

Test for Coefficients of Friction by the Skidding Car Method on Wet and Dry Surfaces

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● THE Mississippi State Highway Department being concerned over the problem of pavement slipperiness directed that a comprehensive study be made to determine the skid-resistant characteristic of the various pavements within the state. Accident reports submitted to the Mississippi Highway Safety Patrol indicated that there were 8,572 rural accidents in 1953 and 8,910 in 1954. Reliable information is not available regarding any direct relation between the number of accidents and the texture of the pavements; however, in many cases the cause of the accident was reported as being that of "slippery" pavement. It was the desire to investigate the validity of these reports as well as that of determining what factors constitute high "skid resistant" pavements which instigated this study.

There are certain fundamental differences in the several types of pavement surfaces (concrete and bituminous) constructed by the State Highway Department. The most important difference insofar as the braking distance or stopping distance after brakes are applied is their surface characteristics.

The coefficient of friction is usually high on all dry surfaces and dry surfaces free of loose sand or gravel presents no skidding hazard, the difference occurs when the surface is wet.

TESTS AND EQUIPMENT

Several individuals and organizations in the past have conducted skid-resistance tests, and it has been found that skidding is a function of tire and pavement texture. It is influenced by tire balance, brake adjustment, pavement irregularities, crown of pavement, and transverse dips. A review of the reports of other skid tests indicated several methods have been used to determine stopping distance including: The stopping-distance method which involves locking the brakes of an automobile and measuring the skidding distance, and the utilization of trailers or towed vehicles as skidding units in which the pull following locking the brakes of the towing vehicle is measured on a dynamometer. A study by Moyer (1) revealed that uniform and accurate results may be obtained by use of the stopping-distance method. In comparing results utilizing both methods, he found that either system yielded practically identical ratings. A similar study made by the Virginia Highway Department (2) in which the stopping-distance method was used, produced results closely checking those found in skid tests conducted by other organizations. Based on this information, it was decided to use the stopping-distance method for this study. Moyer (1) also found that wind velocity and air temperature at the time of the tests were of no practical significance and they were not considered in these tests. Equipment used in the tests included two new four-door sedans, electric detonator, water wagon, and measuring chain. Both automobiles were 1954 Chevrolets, each weighing 3,670 lb and equipped with 6.70 x 15 four-ply Firestone Deluxe Champion Super Balloon Tires. The tires were replaced with identical types at the first sign of tread wear. Prior to each series of tests the air pressure was adjusted to 30 psi.

In each test run the vehicle was driven at an initial uniform speed of 40 mph. It was generally agreed that it would be unsafe to conduct tests on wet surfaces at speeds in excess of 40 mph. At the instant the brakes were applied locking all four wheels an electric detonator loaded with 0.22-cal chalk cartridges was simultaneously fired. The gun was attached to the front bumper and was actuated electrically through the brake-stop light system. The distance from the chalk mark on the pavement to the point the car stopped following the skid represented the actual stopping distance (excluding reaction and perception time) which was measured with a metallic tape to the nearest 0.1 ft.

Three or more runs and measurements were made at each location on dry pavement. The road surface was then thoroughly covered with water prior to each wet run and three runs were made on the wet surface. The results shown are average figures for each series of runs. Where it was noted that there was a malfunction of equipment or an unusual skid occurred, the results were not considered and additional runs were made to secure at least three satisfactory skids.

As nearly as possible, test locations were selected on the basis of desiring to achieve results from all types of surfacing of all ages and conditions, in each of six highway districts. Also any section listed by the district as being reported unduly slick was included in the tests. All tests were conducted on straight level sections of road with the car stopping in the travel lanes. Test runs were made using two drivers throughout the series. These drivers were twenty years old, skillful operators, in good physical condition, and full-time employees of the department. Since the tests were rather severe on the cars, a mechanic accompanied the crew to replace brakes, tires, check steering, and to keep the cars in excellent operating condition.

DISCUSSION OF TEST DATA

Usually there were two sites selected in each location of roadway. At each site there were usually three dry and three wet test runs made. The stopping distances of the test runs at each site were averaged for that site. Then the average was obtained for the location or project from the site averages if there were more than one site. All averages were obtained from the original subtotals and the number of locations or projects. Average coefficients were obtained by applying the formula (3):

$$\text{Coeff. of friction} = f = \frac{V^2}{30S}$$

in which V = initial speed in mph at the time of brake application; and S = stopping distance in ft. In each case average distances were used. The average coefficient was not obtained by adding series of coefficients.

