CORRELATION OF ROUGHOMETER AND SKID TESTS WITH PAVEMENT TYPE, DESIGN AND MIX

A. DUKE MORGAN, *Materials Research Engineer*
North Carolina State Highway and Public Works Commission
Raleigh, North Carolina

SYNOPSIS

During 1949 and 1950 two types of bituminous mixtures on plant-mix pavement projects were studied by the North Carolina State Highway Laboratory; namely, sand-asphalt and asphaltic concrete

The purpose of the study was to correlate riding qualities on recently constructed bituminous pavements with mix design policies and construction practices.

Road roughness measurements on these two types of pavement are reported. Tests were made at the speed of 20 mph in the direction of traffic. The trailer was run in the center of the traffic lane being tested.

Skid resistance measurements on these two types of pavement were made for the purpose of correlating surface texture with mix design in an effort to establish safe limits for gradation of aggregate and bitumen content.

Skid resistance measurements were made by the stopping-distance method On level sections of pavement, the car was brought to initial uniform speeds of 20, 30, and 40 mph in successive tests, and the brakes applied instantly, locking all four wheels At the instant of locking the wheels, a detonator fired a chalk bullet on the pavement The forward skidding, or stopping-distance, was measured at each of the three speeds on a dry surface. The pavement was then flushed with water and the tests repeated

The stabilities of the sand-asphalts were measured in the laboratory by the Hubbard-Field method using the 2-in diameter mold and of the asphaltic concrete using the 6-in mold

In the method of mix design, specimens were compacted under controlled effort at several asphalt contents using the proposed aggregate to determine the asphalt content which gives the most desirable values for unit weight of the total mix, percent voids in total mix, percent voids filled with asphalt, and stability.

Results of these studies lead us to the following observations

(1) Stabilities on sand-asphalts, using 2-in diameter specimens, ranged from a minimum of 150 lb. to a maximum of 1800 lb by the Hubbard Field Method.

(2) Stabilities on asphaltic concrete ranged from 500 lb. to 4500 lb stability on 6-in. diameter specimens by the modified Hubbard Field Method.

(3) Road roughness measurements for sand-asphalt pavements ranged from a maximum of 176 to a minimum of 54 in. per mi.

(4) Road roughness measurements for asphaltic concrete pavements ranged from a maximum of 117 to a minimum of 57 in. per mi

(5) Skid resistance tests on wet sand-asphalt pavements at 40 mph ranged from a skid distance of 69 ft to a skid distance of 126 ft

(6) Skid resistance tests on wet asphaltic concrete pavements at 40 mph ranged from a skid distance of 81 ft to a skid distance of 111 ft

(7) Considering only newly laid pavement, the lowest roughness index was obtained with low stability sand-asphalt mixes

(8) Where the preponderence of sand particles occur between the No. 40 and No 200 mesh sieves, the frictional resistance of the surface is comparatively low

THE PRESENT TREND OF BITUMINOUS SURFACING AND RESURFACING WORK IN NORTH CAROLINA

For many years the North Carolina State Highway and Public Works Commission has been constructing the more standard types of bituminous concrete and sand-asphalt surfaces of conventional thickness, that is, from 1 to 3 in. While we feel there have been some gradual improvements in the mix design for these surfaces, essentially our designs and application for such work have not changed greatly over the past fifteen or twenty years. We have, however, during the past four years, constructed considerable mileage of this type of surface both in one course and two course construction on old concrete pavements which were in varying stages of failure, and new bases consisting of stone and soil.

It is well known that angular and rough-textured aggregates produce a relatively high degree of stability in bituminous mixtures. Hence, the region in central and western North Carolina which has available an abundance of crushed aggregates, enables the engineers to very easily secure durable mixtures which resist shoving and creeping. On the other hand, the most abundant and economical aggregates in the eastern region of the state consist of sands and gravels. The sands are very round and smooth, and the gravels uncrushed which results in relatively low stability.

Stability tests have long been employed by many highway departments as valuable aids in the design of asphaltic paving mixtures. By making such tests, it is possible to select better materials and to find the optimum combination of the selected materials, so that mixtures of good quality can be expected. Common stability tests for such a purpose are those proposed by Hubbard-Field, Hveem, and Marshall.

In the design of bituminous mixtures, more attention should be given to some form of stability measurement. The trend toward coarser type plant mixtures should be noted, and that such mixtures are less susceptible to variations in design with respect to stability due to the structural strength of the aggregate itself. This trend evidences itself in the newer designs which call for thinner dense-mix wearing surfaces and thicker coarse-graded mix binder courses.

The percent asphalt required in a mixture may be determined by a stability test. The amount of asphalt required to secure the most desirable values for solid volume density, unit weight density, percent voids in the total mix, and percent voids filled with asphalt should be determined and considered in making the final or optimum asphalt selection. Past experience has demonstrated how necessary it is that bituminous mixtures must be designed to have adequate workability, durability and density.

The purpose of this investigation was to correlate surface roughness and skid resistance of the finished pavement with design of the bituminous pavement mixtures.

PREPARING LABORATORY TEST SPECIMENS FOR SAND-ASPHALT PAVEMENTS USING THE HUBBARD-FIELD METHOD

The following method calls for the preparation of test specimens in batches of two briquettes, each batch weighing 200 to 230 grams.

Weigh out the dry sand and filler to 0.1 g. Heat the aggregate in the tared mixing dish to 350° F., and mix thoroughly. Place the dish and contents on balance and weigh into it the asphalt heated to 350° F. Thoroughly mix the contents of the dish for 3 to 5 minutes, or as may be necessary to insure thorough incorporation of the asphalt, using a 1-in. putty knife as a mixer and finishing the mixing with an ironing pressure between the flat blade of the knife and the side of dish, to iron out all lumps. Then place approximately 100 G. of mixture in each of two forming molds, numbered 1 and 2, preheated to 250° F. Place the molds with base plates on a hot plate and bring the temperature of the contents of No. 1 mold to 250-260° F. as determined by a thermometer used for stirring the charge. Remove mold No. 1 from hot plate and tamp thoroughly with the No. 1 tamper (blade type), using 60 or more heavy blows. Finish tamping with No. 2 tamper (cylindrical type, weighing approximately 1400 grams) using 15-20 heavy blows. Then insert the plunger and place the mold in the empty water bath on the base of the compression machine. Apply pressure to the top of plunger until a load of 3000 psi. or a dial reading of 9,425 lbs. is reached. Fill the bath with cold water to a depth of 3 in. and allow briquette to cool under pressure for 5 minutes. Then release pressure, remove the mold from the bath and force out briquette. While the first briquette is under pressure, bring the charge in No. 2 mold to 250-260° F. Tamp, compress, and cool as in the case of No. 1. The compressed briquettes should measure approximately one inch in height. After being removed from the mold, the top of each briquette is marked for identification with yellow crayon. The briquettes are allowed to cure in laboratory air overnight and are then placed in a water bath accurately maintained at the temperature of test, usually 140° F., for one hour before testing.

