces containing limestone aggregate, and three portland cement concrete surfaces. In these comparisons, differences in coefficients of friction between the two lanes amounted to as much as 36 percent.

Figures 15, 16, 17 and 18 show typical pavement surfaces in the traffic and passing lanes of two bituminous concrete projects containing different types of coarse aggregate. Photographs taken on many other projects show similar surface conditions in adjacent passing and traffic lanes. It should be noted that in the traffic lanes the coarse aggregates (both gravel and limestone) have been worn and polished and that the bituminous matrix is only slightly depressed around and between the coarse aggregate particles. The coarser sand particles in the matrix are also worn smooth and flat, while in the passing lanes the coarse aggregate and sand particles in the matrix still retain a high degree of angularity; here the difference in elevation between the matrix and the coarse aggregate projections is much more pronounced.

Figure 15. Bituminous concrete gravel aggregate, traffic lane, age 4 years; Coef. 0.55, average daily traffic 3120.

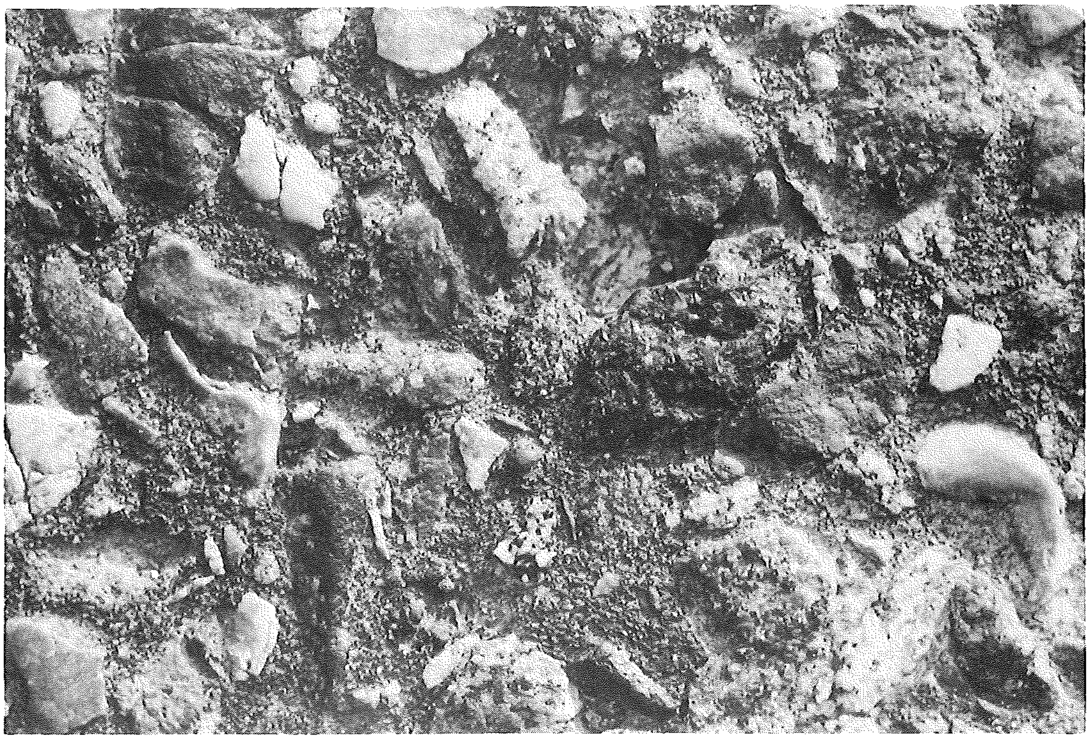


Figure 16. Passing lane of project above; Coef. 0.59.

Figure 17. Bituminous concrete limestone aggregate, traffic lane, age 4 years; Coef. 0.43. Average daily traffic 2940.

Figure 18. Passing lane of project above; Coef. 0.58.

Effect of Asphalt Cement Source: Skid tests were made on a bituminous concrete experimental project (10), in which all construction and material variables were constant, except for asphalt cement obtained from six different sources available to Michigan contractors for bituminous paving work. Appendix B describes the basic mix design and material specifications. Results of skid tests in May 1958 (Table 3), show no marked difference in skid resistance between the six 4-year-old test sections, either in the passing or traffic lanes, although the relative effect of traffic on the two lanes is clearly demonstrated. The average friction value for the passing lane is about 19 percent higher than that of the traffic lane.

Effect of Slag Aggregate: In 1955, slag coarse and fine aggregates were included with gravel aggregates in an experimental section of a programmed bituminous concrete project. Material grading specifications and basic mix design also may be found in Appendix B. Three test areas were established:

Section 1: Fine and coarse slag aggregates,
Section 2: Sand and slag coarse aggregate,
Section 3: Sand and gravel coarse aggregate.

Results of skid tests in 1955, 1957, and 1958 are shown in Table 4. The 1955 tests were made by the stopping distance method because the Department's skid trailer was not available at that time, and at 20 mph because of heavy traffic conditions.

At the beginning, the all-slag-aggregate section showed a slightly better skid-resistant quality than the others, but the 1958 tests show that all test sections are now about the same. Time and traffic can be great levelers and are important factors in the problem of producing high skid-resistant surfaces for the future.

TABLE 3

COMPARISON OF SKID RESISTANCE FOR ASPHALT CEMENTS FROM DIFFERENT SOURCES

M 63-30, C8R - Tested May 6, 1958

Test Area	Asphalt Source*	Traffic Lane	Passing Lane
Sec. 1	Wyoming Crude	0.43	0.51
Sec. 2	Venezuelan Crude	0.44	0.50
Sec. 3	Wyoming Crude	0.43	0.50
Sec. 4	West Texas Crude	0.40	0.51
Sec. 5	Smackover Crude	0.42	0.49
Sec. 6	East Texas Talco Crude	0.41	0.49
	Average	0.42	0.50

Wet Sliding Friction at 40 mph - Average Values

*60-70 Penetration

TABLE 4

FRICTION COEFFICIENTS FOR EXPERIMENTAL BITUMINOUS CONCRETE CONTAINING SLAG AND GRAVEL AGGREGATES

Project M82-47, C2 & C3

(Construction Completed 10-3-55)

Test Area	Stopping Distance Method	Trailer Method		
	at 20 mph	at 20 mph		at 40 mph
	10-7-55	9-11-57	5-2-58	6-6-58
Section 1 Slag CA & FA	1.03	0.51	0.47	0.35
Section 2 Slag CA & Sand	0.91	0.50	0.47	0.35
Section 3 Gravel CA & Sand	0.90	0.47	0.47	0.35

NOTE - Each coefficient value is the average of 4 to 6 tests in both eastbound and westbound directions in heavy traffic lanes.

