Skid Resistance of Bituminous Surfaces

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Seven years of New York State research in skid-resistance measurement of bituminous surfaces are summarized. Development of a skid trailer and test procedure are discussed. Skid testing is recommended only after 5 million vehicles have passed over a surface, so that friction coefficient has declined to a stable level. Testing shows that largest mix aggregates, rather than fines, control skid resistance, which remains at a higher level when hard particles resistant to polishing are included.

•SINCE the early 1930's, highway engineers have been concerned with the problem of pavement slipperiness (1). Increasing volume and speed of motor vehicle traffic have made the skidding problem increasingly serious. In 1960, shortly after organization of the New York State Department of Transportation's Bureau of Physical Research, an investigation was undertaken to determine the factors controlling skid resistance of highway pavements.

First studies concentrated on bituminous pavements, which make up a large percentage of highway surfaces in New York State, both in initial construction and as overlays to upgrade pavements having low coefficients of friction. The study was limited to clean pavements, since even the most skid-resistant surface is slippery if covered by ice, snow, mud, or wet leaves. Pavements having excess asphalt on the surface were also excluded. The objectives of this research program were the following.

1. To select equipment and establish a procedure for measuring pavement coefficient of friction; and
2. To determine the influence of the following pavement factors on skid resistance: (a) mix type, (b) types of fine and coarse aggregate, (c) abrasion resistance of coarse aggregate, and (d) mineral composition of coarse aggregate.

MEASUREMENT SYSTEM AND PROCEDURE

Theoretically, coefficient of friction is independent of the contact area, speed, and weight of a sliding object. This is not true, however, when a rubber tire slides on a wet pavement. To obtain a true indication of pavement slipperiness, it is necessary either (a) to actually bring a car to a skidding stop on a wet pavement and measure its stopping distance, or (b) to build a device that closely reproduces the conditions of a skidding car and gives readings correlating with the stopping distance method.

The stopping distance method has several disadvantages. At least one lane of traffic must be closed and wetted; tests cannot be performed on grades, curves, or highly crowned roads; and accidents are always possible. Because of these limitations and because skid trailers can be correlated with the stopping distance method, New York State decided to use a drag-force-type trailer (Fig. 1) to measure the coefficient of friction of wet pavement, as described in a previous report (2).

In designing the trailer, a primary objective was to reproduce, as closely as possible, the geometry and mechanics of a skidding automobile. The New York State skid trailer has a wheel loading and suspension system typical of American passenger cars.

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Figure 1. Skid trailer and tow truck.

TABLE 1

MEASURING SYSTEM RELIABILITY

Pavement	Coefficient of Friction			
	Min.-Max.	Range	Std. Dev.	Avg.
x	0.53-0.58	0.05	0.015	0.55
y	0.40-0.42	0.02	0.007	0.41
z	0.33-0.36	0.03	0.010	0.35

The standard ASTM test tire (ASTM Designation E 249), used in all testing after 1961, represents a compromise between a bald tire and one designed to give high skid resistance.

Other skid research agencies had found that about 25 to 30 gpm of water should be applied to dry pavement for a one-wheel skid test. This amount is sufficient to prevent any portion of the tire from skidding on dry pavement. Water is applied to the pavement less than 1 ft in front of the tire, and a fairly large pipe opening and low water pressure minimize scour of road film. These test conditions were chosen as generally duplicating what happens on a pavement just as it begins to rain.

Skid resistance tends to vary with season. Lowest readings usually occur during summer and higher coefficients in winter. To minimize this variable, skid testing in this study was limited to summer months.

The coefficient of friction of wet pavements also varies with speed. It was desirable that one test speed be chosen for comparison of different pavements, preferably close to the travel speed of prevailing traffic. However, to test in suburban areas as well as open rural locations, 40 mph was chosen for this study. Testing at the speed limit (50 mph) would have been difficult and hazardous in some instances.

Tests were made on two pavements to determine variation of coefficient with speed. Pavement A with low skid resistance and Pavement B with a high coefficient were selected and tested at speeds ranging from 10 to 60 mph (Fig. 2). Friction decrease with increased speed differed on these two surfaces. Some property or characteristic of the pavement surfaces apparently caused the different rates of coefficient decrease. Further study is needed before coefficients measured for any given surface at one speed can be extrapolated to coefficients at another speed.

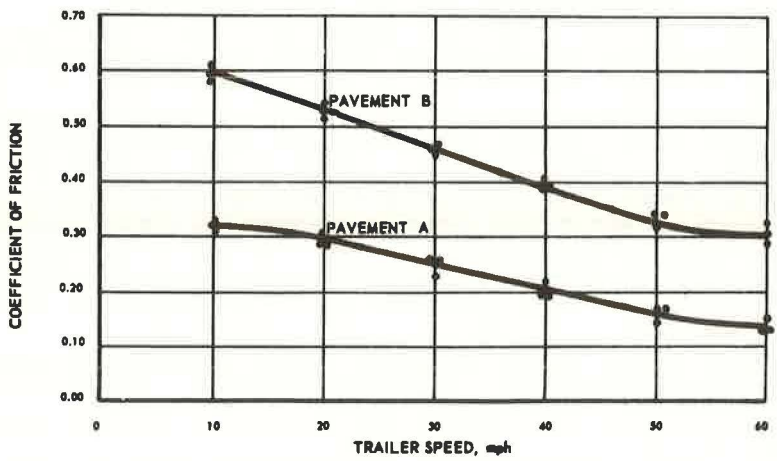

Figure 2. Effect of speed on coefficient of friction.

