FINAL REPORT

SLIPPERINESS OF HIGHWAY PAVEMENTS

PHASE I

by

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(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies.)

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SUMMARY

To gain knowledge of the wet friction levels needed for various traffic conditions, this study evaluated the relationships between (1) accumulated traffic volumes and pavement friction, and (2) percent wet accidents and pavement friction. In addition the study evaluated speed gradients and machine correlations, and selected thirty test sites for continued periodic testing under state funds.

Tests were performed at two-tenth mile intervals on 11,650 lane miles of pavement. The test data will be passed on to the Highway Department to be used as the nucleus of its future road pavement friction inventory.

In the study, sixty-two sites were tested at various speeds with the Council's skid trailer to provide data for developing friction — speed gradient curves. Speed gradients were not found to be different for any of the paving mixes normally used in Virginia, and the average gradient was about 0.7. This conclusion is based on the conditions under which the data were obtained, and would not necessarily be valid for varying water and tire tread depths.

At sixty-one of the sites, stopping distance tests were also performed so that a correlation could be established between the values obtained with the trailer and those obtained with the stopping distance car. The regression analyses performed on these sets of data indicate that the best predicting equations for stopping distance numbers occur when the trailer tests at 30 mph. Also, it appears that the relationships did not change in any orderly fashion with time.

Forty-six sites were tested to determine the relationship between accumulated traffic volumes and friction levels. It was found that non-polishing S-4 and S-5 mixes retain an average PSDN of 48 after 25-30 million vehicle passes. Non-polishing portland cement concrete mixes lost skid resistance more rapidly than do non-polishing S-4 and S-5 mixes, and on the average have a PSDN of about 44 after 20 to 25 million vehicle passes. I-2 and I-3 limestone mixes decrease in friction more rapidly than do the S-4, S-5, and portland cement concrete mixes, and reach an average PSDN of 42 after 16 million vehicle passes.

Five hundred and twenty-one sections on Virginia's interstate system, totaling 312.8 miles, were studied to determine the relationship between the percent of wet accidents and predicted stopping distance skid numbers. The sites were separated into four categories: open roadway, non-open roadway, open interchanges, and non-open interchanges.

It was found that the minimum PSDN for the traffic lanes of interstate roadways with a mean traffic speed of about 65-70 mph should be 42. It can be demonstrated that this value probably is about the same as that recommended by Kummer and Meyers in NCHRP Report 37, assuming that a different relationship exists between skid trailers and the stopping distance method than the one they used.

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INTRODUCTION

Virginia has for some years been quite conscious of the necessity for providing skid resistant roads for the traveling public. Every reasonable effort has been made to provide pavement surfaces that will stop a car traveling at 40 mph on a wet pavement within 133 feet after the brakes are locked, assuming that the car is equipped with good brakes and tires. In order to provide this type of pavement, Virginia has had to prohibit the use of highly polish susceptible aggregate in pavement surfaces on new construction projects, and allow only the fine portion of a bituminous mix to be made of polish susceptible materials on maintenance schedules on the primary system.

While it is true that Virginia has been a leader in combatting pavement slipperiness, it is also a fact that more needs to be learned of the friction requirements of the tire-pavement interface in order to provide safer roads. For instance, the criterion of 133 feet stopping distance from 40 mph under all wet road conditions should not be the sole one; speed limits, geometric designs, and traffic volumes certainly should be considered in determining the amount of tire-pavement friction needed.

PURPOSE

The purpose of this investigation was to provide the state of Virginia with information for determining the wet friction levels needed for various traffic conditions.[1] All pavement friction data for the analyses were obtained with the Council's skid trailer.[2]

SCOPE

The data collection and analyses are indicated in the following outline of the report.

1. Speed Gradients and Machine Correlation and Regression Analyses. Speed gradients were developed from data gathered from various pavement types and materials.

   Several regression analyses were performed between the Council's skid trailer and stop meter stopping distance car so that data collected by the skid trailer (reported as SN) could be used to predict what stopping distance skid numbers would have been obtained by the stopping distance car (reported as PSDN).

2. Traffic volume — PSDN Relationship. This analysis was made on roads constructed of three general types of paving materials: portland cement concrete, polish susceptible bituminous mixes, and polish resistant bituminous mixes.

3. Periodic Test Sites. Sites representative of common Virginia pavements were selected during the study for continued testing under state funds.

4. Percent Wet Accident — Friction Relationships. In compiling the information for determining the wet friction values needed for various traffic conditions, prime consideration was given to ascertaining the relationships between the percent wet accidents and stopping distance skid numbers. To the extent possible the geometric configurations of the roadways were considered. In developing the relationships, only data for the interstate system were analyzed.

   The compiled wet accident data were not limited to skidding accident statistics, since inadequate friction could promote accidents not involving skidding, i.e., breakaway and non-locked wheel deceleration accidents. In addition, it is sometimes impossible to determine from the accident reports whether skidding was a major contributing factor.

5. Appendix 1 — Skid Data. Within the confines of this study 11,650 lane miles of Virginia pavement were tested for skid resistance with the skid test trailer at a speed of 40 mph (in accordance with ASTM designation E274-T65). Included were 3,356 lane miles of interstate roads, or 99.8% of the total interstate system; 3,456 lane miles of arterial roads, or 46.4% of this system; and 3,638 lane miles of primary roads, or 20% of the primary system.