Sheet Asphalt Surfaces

In the course of the skid survey, tests have been made on 13 sheet asphalt surface projects located on State trunklines, mainly in cities. It is expected that more such projects will be included as the test program proceeds. Results from the 13 projects tested, arranged in relation to age, are presented in Table 5. With the exception of one project which had the unusually low friction value of 0.23, the other 12 projects had skid values ranging from 0.37 to 0.55, a very good record when it is realized that the project age ranges from new to 38-year-old construction and that normally, traffic would be heavy. No attempt has been made to determine wear factor because of uncertainty in traffic data.

These tests demonstrate the excellent performance of fine aggregate textured surfaces which continue to wear, exposing new aggregate projections, and thereby providing a consistently high-level, skid-resistant type of surface irrespective of age.

Bituminous Surface Treatments

Bituminous surface treatment projects, including different combinations of aggregates and bituminous binder material, will be given every consideration in the Michigan study because of their susceptibility to sporadic slipperiness within a given project, when wet, with a correspondingly high accident frequency. The friction frequency curve plotted in Figure 19 shows the wide range in friction values found among the projects tested to date. Further, 65 percent of the tests show friction values less than 0.40, and 33 percent below 0.30. Specifications for MSHD Surface Treatments will be found in Appendix C.

TABLE 5

FRICTION DATA FOR SHEET ASPHALT PROJECTS WITH SAND AGGREGATES
(1957-1958 Survey)

Project Number	Age, years	Sliding Coeff. at 40 mph
M 81071, C1R (Sec. 1)	0	0.43[1]
M 81071, C1R (Sec. 2)	0	0.40[1]
82-125, C2 & C3	10	0.50
25052 (Auth.)	14	0.42
73-38, C4	16	0.41
63-61, C4	17	0.44
73-43, C1	19	0.40
63-61, C2	19	0.41
25-7, C4 & C5	24	0.52
25-29, C1 & C2	24	0.45
25033 (City)	34	0.45
25-7, C3	37	0.42
73062 (City)	38	0.23[2]
	Average	0.44

[1] Sheet Asphalt Surface on new 1958 experimental project.

[2] Not included in average.

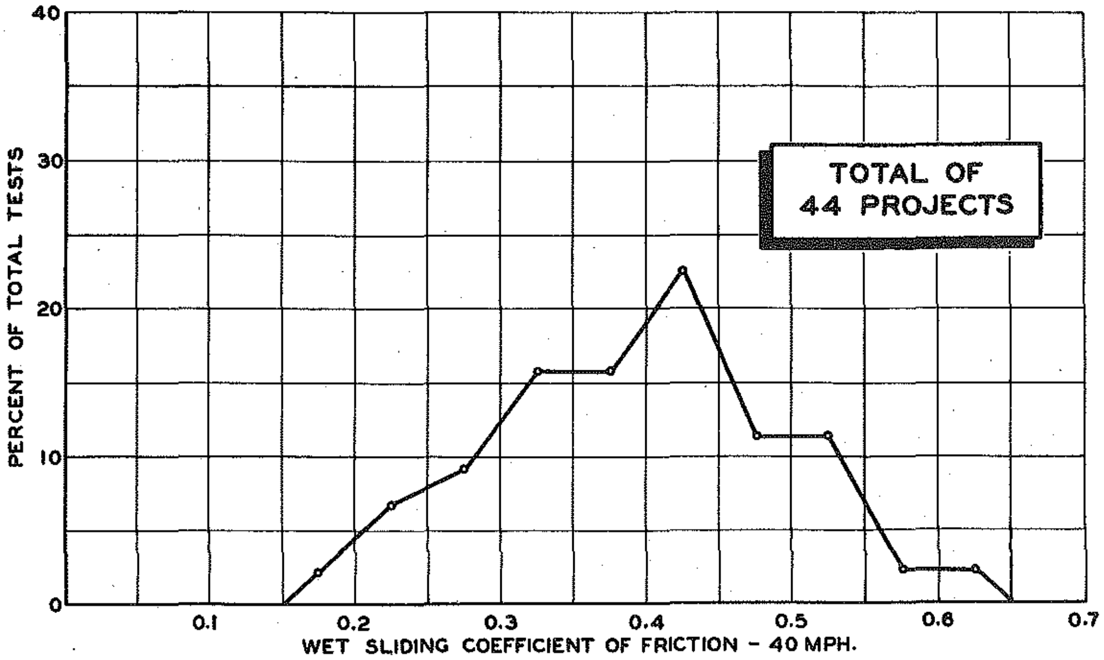


Figure 19. Coefficient frequency distribution: Bituminous surface treatments with gravel and limestone aggregates.