MAKING THE STABILITY TEST

Each specimen is tested by placing it, original top end down, in the testing mold against the shoulder of the orifice and inserting the plunger. The compression machine is operated so as to produce a uniform movement of the testing plunger at the rate of one inch in 25 seconds. As the test mixture is loaded, it commences to distort at the orifice in the testing ring, and the dial pointer rises quite rapidly to a maximum just before the bond is broken. The maximum load registered is recorded as the stability value of the specimen. After testing, the mixture is removed from the mold which is cleaned before inserting the next specimen. The test appears to be of generally satisfactory repeatability and between test specimens of the same batch will usually show a variation of less than 10 percent. The average of two tests is reported as the stability value of the mixture. Care must be taken to maintain uniform temperature of batch and briquettes during test.

A determination of the specific gravity of all test specimens is made prior to subjecting them to the stability test. This serves as a check upon uniformity of preparation and compression, and the specific gravity results are used in computing the voids in the test specimen and voids in mineral aggregate.

Specific gravity is determined by weighing the briquette, first in air and then submerged in water at 77°F., all weights being recorded to the nearest 0.1 gram. If A = weight in air and B = weight in water, specific gravity is calculated according to the following formula·

$$\text{Sp. Gr.} = \frac{A}{A-B}$$

VOIDS IN COMPRESSED PAVING MIXTURE

The percent of voids in the compressed paving mixture may be readily ascertained from its specific gravity if the specific gravity and percent by weight of each constituent are known. In conducting any series of stability tests on sand-asphalt aggregates, the specific gravity of the sand, mineral filler, and asphalt cement should therefore be determined by the methods of the American Society for Testing Materials for apparent specific gravity.

If W, W_1, and W_2 represent the percentage weights and G, G_1, and G_2 represent the specific gravities of the sand, mineral filler, and asphalt respectively of a given mixture, the theoretical maximum density of such a mixture, if it were free from voids, if first determined by the following formula where D represents the theoretical maximum density.

$$D = \frac{100}{\frac{W}{G} + \frac{W_1}{G_1} + \frac{W_2}{G_2}}$$

The actual specific gravity of a test specimen having been determined its percentage of voids is now readily calculated by the following formula in which D = theoretical maximum density, d = actual specific gravity and V = percent of voids.

$$V = \frac{100\ (D-d)}{D}$$

VOIDS IN MINERAL AGGREGATE OF COMPRESSED MIXTURE

Percent of voids in the mineral aggregate, designated V.M.A., of a compressed asphalt paving mixture, excluding the asphalt itself, is readily calculated from the data used in calculating voids in the mixture. Thus, if a compressed mixture has a specific gravity of 2.20 and contains 10 percent of asphalt by weight, it is evident that the apparent specific gravity of the mineral aggregate equals 2.20 - .22 or 1.98. If g = the apparent specific gravity of the mineral aggregate, the formula would be

$$g = d - \left(d \times \frac{W_2}{100}\right) \text{ or } d\left(1 - \frac{W_2}{100}\right)$$

The maximum theoretical density of the mineral aggregate (sand and mineral filler) represented by D would be calculated by the formula

$$D = \frac{W + W_1}{\frac{W}{G} + \frac{W_1}{G_1}}$$

And the V.M.A., or percent of voids, in the compressed mineral aggregate would then be

$$\text{V.M.A.} = \frac{100\ (D_1 - g)}{D_1}$$

In designing an asphalt paving mixture, the V.M.A. should always be considered, as variations in percentage of asphalt may seriously interfere with obtaining the close packing of the aggregate which it is desirable to secure.

STABILITY TESTS PERFORMED USING THE MODIFIED HUBBARD-FIELD METHOD FOR ASPHALTIC CONCRETE

Tests performed using the Hubbard-Field method were in accordance with test procedure outlined in a pamphlet entitled "The Rational Design of Asphalt Paving Mixtures" published by the Asphalt Institute on October 13, 1935.

The Hubbard-Field stability test developed in the laboratory of the Asphalt Institute was originally designed to determine the resistance to deformation of sheet asphalt paving mixtures. Its use, without modification, has been extended to satisfactorily cover stone filled sheet asphalt or fine graded aggregate asphaltic concrete in which the maximum diameter of aggregate particle does not exceed 5/8 in., and the percentage of aggregate retained on the 10-mesh sieve does not exceed 35 percent of the total. The 2-in. diameter test specimen and testing mold, however, make it impossible to test other mixtures in common use where both the maximum size and percentage of aggregate retained on the 10-mesh sieve exceeds these limits. Thus coarse aggregate asphalt concrete and mixtures of stone or gravel products with road oils and cut-backs, such as are widely used in low-cost road construction, cannot be evaluated by this test.

A special mold and testing ring for the coarser mixtures have been developed which promise to be a useful means of determining their relative stability in values which are directly comparable to those obtained on sheet-asphalt mixtures in the smaller mold. This equipment may be considered as an adjunct to the original stability test. While, with certain modifications in method of preparing test specimens, sheet-asphalt mixtures will show the same range of stability when tested in the large mold as in the standard 2-in. mold. The larger size is not convenient for sheet-asphalt and is intended only for use with the coarse aggregate mixtures. This equipment consists of the following pieces:

(1) A cylindrical steel forming and testing mold of approximately 1/2 in. wall thickness, accurately machined to 6 inch internal diameter and measuring 6 in. in height.

(2) A testing ring of tempered steel 3/8 in. thick and of the same outside diameter as the mold or approximately 7 in. The minimum orifice of the testing ring, which is 5-3/4 in. extends for a depth of 1/8 in. after which it tapers out to a diameter of 6 in. at the bottom.

(3) A ring clamp with set screws to hold the testing ring tightly against the bottom of the testing mold.

(4) A plunger consisting of a circular steel plate 5-3/4 in. in diameter in the center of which is screwed a 1-1/4 in. diameter round steel rod 4-3/4 in. long. The top of this rod contains a depression into which the ball end of the testing head of the stability machine fits. It also carries a projecting pin which fits into a slot in a metal tipped handle which may be attached when it is desired to use the plunger as a tamper.

(5) A metal base plate 12 in. square and 1 in. thick.

(6) A portable, metal water bath 14-1/2 in. long, 12 in. wide, and 9 in. deep to the bottom of which are fastened a number of stout metal reinforcing ribs.

(7) A tamper designated as No. 2 consisting of 1.75 in. diameter steel rod 3 in. in length with a hardened steel plate 1.875 in. in diameter attached to the steel rod with countersunk screws. A 0.5 in. steel rod encased in a 1.5 in. wood handle 7.3 in. long is the attached handle. Approximate weight 1100 grams.

(8) A tamper designated as No. 3 is a plunger consisting of a circular steel plate 5.75 in. in diameter, in the center of which is screwed a 1-1/4 in. diameter round steel rod 4-3/4 in. long. The top of this rod contains a depression into which the ball end of the testing head of the compression machine fits. It carries a projecting pin

which fits into a slot in a metal-tipped handle which is attached when it is desired to use the plunger as a tamper.

PROCEDURE

All mixtures are blended in a 3-quart aluminum stew pan with a 1-in. blade putty knife. The No. 2 tamper from the regular equipment is used in addition to the new tamper which is designated as No. 3, for placing the mixtures in the mold.

