Skid Studies at the AASHO Road Test

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A series of six studies conducted periodically throughout the traffic testing period on the AASHO Road Test offered the opportunity to relate the effect of a number of variables on skidding resistance. The design of the skid resistance experiment and the controlled features of the test road made possible the isolation of these variables.

Various plots, diagrams and charts show the effect on the coefficients of friction of number of load applications, magnitude of load, number and spacing of axles, pavement design, and speed of the testing equipment. Certain seasonal or weather effects are also indicated.

● STUDIES of the resistance to skidding of wet and dry flexible-and rigid-type pavements of known design and traffic treatment were conducted at the AASHO Road Test in connection with the primary research.

The five traffic loops, each carrying a selected single- and tandem-axle load in the inner and outer lanes, respectively, were made up of test sections of variable design thicknesses for both the flexible and rigid pavements.

Design variables for the flexible pavement sections were subbase thickness, base base thickness, and surfacing thickness; those for the rigid pavement sections were subbase thickness, surfacing thickness, and surfacing reinforcement. All materials, mix designs, and construction procedures were identical for all test sections.

The uniformly constructed test facility and the controlled test traffic operations offered a unique opportunity to observe the effects of the axle load and arrangement (single or tandem), axle load applications, pavement design and skid test vehicle speed on the skid resistance of the pavement surface.

The experiment included 80 test sections of different design. Sixteen sections, eight in each traffic lane, were selected from each of the five test loops. Six series of tests are reported in this paper. The first was completed prior to any traffic operations and the sixth after more than 1,000,000 loaded axle applications.

The main part of this report is a general discussion of the experiment and the observations. The details of the experiment are included in the appendix. The test data may be obtained in tabular form from the Highway Resarch Board at the cost of reproduction (AASHO Road Test Data System 4340).

THE EXPERIMENT

Five controlled variables were selected for evaluation in this experiment. They were pavement design, axle load and arrangement (Tables 1 and 2), speed of the skid test equipment, pavement surface condition, and load applications. An outline of the first three variables is given in Tables 1 and 2.

In addition to the main experiment, a partial study of the effect of the condition of the pavement surface (wet or dry) was included. All of the sections noted in Tables 1 and 2 were tested in the wet surface study, but only selected sections were included in the dry surface study.

TABLE 1

OUTLINE OF SKID STUDY[a], FLEXIBLE PAVEMENTS

Axle Load[b] (kips)	Sub-base (in.)	2-Inch Surface		3-Inch Surface		4-Inch Surface			5-Inch Surface			6-Inch Surface		
		3-In. Base	6-In. Base	3-In. Base	6-In. Base	3-In. Base	6-In. Base	9-In. Base	3-In. Base	6-In. Base	9-In. Base	3-In. Base	6-In. Base	9-In. Base
2KS	0	x̲	x	x	x̲	-	-	-	-	-	-	-	-	-
	4	x	x̲	x̲	x	-	-	-	-	-	-	-	-	-
6KS	0	x̲	x	x	x̲	-	-	-	-	-	-	-	-	-
	4	x	x̲	x̲	x	-	-	-	-	-	-	-	-	-
12KS	4	-	-	x̲	x	x	x̲	-	-	-	-	-	-	-
	8	-	-	x	x̲	x̲	x	-	-	-	-	-	-	-
24KT	4	-	-	x̲	x	x	x̲	-	-	-	-	-	-	-
	8	-	-	x	x̲	x̲	x	-	-	-	-	-	-	-
18KS	8	-	-	-	-	x̲	x	-	x	x̲	-	-	-	-
	12	-	-	-	-	x	x̲	-	x̲	x	-	-	-	-
32KT	8	-	-	-	-	x̲	x	-	x	x̲	-	-	-	-
	12	-	-	-	-	x	x̲	-	x̲	x	-	-	-	-
22.4KS	8	-	-	-	-	-	x̲	x	-	x	x̲	-	-	-
	12	-	-	-	-	-	x	x̲	-	x̲	x	-	-	-
40KT	8	-	-	-	-	-	x̲	x	-	x	x̲	-	-	-
	12	-	-	-	-	-	x	x̲	-	x̲	x	-	-	-
30KS	12	-	-	-	-	-	-	-	-	x̲	x	-	x	x̲
	16	-	-	-	-	-	-	-	-	x	x̲	-	x̲	x
48KT	12	-	-	-	-	-	-	-	-	x̲	x	-	x	x̲
	16	-	-	-	-	-	-	-	-	x	x̲	-	x̲	x

[a] All sections tested at 30 mph; underline sections at 10, 30, and 50 mph.