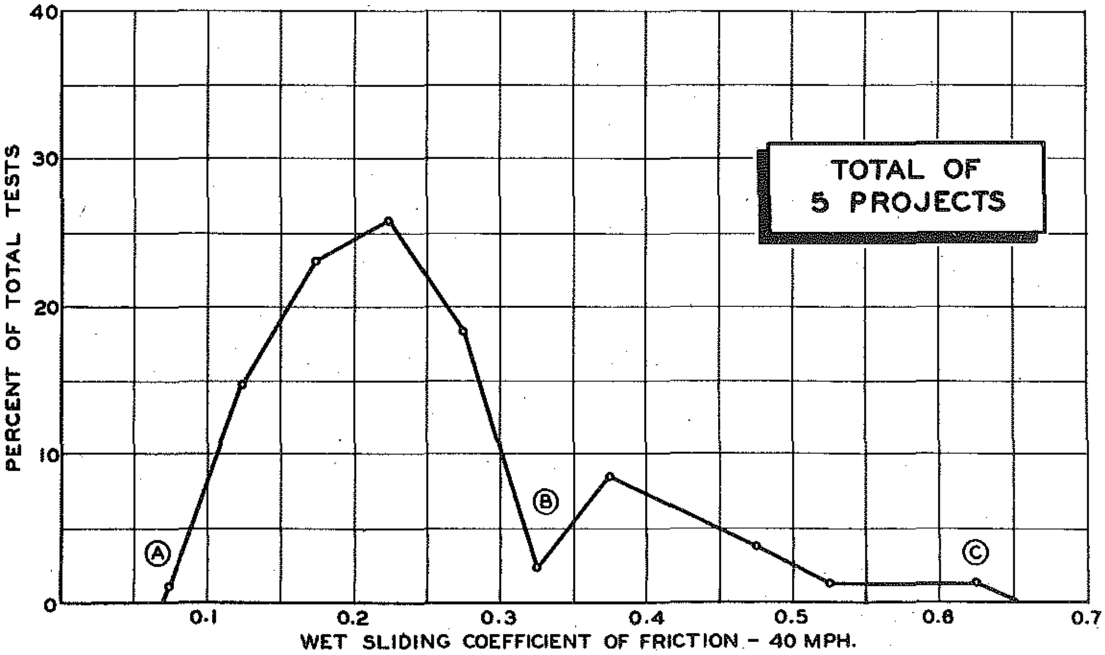


Figure 20. Coefficient frequency distribution: Tests on bleeding bituminous surface treatments.

Effect of Bleeding: Five of the bituminous surface-treated projects mentioned above developed excessive bleeding. These projects were given special attention. A frequency distribution curve based on individual skid test data is shown in Figure 20. The curve is divided into two parts; "A-B" represents all five projects where pronounced bleeding occurred, while "B-C" represents test values from one of the five projects, in an area where bleeding did not develop. The curve is extended (B-C) to show the variance in the skid resistance from place-to-place on this particular bituminous surface treatment project, possibly due to construction differences, varying traffic, and bleeding.

CONSIDERATIONS IN SKID RESISTANCE

In addition to studying the effects of materials and surface types on skid resistance, attention has been given to other important factors, including: 1) the method and speed at which coefficients are determined and the need for establishing correlation between test methods; 2) the effect of daily as well as seasonal variation in coefficients; 3) the establishment of coefficient standards for various surface types and vehicle speeds; 4) methods for increasing friction level; and 5) de-slicking of unsafe pavement surfaces.

Trailer and Stopping Distance Methods

Although both methods provide reliable results, at times it is necessary to convert coefficients from the stopping distance to the trailer method, or vice versa. This cannot be done satisfactorily without the aid of supporting correlative data. Whitehurst and Goodwin (6) have made comparative tests of the two methods under carefully planned conditions on three bituminous concrete surfaces, each containing a different aggregate - limestone, gravel, and slag.

In Figure 21, Curves A and B were developed from their test data for speeds of 10 to 40 mph. Curve A shows the relation between the two test methods at similar speeds for the three bituminous concrete types, indicating that at the same speed, the stopping distance test gives coefficient values 40 to 50 percent higher than the trailer method.

Curve B shows an approximate relationship between the stopping distance test at 20 mph and the trailer method at 40 mph. In this case, coefficients deter-

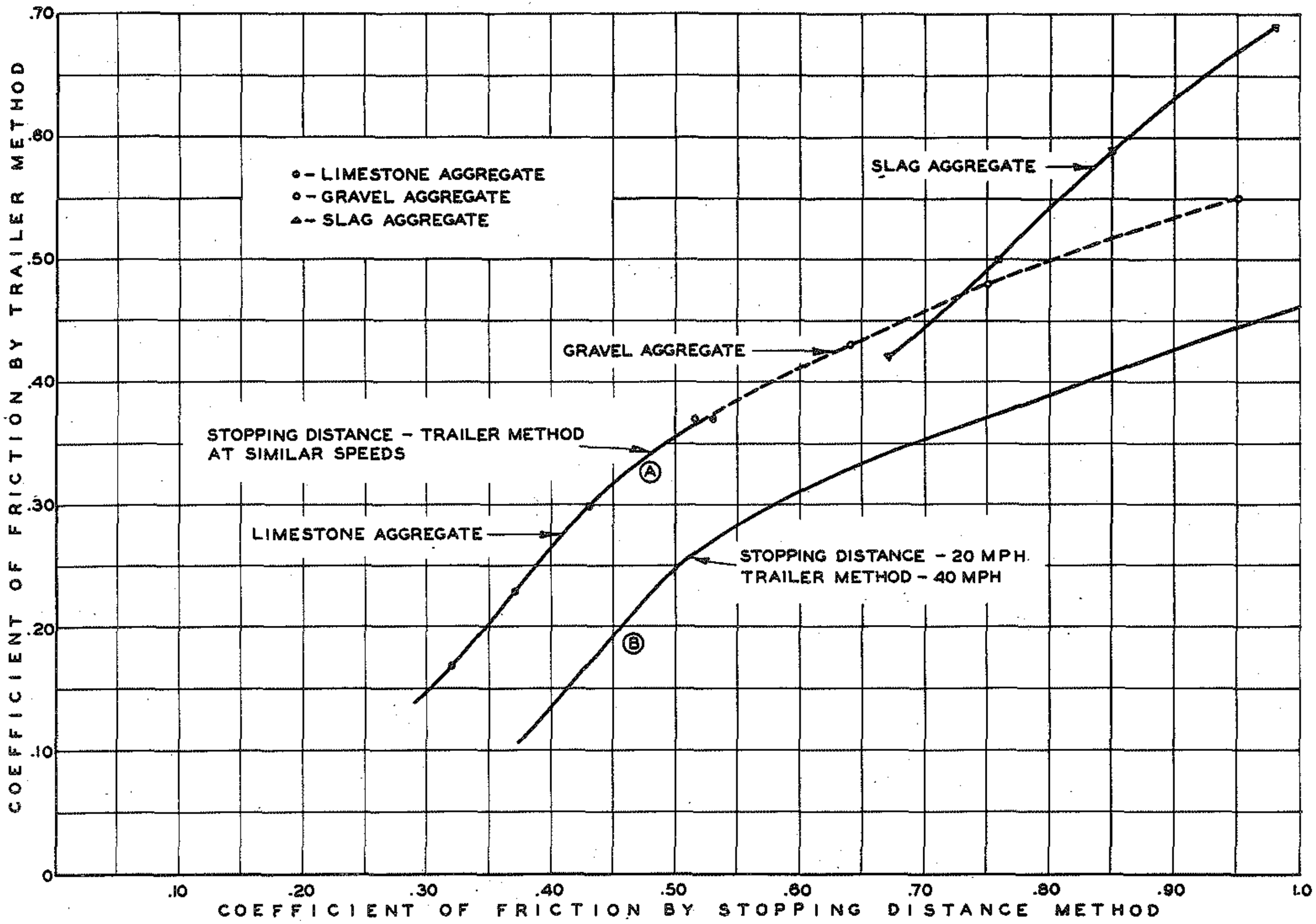


Figure 21. Friction relationships: Trailer and stopping distance methods at different speeds.

mined by the trailer method at 40 mph are about 60 percent less than those obtained on the same surface by the stopping distance test at 20 mph.