Tests were performed every two-tenths of a mile in each lane, and summarized for each lane mile. Sample computer output sheets are shown in Appendix 1. Other information collected was the test speed and standard deviation, the tire tread depth, the test surface temperature and the air temperature. Many of these data, along with additional skid data, have been used in this report. However, the greatest value of this mass of data is that it can serve as the foundation for Virginia's future road survey on skid resistance.

6. Appendix 2 — Data Systems. A great deal of insight was gained into the availability of the type of data needed for this study, in addition to the skid data. Consequently, there will be a considerable spin-off in the form of background knowledge for developing future data storage and retrieval systems for the Department, and relating them to current systems for accident and traffic volume data. These systems will include pavement surface placement data such as those on materials used in the construction, descriptive data such as age, mix type, etc., and skid data. Appendix 2 contains a coding and instruction manual for skid data, sight descriptive data, and general site materials data.

The greatest limitation of the study was the inability to rapidly collect, in a usable form, the amount of roadway geometric and pavement surface descriptive data needed to determine what wet friction levels are needed for various traffic conditions. Of all the data needed, the skid data might be the easiest to collect; the real difficulty is locating and reducing the supporting data into a form compatible with the skid data. In addition to the difficulty cited, the following is noted concerning materials, texture and manufacturing practices.

1. Materials — On roads carrying over 1,000 vehicles per day, Virginia generally does not permit the use of polish susceptible aggregates. Thus the lower range of skid numbers is not included in this study. While this is an admirable situation for a highway department to be in, it does reduce the effectiveness of this type of research.

2. Texture and manufacturing practices — As a general rule Virginia does not have any real harsh textures on its high traffic volume roads. In the past the portland cement concrete roads have been finished with one coverage of a burlap drag and the bituminous roads have all been hot plant mixes laid with a regular paving machine. In addition, the gradation has been such that, for even the coarsest of the surface mixtures, the finished surface was rather smooth. Some intermediate mixes were included in the study. These mixes are coarser than surface mixes but not as coarse as base mixes, and are usually used in a leveling course between the base and surface mixes. However, they are found only on low traffic volume roads.

Speed Gradients and Machine Correlation and Regression Analyses

Speed Gradients

Sixty-two sites were tested at variable speeds in order to develop skid number — speed gradient curves for mix types found in Virginia. The data collect at these sites are presented in Table 1. At sixty-one sites, stopping distance skid tests were performed for at least one test speed. For twenty-one sites, the data shown are the average of tests either in both traffic lanes or both passing lanes on dual divided highways and are the averages of ten tests. Otherwise, at sites where only one lane was tested, indicated by (1), the skid number shown is the average of five tests.

Skid number — speed gradient curves were developed for I-2 and I-3 bituminous mixes, S-4 and S-5 mixes, portland cement concrete mixes, sprinkle mixes (I-2 mix with aggregate sprinkled and rolled into the surface during construction) and Weblite mixes (lightweight aggregate mixes similar to S-5 mixes). See Appendix 3 for a description of Virginia's bituminous mixes. The curves developed for the various mixes are shown in Figures 1 - 5. The sets of curves for each mix type were visually inspected and those appearing to have non-average slopes with regard to the majority have been indicated by heavy lines.

The aggregate type and accumulated traffic data for each site were reviewed in an attempt to determine possible reasons for the non-average slopes. These data are presented in Table II for I-2 and I-3 mixes. Sites 3, 4, 5, 6, and 25 seemed to have steeper than average slopes. Of these, two (4 and 25) were constructed with an extremely polish susceptible limestone Chemstone (2), which may account for the steeper slope. For the other sites (3, 5, and 6) there is no apparent reason for the steeper slope other than for site 5, where the surface was slightly flushed with asphalt. Also, there is no apparent reason for the one site (13), that has a less than average slope.

The aggregate material and accumulated traffic data for the S-4 and S-5 mixes are shown in Table III. As can be seen in Figure 2, there are only three curves with non-average gradients. Two of these sites, 44 and 45, have less than average slopes, and one, site 39, has a slope steeper than average between 40 and 60 mph. As with the I-2 and I-3 mixes, it is difficult to explain the difference in slopes. All the sites, with the exception of site 52, were constructed of 100% non-polishing aggregate, and the sites (44 and 45) with the less than average slopes had more accumulated traffic than any of the other sites. The steeper slope at site 39 may be a reflection of more accumulated traffic than at the other sites with the exception of 37, 44, and 45. It is interesting to note that the one blended limestone mix (site 52) had the same general slope as the other mixes, but it also had a low accumulated traffic volume.

Table IV contains the aggregate material and accumulated traffic data for portland cement concrete mixes. As shown in Figure 3 seven sites had steeper than average slopes, which again are difficult to explain. All mixes had similar materials and all were finished with a light burlap drag, thus little difference in texture is likely, except as affected by accumulated traffic. It is interesting to note that of the seven sites with steeper than average slopes, five (32, 34, 58, 60, and 62) were in passing lanes and had relatively low accumulated traffic, and thus probably had more texture than many of the other sites. This occurrence, i.e., steeper slopes associated with more texture, seems improbable; but it must be remembered that there was actually little texture at any of the sites. Also, of the five sites mentioned, only one (58) had a lower skid number at any test speed than the traffic lane (s) at the same location. The steeper slope at these sites may indicate a rapid deterioration of the effect of a small amount of texture. This possibility is supported by the fact that in most cases the steeper slopes occur between 20 and 40 mph and are of little difference between 40 and 60 mph.

No additional tables were prepared for the sprinkle mixes since the materials data are available in Table I, and accumulated traffic volumes are the same for all sites (650,090).