In order to properly evaluate the reported "slick" surfaces as to their being excessively slippery when wet, it was evident some criterion was required. Moyer (1) found that a coefficient of 0.30 at speeds above 30 mph were safe for ordinary driving conditions. However, for emergency braking a coefficient of 0.40 to 0.60 was required; therefore, a coefficient of 0.40 was selected as the minimum from a safety viewpoint, and this coefficient was adopted as the criterion. Surfaces having a factor of less than 0.40 are considered to be sub-standard and undesirable.

During the initial portions of the study, it became evident that the

age of the road and the volume of traffic had a direct bearing on the condition of the surface, and consequently, on the coefficient of friction and stopping distance. These factors were taken into consideration with the adoption of the "traffic Index", ($\frac{L}{1}$) a composite figure derived from the age of the road and the average daily traffic as reflected on the 1954 traffic flow map. This index is calculated as follows:

$$\text{Traffic index} = \frac{\text{Age (In Months)} \times \text{Avg. daily traffic}}{100}$$

The Mississippi State Highway Department set out in 1955 to measure the dry and wet stopping distances on all major types of surface on the state-maintained system. This study also included different finishes on concrete pavement, as well as the effect of percentage of crushed particles in gravel seal aggregate used as the final course in a double bituminous surface treatment. Tests completed during 1957 are included in this report.

Sections included in this study were scattered throughout the state, and their surface characteristics were most varied. For example, in double bituminous surface treatments, the following are included: slag on slag, slag on gravel, gravel on gravel (both courses being of uncrushed material), gravel on gravel (50 percent crushed particles in seal), and gravel on gravel (85 percent minimum crushed particles in seal).

Cold mix surfaces tested are: slag mixtures, asphaltic limestone mixtures without quartz sand, asphaltic limestone mixtures with quartz sand, and crushed reef shell with quartz sand.

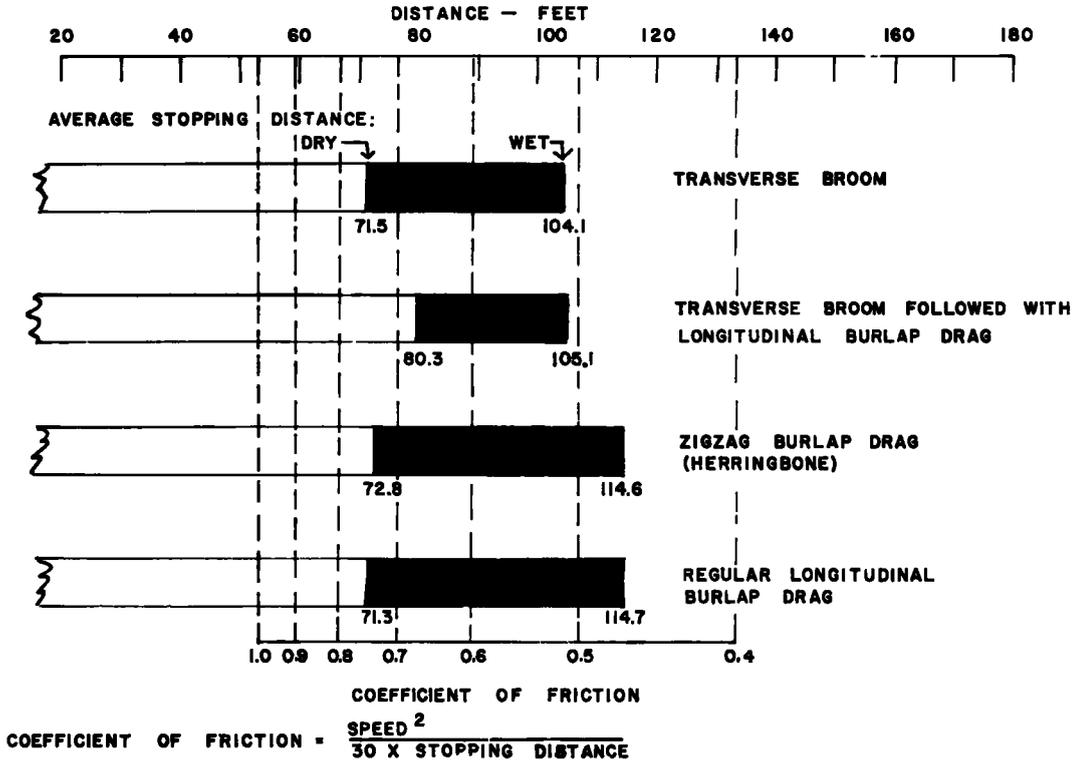


Figure 1. Relative stopping distances on cement concrete pavement with various types of finish; age, 264 days; testing speed, 40 mph; US 51 south of Jackson.