To determine the reliability of the measuring system, several tests were performed on sections of three different pavements. The resulting narrow range and small standard deviation (Table 1) indicate that the trailer yields highly reproducible measurements over a wide range of coefficients.

Trailer readings also correlate very well with distance required to stop a car. At the 1962 correlation study at Tappahannock, Va. (3), the New York trailer and Purdue University car each tested five surfaces having a wide range of friction coefficients. The car's stopping distance (measured from the point where brakes were applied, as identified by chalk fired at the pavement when wheels locked at 40 mph) was converted to a coefficient of friction (C_f) by the following:

$$C_f = \frac{V^2}{30S}$$

where

V = initial car speed, mph, and
S = stopping distance, ft.

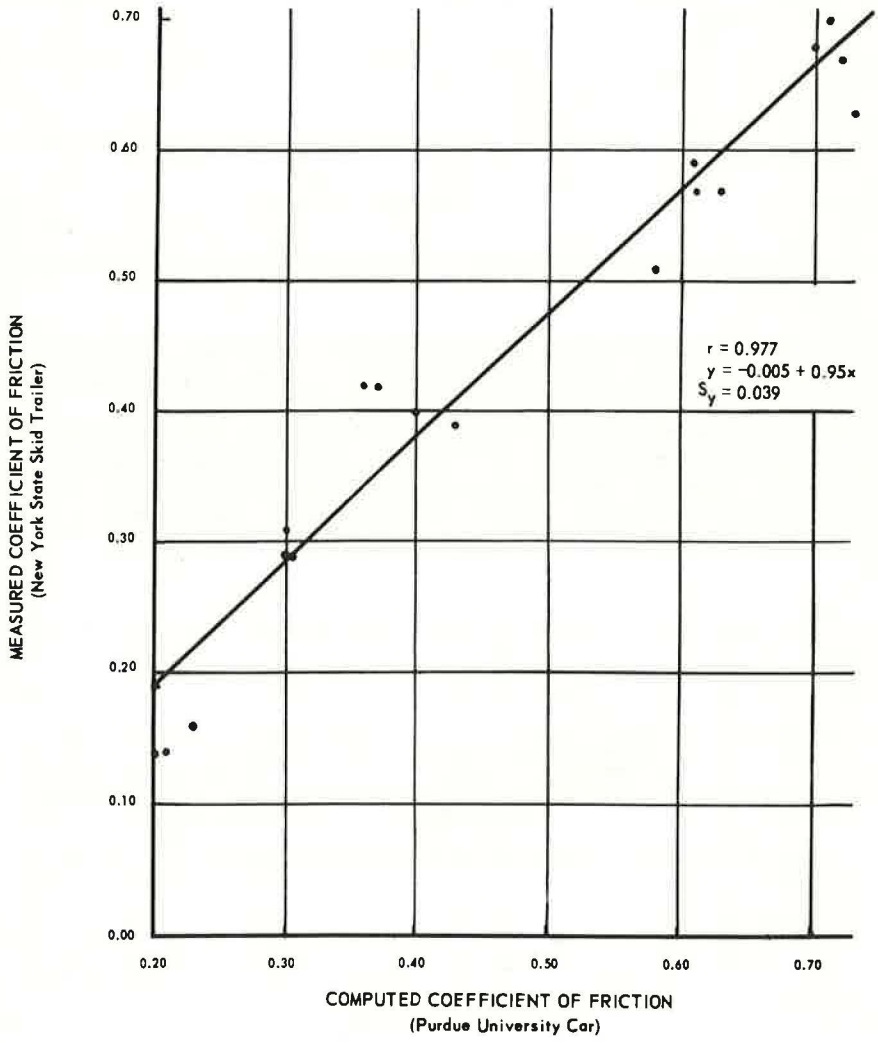

Figure 3. Correlation of two skid measuring methods.