There appears to be a great need for more complete data on correlations of this type, particularly at speeds considerably higher than 40 mph, and for different surface types.

Effect of Speed

Speed is an important factor in wet-surface skid resistance. A limited number of skidding tests at varying speeds have been made in Michigan on four basic types of pavement surfaces at speeds up to 50 mph. Results of these tests are shown in Figures 22, 23, 24, and 25. These data show that skid resistance varies with speed even among projects of similar material, as well as between basic surface types. However, different surface types have distinct speed-coefficient relationships. In a broad sense, the Michigan data demonstrate that there is little dissimilarity in the average speed-coefficient relationship for three basic highway surface types: portland cement concrete, bituminous concrete, and sheet asphalt. However, in the case of tests on bituminous surface treatments the curves show a much poorer speed-coefficient relationship.

Similar speed-coefficient relationships are needed at higher speeds, in light of current and future highway speeds. Skid tests at higher speeds are planned in Michigan when adequate equipment is available.

Effect of Temperature

It is known that the physical texture of a road surface changes with the seasons (11), affecting skid resistance. Pavement temperature at the hour of test

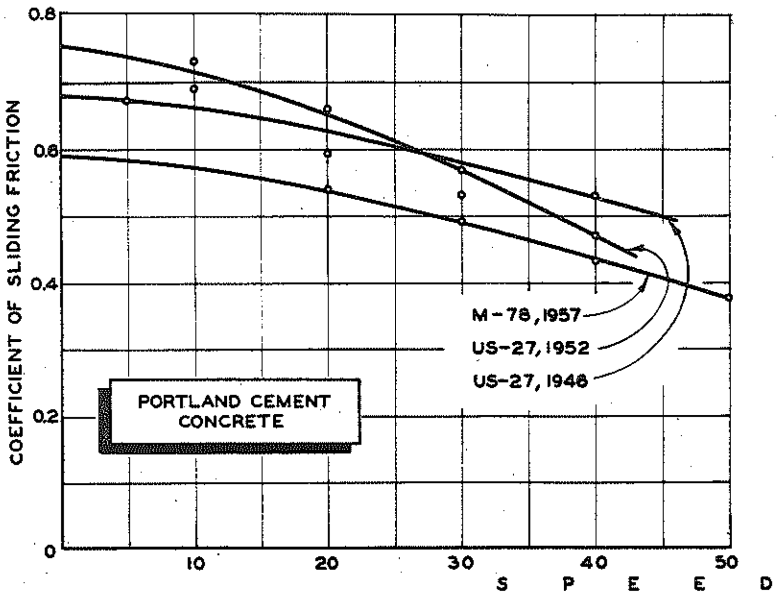


Figure 22.

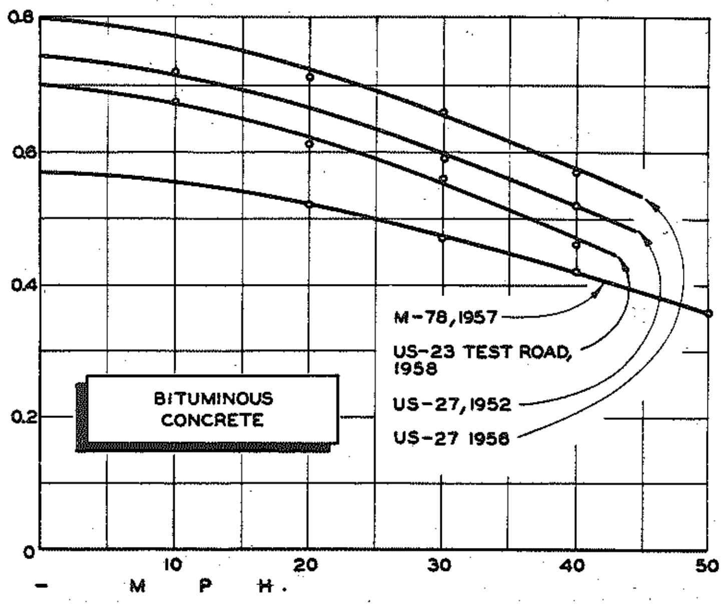


Figure 23.

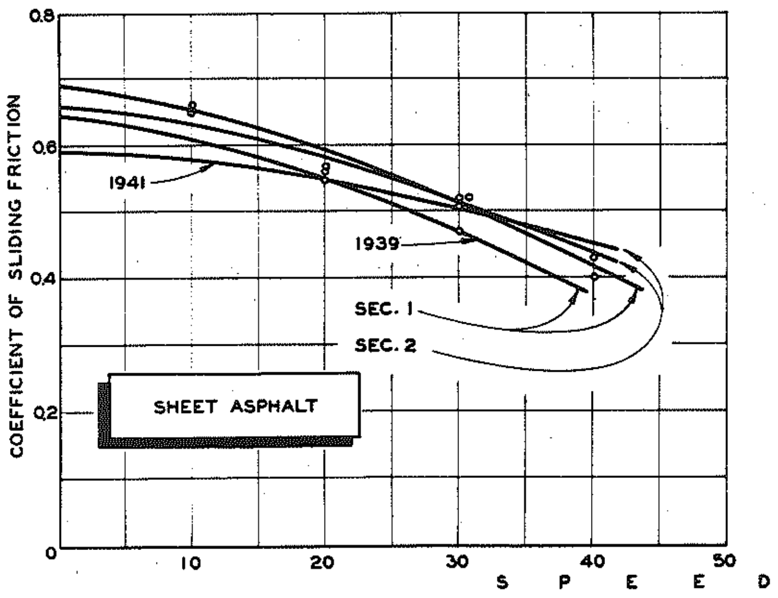


Figure 24.