Mixing - Into the tared dish is weighed the several mineral constituents of the mix so as to produce a total weight of 2,000 grams of aggregate. After thorough dry mixing, the dish and contents are placed on a hot plate and brought to the desired temperature, 300 to 350° F. The aggregate is again stirred, re-weighed, and adjusted for any change in weight. With the putty knife, a crater is formed in the aggregate to hold the hot asphalt which is heated to 300° F. and carefully weighed in by pouring from the can in which it was heated. Mixing is accomplished by stirring the mass, beginning first with the putty knife at the center and stirring the central portion in such manner as to prevent contact of asphalt with the dish until the aggregate has absorbed the main portion. The motion of the blade may now be changed to produce an ironing effect that will blade out any lumps formed and assist in thorough distribution of the asphalt. The mixing is finished by a final stirring of the entire mass from the dish wall inward. The whole mixing operation is finished in from 5 to 6 minutes.

Compression - The mix is immediately transferred to the mold which, with the base plate, has been previously warmed to a temperature of 100 to 125° F. About half the mix is placed in the mold using a hot spoon. The putty knife is again used and the mass restirred in the mold with careful blading at the sides to prevent the formation of pockets. This portion is tamped with the No. 2 tamper, 50-60 blows. The balance of the mix is then placed in the mold, stirred, and bladed as before, tamped 50-60 blows with the No. 2 tamper, and 50 blows of the No. 3 tamper. The temperature recorded by a thermometer forced into the middle of the briquette should read about 100° C. The briquette is allowed to cool to 80° C. when a final tamping of 50 blows of the No. 3 tamper is given. The briquette is now cooled in the mold by immersion in a cold water bath at approximately 72° F. (or room temperature). The briquette may then be forced out easily by hand with the No. 3 tamper.

Specific Gravity - Specific gravity of the compressed mixture may be calculated by displacement of water, or by volume determination, using an Ames dial to measure the height of the specimen as molded. Voids in the mineral aggregate and voids in the mix are calculated by the method described in connection with the original stability test. Stability is determined at 140° F. by placing the mold and briquette in the water bath at 140° F. for one hour, then bringing the assembly in place on the testing ring under the head of the compression machine and applying the load at the standard rate of 1 in. in 25 seconds and noting the maximum load required to cause failure.

SKID RESISTANCE MEASUREMENTS

The skid resistance measurements were made by the forward skidding, stopping distance method. This procedure has previously been described by Professor Moyer (1)[1] and Shelburne and Sheppe (2).

[1] Numbers in parentheses refer to references at the end of the paper.

A 1948 Fleetmaster Chevrolet car weighing 3100 lbs. and equipped with 6.00 by 16 in. 4-ply tires was used throughout the tests. Prior to performing the tests the speedometer was calibrated by means of a stopwatch over two measured miles. Six calibration runs were made at each speedometer reading of 20, 30, and 40 mph and the time checked carefully. Results of the calibration are shown graphically in Figure 1.

All skid measurements were performed on tangents with relatively even surfaces and on level sections of pavement. Before each series of tests, the air pressure in each tire was adjusted to 30 p.s.i. In performing the tests the car was brought to an initial uniform speed of 20, 30, or 40 mph and the brakes applied hard instantly to lock all four wheels. At the instant the wheels were locked, an electric detonator loaded with a 22 blank cartridge fired a chalk bullet on the pavement. The gun was attached to the front bumper of the car and actuated electrically through the brake pedal. The distance from the chalk mark to the gun was measured by means of a steel tape. Three measurements were made at each speed and results reported are average values.

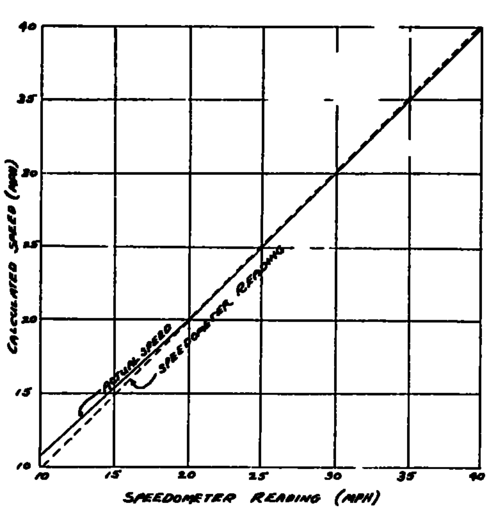

Figure 1 Speedometer Calibration

Four sets of new natural rubber tires were used in the tests. They were replaced at the end of 5000 mi. At this mileage the tread was still very good.

In performing the tests, measurements were made at the three speeds with the surface in a dry condition. The pavement was then flooded with water and the tests repeated. This method of producing a wet pavement is believed to be comparable to natural wet weather conditions. After each of the three measurements, wet, at one speed, the flooding of the surface with water was repeated. By this method it was possible to maintain uniformly wet surfaces.

As a matter of record both air and pavement temperatures were taken for each test. Since the tests were performed intermittently during a 10-month period, air temperatures ranged from 34° to 96° F. and averaged 78° F. Corresponding pavement temperatures varied from 37° to 110° F. and averaged 83° F.

The same driver was used throughout the series of tests. The car was maintained in excellent operating condition. This required frequent balancing of wheels and adjusting of brakes. The roundness of the tires was also checked. At the 40 mph on a wet surface, there was some side skidding as the car came to rest. Check tests were made until the side skidding was eliminated.

When these tests were conducted on the primary highway system, the State Highway Patrol directed traffic during the tests.

DESCRIPTION OF SURFACES TESTED FOR SKID RESISTANCE

The surfaces tested were selected with the view of determining skid resistance qualities of the two types of pavement, namely, sand-asphalt and bituminous concrete. It is realized that there is considerable variation in surfaces of the same type, due primarily to asphalt content and the aggregate characteristics such as particle shape and gradation.

The pavements tested were two lanes in width. All tests were made in the direction of traffic and in the traffic lanes, but not in the center of the highway. All tests on each surface were made in the same lane and direction, so as to take advantage of alignment and grade.

On the basis of average 24-hr. counts, traffic on the roads tested varied from 100 vehicles to 6000 per day.

For the year ending December 31, 1949, an average of the traffic counts at the 43 locations was 1870 vehicles. Since 42 percent of these sand-asphalt surfaces are on secondary roads, the traffic count is considerably less than for the projects on the primary system.