[b] S = single axle; T = tandem axle.

TABLE 2

OUTLINE OF SKID STUDY[a], RIGID PAVEMENTS

Axle Load[b] (kips)	Sub-base (in.)	3.5-In. Surface		5.0-In. Surface		6.5-In. Surface		8.0-In. Surface		9.5-In. Surface		11.0-In. Surface	
		Non-Reinf.	Reinf.	Non-Reinf.	Reinf.	Non-Reinf.	Reinf.	Non-Reinf.	Reinf.	Non-Reinf.	Reinf.	Non-Reinf.	Reinf.
2KS	3	x̲	x	x	x̲	-	-	-	-	-	-	-	-
	6	x	x̲	x̲	x	-	-	-	-	-	-	-	-
6KS	3	x̲	x	x	x̲	-	-	-	-	-	-	-	-
	6	x	x̲	x̲	x	-	-	-	-	-	-	-	-
12KS	3	-	-	x	x̲	x̲	x	-	-	-	-	-	-
	6	-	-	x̲	x	x	x̲	-	-	-	-	-	-
24KT	3	-	-	x	x̲	x̲	x	-	-	-	-	-	-
	6	-	-	x̲	x	x	x̲	-	-	-	-	-	-
18KS	3	-	-	-	-	x	x̲	x̲	x	-	-	-	-
	6	-	-	-	-	x̲	x	x	x̲	-	-	-	-
32KT	3	-	-	-	-	x	x̲	x̲	x	-	-	-	-
	6	-	-	-	-	x̲	x	x	x̲	-	-	-	-
22.4KS	3	-	-	-	-	-	-	x	x̲	x̲	x		
	6	-	-	-	-	-	-	x̲	x	x	x̲	-	-
40KT	3	-	-	-	-	-	-	x	x̲	x̲	x	-	-
	6	-	-	-	-	-	-	x̲	x	x	x̲	-	-
30KS	3	-	-	-	-	-	-	-	-	x	x̲	x̲	x
	6	-	-	-	-	-	-	-	-	x̲	x	x	x̲
48KT	3	-	-	-	-	-	-	-	-	x	x̲	x̲	x
	6	-	-	-	-	-	-	-	-	x̲	x	x	x̲

[a] All sections tested at 30 mph; underlined sections at 10, 30, and 50 mph.

[b] S = single axle; T = tandem axle.

Design variables for the rigid pavement sections included two levels of surfacing and subbase thickness for each axle load and arrangement. To insure a reasonably balanced experiment for the duration of the Road Test the higher levels of design for each axle load were selected for study. The possible effect of the joint spacing was observed by the inclusion of both reinforced and plain concrete sections. Transverse contraction joints, formed by sawing, were spaced at 40 ft in reinforced sections and 15 ft in nonreinforced sections.

Similarly, the design variables for the flexible pavement sections included two highest levels of surfacing, base and subbase thickness for each axle load and arrangement.

The possible effect of the speed of the skid test vehicle was investigated in a partial study. All sections given in Tables 1 and 2 were included in the main experiment at 30 mph. In addition, those underlined were tested at 10 and 50 mph.

The most pronounced effect on the skid resistance coefficients was anticipated to be as a result of the accumulation of load applications. To determine this possible effect, the six series of tests were scheduled at fairly regular intervals during the test traffic phase of the Road Test. The date of each series and the accumulated axle applications are given in Table 3.

TABLE 3

HISTORY OF AXLE APPLICATIONS

Series	Date	Accum. Axle Applications
1	Fall 1958	0
2	Spring 1959	108,000
3	Summer 1959	232,000
4	Spring 1960	586,000
5	Summer 1960	851,000
6	Fall 1960	1,101,000

A total of 6 single- and four tandem-axle loads was selected. The pavement designs for the single-axle loads of 2, 6, 12, 18, 22.4 and 30 kips and for the tandem-axle loads of 24, 32, 40 and 48 kips are given in Tables 1 and 2.

Other variables in the test could be classified as uncontrolled. Of these the most important appeared to be the environmental conditions. Among the environmental conditions measured independently were the air temperature, pavement temperature, and the rainfall preceding the test series. Air temperature varied between 36 and 94 F, pavement temperature between 37 and 123 F, and the two-week rainfall prior to the test series varied from 0.36 to 1.77 in.

The dry surface studies were run in three series of tests. The sections selected for this study were those chosen for the special speed study and were in traffic lanes carrying vehicles with axle loads of 22.4 kips single and 40 kips tandem.