The sprinkle materials indicated were placed on 100% limestone I-2 mixes. As can be seen from Figure 4, sites 19 and 20 had less than average slopes. Since for both of these sites the sprinkle material was slag, it appears that the difference in the slopes is attributable to this material.

Mix data and accumulated traffic data for the Weblite mixes are presented in Table V. In some instances the same site was tested twice (at different times), as indicated in Table V by a site number in parentheses. For instance, site 11 is the same site as site 10, site 26 is the same as 9, etc.

Two sites, 26 and 11, had slopes which were abnormal as compared to the other curves. In order to better analyze the possible reason for this difference, the sites were broken into groups so that identical sites could be more easily compared. These curves are presented in Figure 6, and it appears that the non-average slopes of sites 11 and 26 are probably due to testing errors.

Other things are interesting to note from Figure 6. First, generally the skid numbers are higher where the percent of Weblite in the mix is relatively high. Second, the effect of accumulated traffic is clearly illustrated between groups 2 and 3, where the skid number is much lower in the traffic lanes. Third, the tests run in the spring (solid circles) yield higher skid numbers than those run in the late summer (open circles), which is an occurence to be expected according to many researchers.[3] The one unexplained variation between groups 4 and 5 may be due to a difference in the asphalt contents of the two mixes (7.5% for group 4 and 8.1% for group 5). One last observation is that the slopes appear to become slightly steeper for the groups having the lower skid numbers.

In order to compare slopes between mix types several average speed gradients were developed for each mix. Average speed gradients were developed for sites where the 40 mph trailer skid number was 30-39, 40-49, 50-59, 60-69, 70-79, 80-89, and 90-99. These average speed gradients are shown in Figures 7-11 for the various mixes.

It is evident from these figures that there are very few differences in the slopes of the average curves shown, either within or between mixes. This absence of differences is even more clearly illustrated in Figure 12, where the total average curves for each mix type are shown. As can be determined from these curves the average gradient is 0.7, i.e., for each mile per hour increase in speed the skid number decreases by 0.7.

Based on the surfaces tested and the method of test, there do not appear to be any significant differences in the skid number—speed gradients for common mix types found in Virginia. More differences exist within given mix types, and they are probably due in most cases to the different materials used in the mixes. The authors certainly feel more research is needed in this area, especially on the effects of tire tread depths and water depths at the time of testing.

Machine Correlation and Regression Analyses

In the opinion of the authors, skid data are more meaningful if analyzed and reported as stopping distance skid numbers. For this reason, several regression analyses were performed with the trailer skid numbers as the independent variable and the car stop meter skid numbers as the dependent variable. Later these equations will be used to determine predicted car skid numbers (PSDN). Each data point used in the various analyses is an average value of five tests for both the car and trailer.

As mentioned earlier, at sixty-one of the sixty-two sites where the trailer tested at variable speeds the stopping distance car was used to obtain tests at 40 mph, and in some cases at variable speeds. Results from twenty-three of the regression analyses are shown in order to determine how much the relationship might change with time.

Several things shown in Table VI are of interest. First, the best relationships are obtained with the trailer tests at 30 mph. These analyses (trailer at 30 mph) show the highest correlation coefficients and lowest standard errors in the five groups for which trailer speed was used. Normally, trailer testing in Virginia is done at 40 mph. Perhaps, based on the results shown in Table VI, consideration should be given to lowering the test speed to 30 mph. Second, though the curves did change from group to group, there did not appear to be any orderly change with regard to time. Curves from each group for the trailer at 40 mph versus the car at 40 mph analyses are shown in Figure 13 and the same data for the 30 mph analyses are shown in Figure 14. Because no noticeable effect of time could be established, the 40 mph analyses for all sites (I-62) was used for predicting stopping distance skid numbers.