The sand-asphalt pavement consists of one or more courses of sand-asphalt laid on a prepared soil type base course which is constructed according to standard specifications,

TYPICAL GRADATION

SAND ASPHALT

N. C. Project	N. C. Specification Section No.	Special Provisions	Grading	Pct. AP-3	Percent Passing Larger Sieve and Retained on - Numbers 4	10	40	80	200	-200
3-6-30-132	125-1.2	5% Min.-200	B	7.77		1.60	38.90	26.70	15.20	7.10
3-7-28-15	125-1.2	5% Min.-200	B	7 77			21.40	55 20	10.10	5.53
3-7-28-16	125-1.2	5% Min -200	B	7.76		0 30	21.50	54.10	10.30	6.04
3-6-31-123	125-1.2	5% Min.-200	B	8 00			17.50	46.70	21.90	5.90
1-7-6-85	125-1.2	5% Min.-200	B	7.83	0.70	7.50	26.20	29.00	22.10	6.67
2-102	125-1.2	5% Min.-200	B	8 00		0.20	6.20	43.90	34.60	7.10
		% Retained								
2-115	125	No. 10 0-15		7.01		0.60	6.70	44.50	40.10	1.09
		40 0-60								
		80 20-80								
		200 0-50								
		-200 0-12								
		Bit. 6½-7½								

BITUMINOUS CONCRETE

N. C. Project	N. C. Specification Section No.	Special Provisions	Grading	Pct. AP-3	4	10	40	80	200	-200
1706	140	(2-28-50)		5.72	27.35	10 50			54.20	2 23
4771	126	25% Min -No. 10	A	6 00	17.00	18.35			57 55	1.10
4772 •	126		A	5.70	17.40	14.27			54 10	8.53
4722	126	5% Min.-200	A	5 73	34 15	16.95			37.05	6 12
3530	126	5% Min.-200	A	(AP-5)	31.95	20.40			35.15	6.47
		AP-5 Used		6.03						
		instead of AP-3								
		% Retained								
10-6-96-141	125	3/4-4 0-10		6.71	25.00	16.10			50 00	2 19
		4-10 0-30								
		10-40 20-60								
		40-80 10-60								
		80-200 5-30								
		-200 2-8								
		AP-3 6½-8½								

on old bituminous surface treated roads, on old cement concrete pavements, or old and new traffic bound stone bases. It is a hot plant-mixed material composed of 85-100 penetration asphaltic cement in the amount of 5.0 to 9.0 percent combined with natural non-commercial or commercial sand, or a combination of sand and stone screenings. All aggregates pass a No. 4-mesh sieve with 0 to 10 percent passing the No. 200-mesh sieve. The North Carolina specifications do not require a stability test. Natural non-commercial sand is the most commonly used aggregate for this type of surface.

The asphaltic concrete pavement consists of a fairly dense-graded bituminous surface. These wearing courses are usually about one inch thick and placed on a binder or leveling course usually from one to two inches in thickness. The binder is a hot plant-mixed material composed of 85-100 penetration asphaltic cement (5.0 to 8.0 percent) combined with crushed stone or gravel coarse aggregate and sand or stone screenings, or a combination thereof. In some cases, a non-commercial sand is combined with the coarse aggregate. The aggregate is uniformly graded from coarse to fine with 100 percent passing the 3/4-inch sieve and 5 percent to 10 percent passing the No. 200-mesh sieve. Specifications and Special Provisions for this type surface are varied within the above limits in order to obtain the most desirable mix with the materials available.

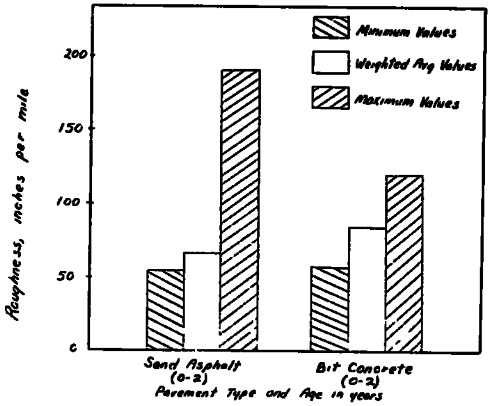

Figure 2 Roughness Values for the two types of Bituminous Pavement surfaces in North Carolina

The bituminous concrete surfaces studied were from one to five years old.

DISCUSSION OF SKID RESISTANCE TEST DATA

The complete data for more than 1500 stopping distance tests on 43 pavement surfaces are presented in Table 1. These stopping distances are actual average forward skidding distances and do not include driver reaction time. Table 1 includes the average coefficient of friction as computed from the following standard stopping distance formula:

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

Where F = Average coefficient of friction,
V = Initial speed in miles per hour at the time of applying brakes.
S = Average stopping distance in feet.

Results are grouped according to the two pavement types previously described for both dry and wet surfaces. Average values are given by groups of each type shown in Table 2 as well as grand average for both types.

Considering data in Table 1 for a speed of 40 mph, stopping distances from 60.1 to 88.3 and averaging 68.7 ft., were measured on dry surfaces. Corresponding computed coefficients of friction ranged from 0.89 to 0.60 and averaged 0.78. Thus it can readily be seen that all 43 surfaces have excellent skid resistance when tested dry.

Values for the same surfaces when

TABLE 1

SKID RESISTANCE

SAND-ASPHALT

Project	Route	DRY Speed		Speed		Speed		WET Speed		Speed		Speed	
MPH		20		30		40		20		30		40	
		S D	C	S D	C	S D.	C	S.D.	C	S D	C	S.D.	C
2-9-22-204	Co Rd	17.9	75	40 1	75	73.6	72	21 5	.62	49 5	61	88 1	60
3-6-28-126	US 17	15.5	86	35 9	84	63 8	84	20 2	66	46.0	65	90 9	.59
3-9-31-204	Co Rd	18 3	73	39.7	76	67.0	80	19 5	68	45 1	67	82.3	.65
3-7-28-15	Co Rd	16 0	83	39.2	77	65 3	82	17.8	75	42 2	71	81.2	.66
3-7-28-16	Co Rd	16.2	.82	37 4	80	66.3	.81	17 7	.75	37 4	.80	74.7	71
2-102	Co.Rd.	16 5	81	34 8	86	64 5	.83	18.8	71	38.5	.78	71.4	.75
2-9-23-201	NC 55	16 5	81	39 6	76	65 8	.81	20.3	.66	46 3	.65	86 5	.62
3-9-32-203	Co Rd.	19 5	68	43.5	69	74 3	.72	18 2	73	47.4	63	85.0	.63
3-6-31-123	US 117	16.4	81	36 2	83	64 0	.83	33.1	65	66.0	.45	126.3	42
6-9-57-210	Co Rd	16 9	79	37 4	80	65 8	.81	21.3	63	46.4	65	86.9	61
3-6-28-122	US 17	16 5	81	38 3	.78	67 2	79	20.6	65	49 2	61	94.7	.56
3695	NC 24	17 6	76	38 0	79	64.4	83	22 0	.61	49.5	.61	90.8	59
3334	NC 211	15 4	87	36 3	.83	64 3	83	17.6	.76	42.8	70	89.4	.60
3-6-30-132	NC 210	25 2	53	50.4	.60	83 8	64	30 9	43	70.0	43	121.3	44
1-7-6-85	Co Rd	16 5	81	37 6	.80	69.6	.77	17.3	.77	40 2	75	78.7	68
2200	US 117	15 9	84	38 1	.79	68 9	77	23 9	.56	53 9	56	112.4	.47
1-9-8-201	Co Rd	15 5	.86	37 2	81	65 3	.82	16.4	.81	48.7	62	82 9	.64
2-9-18-202	Co Rd.	15 7	85	35 8	84	62 4	85	20 4	65	52.1	.58	89.5	60
2-652	Co Rd	15 8	84	35 4	.85	60 1	.89	20 7	.64	49 8	60	87.2	.61
2-9-24-206	Co Rd	17 4	76	38 5	78	65 7	81	16 5	81	36 8	82	68 7	.78
1076	NC 97	16 1	.83	37.9	79	62 5	85	18 4	72	42 8	.70	79.7	67
2223	NC 41	16 1	83	37.2	81	64 8	82	17 5	.76	43.3	.69	80.4	66
2-9-24-209	Co.Rd.	16.2	82	36.3	.83	64.8	.82	19.5	68	49 1	.61	85 4	.62
1-9-12-201	Co Rd.	16 0	83	37.1	.81	65 8	81	17 3	77	40.5	74	73.9	72
6-9-57-209	Co Rd.	16 9	79	38 4	78	66.7	80	20 5	65	50 1	.61	94.4	56
3-9-34-210	Co Rd	18.5	72	42 4	71	70 7	76	20 4	.65	46.4	65	81.4	65
2-454	Co Rd	16.5	81	37 3	80	68 8	.77	20 5	.65	48.4	.62	86 8	61
2-115	Co Rd	18 7	.71	39 1	.77	64 9	.82	19.4	68	40 8	74	76 4	70
2620	US 258	23 9	56	50 3	.60	79 8	.67	25.5	52	62 8	.48	108 5	49
Craven Co.	US 70	24 0	55	52 3	.57	80.0	67	25 4	.52	53 9	56	99 3	54
Carteret Co.	US 70	23.5	57	50 5	59	84 2	63	24.8	.54	57 4	52	99.3	.54
Pasquotank Co	US 17	23 3	.57	48.5	.62	80 5	.66	28 3	47	55·7	54	107 4	.50
Rowan Co.	US 70 & 29	16 4	.81	37 4	80	65 3	.82	20 8	.64	49.8	.60	95.6	56
Vance Co	US 1	25 6	52	52 1	57	88 3	60	29.9	45	65.8	46	111 0	48
Cleveland Co.	US 29	16 9	79	37.5	.80	65.6	.81	26 2	51	64 2	47	127.7	42
TOTAL		17 99	.758	40 11	759	68.99	.780	21 40	650	49 39	625	91 32	598