The mix designs, method of placement and finishing techniques of the surfacing courses, either asphaltic or portland cement concrete, were essentially the same throughout the Road Test. Figure 1 is a typical example of the surface texture of the two pavement types at the start of test traffic.

The General Motors skid trailer (Fig. 2) was used in all test series of the skid study. The skid resistance is described by the coefficient of friction and is computed from the known characteristics of the testing equipment and the measured force required to pull the trailer with the wheels locked (1).

TEST RESULTS

Despite rigid inspection of the finishing operations for both types of pavements, substantial differences were noted in the coefficients of friction before the start of test traffic. Values of the coefficients of friction for the flexible pavement sections ranged from 0.76 for those designed for the 2- and 6-kip single-axle loads to 0.67 for those designed for the 40-kip tandem-axle loads. For the rigid pavement sections the range was from 0.70 for those designed for the 2- and 6-kip single-axle loads to 0.60 for those designed for the 22.4- and 30-kip single-axle loads. Thus, the initial coefficients of friction for both rigid and flexible pavements were higher for those sections designed for the 2- and 6-kip single-axle load sections. An explanation of this might be in the lighter roller weights used on the thinner designs for the flexible sections and in the stiffness of the mix required for the rigid sections.

Standard deviations of the mean coefficients of friction for the first series were 0.030 for all flexible pavement sections and 0.050 for all rigid pavement sections. The initial variations between the pavements for each load were observed throughout the testing period. However, variations within sections for the same load were reduced considerably with each series of tests. Standard deviations for the last series of tests were 0.020 for all flexible pavement sections and 0.025 for all rigid pavement sections. The test indicated the replication error of the testing equipment was within 0.020 units.

Effect of Pavement Design

The design variable was investigated because of the belief that the increasing roughness of the thinner pavement designs might introduce an increase in the coefficients of friction. With reference to Tables 1 and 2, the range of design thicknesses incorporated within this experiment is from 5 to 31 inches for the flexible pavement sections and from 6.5 to 17.0 inches for the rigid pavement sections.

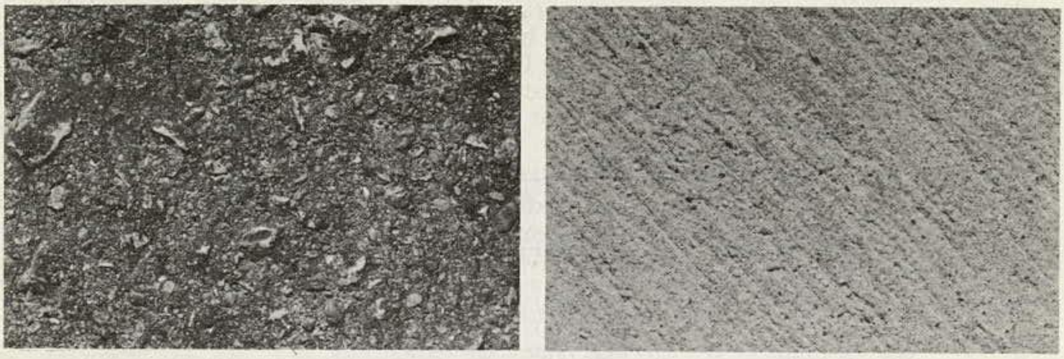

Figure 1. Typical example of surface texture of (left) asphaltic concrete and (right) portland cement concrete at start of test traffic.

Table 4 allows comparison of mean coefficients of friction for wet pavements across the various design levels. Comparisons can be made to examine the effect of surfacing, base and subbase thicknesses and the effect of joint spacing in the portland cement concrete on the coefficients of friction. Results from the six test series were combined to develop these means.

For example, the greatest difference between the coefficients for the effect of the concrete reinforcement or joint spacing is 0.01 units. This difference, occurring in all loops, is well within the replication error of the experiment and cannot be considered significant.

Similar comparisons of the effect of the design variables on the coefficients of friction indicated quite clearly that, within the limits of the study, pavement design has no significant effect on the resistance to skid.

Effect of Axle Load and Arrangement

The effect of axle load and axle arrangement (single or tandem) on the pavement surface wear is shown in Figures 3 and 4. The reduction of the coefficient of friction is plotted against wheel load with the reduction plotted upwards, indicating a decrease in the coefficient. Each plotted point is the mean of 48 tests, six series on the eight sections for each load. There appears to be a clear distinction between the single-axle loads and tandem-axle loads, the tandem-axle loads causing a greater reduction in the coefficients of friction.