Hot mix pavements tested are: sand asphalts, modified sand asphalts, and asphaltic concrete. Concrete pavements tested consisted of new and old pavements.

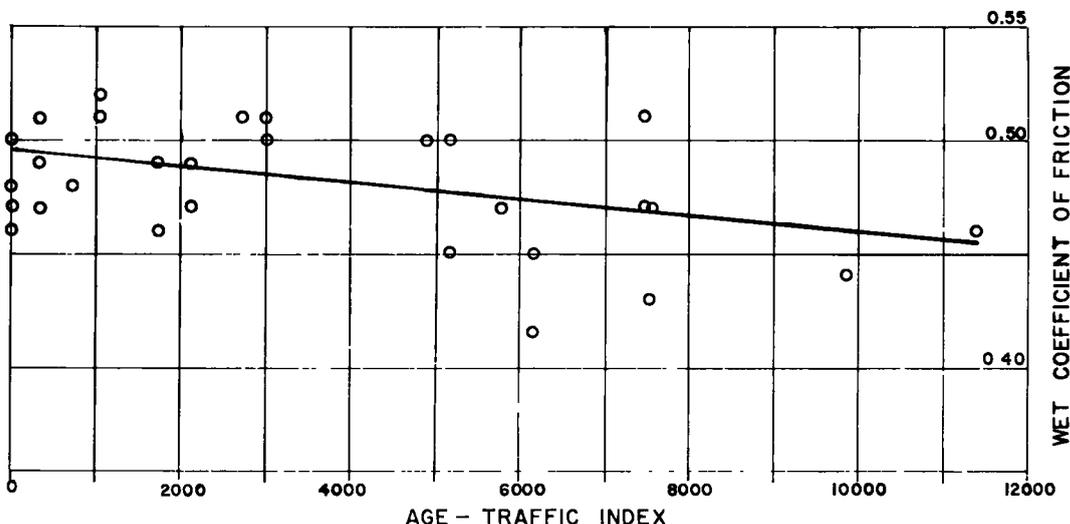
Tests were made on about 200 projects, and data from approximately 2,000 skid measurements are included in this report.

DEVELOPMENT OF DATA

(Concrete Pavement - Four Types of Surface Finish)

<u>Surface Finish</u>	<u>Stopping Distance</u>		<u>Coefficient of Friction - Wet</u>
	<u>Dry (in ft)</u>	<u>Wet</u>	
Transverse broom	71.5	104.1	0.52
Transverse Broom (followed with longitudinal burlap drag)	80.3	105.1	0.51
Herringbone (zigzag burlap drag)	72.8	114.6	0.47
Burlap drag (conventional finish)	71.3	114.7	0.47

(AGE-TRAFFIC INDEX = AGE IN MONTHS X AVERAGE DAILY TRAFFIC \div 100)



aggregates (which, in many cases, take on a high polish, when exposed to heavy rubber-tired traffic), the wet stopping distance increases.

Another contributing factor towards reduction of coefficient of friction on some pavements is the accumulation of oil drippings.

Figure 3 was prepared to show the decrease in wet coefficient of friction as the percentage of uncrushed gravel increased in bituminous hot mix pavements.

You will note that mixtures containing all fine material (nothing retained on No. 10 sieve) had wet coefficient of friction ranging from 0.5 to above 0.60. On the other hand, sections having 40 percent or more uncrushed gravel material retained on No. 10 sieve had wet coefficient of friction ranging from 0.42 to 0.51. The sand in all these mixtures is natural quartz sand. These data appear to support Shelburne and Sheppe in their statement that sandpaper-like textured pavements, properly constructed, yielded excellent stopping distances.