TABLE I

SKID DATA COLLECTED FOR DEVELOPMENT OF SKID NUMBER — SPEED GRADIENT CURVES

Site	County	Route	Lanes	Location	Speeds Tested - Car *					Speeds Tested - Trailer **					Mix Type
					20	30	40	50	60	20	30	40	50	60	
1	Shenandoah	55	Traffic	0.5 Mi. West Rt. 11			46			67	62	56	50		I - 2
2	"	55	"	1.3 Mi. West Rt. 11			42			66	58	54	51		I - 3
3	"	55	"	0.5 Mi. West Rt. 81			46			68	62	52	50		I - 2
4	"	55	"	1.5 Mi. West Rt. 714	40	42	36	32		50	48	41	36		I - 3
5	"	55	"	0.6 Mi. West Rt. 741	48	46	46	44		66	60	51	46		I - 3
6	"	55	"	0.6 Mi. West Rt. 756	54	54	55	53		78	68	60	57		I - 2
7	Bedford	460	Passing (1)	0.2 Mi. West Rt. 680		61	65	65			88	84	81		Weblite
8	"	460	" (1)	0.6 Mi. West Rt. 680		64	61	61			84	73	72		Weblite
9	"	460	Traffic (1)	"		54	52	48			59	52	48		Weblite
10	"	460	" (1)	0.4 Mi. West Rt. 680		52	45	44			69	60	55		Weblite
11	"	460	" (1)	0.3 Mi. West Rt. 680		56	52	45			75	70	57		Weblite
12	"	460	" (1)	0.2 Mi. West Rt. 680		57	54	51			78	66	66		Weblite
13	Shenandoah	55	" (1)	Int. Rts. 55 & 794		42	42				54	52			I - 2
14	"	55	"	0.1 Mi. West Rt. 761		39	41				57	53			I - 3
15	"	55	"	0.5 Mi. West Rt. 81		47	46	45			58	54	48		I - 2
16	Rockingham	340	"	0.95 Mi. North Rt. 659		62	58				82	70			Sprinkle Weblite
17	"	340	" (1)	1.0 Mi. North Rt. 659		52	51				72	60			Sprinkle Granite
18	"	340	" (1)	1.0 Mi. North Rt. 659		63	58				78	60			Sprinkle Weblite
19	"	340	" (1)	1.75 Mi. North Rt. 659		64	63				83	79			I-2 Sprinkle # 8 Slag
20	"	340	" (1)	1.7 Mi. North Rt. 659		64	64				89	83			Sprinkle Slag Sand
21	"	340	" (1)	1.9 Mi. North Rt. 659		63	64				89	78			Sprinkle Fine Weblite
22	"	340	" (1)	1.7 Mi. North Rt. 659		63	62				82	67			Sprinkle #8 Crushed Gravel
23	Shenandoah	55	"	0.2 Mi. West Rt. 628		47	44				56	50			I - 3
24	"	55	"	0.4 Mi. West Rt. 628		51	48				63	58			I - 2
25	"	55	"	0.4 Mi. West Rt. 754		34	34				44	36			I - 3
26	Bedford	460	Traffic (1)	0.6 Mi. West Rt. 680		56	52	40			75	70	48		Weblite
27	"	460	Passing(1)	0.6 Mi. West Rt. 680		64	59	58			88	80	78		Weblite
28	"	460	Traffic (1)	0.2 Mi. West Rt. 680		59	55	52			80	72	68		Weblite
29	"	460	Traffic (1)	0.4 Mi. West Rt. 680		51	45	40			67	57	48		Weblite
30	"	460	Passing (1)	0.4 Mi. West Rt. 680		69	67	66			96	93	92		Weblite

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TABLE I (continued)

Site	County	Route	Lanes	Location	Speeds Tested - Car * 20	30	40	50	60	Speeds Tested - Trailer ** 20	30	40	50	60	Mix Type
31	Greenville	95	Traffic (1)	0.23 Mi. North Rt. 627			59			80		64		52	Concrete
32	"	95	Passing (1)	" " "			63			98		80		60	Concrete
33	"	95	Traffic	2.7 Mi. North Rt. 629			54			82		66		54	Concrete
34	"	95	Passing	2.7 Mi. North Rt. 629			61			96		76		56	Concrete
35	Sussex	301	Traffic (1)	5.1 Mi. North Greenville			56			91		73		60	S - 4
36	"	301	Passing (1)	5.1 Mi. North Greenville			60			98		82		68	S - 4
37	"	301	Traffic (1)	1.5 Mi. North Greenville C. L.			53			77		65		52	S - 4
38	"	301	Passing (1)	1.5 Mi. North Greenville C. L.			61			94		78		62	S - 4
39	Prince George	95	Traffic	9.0 Mi. North Sussex C. L.			60			89		74		55	S - 5
40	"	95	Passing	9.0 Mi. North Sussex C. L.			64			95		78		62	S - 5
41	Henrico	95	Traffic (1)	1.25 Mi. South Rt. 668			40			71		58		49	Concrete
42	"	95	Center (1)	1.25 Mi. South Rt. 668			46			79		65		53	Concrete
43	"	95	Passing (1)	1.25 Mi. South Rt. 668			51			85		71		60	Concrete
44	Hanover	95	Traffic (1)	9.8 Mi. North Henrico C. L.			55			85		71		62	S - 4
45	"	95	Passing (1)	9.8 Mi. North Henrico C. L.			57			86		76		65	S - 4
46	Henrico	95	Traffic (1)	3.3 Mi. North of Grooves			44			71		58		49	Concrete
47	"	95	Center (1)	3.3 Mi. North of Grooves			52			79		65		53	Concrete
48	"	95	Passing (1)	3.3 Mi. North of Grooves			57			83		68		59	Concrete
49	"	95	Traffic (1)	2.7 Mi. North of Grooves			48			71		60		50	Concrete
50	"	95	Center (1)	2.7 Mi. North of Grooves			54			77		64		51	Concrete
51	"	95	Passing (1)	2.7 Mi. North of Grooves			55			82		66		55	Concrete
52	Lee	58	Traffic	Rt. 421 to Powell Ridge							70	64			S - 4
53	Caroline	95	Traffic	1.0 Mi. North of Rt. 207			53			82		68		60	Concrete
54	"	95	Passing	1.0 Mi. North of Rt. 207			57			88		75		64	Concrete
55	"	95	Traffic	7.0 Mi. North of Rt. 207			48			74		61		49	Concrete
56	"	95	Passing	7.0 Mi. North of Rt. 207			54			88		68		56	Concrete
57	Spotsylvania	95	Traffic (1)	4.2 Mi. North Caroline C. L.			41			64		49		41	Concrete
58	"	95	Passing (1)	4.2 Mi. North Caroline C. L.			44			70		47		40	Concrete
59	Stafford	95	Traffic (1)	1.4 Mi. North Spotsylvania C. L.			48			76		61		52	Concrete
60	"	95	Passing (1)	1.4 Mi. North Spotsylvania C. L.			52			85		64		54	Concrete
61	Prince William	95	Traffic (1)	5.5 Mi. North Stafford C. L.			40			67		48		37	Concrete
62	"	95	Passing (1)	5.5 Mi. North Stafford C. L.			51			85		62		47	Concrete

* Car values in stopping distance numbers (SDN).
** Trailer values in skid numbers (SN).