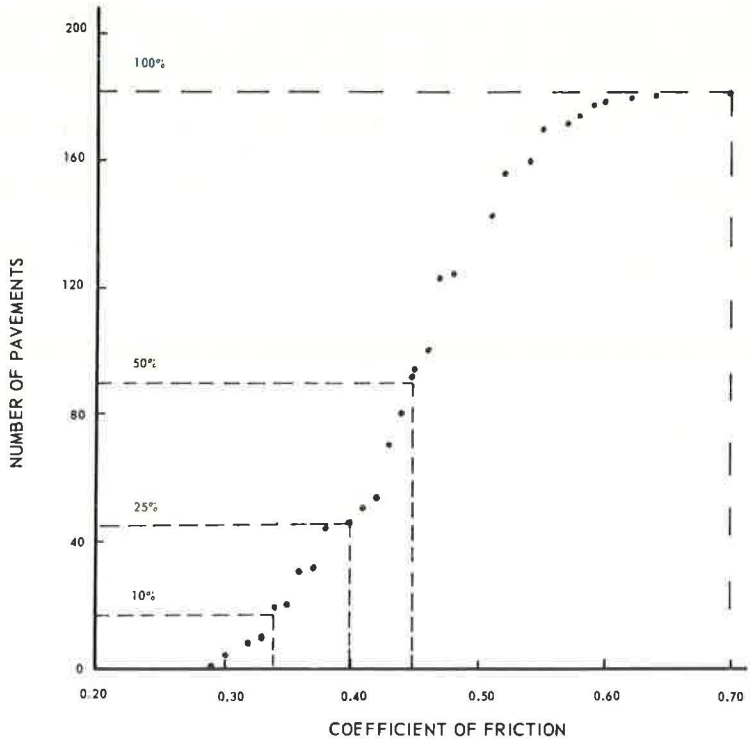

Figure 4. Cumulative frequency distribution of friction coefficient of new bituminous pavements.

Trailer and car coefficients were plotted in Figure 3. Trailer measurements were made at 40 mph using the truck's watering system. An excellent correlation was obtained [coefficient of correlation (r) = 0.977] between the trailer and car.

Initially, only new bituminous concrete pavements were skid tested because information concerning their construction material was readily available. Little was learned from this study, since recently placed pavements generally have high coefficients. Figure 4 is a cumulative frequency polygon showing results of skid tests on 182 bituminous pavements less than 3 months old; 75 percent had coefficients above 0.40.

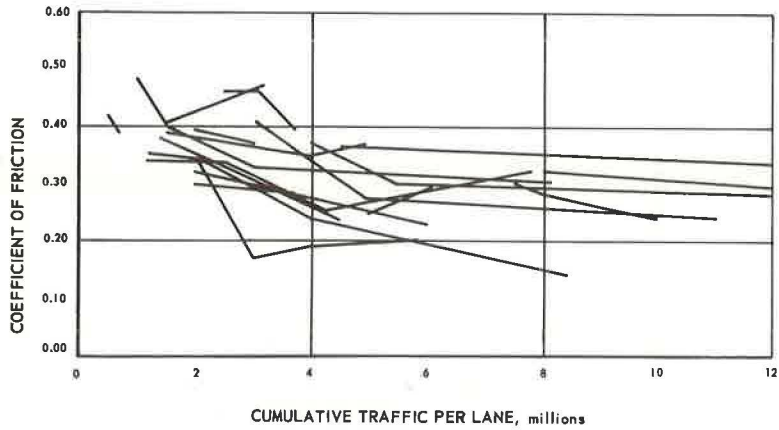

Figure 5. Effect of traffic on 19 limestone surfaces (with 1 truck equivalent to 11 cars).

Nineteen pavements tested during their first year were retested the following summer. In all cases, coefficients were lower. The effect of traffic on their skid resistance is indicated in Figure 5. In calculating traffic volume, each truck was assumed to have the same effect as 11 cars, an approximation made to take into account the greater number of tires, using harder rubber and higher inflation pressures. The lines in the figure connect the results of tests performed at different times on the same pavement. It was clear that as traffic used a pavement, skid resistance decreased, rapidly at first and then more gradually. After 5 million vehicles passed over a surface, a nearly stable coefficient was reached, dropping 0.02 or less with each additional 1 million vehicle passes. Therefore, it was decided that a pavement should be exposed to 5 million vehicle passes before final evaluation of its skid resistance.

In summary, to measure a pavement's coefficient of friction, the trailer is towed at 40 mph and water (25 gpm) is applied to the dry road directly in front of a standard test tire (ASTM Designation E 249). Either or both trailer wheels are locked for about 2 sec. Drag force is measured between the sliding tire and the wet pavement. This force divided by wheel load gives the pavement's coefficient of friction. Testing was limited to summer months and data evaluation to pavements that had carried more than 5 million vehicles.

LABORATORY STUDY

During the first 2 years of field testing, some pavements were found to have good skid resistance after 5 million vehicle passes, whereas others had low coefficients with the same traffic. A laboratory investigation was undertaken to determine which pavement variables, especially aggregate type, affected skid resistance.

A laboratory study was considered the fastest and most practical way to evaluate the many combinations of crushed stone and natural sand used in New York State top course mixes. An apparatus similar to that devised by Maclean and Shergold (4) simulated traffic wear of aggregates in a bituminous mix (Fig. 6). It consisted of a wheel with a bald pneumatic tire, driven by an electric motor. The tire rode on 20 wire-reinforced asphalt-concrete samples, which in turn were mounted on the perimeter of a 48-in. diam wheel revolving at 100 rpm. Dry aluminum oxide and carborundum grits were introduced between the tire and samples. The bald tire was chosen as providing uniform wear across the samples after it was found that a treaded tire left an undesirable pattern.