TABLE 1 Continued

ASPHALTIC CONCRETE													
1706	US 301	15.3	.87	37 5	80	65.5	.81	23 0	58	59.0	.51	106.6	.50
3530	City Street	18 0	74	39.7	.76	67.7	.79	25.4	52	57.5	.52	111.4	.48
4771	US 1	16 5	81	38 7	.76	66 6	.80	22.3	60	55.2	54	98 5	.54
4772	US 1	16.8	.79	39.8	.75	68.2	.78	22 4	60	50.7	.59	90.3	.59
4722	US 158	16.4	.81	39.4	.76	68.9	.77	17.0	.78	41.0	.73	81 1	.66
10-6-96-141	US25 &70	19.0	70	40 5	.74	73 2	73	25 2	.53	63 1	.48	110.0	48
Guilford Co.	US29 &70	16.9	.79	37.6	.80	64 6	.83	22 7	.59	55 6	.54	110 0	48
Guilford Co.	US 70	18.2	73	38 3	.78	64 5	.83	20.3	.66	48 9	61	92 3	58
TOTAL		17.14	.780	38.94	769	67 40	.793	22 29	608	53 88	.565	100 03	.539
GRAND AVERAGE		17.83	.762	39 89	761	68 70	.782	21 57	.642	50 23	614	92 94	.587

TABLE 2

SKID RESISTANCE TESTS AT DIFFERENT TEMPERATURES

Project		DRY						WET					
		Speed		Speed		Speed		Speed		Speed		Speed	
MPH		20		30		40		20		30		40	
	Temp.	S.D.	C	S.D.	C	S D	C	S D	C	S D	C	S.D	C
4211	68°	17.4	.76	38.8	77	69 7	76	22.2	60	51 9	58	105.2	51
4211	84°	21.5	.62	54 2	.55	90.5	.58	32 0	42	72.5	.41	125.3	42
3-9-32-203	70°	17.8	.75	38.4	.78	66 3	81	18 0	74	43.0	.70	78 3	.69
3-9-32-203	98°	19.5	68	43 5	.69	74.3	72	18 2	.73	47 4	.63	85 0	63

S D. = Skid Distance
C = Coefficient

wet (at 40 mph ranged from 71.4 to 127.7 and averaged 92.9 ft. The corresponding computed coefficients of friction varied from 0.75 to 0.42 and averaged 0.587. If the surfaces are rated according to previous investigators on the basis of stopping distances of 133 ft. (coefficient of friction 0.4) then all 43 surfaces would fall within this limit. According to AASHO design standards (5) in which a factor of safety of 1.25 is used, the safe braking distance on wet level surfaces at 40 mph should not exceed 113 ft. If the 43 surfaces are evaluated on this basis, then all but three are found to be within this limit. The three locations not meeting AASHO requirements are projects 3-6-31-123, 3-6-30-132, and Cleveland County US 29. Two of the projects are sand-asphalt pavements which contained very fine siliceous sand and an excess of asphalt which, under heavy traffic, was worked to the surface resulting in a slightly glazed surface texture and voids overfilled with asphalt. These surfaces contained aggregates with high abrasion loss. In fact, since project 3-6-31-123 was tested, it has been resurfaced with a non-skid pavement. The project in Cleveland County on US 29 showed a slight excess of asphalt. Polishing of the limestone aggregate which was used in this mix may be a contributing factor.

With fine-textured surfaces such as sand asphalt, the aggregate particle shape, gradation and percentage of asphalt is very important from a skidding standpoint. An important factor in surfaces having high coefficient of friction is the presence of gritty particles which give the surface a "sand paper" texture.

Project 4211 shown in Table 2 consisted of granite screenings graded from coarse to fine with 100 percent passing the No. 4 sieve and 2 to 4 percent passing the No. 200 sieve. The optimum percentage of asphalt by the Hubbard-Field method was 7.25 percent. Eight and fifteen one-hundredths percent asphalt was extracted from cores taken from the pavement in place. It is believed that the surface voids were overfilled with asphalt which produced a slippery surface as shown by the skid resistance test.

A fairly definite increase in the coefficient of friction was observed with a decrease in temperature. The heat of the tire which developed at the higher speeds when sliding straight ahead was largely responsible for consistently lower coefficients observed in this form of skidding as shown on Projects 4211 and 3-9-32-203. On low stability sand-asphalt pavements when the air temperature is high, the coefficients are consistently high. In this case, the wheels plow into the hot pavement as the skid progresses. This is especially true at 40 mph.

INFLUENCE OF BRAKING STRESSES

Upon failure, a bituminous mixture will be squeezed from under the tire towards each side of the longitudinal lane followed by the wheel. In actual service, however, in addition to the tendency to be squeezed from under the wheel at right angles to the direction of travel, bituminous pavements are subjected to braking and acceleration stresses. These latter forces are usually applied in the direction of travel, and they, therefore, attempt to shove the pavement either ahead of (for braking), or behind (for acceleration) the wheel. Since they may often provide the most critical conditions of design for bituminous pavements carrying moving loads, the influence of these braking and acceleration stresses must be considered in a quantitive manner, if possible. From its very nature, it is probable that braking stresses are generally more severe than acceleration stresses.