In the testing of stopping distances on sand asphalt pavements, it was

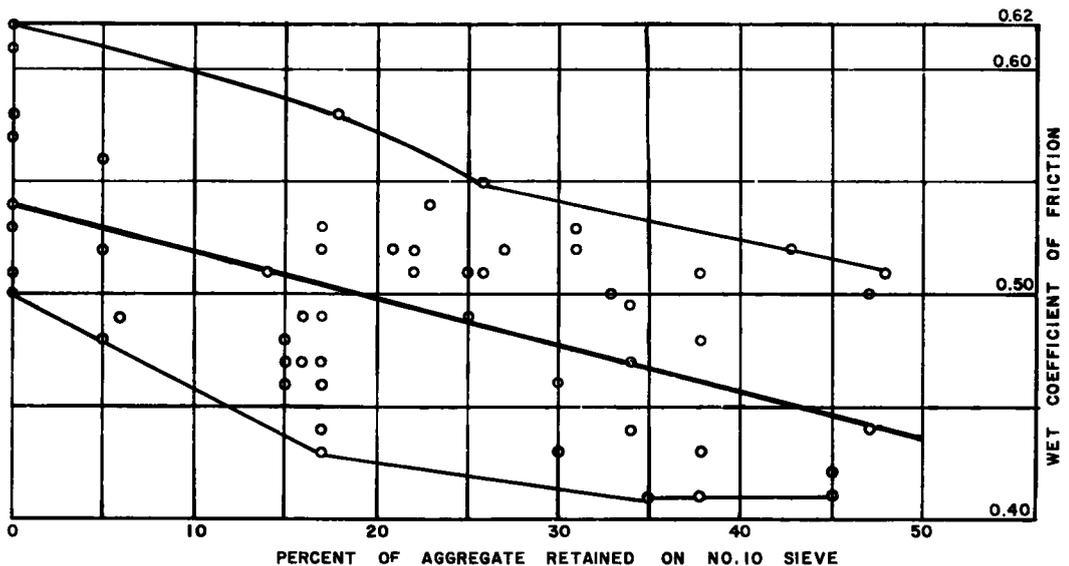


Figure 3. Wet coefficients of friction versus percentage of aggregate retained on No. 10 sieve; testing speed, 40 mph; bituminous hot mix-uncrushed gravel.

noticed that there was very little tendency for the vehicle to skid side-wise—instead the vehicle moved forward in a straight skid.

Figure 4 was prepared to show the effect of wet coefficient of friction of double bituminous surface treatment when the amount of crushed gravel particles used in the seal is varied. The Age-Traffic Index of these projects has been plotted against the wet coefficient of friction.

The top curve represents projects where the gravel seal aggregate contained more than 90 percent crushed particles. Shortly after the projects were constructed, the wet coefficient of friction measured 0.58 or better. On the other hand, projects containing 50 to 70 percent crushed gravel particles in the seal, gave a wet coefficient of friction of 0.45 to 0.48, a much lower value than the "90 percent crushed" jobs.