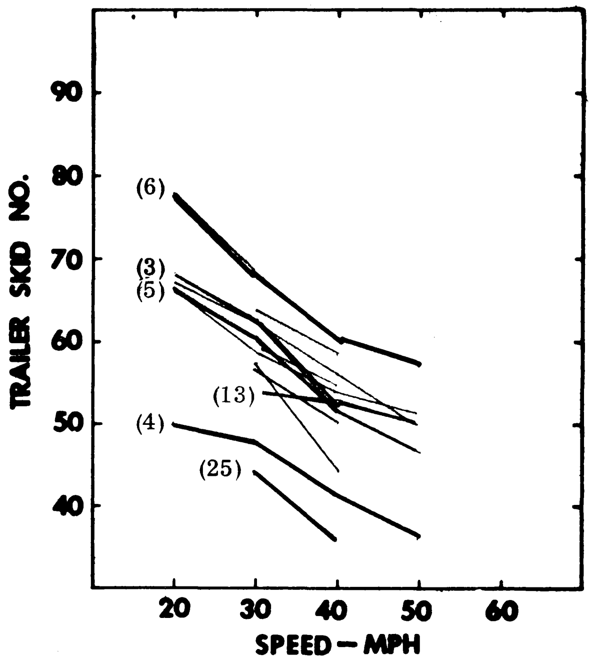

Figure 1. Skid number-speed gradient curves for I-2 and I-3 mixes.

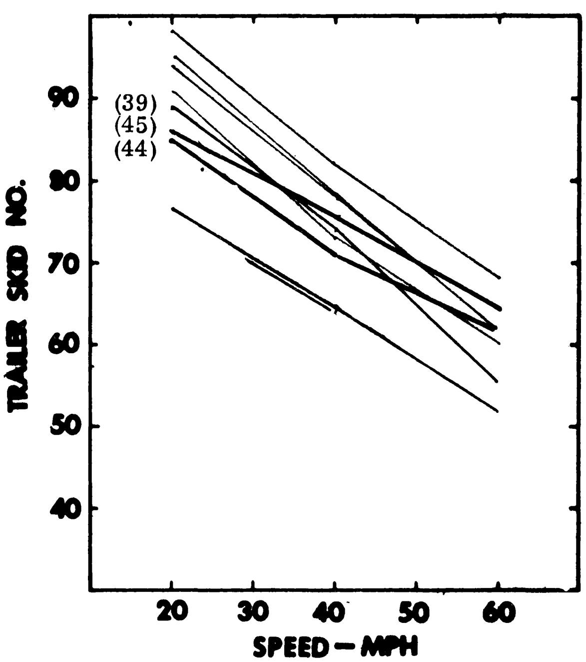

Figure 2. Skid number-speed gradient curves for S-4 and S-5 mixes.

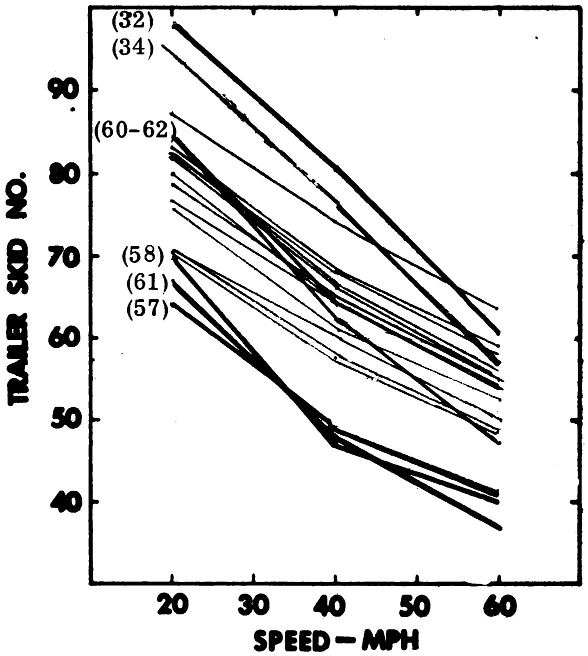

Figure 3. Skid number-speed gradient curves for portland cement concrete mixes.

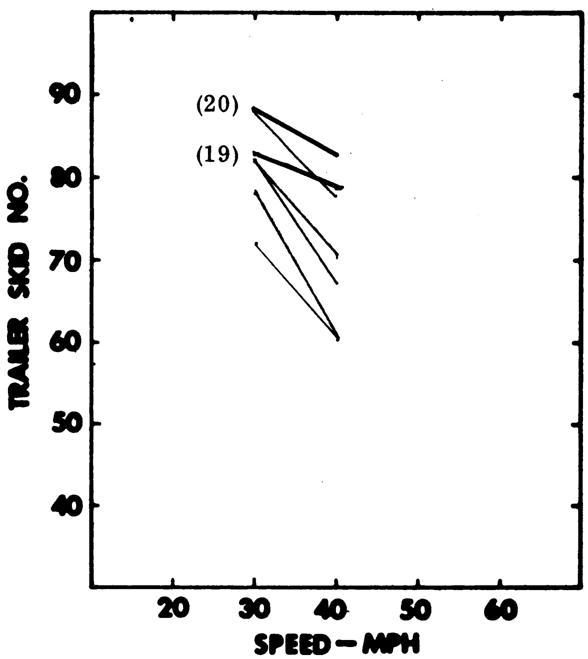

Figure 4. Skid number-speed gradient curves for sprinkle mixes.