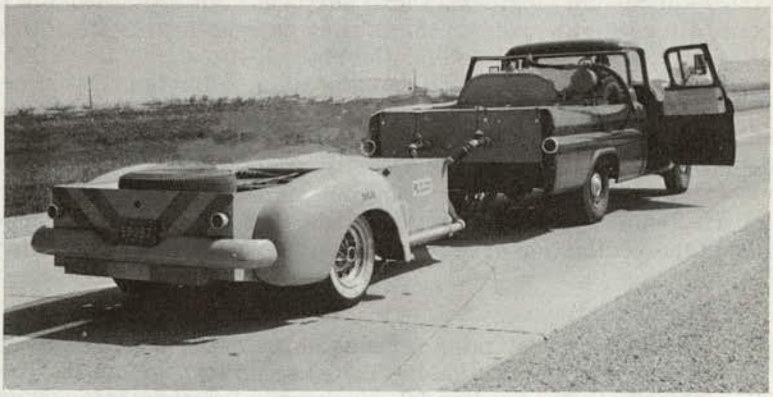

Figure 2. General Motors skid trailer.

There is little indication of any over-all trend that would suggest a reduction of the coefficient of friction due to an increase in load in the lighter axle loadings. However, there is a slight indication that this may be true for the heavier axle loadings. For both the flexible and rigid pavements a greater reduction of the coefficient of friction was experienced with the 30-kip single- and 48-kip tandem-axle loads than for the 22.4-kip single- and 40-kip tandem-axle loads.

The high reduction in the coefficient of friction for test sections designed for the 3-kip wheel load suggests a possible effect of the front axle. The only axle loads counted as axle load applications were those with the selected load. To keep the rate of selected load applications the same for pick-up trucks and tractor-trailer combinations, it was necessary to have double the number of vehicle trips carrying the 3-kip wheel load. The greater number of uncounted steering axles may account for the high reduction in the coefficient of friction.

Effect of Test Vehicle Speed

Figures 5 and 6 show the effect of the speed of the testing vehicle on the coefficient of friction measured on wet pavements. In each figure, the curves show, along with the mean relationships for all series of tests, the relationships when the test sections were newly constructed and at the end of the traffic testing period.

For each test series the results of the measurements on the 2-kip and 6-kip single-axle load sections were deleted because of incomplete data. Thus a point on the curve is the mean of 32 tests—four tests for each of the remaining loads. A point on the curve for all test series is the mean of 192 tests—four tests for each of the remaining loads for each series.

For all tests on wet pavements the measured coefficient of friction was substantially reduced with an increase in speed of 20 mph. The relationship appears to be curvilinear within the range of the test data. For tests on dry pavements the speed of the testing equipment had very little effect.

Dillard and Allen (2) have shown that for an excellent pavement the coefficient of friction was only slightly affected by the speed of the testing equipment, whereas for a poor pavement there was a substantial reduction. The curves for test series 1 and 6 (Fig. 5 and 6) clearly indicate that the condition of the pavements on the Road Test had little effect on the influence of the speed of the test vehicle.

Effect of Pavement Surface Condition

Figures 7 and 8 for the rigid and flexible pavement surfaces, respectively, show the effect of pavement surface conditions (wet or dry) on the coefficient of friction. Each point is the mean of four coefficients of friction of four test sections.

Dry tests show to a marked degree an increase in the coefficient for both pavement types. The over-all trend of the dry surface coefficient of friction is a decrease with the increasing load applications. Differences between axle loads and axle arrangements do not appear to influence the coefficient within the range of the tests. Also the seasonal variations do not appear to have any significant effect on the dry surface condition coefficients.

Effect of Axle Load Applications

With a range of loaded axle applications from 0 to 1, 100, 000 for all loads, the influence of the number of applications on the coefficient of friction was expected to be the most significant finding of this experiment.

As mentioned previously (see Table 3), the six test series were conducted as nearly as possible at regular intervals throughout the test traffic phase of the Road Test.

A typical set of data representing the change in coefficient of friction at 30 mph with increasing load applications for the 22.4-kip single-axle load is shown in Figure 9.

The over-all trend of the data is a decrease in the coefficient of friction with an increase in axle applications. However, the coefficients show an increase for two periods: from the summer 1959 test series to the spring 1960 test series, and from the summer 1960 to the fall 1960 test series.

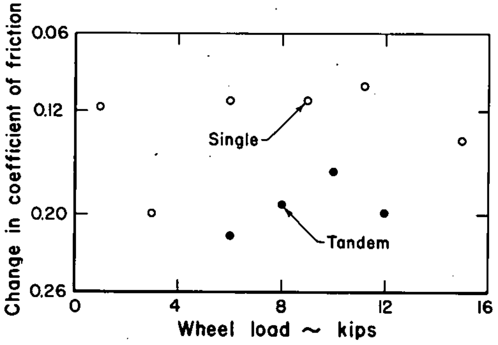

Figure 3. Influence of wheel load on rigid pavement coefficient of friction.