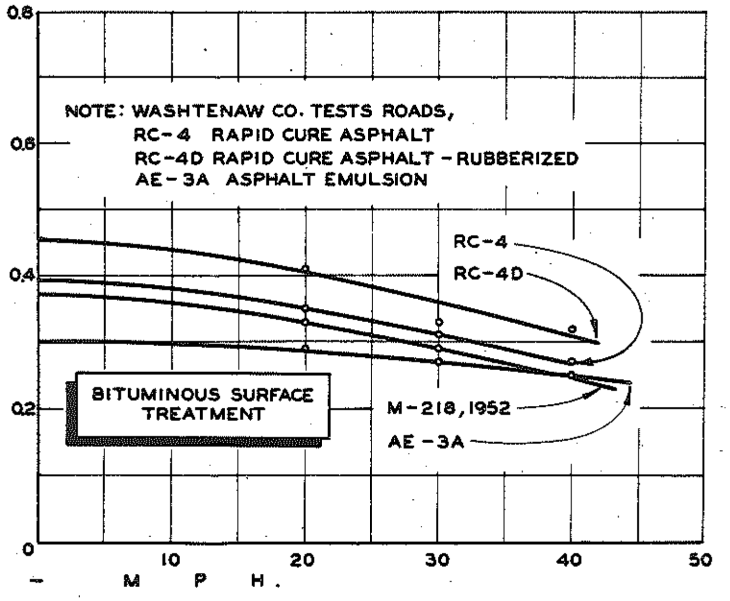


Figure 25.

SPEED - FRICTION RELATIONSHIPS

also has a certain amount of influence on the results; to gather data on this factor, skid tests were conducted during a 24-hour period at the same location on two adjacent types of new surface (portland cement concrete and bituminous concrete). The results of this initial test are shown in Figures 26 and 27. These data indicate a difference of approximately 15 percent during a 24-hour change in pavement temperature of about 30 degrees. Further observations of this nature are contemplated in the Michigan study.

Skid Resistance Standards

Published information (5) indicates that to ensure reasonable freedom from skidding, a coefficient of at least 0.4 is necessary on wet surfaces, at the speed of the traffic using any particular section of road.

From speed coefficients plotted in Figures 22 and 23, and drawing on the speed coefficient data developed by Giles and Lander (12) at speeds up to 100 mph, it is possible to estimate approximate values by the trailer method at 40 mph which will ensure a coefficient of 0.4 at higher speeds, as shown in Figures 28 and 29.

Concerning modern traffic speeds, the values in Table 6, based on data in Figures 28 and 29, indicate that the two surface types, when tested by the trailer method at 40 mph, should have coefficients no less than 0.5 to ensure reasonably safe stopping distances at all speeds under wet conditions. It is recognized that this deduction is based on rather limited information, but as more coefficient data become available through continued skid tests, certain refinements may be expected.

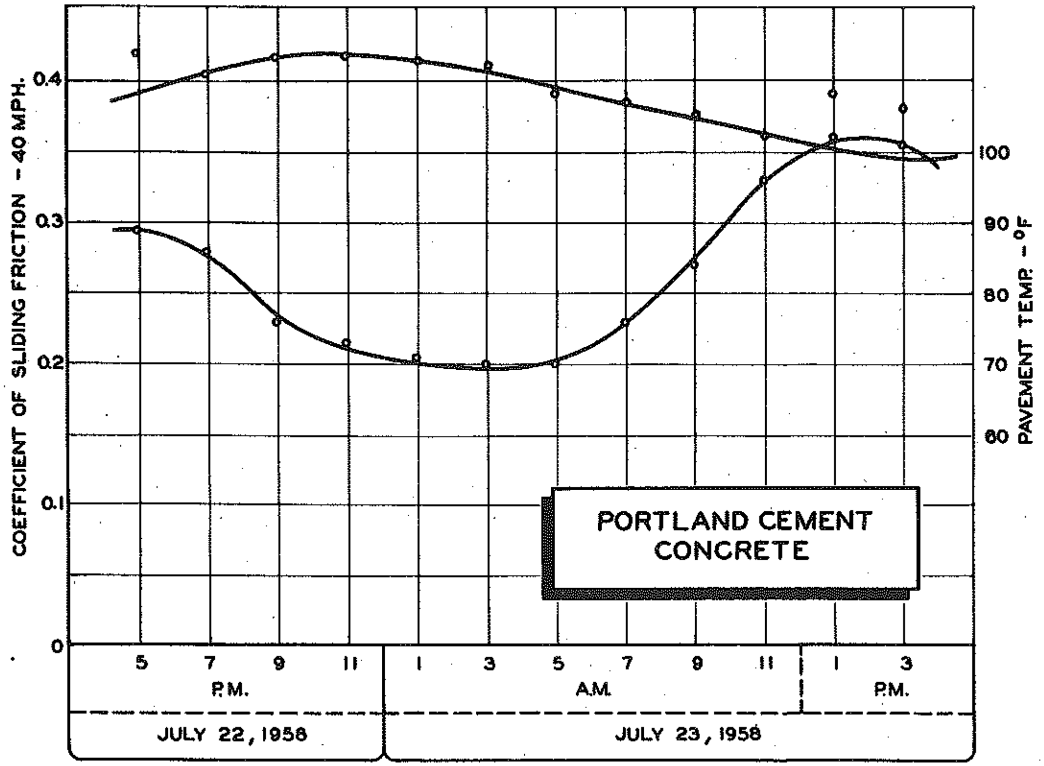


Figure 26.