The British portable tester (BPT) was used to measure the skid resistance of the samples (Fig. 7). For its use, readings

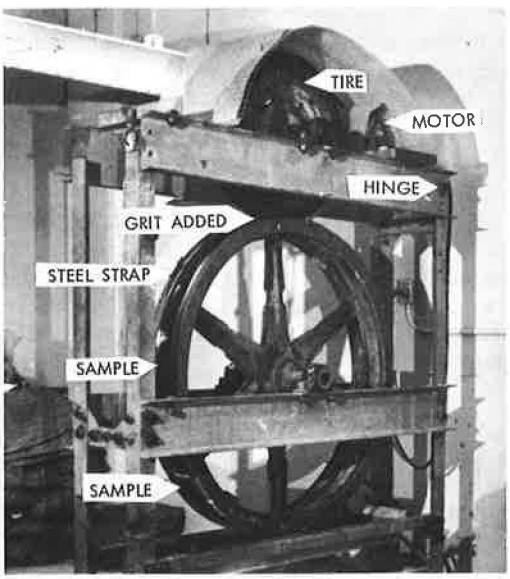

Figure 6. Polishing wheel.

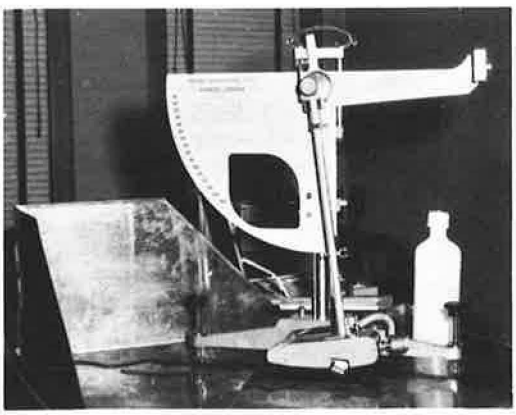

Figure 7. British portable tester.

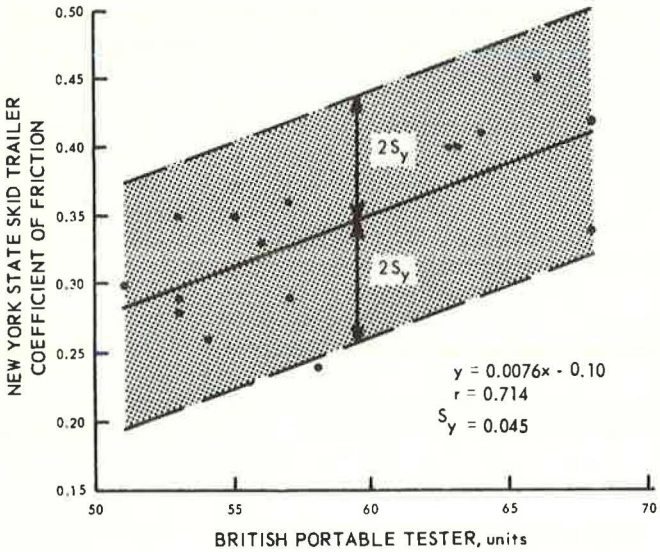

Figure 8. Correlation of British portable tester and New York State skid trailer (40 mph).

of the BPT and New York State trailer had to be correlated. Samples were taken from the wheelpaths of 16 pavements tested with the trailer. In Figure 8, skid trailer coefficients for these surfaces are plotted against BPT measurements taken on the samples at 78 F. Each point is an average of four or more readings with each machine. A fair correlation (r = 0.714) was obtained, but the standard error of estimate was large (0.045). A BPT value of 60 corresponds to a trailer coefficient of friction between 0.26 and 0.44. This confidence interval is too wide and covers almost the entire range of trailer coefficients for the samples.

However, since aggregates with known skid characteristics were included in the samples, the laboratory experiment was continued because it was thought that relative BPT values would be useful. Sieve size No. 80 grits were used to polish the samples for 240,000 revolutions of the sample wheel. BPT readings at that time ranged from 45 to 53 units for all surfaces, too narrow a range for evaluation of 20 different surfaces. For an additional 160,000 revolutions, grit size No. 240 was used as an abrasive. The range of BPT readings changed very little and no further polishing was attempted. Because of poor correlation between the trailer and portable tester, and the small range of BPT units on surfaces polished in the laboratory, this technique was abandoned.

INFLUENCE OF PAVING MIXES AND MATERIALS

During the 7 years the skid trailer has been in operation, tests have been performed on pavements constructed from nearly every aggregate source in the State. Measured coefficients of friction have been compared for many properties that vary in a bituminous mix.

Friction Coefficients of Common Mix Types

Three mixes are commonly used for New York State surface courses: asphalt concrete Types 1A and 1AC, and stone-filled sheet asphalt Type 2A. Mix specifications are summarized in Table 2. To determine whether mix types differed in skid resistance properties, tests were run on numerous surfaces of these types, all of which had carried over 5 million equivalent vehicles. Mean coefficients for the three mixes (Fig. 9) did not vary significantly at the 95 percent confidence level.