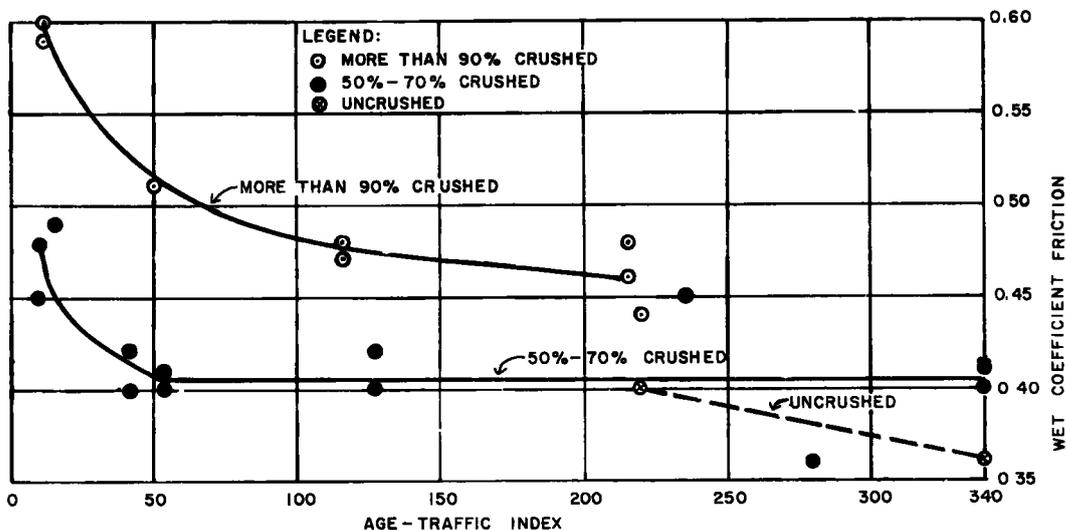


Figure 4. Wet coefficient of friction versus age-traffic index to show the effect of crushed particles in gravel aggregate seal; testing speed 40 mph; double bituminous surface treatment, gravel/gravel. (Age-traffic index = age in months x average daily traffic \div 100. In general, wet coefficients of friction below 0.40 are caused by excess bitumen and/or polished aggregate.)

It is noticed that at an age-traffic index of 50 (or, say, 500 vehicles per day for 10 months) the wet coefficient of friction for both the "90 per cent crushed" jobs and the "50 to 70 per cent crushed" jobs dropped considerably. This is probably caused by the embedment or seating of the seal aggregate particles in the mat. You will note that it takes approximately three years for a traffic count of 500 vehicles per day to reduce the wet coefficient of friction on the "90 per cent crushed" jobs to a value equal to that of the "50 to 70 per cent crushed" jobs when first constructed.

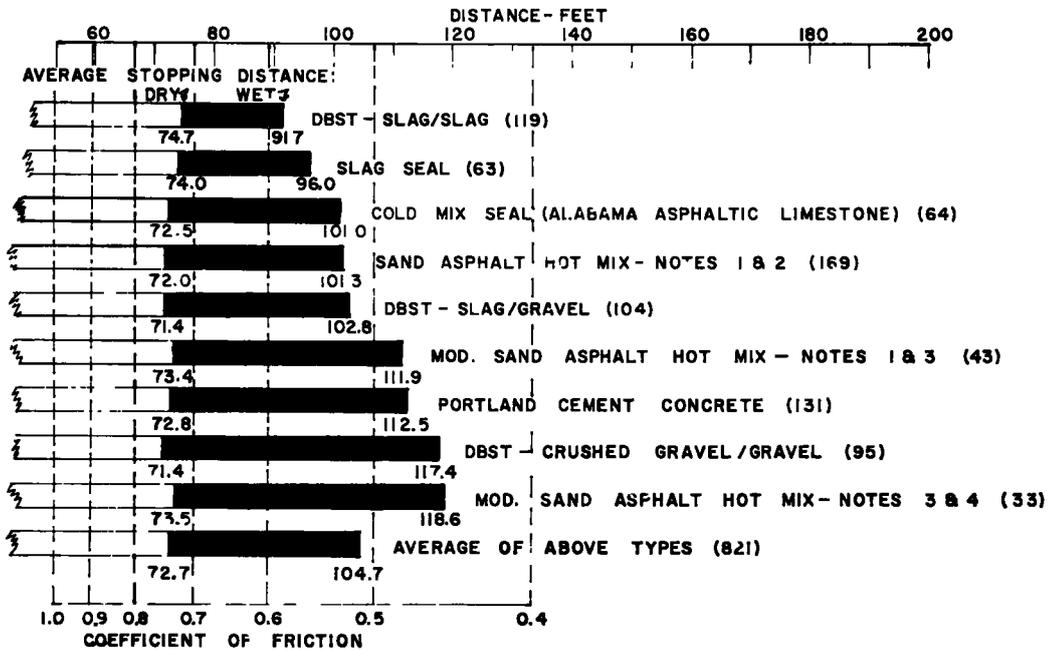
It is noted that the friction value, both in dry and wet tests, follows the same pattern, the highest values being obtained on the more angular aggregate.

Only two projects using uncrushed gravel in the primary and seal courses were available for tests. One of these projects had a wet coefficient of friction of 0.40, and the other project 0.36.

Previous investigators have found a considerable decrease in the friction value of rounded aggregates, particularly in the wet test. It follows that considerable improvement could be effected by using sharp sand or angular chips instead of rounded gravel in small sizes for the seal course.

Generally, a wet coefficient of friction below 0.40 on this type of construction was caused by excess bitumen (bleeding) and/or polished aggregates, or both. Excess asphalt has a pronounced effect in reducing friction values.

Figure 5 records the average stopping distances for several of the various types of surfaces tested, which had wet coefficient of friction of 0.40 or higher.