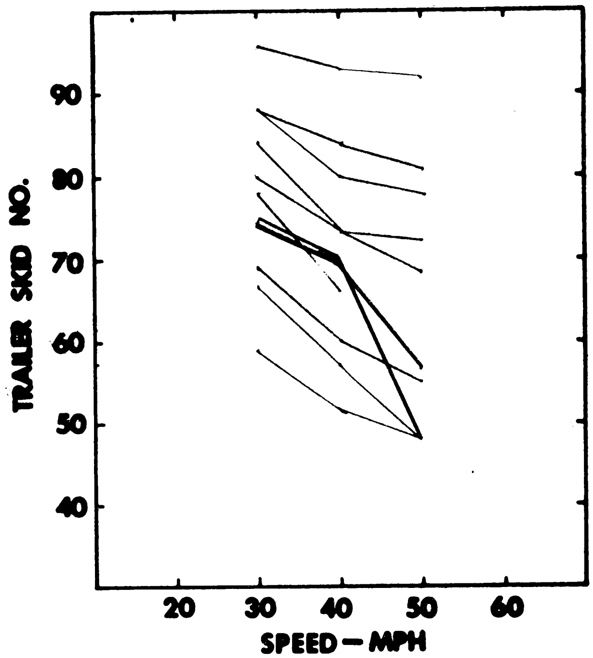

Figure 5. Skid number-speed gradient curves for weblite mixes.

TABLE II

DESCRIPTION OF AGGREGATE MATERIALS AND ACCUMULATED TRAFFIC FOR I-2 AND I-3 MIXES

Site	Year Placed	Description of Aggregate Materials	Accumulated Traffic (Hundreds)
1	1965	100% Chemstone Limestone (1)	11,200.9
2	1962	100% Tom's Brook Limestone	15,676.8
3	1965	100% Chemstone Limestone (1)	7,382.1
4	1961	100% Chemstone Limestone (2)	9,248.2
5	1962	100% Tom's Brook Limestone (Flushed)	8.550.1
6	1965	100% Chemstone Limestone (1)	5,908.4
13	1965	100% Chemstone Limestone (1)	11,200.9
14	1962	100% Tom's Brook Limestone	15,676.8
15	1965	100% Chemstone Limestone (1)	7,382.1
23	1962	100% Tom's Brook Limestone (Flushed)	8,550.1
24	1965	100% Chemstone Limestone (1)	5,908.4
25	1961	100% Chemstone Limestone (2)	9,248.2

TABLE III

DESCRIPTION OF AGGREGATE MATERIALS AND ACCUMULATED TRAFFIC FOR S-4 AND S-5 MIXES

Site	Year Placed	Description of Aggregate Materials	Accumulated Traffic (Hundreds)
35	1969	15% #78 Granite, 17% #10 Granite, 68% Local Sand	17,636.8
36	1969	15% # 78 Granite, 17% # 10 Granite, 68% Local Sand	4,409.0
37	1967	Unknown - 100% Polish Resistant	53,468.0
38	1967	Unknown - 100% Polish Resistant	13,367.0
39	1969	80% S-5 Blend Southern Materials, 20% Conc. Sand	25,211.7
40	1969	80% S-5 Blend Southern Materials, 20% Conc. Sand	6,014.0
44	1969	Unknown - presumed Massaponax or Mattaponi Sand and Gravel Company	314,676.2
45		Unknown - presumed Massaponax or Mattaponi Sand and Gravel Company	136,390.8
52	1968	55% Natural Concrete Sand, 45% #10 Limestone	9,198.0

TABLE IV

DESCRIPTION OF AGGREGATE MATERIALS AND ACCUMULATED TRAFFIC FOR PORTLAND CEMENT CONCRETE MIXES

Site	Year Placed	Description of Aggregate Materials	Accumulated Traffic (Hundreds)
31	1959	# 4 Granite and Silica Sand	146,631.4
32	1959	# 4 Granite and Silica Sand	28,555.8
33	1963	# 4 Granite and Silica Sand	123,176.8
34	1963	# 4 Granite and Silica Sand	24,812.5
41	1959	# 3 and # 57 Granite and Silica Sand	151,505.9
42	1959	# 3 and # 57 Granite and Silica Sand	239,650.1
43	1959	# 3 and # 57 Granite and Silica Sand	100,754.6
46	1962	# 3 and # 57 Crushed Stone and Silica Sand	228,703.0
47	1962	# 3 and # 57 Crushed Stone and Silica Sand	145,241.0
48	1962	# 3 and # 57 Crushed Stone and Silica Sand	92,753.7
49	1962	# 3 and # 57 Crushed Stone and Silica Sand	228,703.0
50	1962	# 3 and # 57 Crushed Stone and Silica Sand	145,241.0
51	1962	# 3 and # 57 Crushed Stone and Silica Sand	92,753.7
53	1964	# 3 and # 57 Crushed Stone and Silica Sand	245,919.6
54	1964	# 3 and # 57 Crushed Stone and Silica Sand	90,053.8
55	1964	# 3 and # 57 Crushed Stone and Silica Sand	243,136.3
56	1964	# 3 and # 57 Crushed Stone and Silica Sand	88,301.9
57	1964	# 3 and # 57 Crushed Stone and Silica Sand	243,136.3
58	1964	# 3 and # 57 Crushed Stone and Silica Sand	88,301.9
59	1965	# 3 and # 57 Crushed Stone and Silica Sand	213,223.9
60	1965	# 3 and # 57 Crushed Stone and Silica Sand	81,057.4
61	1969	# 3 and # 57 Crushed Stone and Silica Sand	111,876.7
62	1964	# 3 and # 57 Crushed Stone and Silica Sand	62,204.5