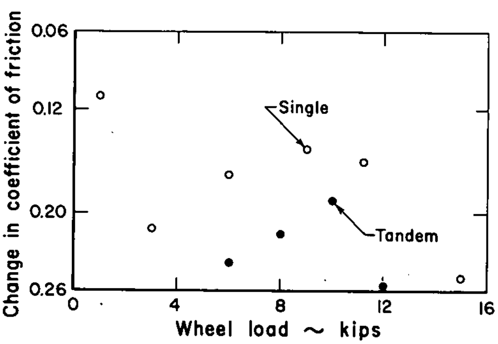

Figure 4. Influence of wheel load on flexible pavement coefficient of friction.

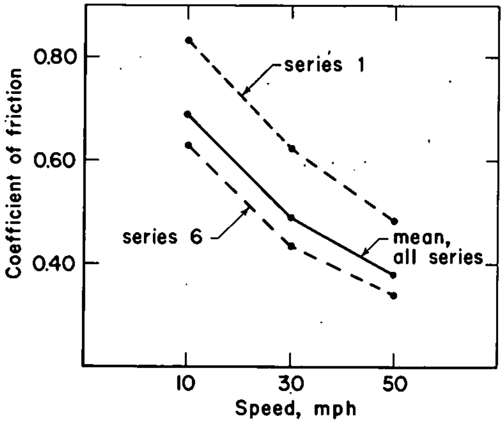

Figure 5. Influence of test vehicle speed on rigid pavement coefficient of friction.

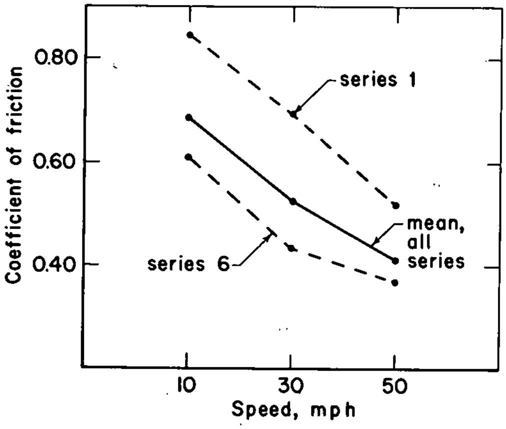

Figure 6. Influence of test vehicle speed on flexible pavement coefficient of friction.

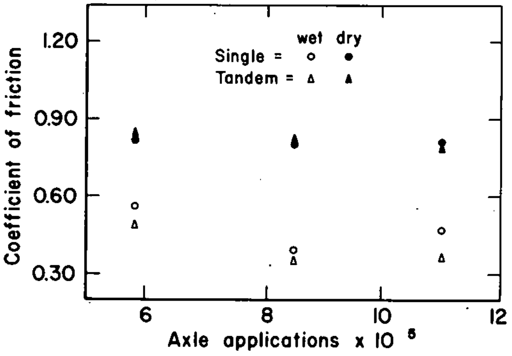

Figure 7. Influence of pavement surface conditions on rigid pavement coefficient of friction.

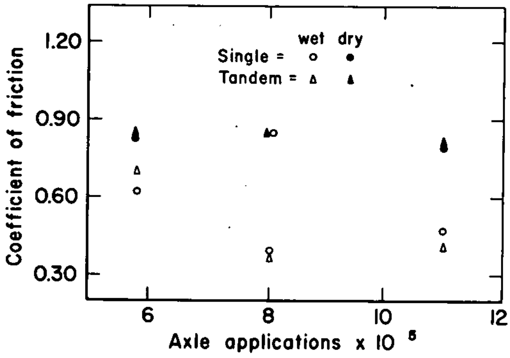

Figure 8. Influence of pavement surface conditions on flexible pavement coefficient of friction.

The first increase may be attributed to the influence of the freeze-and-thaw cycles and the scouring of the pavement surface by heavy rainfall immediately prior to the tests. The second increase could be associated with rainfall before the latter test series, which reduced the accumulation of dust and oil slicks on the pavement surface. Furthermore, the heavy rainfall prior to the summer 1959 tests may have reduced the dust and oil slick on the pavement surface, resulting in a higher coefficient of friction than one would normally expect. The scouring effect of heavy rainfall would appear, therefore, to have a significant effect on the coefficient of friction. Table 5 gives the rainfall accumulation for the two-week period preceding each test series.