Effects of Fine Aggregates

Two studies were made to determine possible effects of fine aggregate on skid resistance. For the first, it was known that varying amounts of natural siliceous sand had been used in place of screenings as the fine aggregate in Types 1A and 1AC asphalt concrete mixes, in some Department of Transportation districts. This had been done on the assumption that the hard sand would help retain good skid resistance. Coefficients of friction of certain pavements (all with at least 5 million equivalent vehicle passes)

TABLE 2

BITUMINOUS PLANT MIXTURES FOR STANDARD TOP COURSES

Item	Type 1A		Type 1AC		Type 2A	
	General Limits (% passing)	Job Mix (% tol.)	General Limits (% passing)	Job Mix (% passing)	General Limits (% passing)	Job Mix (% tol.)
Screen size:						
1 in.	100	±0	—	—	—	—
½ in.	95-100	±5	100	0	100	0
¼ in.	65-85	±5	95-100	±5	90-100	±5
⅛ in.	32-65	±6	45-70	±6	65-80	±4
No. 20	15-39	±7	8-40	±7		—
No. 40	7-25	±6		—	35-70	±4
No. 80	30-12	±3	3-15	±3	17-40	±3
No. 200	2-6	±6	2-8	±2	5-12	±2
Asphalt cement:						
Percent	5.8-7.0	±0.4	6.0-8.0	±0.4	7.5-8.5	±0.4
Penetration	85-100		85-100		60-70	
Placing temperature	225-300 F		250-325 F		275-350 F	
Texture	Granular		Smooth-Gritty		Smooth-gritty	
Typical uses	Interurban, urban resurface, urban				Urban	

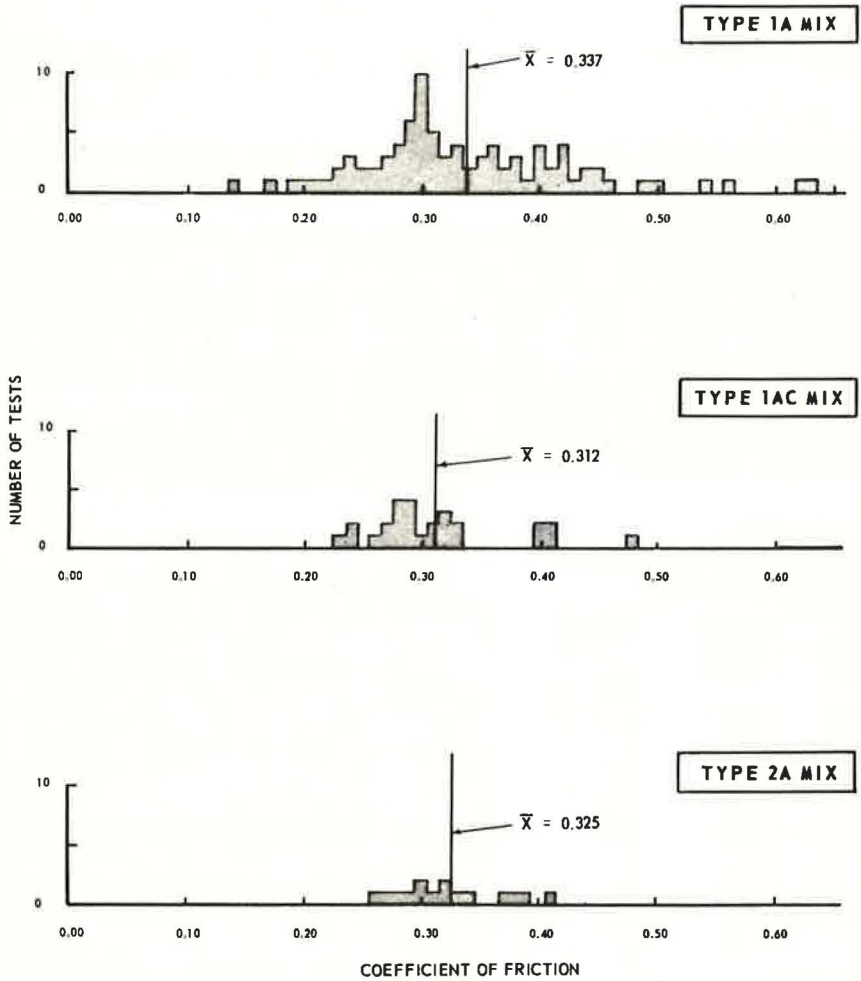

Figure 9. Skid resistance of three most common bituminous top courses specified by New York State.