TABLE V

DESCRIPTION OF AGGREGATE MATERIALS AND ACCUMULATED TRAFFIC FOR WEBLITE MIXES

Site	Year Placed	Description of Aggregate Materials	Accumulated Traffic (Hundreds)
7	1966	57% Limestone Screenings, 43% Weblite	7,695.6
8	1966	80% Limestone Screenings, 20% Weblite	7,695.6
9	1966	80% Limestone Screenings, 20% Weblite	43,698.3
10	1966	71% Limestone Screenings, 29% Weblite	43,698.3
11 (10)	1966	71% Limestone Screenings, 29% Weblite	43,698.3
12	1966	71% Limestone Screenings, 29% Weblite	43,698.3
26 (9)	1966	80% Limestone Screenings, 20% Weblite	49,698.3
27 (8)	1966	80% Limestone Screenings, 20% Weblite	8,795.0
28 (12)	1966	71% Limestone Screenings, 29% Weblite	49,698.3
29 (10)	1966	71% Limestone Screenings, 29% Weblite	49,698.3
30 (7)	1966	57% Limestone Screenings, 43% Weblite	8,795.0

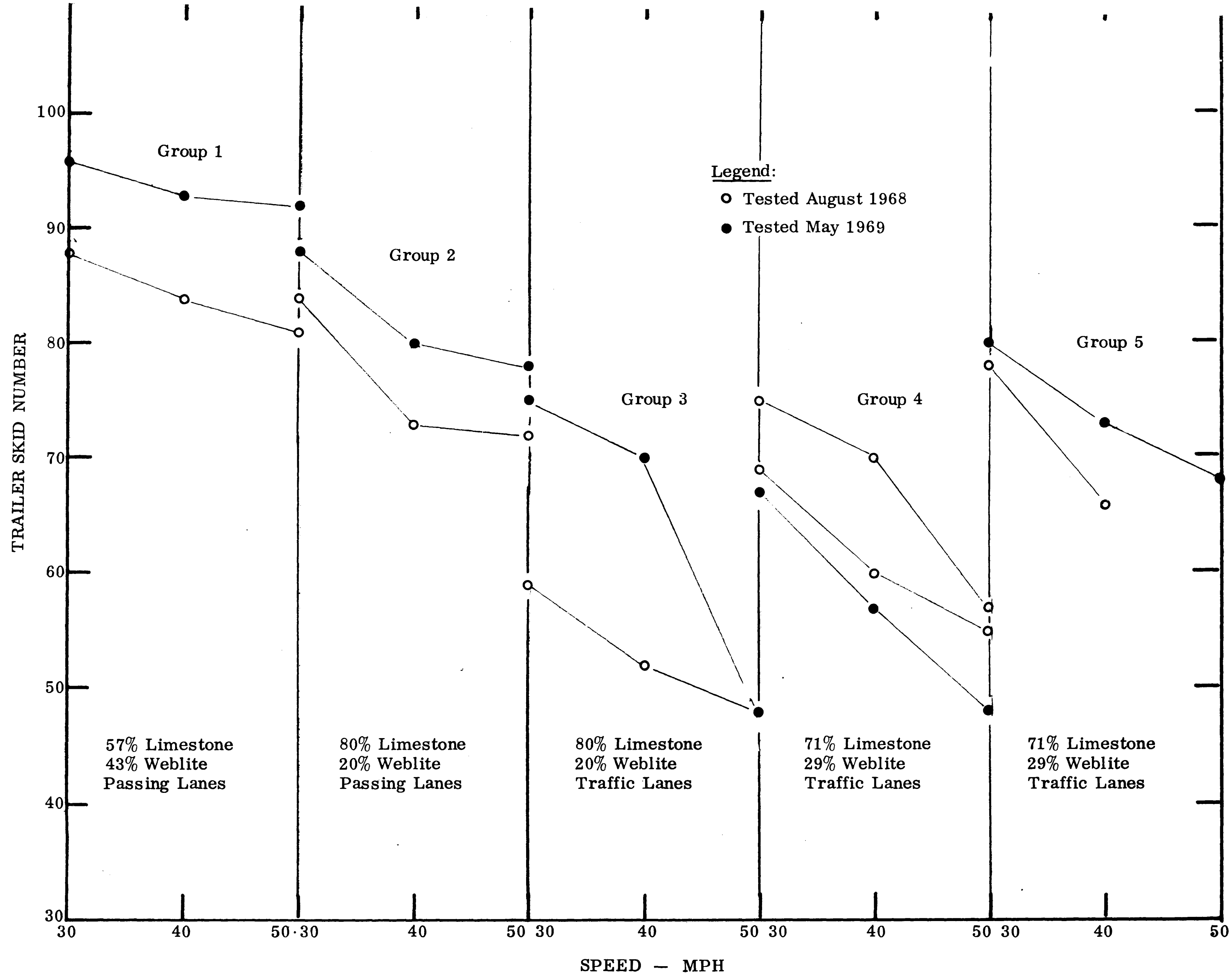

Figure 6. Skid number-speed gradient curves for Weblite mixes.