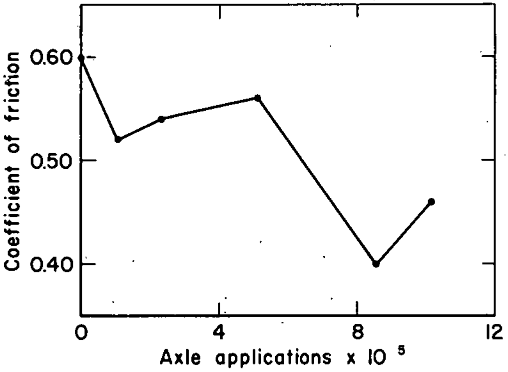

Figure 9. Influence of axle applications on coefficient of friction.

Other weather phenomena recorded during the test series are also given in Table 5. No apparent effect of these phenomena was observed, but further investigation of possible interactions may show some influence on the coefficient of friction.

TABLE 4

MEAN COEFFICIENT OF FRICTION FOR VARIOUS COMBINATIONS[a] OF PAVEMENT DESIGN AND LOAD[b]

Design Feature	Axle Load 2-6KS	 12KS 24KT	 18KS 32KT	 22.4KS 40KT	 30KS 48KT
Rigid pavement:					
Reinforced	0.57	0.50	0.52	0.50	0.46
Nonreinforced	0.56	0.49	0.53	0.50	0.47
Surface thickness:					
Second level	0.57	0.49	0.53	0.50	0.46
Third level	0.57	0.51	0.52	0.50	0.47
Subbase thickness:					
3 in.	0.57	0.51	0.53	0.49	0.47
6 in.	0.57	0.49	0.52	0.50	0.46
Flexible pavement:					
Surface thickness:					
First level	0.62	0.56	0.56	0.54	0.50
Second level	0.62	0.53	0.55	0.54	0.47
Base thickness:					
First level	0.62	0.53	0.56	0.54	0.49
Second level	0.62	0.56	0.56	0.55	0.48

[a] Flexible subbase values not shown—incomplete study.

[b] All values are the mean of six series of tests except those for the 12-kip single- and 24-kip tandem-axle loads, which were the mean of four series.

TABLE 5

RECORDED WEATHER PHENOMENA

Series	Rainfall, Two Weeks Preceding (in.)	Temperature Range (°F) Air	Rigid Pvt.	Flexible Pvt.
1	1.22	80-47	84-55	73-91
2	1.77	86-45	102-45	107-46
3	1.63	94-73	113-78	123-84
4	0.53	63-36	63-37	65-37
5	0.36	88-65	119-80	117-81
6	0.79	60-37	62-40	67-39

SUMMARY

In the research investigation reported here, the unique characteristics of the design, construction and treatment of the test sections on the AASHO Road Test presented an opportunity to evaluate certain controlled variables fully.

From the observations made previously in this report, the following briefly summarizes the effect of the variables on the coefficient of friction:

1. The coefficients of friction remained reasonably constant throughout the entire range of design thicknesses selected for study. However, this observation is limited, because the pavements selected for skid testing represented the thicker designs in each loop.

2. The coefficients of friction of pavement sections exposed to tandem-axle loads were considerably less than those for pavement sections exposed to single-axle loads. There appeared to be little effect of axle load on the coefficients of friction, except possibly for the increases observed with the heavier loads in the experiment.

3. A pronounced effect of the test vehicle speed on the coefficients of friction measured on wet pavements was noted in all test series. Pavement conditions from very good to fair did not appear to influence the relationship.

4. The findings of the surface condition study were as predicted. The coefficients of friction for the wet surface condition were in all instances considerably lower than the coefficients for the dry surface conditions.

The influence of axle load, axle arrangement, test vehicle speed and pavement design was not significant in the dry surface study; however, a general downward trend in the coefficients of friction was noted when related to the number of axle applications.

5. The most pronounced influence on the coefficients of friction was noted when viewed with the number of axle applications. This relationship, however, is affected by certain environmental factors. Careful observation of the phenomena contributing to the seasonal vairations allows for an explanation of the deviations from the downward trend.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to the General Motors Corporation for the use of the skid test equipment and for the assistance of thier personnel in preparing the data for analysis.

Indebtedness also is acknowledged to the staff members of the AASHO Road Test for thier assistance in the design of the experiment and in the interpretation of the test results.

REFERENCES

1. Skeels, P. C., "Measurements of Pavement Skidding Resistance by Means of a Simple Two-Wheel Trailer." HRB Bull. 186 (1958).

2. Dillard, J.H., and Allen, T.M., "Comparison of Several Methods of Measuring Road Surface Friction." HRB Bull. 219 (1959).