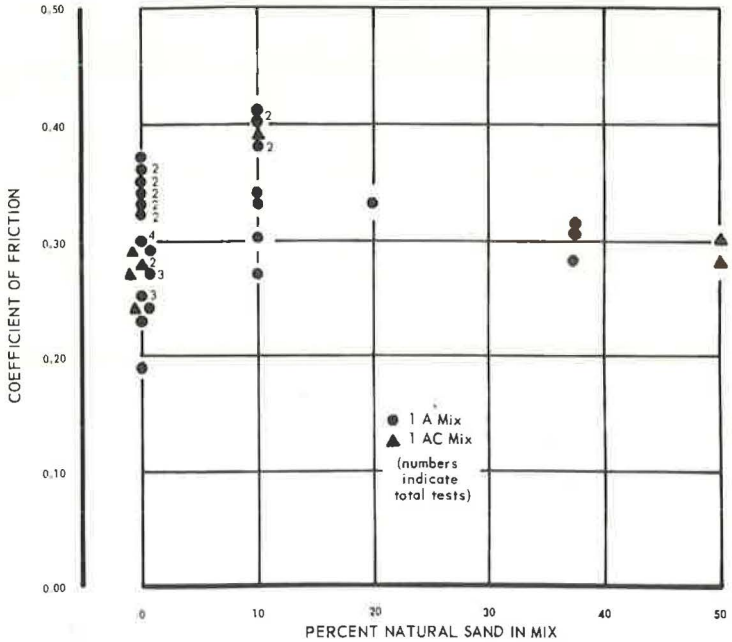

Figure 10. Effect of natural sand in mix (percent sand based on total aggregate weight).

containing limestone coarse aggregate with varying amounts of this sand are shown in Figure 10. Using 50 percent sand did not increase skid resistance, when softer coarse aggregate was present in the mix.

In the second study, pavements containing only hard siliceous sand as aggregate (sand-asphalt mixes) retained excellent skid resistance (Table 3). This Long Island sand has over 90 percent feldspar and silica content (Mohs hardness of 6 and 7, respectively). However, additions of only 5 percent crushed dolomitic limestone (Mohs hardness = 3) of No. 1A size (primarily ⅛ to ¼ in.) to the sand mixes in all cases decreased the coefficients of friction. Skid resistance was even lower when pavement contained 50 percent dolomitic limestone and 50 percent sand.

It is apparent that skid resistance of a bituminous mix is governed by its largest aggregate. In New York State 1A and 1AC mixes, the coarse aggregate (or stone) determines the pavement's skid resistance.

TABLE 3

INFLUENCE OF COARSE AGGREGATE ON SKID RESISTANCE

Dolomite Coarse Aggregate Added to Silica Sand	Cumulative Traffic, millions	Coefficient of Friction	
		Test	Avg.
None	6	0.52	0.49
	30	0.45	
	5	0.41	
5 Percent	6	0.39	0.38
	35	0.34	
	35	0.36	
	50+	0.41	
	18	0.32	
	22	0.29	
50 Percent	41	0.29	0.29
	50+	0.28	
	50+	0.27	

Effect of Coarse Aggregate

Having established that skid resistance is governed by coarse aggregate, pavements were evaluated according to the type of stone (over ⅛ in.) they contained, regardless of their fine aggregate. Most pavements containing limestone or dolomite coarse aggregate had friction coefficients below 0.32 after 5 million vehicle passes, although some roads with similar coarse aggregate types remained skid resistant after more than 10 million vehicle passes. Stone in the latter pavements was found to contain hard, sand-sized particles embedded in the softer dolomite or limestone matrix. Traffic wore away the soft material, exposing the hard impurities and producing a sandpaper

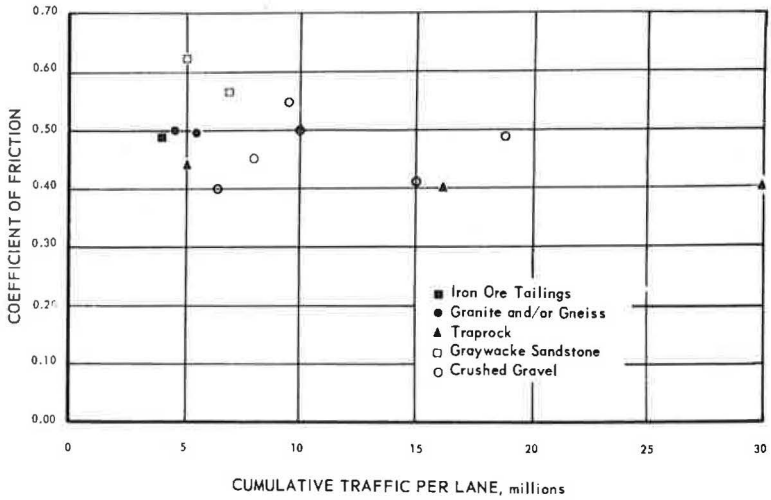

Figure 11. Skid resistance of bituminous-concrete surfaces containing hard and angular coarse aggregates.

texture on the coarse aggregate. This differential wear resulted in pavements with high coefficients.

Pavements containing only hard angular aggregate (Mohs hardness = 6+) remained skid resistant after prolonged exposure to heavy traffic. Friction coefficients of 14 such surfaces (Fig. 11), containing traprock, sandstone, crushed gravel, iron ore tailings, or granite as coarse aggregates, remained at or above 0.40 after cumulative traffic in excess of 4 million vehicles.

Skid resistance was primarily controlled by the ability of larger aggregates to resist traffic's polishing action. To evaluate wearing characteristics of certain New York State aggregates of known skid resistance, Los Angeles, Deval, and Dorry abrasion tests were run[1]. Figure 12 shows coefficient of friction as a function of percent loss in these various abrasion tests. Statistical analysis of the data provides 99 percent confidence that no correlation existed between coefficient of friction and loss in any of the three abrasion tests.