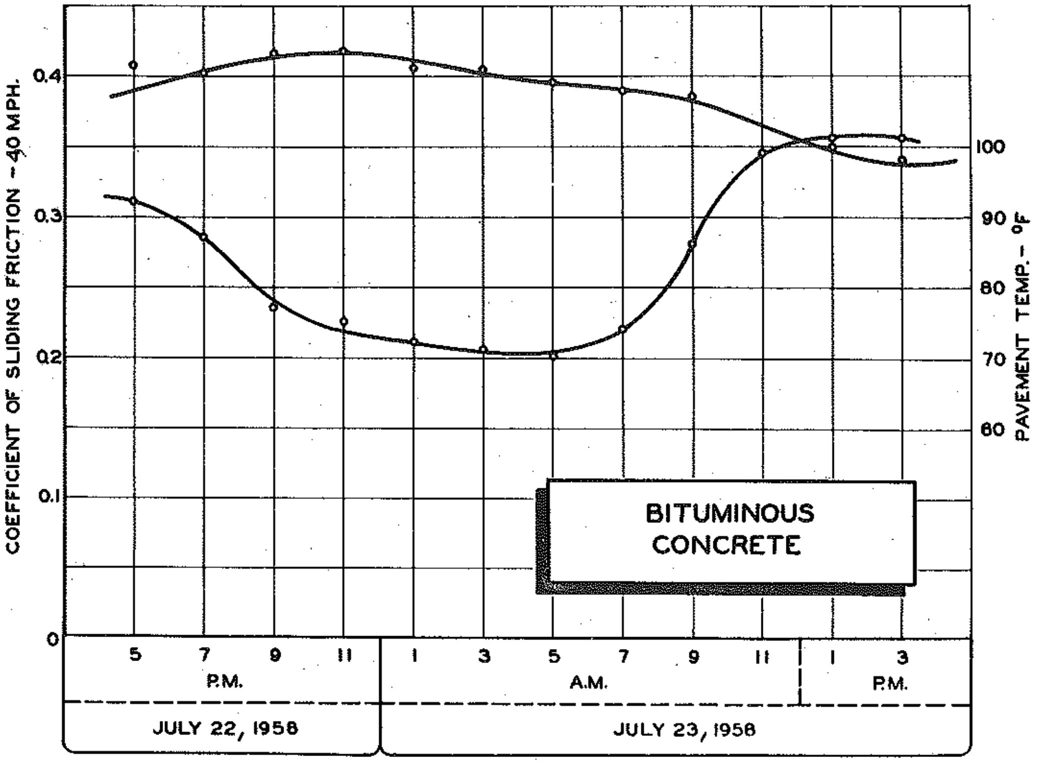


Figure 27.

HOURLY TEMPERATURE - FRICTION RELATIONSHIPS

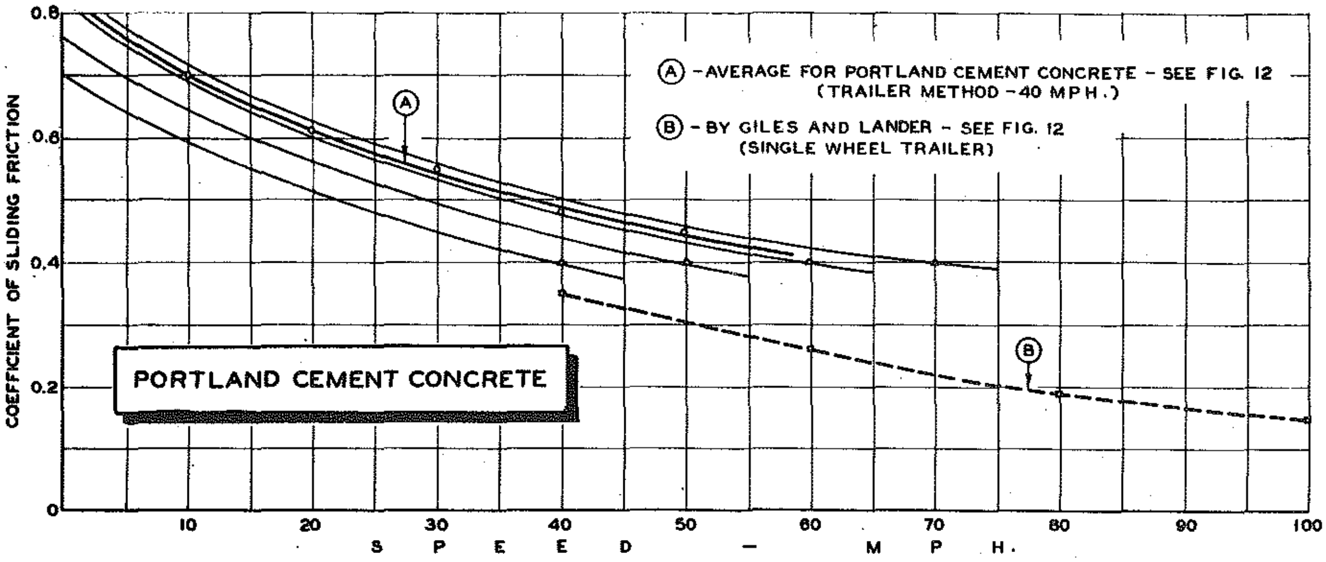


Figure 28. Portland cement concrete.