The skid resistance factors of rubber tires on sand-asphalt and bituminous concrete road surfaces are very complex, and are influenced by many variables and test conditions. While an effort has been made in this investigation to examine the effect of some of the variables, it is our desire to explore the effect of age and traffic conditions on these same types of bituminous pavements over a period of a number of years. The test results to date have revealed the effect on skid resistance of some of the variables which have been summarized in the discussion which follows, to include:

1. Effect of speed.
2. Effect of wet versus dry surface condition.
3. Effect on friction values of low stability sand-asphalt mixes and stable bituminous concrete mixes.
4. Seasonal effect on various surfaces.
5. Friction values as affected by bitumen content.

The two variables, effect of speed and wet versus dry surface condition, listed as Items 1 and 2 above, and friction values as affected by bitumen content, listed as Item 5 are important considerations on which some work is reported here.

The locked wheel braking tests

closely simulate actual vehicle operation and provide an accurate measure of the road and tire friction developed by a passenger car when making an emergency stop for similar road and new tire conditions.

In tests with the same car with adequate brakes properly adjusted, consistent results are obtained on any given surface for the same test conditions.

The coefficient of friction between pavements and tire is usually 0.8. This value tends to decrease as vehicle speed increases. For safety reasons, it is desirable to design and construct bituminouspavements having a very high coefficient of friction between pavement and tire.

ROAD ROUGHNESS

Road roughness measurements on the two types of Bituminous pavement, sand-asphalt and asphaltic concrete pavement, are included in this report. As previously stated, the purpose of the study was to obtain data on riding qualities of recently constructed bituminous pavements, also skid resistance that could be used in evaluating design and mix policies and construction practices.

A "Road Roughness Indicator" designed by the Bureau of Public Roads and constructed by the North Carolina State Highway and Public Works Commission was used for these tests. This machine was described in a paper presented to the Highway Research Board (3) in 1940 and later published in Public Roads (4). This machine measures the ittegularities in the road surface which are transmitted through a standard tire to the axle of the wheel. The vertical movements of the axle are transmitted by a wire cable to a double-acting ball clutch integrator which in turn transmits the accumulated vertical movements in inches to an electric counter mounted on a board in the tow car. A similar electric counter records the revolutions of the trailer wheel and thus provides an accurate and dependable measure of the travel distance. The roughness tests have been standardized at a speed of 20 mph, and the measurements are recorded on a data sheet by an observer for each half mile and at the end of the project. The data are summarized by expressing the roughness of each section of road in terms if a standard unit known as Roughness Index (RI), which is the roughness in inches of vertical movement per mile.

Before the tests were started, the speedometer of the towing vehicle was calibrated over two measured miles to determine the number of wheel revolutions in a measured mile.

A further test to determine the accuracy of the distances measured by the machine consisted of repeat tests made over a five-mile section

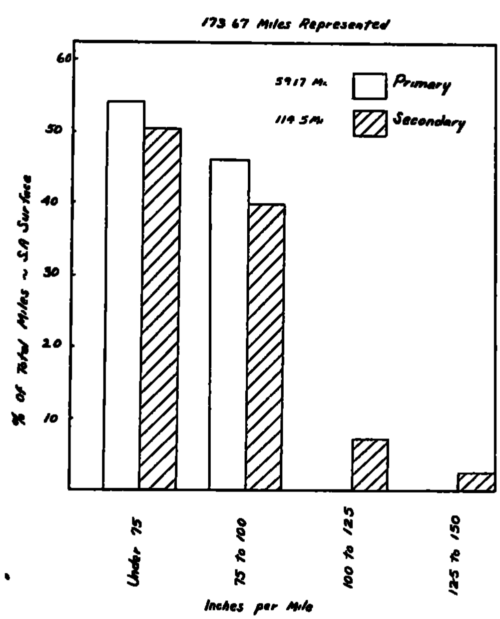

Figure 3. Distribution of Surface-roughness Measurements for Sand Asphalt pavement for the Primary and Secondary Road System

of new cement concrete pavement.

All tests were run at 20 mph in the direction of traffic with the trailer wheel in the center of the wheel tracks.

The measurements included in this report were started in January, 1950, and completed in December, 1950. Only one driver was used on this work and all readings were recorded by one man. Other older projects which had similar design and mix were tested for comparison with those recently constructed.

The test data including the average 24-hour traffic count have been tabulated for the two types of pavement. The values for roughness measurements are shown in inches per mile for one-half mile intervals. In tabulating the maximum and minimum values, only those for one-half mile were used. A summary of test results with maximum, minimum, and average values for the two types of surface tested was prepared to facilitate comparison of surfaces by type.

The results of tests on 46 sand asphalt projects are shown in Table 3. The majority of these projects were constructed in 1949 and 1950. Two projects were constructed in 1948. Traffic on these roads varies from 100 vehicles per day to 1400 vehicles per day and averages 465 for all sand asphalt tested.

Roughness measurements for sand asphalt averages 78.6 with a maximum of 176 and a minimum of 54 in. per mi.

The results of tests on 32 bituminous concrete pavement projects which total 138.5 mi. are shown in Table 4. Fifteen of these projects were constructed in 1949, fifteen in 1950, and one in 1948. Traffic on these roads varies from 210 vehicles per day to 6000 vehicles per day and averages 1895 for all bituminous concrete tested.

Roughness measurements for bituminous concrete pavement averages 82.4 with a maximum of 117 and a minimum of 57 in. per mi.

It is interesting to note the range between maximum and minimum of the two surface types. Sand asphalt has the lowest average roughness yet has the highest range (122 in. per mi.) between maximum and minimum.

The roughness measurements of each type of surface are affected by many factors. Common to both types of surfaces are the effects of subgrade or base support, workmanship, age, amount of traffic, mix design, and traffic densities which are influenced by the characteristics of the materials and traffic conditions.

Workmanship determines whether a surface will be constructed to the standard specified in the mix design as necessary for smooth riding surface. A perfect example of this is project 3-7-28-15. This project had a stability of 800 lbs. and a density of 2.12 at the time it was constructed, yet the traffic

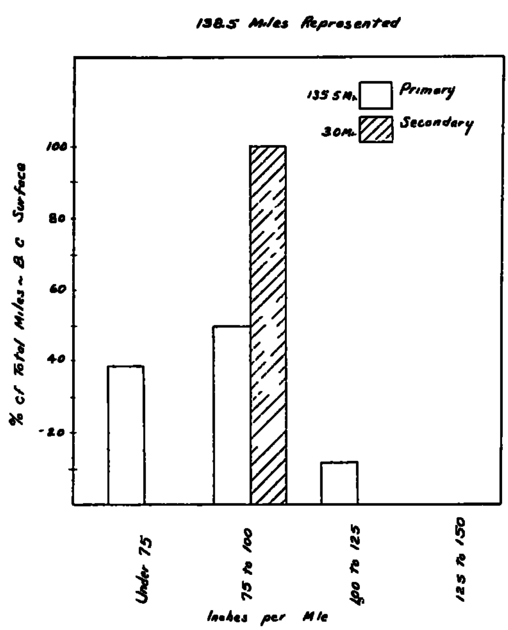

Figure 4. Distribution of Surface-roughness Measurements for Bituminous Concrete Pavement for the Primary and Secondary Road System