Appendix

DETAILS OF THE EXPERIMENT

Measurement of Coefficient of Friction

The coefficient of friction is defined in this report as the ratio of the horizontal force required to pull the trailer at a constant speed with the wheels locked to the vertical reaction at the wheels. The vertical reaction is determined by subtracting from the static weight on the trailer wheels the force exerted by a couple produced by the force in the drawbar and the wheel friction. Thus, by measuring the drawbar force the coefficient of friction may be determined. The General Motors skid trailer is designed to measure this force.

Materials Specification and Finishing Techniques

Portland Cement Concrete. Two coarse aggregates and one sand were blended together for the portland cement concrete. Both the coarse aggregate and the sand were obtained near the project site: the aggregate was predominantly dolomite and the sand was mostly siliceous.

The two coarse aggregates had maximum sizes of 2½ in. and 1½ in. and the sand had a fineness modulus of 2.90. The sieve analysis for the coarse aggregates and sand are given in Table 6; the lithological analysis for the coarse aggregates, in Table 7. Type 1 portland cement was supplied by one manufacturer from one continuous grinding and burning operation.

The design characteristics of the portland cement concrete are given in Table 8. Mean 14-day compressive strengths for concrete containing the 2½ in. and 1½ in. maximum size aggregates were 3,966 and 4,004 psi, respectively. Mean 14-day flexural strengths for concrete containing the 2½ in. and 1½ in. maximum size aggregates are 636 and 668 psi, the means of 394 and 67 tests, respectively.

The portland cement concrete was finished by the non-vibratory method. After the concrete had been deposited and spread between the forms, it was accurately struck off, screeded and consolidated with at least two passes of a non-vibrating finishing machine. It was further smoothed and consolidated by a mechanical longitudinal float. The floating operation was continued until the surface of the concrete was smooth, and at the proper crown and grade.

The surface was checked with a 10-ft straightedge; when most of the water sheen had disappeared, it was belted with one application of a mechanical belt. This was followed by edging, and final finish was obtained with two passes of a double thickness burlap drag.

Immediately after the finished concrete had attained sufficient set it was covered with two layers of burlap, which was saturated with water and kept wet until moved. The morning following the placement of the concrete, the forms and burlap were removed and the surface and edges of the pavement were covered with a layer of clean straw. The straw was then saturated with water, attaining a wet thickness of approximately 8-in., and was kept wet for the first three days. It was thoroughly wet down on the morning of the fourth day and remained in place until after test beams indicated that the concrete had attained a flexural strength of at least 500 psi.

Asphaltic Concrete, Surface Course. The coarse aggregate was predominantly crushed dolomitic limestone from near the project site. The maximum size for the surfacing course was ¾ in. Two sands, coarse and fine, were blended together for the fine aggregate to a specified fineness modulus of 2.35. The grain size analysis and percent of asphalt for the 96 extraction tests on surface course material is given in Table 9.

TABLE 6

SUMMARY OF GRADATION TESTS ON PCC AGGREGATES

Sieve Size	Gradation Formula Tolerances	Mean Percent of Material Passing	Standard Deviation
(a) Coarse Aggregate Size A (170 Tests)			
2½ in.	100	100	-
2 in.	90-100	96.3	3.45
1½ in.	62±7	63.5	6.11
1 in.	10±5	10.6	3.18
½ in.	0-5	3.8	2.14
(b) Coarse Aggregate Size B (171 Tests)			
1½ in.	100	100	-
1 in.	90-100	94.1	1.30
½ in.	38±5	37.9	1.65
No. 4	0-10	1.5	0.78
(c) PCC Sand (80 Tests)			
⅜ in.	100	100	-
No. 4	95-100	99.0	0.97
No. 8	85±5	84.1	1.55
No. 16	67±4	67.0	1.83
No. 30	46±4	45.4	1.51
No. 50	13±3	12.3	0.73
No. 100	3±2	2.7	0.46

TABLE 7

LITHOLOGICAL ANALYSIS OF PCC COARSE AGGREGATES

Rock Type	Percent Passing, by Weight					
	2 - 1½	1½ - 1	1 - ¾	¾ - ½	½ - ⅜	⅜ - No. 4
Dolomite	38	47	38	64	59	59
Argillaceous limestone	28	27	23	9	12	14
Soft sandstone	15	12	11	8	11	11
Hard sandstone	0	5	6	4	5	3
Chert	13	4	18	8	7	7
Diabase	4	0	0	2	2	2
Granite	2	2	2	3	3	4
Quartz	0	3	2	2	1	0

Other characteristics of the surface material are: Marshall stability, 2,000 lb; flow, 0.11 in.; voids by volume, 3.6 percent; and voids filled with asphalt, 77.9 percent.