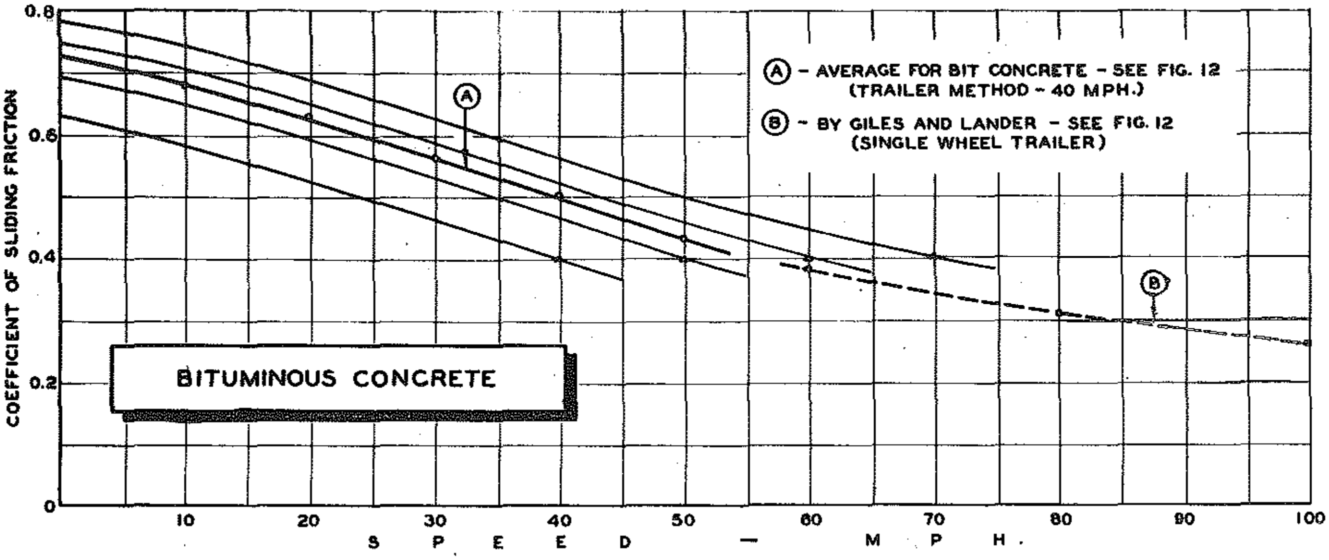


Figure 29. Bituminous concrete

METHOD USED IN DETERMINING MINIMUM COEFFICIENT LIMITS

TABLE 6

MINIMUM COEFFICIENT LIMITS BASED ON AVAILABLE MEASUREMENTS

To Ensure a Coefficient of 0.4 at a Speed in mph of:	The Coefficient at 40 mph (by Trailer Method) should be at least:	
	On Portland Cement Concrete	On Bituminous Concrete
40	0.40	0.40
50	0.44	0.47
60	0.48	0.51
70	0.51	0.55

Thompson (7) mentions standards for skidding resistance converted to 40 mph having been suggested by J. E. Gray, Engineering Director of the National Crushed Stone Association, as based on the recent work of George Giles of Britain's Road Research Laboratory (13):

1. Coefficient of 0.66 and greater: good resistance to skidding, fulfilling requirements even for fast traffic.
2. Coefficient of 0.56 to 0.66: generally satisfactory, meeting most requirements except for curves on roads under fast traffic.
3. Coefficient of 0.46 to 0.56: satisfactory for conditions at critical sites such as junctions and curves.

Surface Friction in Pavement Design

Since pavement surfaces in general exhibit variance in skid resistance from excellent to very poor, under similar traffic conditions and age, it would seem desirable that research be directed toward design providing a built-in, uniform, and permanent skid-resistant surface for all pavement types. Virginia has made valuable contributions to the design of skid-resistant pavements. (8)

Studies to this end were started by Michigan in June 1958, with the construction of a one-mile section of experimental bituminous surface incorporating seven different mix designs using fine aggregate materials. The surface course was laid one-half inch thick. Skid test measurements will be made periodically to study changes in surface friction with wear. Types of materials used include bituminous concrete sand (3BC), concrete sand (2NS), slag sand (3BCS), crushed gravel (31X and 31W).

De-Slicking of Unsafe Surfaces

Several States (14, 15), including Michigan, are studying special non-skid surface treatments for increasing the coefficient level of surfaces, particularly in areas exhibiting many cases of skidding accidents. Materials under consideration for this purpose consist essentially of a surface course of sharp sand, flint, aluminum oxide grits, or other abrasive aggregates utilizing as a binder, a synthetic epoxy resin, a mixture of asphalt and rubber latex, or other binder types applied in thin layers of 1/8 inch or less.

This appears to be a logical and efficient means of providing a safe, highly skid-resistant surface in critical areas not warranting a full-course surface treatment.

Michigan has under study one high-accident intersection which received a non-skid surface treatment in the Fall of 1957, using two types of binder materials with aluminum oxide grits. One binder was of the epoxy resin type and the other a compound of asphalt and latex. This year (1958) two additional critical intersections will receive non-skid surface treatments in which two new and different types of binding materials with aluminum oxide grits will be studied.

In conclusion, consideration should be given to the possibility of using design processes, thin fine-aggregate surface courses, or the de-slicking methods just discussed, to achieve desired skid resistance on new pavements which may not meet a designated friction standard.

CONCLUSIONS

The conclusions which can be drawn from this progress report are as follows:

1. Stone sand having the chemical and physical properties of that used in Michigan is not a desirable fine aggregate for concrete pavements from the standpoint of skid resistance.

2. By use of a wear factor such as the one described in this paper, it is possible to determine the relative skid-resisting properties of wet highway surfaces with a fair degree of certainty.

3. In general, the results show that highway surfaces may be rated in accordance with their ability to produce skid-resisting surfaces under similar wear.

4. The suitability of coarse aggregates for bituminous concrete is determined largely by its mineral and physical characteristics as estabilished by geological origin. Results show a marked difference in the skid-resisting characteristics of materials from different sources.

5. Aggregate heterogeneity is a property which should be investigated in relation to the skid resistance of bituminous surfaces.

6. Asphalt cements from six sources showed no apparent individual effect on skid-resistance properties of a bituminous concrete surface.

7. Slag aggregates in bituminous concrete tend to produce better skid-resistant surfaces when new than do other aggregates, but this characteristic disappears with wear.

8. Results indicate that bituminous surface mixtures made with fine aggregates can produce good skid-resistant properties. Sheet asphalt surfaces which wear without polishing appear to have the ability to retain their high, uniform, skid-resistance properties, while those which do not wear in this manner have lower coefficients.

9. Bituminous surface treatments generally do not produce satisfactory skid-resistant surfaces. They are susceptible to bleeding, and to variance in skid-resistance properties which may become quite extensive throughout the length of any one project.

10. In this country, practically all speed studies on wet surfaces have been made at speeds below 50 mph. There is a great need for skid resistance data on all types of surfaces at speeds considerably above 50 mph.

11. There is need for recognizing some standard method of determining the coefficient of sliding friction under wet conditions. The trailer method at 40 mph is a rapid method which gives accurate and reproducible results under a range of speeds.

12. It is necessary that a skid-resistance standard, which remains a constant under all conditions, be established for surface types at designated speeds.

13. Greater emphasis should be placed on research leading to the development of built-in, uniform, high-level, permanent skid resistances.

14. The development of thin non-skid surface treatments should be encouraged as a means of restoring slippery surfaces in critical areas to a safe condition.

ACKNOWLEDGEMENT

The work described in this report has been conducted as part of the Michigan State Highway Department's program of research vested in the Research Laboratory Division of the Office of Testing and Research, of which Mr. W. W. McLaughlin, Testing and Research Engineer, is the head.