In January 1965, Gray and Renninger (6) reported an acid leaching procedure for evaluating skid resistance properties of carbonate aggregates. Aggregates were allowed to react with dilyte hydrochloric acid until all carbonates had dissolved. The percentage by weight of hard, acid-insoluble, sand-sized particles was then determined. About 10 percent hard impurities in the soft matrix significantly affected skid resistance.

Skid tests were conducted in the summer of 1965 on 31 New York State highways having limestone, dolomite, or traprock aggregate with large cumulative traffic volumes. Aggregate was extracted from samples taken from each surface. Acid leaching was performed on only the large stone (over ¼ in. from 1A mixes and over ⅛ in. from 1AC mixes). The acid was changed as needed until all reaction stopped. The residue was washed, and all material passing the No. 200 sieve was discarded. The clay and silt-sized particles either floated away or passed through the No. 200 screen. Remaining particles were found to be mostly silica, with a small quantity of other hard material which was not classified.

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[1]Los Angeles: ASTM C 131 (small-sized coarse aggregate)
ASTM C 535 (large-sized coarse aggregate)
Deval: ASTM D 289 (coarse-graded aggregate)
Dorry: USDA Bulletin No. 347 (March 17, 1916).

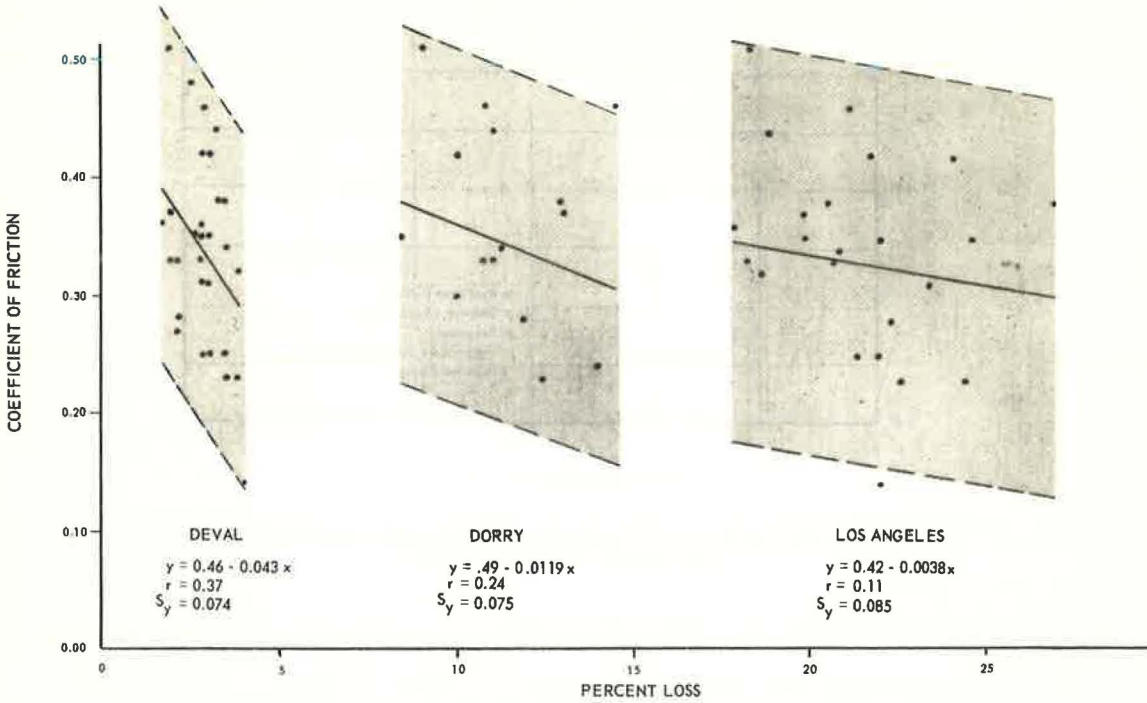

Figure 12. Relationship between coarse aggregate abrasion resistance and pavement friction coefficient.