TABLE 3

ROAD ROUGHNESS AND STABILITIES

SAND ASPHALT PAVEMENTS

Project	Date Comp.	Length Tested	Roughness Avg.	Measurements Max	Measurements Min	Avg. 24-Hr Traffic Count	Lbs. Stability	Density
1201	1949	5.0	73.7	81 0	68 0	180	320	2 01
1346	1950	4.0	73.0	80 0	67.0	160	597	2 10
1-7-6-85	1949	3.0	74 6	81.0	70 0	200	1225	2.14
1-7-6-19	1949	2.0	85.1	99.0	75.0	225	400	2 09
2-9-16-201	1949	7.0	66.0	73.0	60.0	100	275	2 75
2-556	1949	4.0	82.7	88.0	78.0	190	263	2 63
2-7-24-16	1949	6.0	73.0	78.0	69.0	500	940	2.05
2-9-24-202	1949	4.0	80.6	96 0	74.0	360	1080	2.07
2-9-18-201	1949	3.0	69.0	73 0	61.0	210	1350	2 15
2-102	1950	5 0	67.7	75.0	63 0	450	260	1 80
2-7-23-3	1949	3.0	66 7	73.0	60 0	210	850	2 00
1056	1949	4.0	72.9	79 0	69 0	1070	655	2.10
2-115	1950	6.0	57.9	62 0	54.0	300	160	1.73
2551	1949	6.0	74.2	79.0	70.0	500	685	2.10
2-7-21-19	1950	5.0	85.0	97.0	78.0	190	640	2.11
2-9-21-201	1950	3 0	84 7	98.0	74 0	200	720	2 12
2-9-17-201	1949	4 0	83.6	91.0	77 0	350	210	1.98
2566	1950	4.0	71.8	76 0	68.0	1150	340	2.01
2-402	1950	4 0	74 0	85.0	63 0	360	480	1.99
3-7-28-15	1949	3.0	142.7	176.0	114 0	330	800	2 12
3-7-28-16	1949	3 0	114.4	132 0	97 0	150	850	2.13
3-7-28-09	1949	3.0	115.9	124 0	107 0	180	940	2.15
3-6-31-123	1949	7 0	92.2	113 0	83.0	1400	380	1.91
3-7-30-19	1949	1 0	78 3	86 0	71.0	225	300	2.09
3-7-30-20	1949	3 0	87 6	97.0	77.0	130	340	2 09
3-7-30-21	1949	4.0	92 0	108.0	75.0	1150	480	2.13
3-7-30-201	1949	3.5	83 7	89 0	75 0	120	500	2 13
3-6-30-132	1949	2 0	78.0	85.0	71.0	400	460	2.11
3393	1949	6.0	79.0	97 0	70 0	180	290	1 99
3-7-30-22	1949	1.0	78.0	81 0	75 0	180	310	2 01
3-7-29-08	1949	6.0	66.0	77 0	57.0	400	1140	2 20
3262	1949	4.0	63.0	70 0	56 0	500	600	2 04
3-202	1949	3.0	63.4	74.0	56.0	180	127	1.27
3-7-29-17	1949	3 0	72.0	78.0	66.0	200	930	2 07
3-7-29-13	1949	4 0	74.0	79.0	67.0	200	500	2.05
3-7-29-15	1949	3.0	75.0	78 0	68.0	125	580	2 07
3334	1949	0.8	95 5	108 0	83.0	560	600	2 04
4-7-38-42	1949	5.0	64.9	73.0	58.0	210	1610	2.18
4-402	1949	2.0	100 3	106.0	97.0	250	390	2 01
4-7-40-17	1948	3 0	98.3	102.0	94 0	310	500	2.14
4-7-38-40	1949	1.0	90 8	93 0	90 0	180	1560	2 16
4-7-39-16	1949	2.0	85.8	91 0	81.0	210	409	2 01
4-7-39-18	1949	2 0	81.0	86.0	79 0	440	500	2 05
3864	1948	11.0	81 1	88 0	76 0	1250	2060	2.38
6-9-57-203	1949	0.37	94 2	101.0	85.0	150	1120	2 23
6-9-57-205	1950	5.0	64 7	69 0	61.0	1250	1120	2.23
46 Projects		173.67						

Weighted Avg 78 6267 Roughness   Weighted Avg 670 565 Stability
Weighted Avg. 464 809 Traffic Count   Weighted Avg. 2 10333 Density

TABLE 4

ROAD ROUGHNESS AND STABILITIES

BITUMINOUS CONCRETE PAVEMENTS

Project	Date Comp.	Length Tested	Roughness Avg.	Measurements Max	Measurements Min	Avg. 24-Hr. Traffic Count	Lbs. Stability	Density
1706	1949	6.0	73.5	79.0	66.0	2250	920	2.08
1384	1949	6 0	63 2	73.0	62.0	1100	1300	2.29
3530	1949	1.0	100.8	106.0	95.0	6000	4500	2.28
3-6-29-124	1950	6 0	73 6	93.0	58.0	2200	1180	2.23
4789	1949	1.0	72.0	77.0	68 0	1000	2050	2.18
4771	1949	2 5	74.5	81 0	69 0	3000	1510	2.04
4-6-38-166	1948	4.0	86.6	92.0	72.0	850	1835	2.20
2830	1949	1 0	79.5	82.0	78 0	2400	1940	2 30
4-6-39-123	1949	8.0	86 4	94.0	77.0	2200	1650	2 21
1614	1950	5.0	71.5	66.0	79.0	3800	2050	2.24
4772	1950	8.0	68.6	75.0	65.0	1800	1220	2.20
2851	1950	4.0	72.0	79.0	65.0	2500	1940	2.30
4722	1950	4.0	75.3	91 0	71 0	2450	4360	2.21
4330	1949	6.0	84 6	91.0	80.0	2270	2870	2.20
5-6-45-128	1949	3 0	85.8	90.0	82.0	2400	2740	2.19
3391	1950	5 0	60.8	66.0	57.0	1520	1980	2.29
5816	1950	4.0	73 6	79.0	69.0	3410	2980	2.31
6-7-56-30	1950	4.0	102.5	117.0	92.0	210	705	2 03
6-6-54-119	1950	5.0	69.6	76.0	63.0	1590	1300	2.19
7-6-61-176	1950	5.0	104.1	109.0	97.0	1000	720	2.18
6643	1950	5.0	85.0	89.0	81 0	1480	2200	2.26
6675	1950	4.0	84.0	91.0	81.0	1070	2700	2.32
7434	1949	4.0	99.0	105 0	94.0	1750	3100	2.24
7453	1949	6.0	101.4	109.0	95.0	2900	3500	2.25
8822	1950	4.0	90.0	98.0	81.0	2400	1420	2.22
9-9-80-201	1950	3.0	84.2	91.0	81.0	250	980	2.16
8444	1949	6 0	92 2	99.0	83.0	1910	1820	2.21
9514	1949	5 0	97.6	109.0	87.0	1380	4300	2.38
8361	1949	3.0	93.6	100.0	86.0	1500	4360	2.24
8280	1949	5.0	81.8	89 0	78.0	1000	1640	2.26
10-6-96-141	1950	5.0	86.1	92 0	81 0	1600	2460	2.25

31 Projects

Weighted Average 82.42 Roughness 1895.60 Traffic Count

Regular Average 2200.97 2.2239

Grand Total Weighted Avg - Roughness 80.31
Grand Total Weighted Avg - Traffic Count 1,099.60
Grand Total Regular Avg. - Lbs Stability 1,286.70
Grand Total Regular Avg - Density 2.1525

Total Miles Tested - 312.00

31 Projects of Bit. Concrete 138.5 Miles
46 Projects of Sand-Asphalt 173.5 Miles

TOTAL 312 0 Miles

count is only 330 vehicles per day. The maximum roughness is 176 in. per mi., minimum 114 and weighted average of 142.7. The skid resistance coefficient at 40 mph when wet is 0.66 or a stopping distance of 81.2 ft.