NOTE 1: UNCRUSHED GRAVEL AGGREGATE
 2: LESS THAN 25% PLUS NO. 10
 3: MORE THAN 25% PLUS NO. 10
 4: 25%-35% OF GRAVEL AGGREGATE IS CRUSHED.
 NUMBER IN (-) INDICATES NUMBER OF TESTS
 INCLUDED IN AVERAGE.

Figure 5. Average stopping distances for various types of surface having coefficient of friction of 0.40 or more; testing speed, 40 mph.

Data developed and shown on Figure 5 follow:

Surface Type	No. of Tests	Stopping Distance (ft)		Coefficient of Friction	
		Dry	Wet	Dry	Wet
D.B.S.T. - slag slag	119	74.7	91.7	.71	.58
Slag seal	63	74.0	96.0	.72	.56
Cold mix - Ala. Asp. L.S.	64	72.5	101.0	.74	.53
Sand Asphalt Hot Mix	169	72.0	101.3	.74	.53
D.B.S.T. - Slag/Gravel	104	71.4	102.8	.75	.52
Mod. Sand Asphalt Hot Mix	43	73.4	111.9	.73	.48
Portland Cement Concrete	131	72.8	112.5	.73	.47
D.B.S.T. - Cr. Gvl./Gvl.	95	71.4	117.4	.75	.45
Mod. Sand Asphalt Hot Mix	33	73.5	118.6	.73	.45
Average	84	72.7	104.7	.74	.51

Twenty-eight of approximately 200 projects tested were found to have sections having coefficients of friction (wet pavement) under 0.40. The average data for the group that tested below 0.40 are, in part, as follows:

	Dry (Ft.)	Wet (Ft.)	Coefficient of Friction	
			Dry	Wet
Average Stopping Distance	77.1	152.7	0.69	0.35
Minimum Stopping Distance		135.2		0.39
Maximum Stopping Distance		219.6		0.24*

Most of the sections in this group which fell below the value of 0.40 could be attributed to excess bitumen or polished aggregates.

The Maintenance Division was notified of the sections falling below a value of 0.40 and these sections have been resealed to improve the friction value.

Figure 5 records the average values established for types of pavement listed. The present finish of portland cement concrete pavement is the burlap drag finish.

Surfaces can be constructed with extremely high frictional values; however, as the coefficient of friction increases, the tire wear also increases. Dr. Moyer found that tire wear for a coefficient of friction in the range of 0.50 to 0.60 at a 40-mile speed averaged from one-half to one-third of the tire wear on sharp stone and gravel, yielding coefficients of 0.70 to 1.10.

Tire wear at a speed of 60 mph on highly abrasive surfaces (values above 0.70) was found to be eleven times greater than at 35 mph on surfaces with lower coefficients of friction.

A recent article by George Giles of the Road Research Laboratory of England and abstracted by J. E. Gray, Engineering Director of National Crushed Stone Association, appeared in the Crushed Stone Journal of June, 1957. The suggested standards for skidding resistance converted to 40 mph speed follow:

1. Coefficient 0.66 and greater—A good resistance to skidding, fulfilling requirements even for fast traffic.
2. Coefficient 0.56 to 0.66—Generally satisfactory, meeting most requirements except for curves on a road under fast traffic.
3. Coefficient 0.46 to 0.56—Satisfactory, except for conditions at critical sites such as junctions and curves.

In conclusion, if good resistance to skidding is to be obtained in a pavement surface when the pavement is wet, the composition of the mix must be all right and the aggregates must be of the kind that will remain harsh and resist severe polishing under traffic.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the assistance of the many individuals and agencies who helped to make this report possible. All districts and many Divisions of the Highway Department, as well as the Highway Safety

*A double bituminous surface treatment project sealed in late fall; a large portion of the seal aggregate did not stick in some sections. These sections were resealed the following spring, and the result was excess bitumen. These sections were bleeding badly at time of tests and "Slippery When Wet" signs were found on the project.

Patrol, willingly furnished personnel and equipment wherever needed. The Equipment Division furnished and maintained the test cars in excellent operating condition.

The study was authorized by T. C. Robbins, Director, and was conducted under the general supervision of H. O. Thompson, A. M. White and Jack W. Chambliss. S. A. Tomlinson, Fay Lossing and R. M. Genthon assisted in the analysis and interpretation of the data. Field crews were under the supervision of Oris Gary.

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