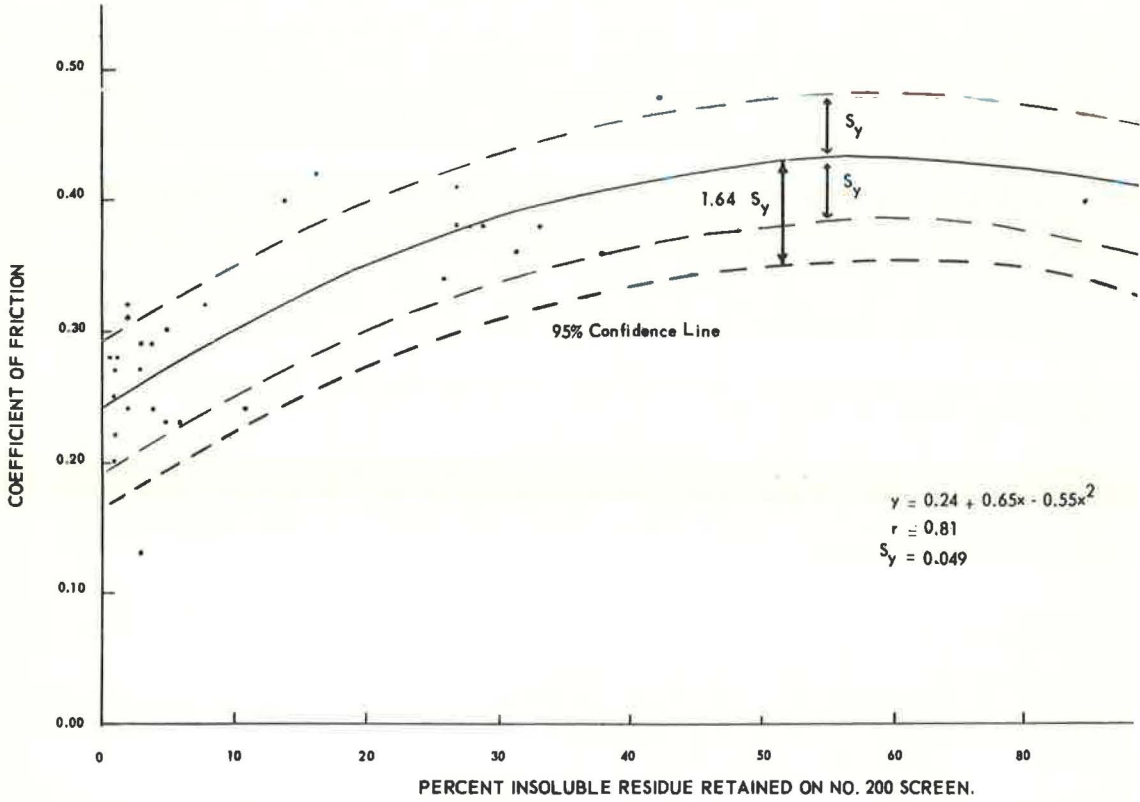

Figure 13. Correlation of pavement skid resistance with acid-insoluble material in coarse aggregate.

The residue was weighed and its percentage by weight computed. The relationship between skid resistance and percent acid-insoluble residue retained on the No. 200 screen is shown in Figure 13.

The coefficient of friction increased with increasing percent insoluble residue in the larger-sized aggregate. For example, reading along the 95 percent confidence line, a pavement with aggregate containing 40 percent insoluble residue should retain a coefficient of friction of 0. 33 or more. A good correlation (r = 0. 81) was obtained.

Continuation of Field Studies

Experimental surfaces are being placed on State highways to determine the most practical and economical way to construct skid-resistant bituminous-concrete pavements. Surface textures of these experimental pavements range from a fine sheet asphalt to an open-graded asphalt concrete. These surfaces contain varying quantities of hard, acid-insoluble materials and are being placed in areas of high traffic volume to obtain results as quickly as possible.

CONCLUSIONS

1. The New York State skid trailer produces valid skid-resistance measurements, highly reproducible over a wide range of coefficients. This system correlates very well with the stopping distance method.
2. In 2 years of testing, it was demonstrated that new pavement skid resistance declines rapidly at first and then more gradually. After about 5 million equivalent vehicle passes (1 truck = 11 cars), a nearly constant coefficient is reached. Testing is recommended at this level of wear, when long-term skid-resistance properties can be validly measured.
3. Three standard New York State bituminous mix types are very similar in skid resistance characteristics at 40 mph, none showing any superiority to the others.
4. Skid resistance of a bituminous surface is governed by the larger aggregates in the mix, rather than the properties of the fines. Coarse aggregate containing hard impurities resistant to polishing by traffic is superior to that composed entirely of softer material.

ACKNOWLEDGMENTS

This investigation was conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads, under the State-Federal Highway Planning and Research program.

The work was performed by personnel of the Bureau of Physical Research, New York State Department of Transportation, Malcolm D. Graham, Director. Many Bureau employees were involved in this study, with the major portion of the field work performed by John L. Whitmore.

New York State Department of Transportation personnel throughout the State were helpful in selecting test sites, supplying plant data, and collecting aggregate and pavement samples.

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Discussion

GLENN G. BALMER, Highway Research Engineer, Bureau of Public Roads — The authors of this paper are to be congratulated for such a realistic investigation and analysis of a timely problem.

It is gratifying to find confirmation of the acid-insoluble residue test as an analysis of the skid-resistant characteristics of aggregates similar to the results obtained in the paper, "Laboratory Studies of the Skid Resistance of Concrete," published in the ASTM Journal of Materials, Vol. 1, No. 3, September 1966.

The residue test is a simple means of determining the skid-resistant quality of the surface aggregates prior to construction of the pavement. This test can be conducted when the friction characteristics of the aggregates are unknown or doubtful, and avoid construction of pavements with inferior friction surfaces and also avoid expensive pavement resurfacing or other treatments to improve skid resistance.