Bituminous construction was performed in lane widths. Two spreading and finishing machines were used, one for each lane. While construction operations were being performed in one lane, the other machine was being positioned in the opposite lane so that the crew could move back and immediately start spreading in that lane. Sufficient material was kept on hand at all times to insure a continuous spreading operation throughout a test section. Delays in operation were confined to transition areas, except on rare occasions due to equipment failure.

TABLE 8

DESIGN CHARACTERISTICS PORTLAND CEMENT CONCRETE

Item	Surface Thickness 5 In. and Greater	 2.5-3.5 Inches
Cement content (bags/cu yd)	6.0	6.0
Water-cement ratio (gal/bag)	4.8	4.9
Volume of sand (% total agg. vol.)	32.1	34.1
Air content (%)	3-6	3-6
Slump (in.)	1.5-2.5	1.5-2.5
Maximum aggregate size (in.)	2.5	1.5

TABLE 9

SUMMARY OF EXTRACTION TEST RESULTS[a]

Sieve Size	Mix Design	Mean Value	Standard Deviation
¾ in.	100	100	-
½ in.	90±5	92	2.43
⅜ in.	80±5	81	3.17
No. 4	64±5	63	4.06
No. 10	45±4	46	2.99
No. 20	31±4	34	1.66
No. 40	20±4	22	2.06
No. 80	11±3	13	1.07
No. 200	5±1	5.9	1.16
Asphalt[b] (%)	5.4±0.3	5.2	0.18

[a] Ninety-six tests on surface course mixture.

[b] Percent asphalt by total weight of mix. Control tests have shown that the extraction tests underestimated asphalt by 0.1 to 0.2 percentage points.

TABLE 10

ROLLING WEIGHTS AND TEMPERATURES FOR BITUMINOUS CONCRETE CONSTRUCTION

Roller Set	Roller Weights (lb/in. width) Three Wheel[a]	 Pneumatic Tired	 Tandem	Section Thickness[b] (in.)
Heavy	300	300	250	15 (also all 9" base sections)
Intermediate	214	250	190	8 to 15
Light	180	200	120	8 or less

Mat Rolling Temperatures (°F) Three Wheel	 Pneumatic Tired	 Tandem
250 - 275	190 - 220	-[c]

[a] Based on 9-in. tire tread, inflation pressure 75 psi.

[b] Subbase plus base.

[c] While mat was still workable but had cooled sufficiently to prevent shoving.

TABLE 11

TIRE SIZES AND PRESSURES

Axle Load (kips)	Tandem or Single Axle	Tire Size	Tire Pressure (psi)
2	S	6:70x15	24
6	S	7:00x16	45
12	S	7:50x20	75
24	T	7:50x20	75
18	S	10:00x20	75
32	T	9:00x20	70
22.4	S	11:00x20	75
40	T	11:00x20	75
30	S	12:00x24	80
48	T	12:00x20	80

Compaction of each layer of bituminous mixture required the use of a three-wheel roller followed by a self-propelled pneumatic-tired roller, with final rolling by a tandem roller. Pneumatic-tired rollers were not being used extensively for compacting bituminous concrete, but experimental work indicated that the attained level of density more nearly corresponded to that produced by traffic on existing highways. The other requirements pertaining to the time of rolling and the speed and procedure for compacting the bituminous concrete courses were in line with normal construction practice.

The thickness of the subbase plus base was used as a guide in selecting the proper set of rollers for each structural section. At any indication that a section was being damaged or might be damaged, the set of rollers being used was immediately removed and replaced with the next lighter set of rollers or the number of passes of the rollers was reduced. Roller weights and mat temperatures used are given in Table 10.

Usually one pass of the three-wheel roller followed by eight passes of the pneumatic-tired roller was sufficient to obtain the required density on the layer being compacted. The tandem roller was considered only as a finish roller to remove the roller marks of the three-wheel and pneumatic-tired rollers, and sufficient number of passes were made over a layer to accomplish this. Experimental work indicated that little, if any, additional increase in density was obtained with the tandem roller.

A steel bristle broom drag was placed behind the spreading and finishing machine for the placement of the surface course to correct any slight tearing that might occur.

Tire Sizes and Pressures

Table 11 gives details of tire sizes and pressures for each load. Numerous makes of new tires and types of recaps were used in the operation and no attempt has been made to assoicate any make with a particular axle load. The pressure shown should be considered as nominal cold measurement.