The authors gratefully acknowledge the able assistance of many members of the laboratory staff; in particular, Onto L. Lindy, Paul Schafer, and Walker J. Hall of the Physical Research Section, who were responsible for collecting the skid test data during the 1957-1958 survey and to Stanley W. Ruis and Erich Kauffmann of the Materials Section for their painstaking work in compiling the field data and making the necessary computations.

REFERENCES

(1) "Abstracts from Michigan's Studies of Slipperiness of Concrete Pavements Constructed with Stone Sand as the Fine Aggregate: prepared for ASTM Committee C-9." Michigan State Highway Department Research Report No. 242, Oct. 20, 1955.

(2) Skeels, P. C., Stonex, K. A., and Finney, E. A., "Road Surface Friction from the Standpoint of Automotive and Highway Engineers," Proceedings, Association of Asphalt Paving Technologists, Vol. 25, pp. 253-78 (1956).

(3) Brown, M. G., and Finney, E. A., "Michigan's Skid Testing Program." Proceedings, Highway Research Board, Vol. 37 (1958).

(4) Brown, M. G., Milliman, Paul, and Otto, Gale, "Michigan's Skid Testing Equipment." Michigan State Highway Department Research Report No. 294, Aug. 12, 1958.

(5) "A Policy on Sight Distances for Highways." American Association of State Highway Officials, pp. 3-4 (1940).

(6) Whitehurst, E. A., and Goodwin, W. A., "Pavement Slipperiness in Tennessee." Proceedings, Highway Research Board, Vol. 34, pp. 194-209 (1955).

(7) Thompson, H. O., "Road Tests Determine: What Makes Autos Skid." Engineering News-Record, Feb. 6, 1958, pp. 54-57.

(8) Nichols, H. P. Jr., Dillard, J. H., and Alwood, R. L., "Skid Resistant Pavements in Virginia," Highway Research Board Bulletin No. 139, pp. 35-59 (1956).

(9) Breyer, H., "Roughness and Slipperiness of Paving Stones and Street Pavements." Strassen und Tiefbau, March, 1954.

(10) Parr, Ward K., Serafin, P. J., and Humphries, Tom, "Michigan State Highway Experimental Bituminous Concrete Construction Project." Proceedings, Association of Asphalt Paving Technologists, Vol. 24, pp. 125-77 (1955).

(11) Grime, G. and Giles, C. G., "The Skid-Resisting Properties of Roads and Tyres." Proceedings of the Automobile Division, Institution of Mechanical Engineers, pp. 19-30 (1954-55).

(12) Giles, C. G., and Lander, F. T., "The Skid-Resisting Properties of Wet Surfaces at High Speeds." Journal of the Royal Aeronautical Society, Feb. 1956, pp. 83-94.

(13) Giles, C. G., "The Skidding Resistance of Roads and the Requirements of Modern Traffic." Proceedings, Institution of Civil Engineers, Feb. 1957, pp. 216-49.

(14) "Road Roughness and Slipperiness: Some Factors and Test Methods." Highway Research Board Bulletin No. 139 (1956).

(15) "Development of New Non-Skid Road Surface Treatments." Highway Research Board Bulletin No. 184 (1958).

APPENDICES

A. Portland Cement Concrete

B. Bituminous Concrete

C. Bituminous Surface Treatment

Appendix A. Portland Cement Concrete

1. Approximate Mix Proportions by Volume (Dry loose measure):

   1 part cement (type IA)

   2 parts sand (2 NS grading)

   3-3/4 parts gravel, stone, or slab (4A & 10A or 6A)

   Estimated cement content: 5.5 sacks/ cu yd

2. Fine and Coarse Aggregates:

2 NS Gradation		Sieve Size, inch	Coarse Aggregate Gradation Percent Passing		
Sieve Size No.	Percent Passing		4A*	6A	10A*
3/8 in.	100	2-1/2	100	--	---
4	95-100	2	95-100	100	---
8	65-95	1-1/2	65-90	95-100	100
16	35-75	1	10-40	60-90	95-100
30	20-55	1/2	0-20	25-55	35-65
50	10-30	3/8	0-5	---	---
100	0-10	No. 4	---	0-8	0-8

*4A and 10A, when used in a concrete mix, are combined 50-50.

Appendix B. Bituminous Concrete

1. Basic bituminous mixture design:

Coarse aggregate (retained on No. 10 sieve)	50-55 percent
Fine aggregate (passing No. 10; retained on No. 200 sieve)	30-35 percent
Filler (passing No. 200 sieve)	5.5-6 percent
Asphalt cement	5.5 percent
Marshall stability	1500-3000 lb

2. Revisions in Material Specifications:

	Prior to 1944	1944-1948	Since 1948
Asphalt Cement	Pen. 85-100	Pen. 85-100	Pen. 60-70 or 80-100
Mineral Filler	Limestone dust	Limestone dust	Fly Ash or Limestone dust
Coarse Aggregate	100% pass. 1/2 in. 15-45% pass. No. 4 (Dept. Spec. 26A)	90-100% pass. 1/2 in. 0-25% pass. No. 4 (Dept. Spec. 26A mod.)	90-100% pass. 1/2 in. 10-25% pass. No. 4 0-10% pass. No. 10 (Dept. Spec. 25A)

3. 3 BC Fine Aggregate:

Passing No. 4	100 percent
Passing No. 4 retained on No. 10	0-5 percent
Passing No. 10 retained on No. 40	15-35 percent
Passing No. 40 retained on No. 80	30-60 percent
Passing No. 80 retained on No. 200	15-35 percent
Passing No. 200	0-5 percent

Appendix C. Bituminous Surface Treatment

Prime or Bond Coat:	MC-1 or AE-2; approx. 0.25 gal/sq yd
Surface Coat:	AE-3 Asphalt Emulsion or RC-4 Cutback Asphalt; approx. 0.35 gal/sq yd
Cover Material:	Approx. 23 lb/sq yd - gravel, stone or slag 26A, 31A - 100 percent crushed material 26B, 31B - 50-40 percent crushed 26D, 31D - 0 percent crushed

Coarse Aggregate Gradation,
Total Percent Passing

Sieve Size	26A, B, or D	31A, B, or D
5/8 in.	100	---
1/2 in.	90-100	---
3/8 in.	60-85	100
No. 4	10-35	35-65
No. 10	0-10	0-15