There is a progressive, although slow, distortion of a pavement surface with age. The amount and weight of traffic causes a gradual settling or breaking of the surface.

When testing pavement surfaces for riding qualities, the problem of evaluating the road roughness measurements presents itself.

Certain ranges of roughness were arbitrarily selected to describe the riding qualities of a surface as excellent, good, fair, or rough as shown in Table 5.

TABLE 5

SUGGESTED STANDARDS FOR EVALUATING PAVEMENT SURFACES

Roughness Measurements (In. Per Mi.)			Riding Qualities
Below	--	75	Excellent
75	--	100	Good
100	--	125	Fair
Above	--	125	Rough

It is realized that this classification is subject to debate and that the type of irregularity in the surface and the speed of the car have a very decided effect on the riding qualities of any pavement.

SUMMARY AND CONCLUSIONS

The more important results and conclusions in the current investigation of skid resistance and road roughness in North Carolina may be summarized as follows:

SKID RESULTS

Based upon more than 1500 measurements of forward skidding distances on 43 pavement surfaces under conditions of tests previously described, the more important results have been summarized as follows:

1. On relatively smooth level pavements, the stopping distance method is an excellent means of determining the average skid resistance. The equipment involved is relatively simple and inexpensive. Tests can be performed and checked in a short time.

2. At 40 mph, the stopping distance varied from 60.1 to 88.3 ft. on a dry surface and from 71.4 to 127.7 ft. on a wet surface. Corresponding coefficients of friction ranged from 0.89 to 0.60 on a dry and from 0.75 to 0.42 on a wet surface. These data indicate clearly that stopping distances at 40 mph are critical only on the wet surfaces. It was considered unsafe to conduct tests on wet surfaces at a speed greater than 40 mph.

3. The data can be used to establish policies concerning the design, construction, and maintenance of surfaces with good non-skid characteristics. The data obtained check reasonably close with that of previous investigators. (See Table1)

4. The results obtained at the three speeds can be used to predict stopping distances at other speeds. (See Table 1)

5. All of the pavements tested in a dry condition were found to have satisfactory resistance to skidding for speeds of 40 mph or less.

6. Forty of the forty-three surfaces tested wet were considered to have satisfactory non-skid characteristics. One of the three surfaces (Project 3-6-31-123) found to be unsafe from a skidding standpoint has been resurfaced.

7. For the surfaces tested wet, the two groups listed in accordance with the stopping distance from the lowest average to the highest average are as follows:

Sand asphalt at 40 MPH Wet Average 91.32 Feet.

Asphalt Concrete at 40 MPH Wet Average 92.94 Feet.

It should be pointed out that this rating applies only to the surfaces tested, and since only a few surfaces are included in the asphaltic concrete group, too much emphasis should not be placed on this comparison.

8. Skidding resistance varies with the texture and composition of the pavement surface. Those surfaces having a harsh, gritty, "sand paper" texture were found to have short stopping distance.

9. With sand asphalt containing screenings, the stopping distance at 40 mph on a wet surface varied directly as the abrasion loss of the stone screenings, other factors being equal. In other words, long stopping distances were measured on the sand asphalt surfaces containing 100 percent stone screenings with high abrasion loss and shorter stopping distances were encountered with surfaces containing low abrasion stone screenings. Typical examples are Vance County US 1 with a wear test if 67 and skid distance of 111.0 ft; Rowan County US 29 with a wear test of 36 and a skid distance of 95.6 ft.

10. A slight excess in the percent asphalt will have a more pronounced effect in reducing the friction values than the particle shape of the aggregate. Excessive asphalt tends to decrease the stability of the pavement.

11. Higher friction values have been observed in the Winter tests than in the Summer tests. This is especially true where the pavements have low stabilities.

ROUGHNESS RESULTS

The more important results of the road roughness measurements on the two types of pavement (77 projects) totaling 312 mi. and representing approximately 800 mi. are summarized as follows:

1. The Road Roughness Indicator is a convenient, satisfactory, and rapid means of evaluating riding qualities of pavement surface.

2. Test results can be recorded in a form convenient for study or comparison of two or more projects.

3. Repeat tests with the Road Roughness Indicator give results that check closely considering the inability of the driver to follow in exactly the same path on each run.

4. Riding qualities of all pavements and, therefore, road roughness measurements are affected by such factors as workmanship during construction, pavement age, amount and type of traffic.

5. Riding qualities of any relatively thin surface course such as sand asphalt and bituminous concrete are influenced by the stability of the base and surface course.

6. Texture of bituminous surfaces has a bearing on road roughness measurements.

7. Sand asphalt surfaces were found to have the best riding qualities.

8. Bituminous concrete surfaces were slightly rougher than sand asphalt.

ACKNOWLEDGMENTS

The author wishes to acknowledge, with sincere appreciation, the help given by all those who have assisted in this investigation. Special credit should be given to Messrs H. C. Gillis, George Moore, and Luther Tyson of the Highway Equipment Division for their work in building the "Road Roughness Indicator" and certain other items of test equipment used in both the roughness and skid resistance tests.

Special thanks are extended to Mr. C E. Proudley, Chief Materials and Test Engineer, for the helpful criticism and suggestions in the preparation of this report. Other special commendation should be given

to Messrs. C. R. Penny and J. T. Norton for their skillful handling of the equipment during tests.

REFERENCES

1. Moyer, R. A., "Motor Vehicle Operating Costs, Road Roughness and Slipperiness of Various Portland Cement Concrete Surfaces," *Proceedings,* Highway Research Board, Vol. 22, pp. 13-52., 1942.

2. Shelburne, T. E. and Sheppe, R. L., "Skid Resistance Measurements of Virginia Pavements," Highway Research Board, *Research Report No. 5-B,* 1948.

3. Buchanan, J. A., and Catudal, A. L., "Standardizable Equipment for Evaluating Road Surface Roughness," *Proceedings,* Highway Research Board, Vol. 20, pp. 621-634, 1940.

4. *Public Roads,* Vol. 21, No. 12, pp. 227-234, Feb. 1941.

5. American Association of State Highway Officials. "A Policy on Sight Distance for Highways," 1940.