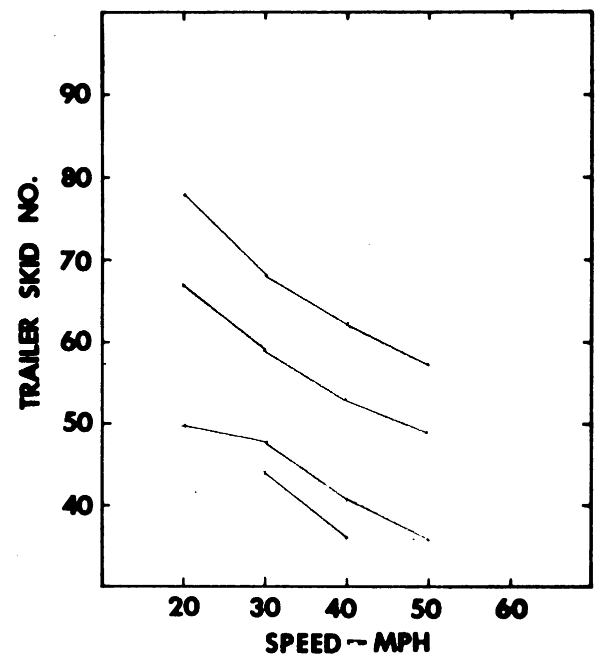

Figure 7. Average skid number-speed gradient curves for I-2 and I-3 mixes.

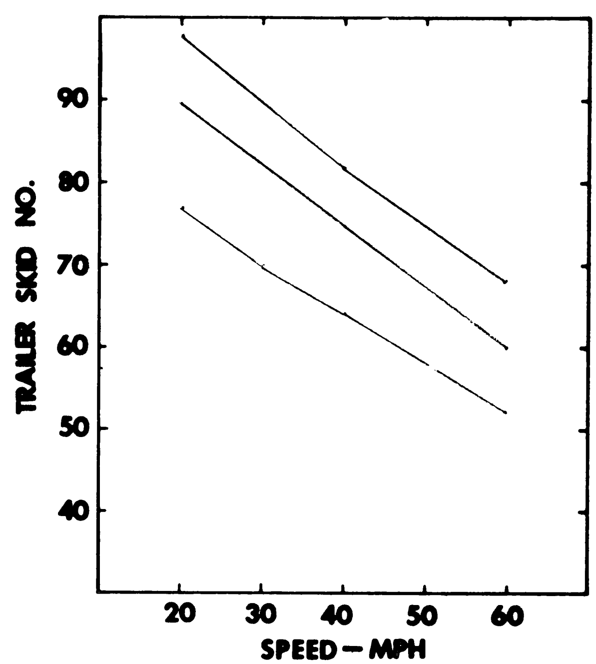

Figure 8. Average skid number-speed gradient curves for S-4 and S-5 mixes.

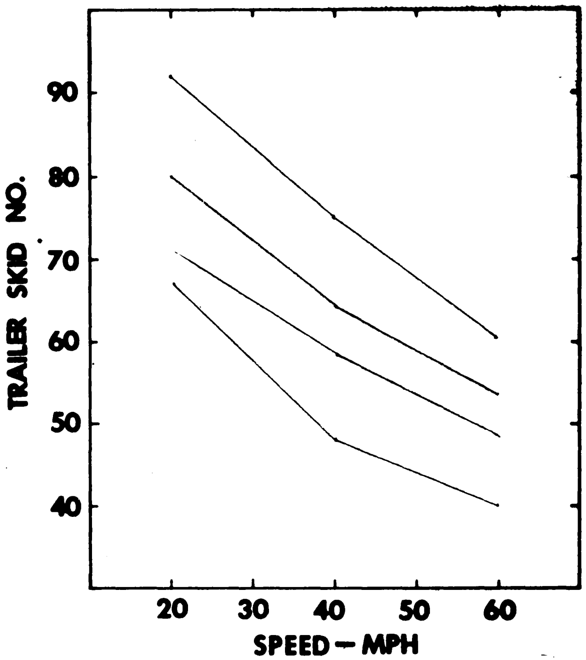

Figure 9. Average skid number-speed gradient curves for portland cement concrete mixes.

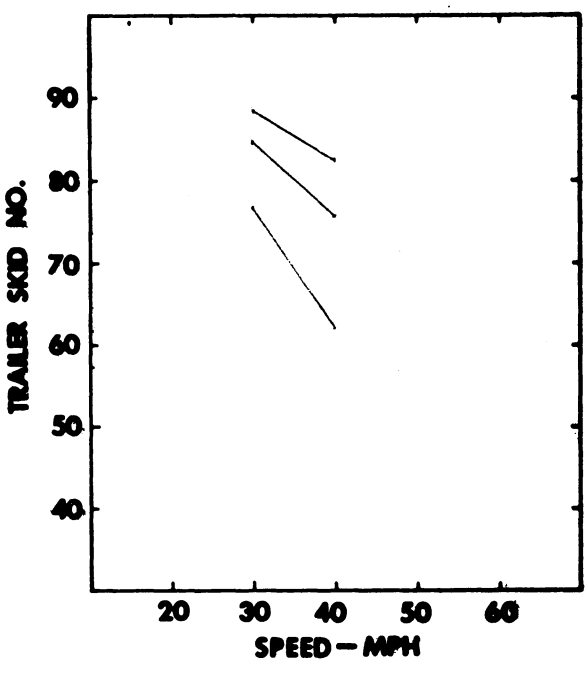

Figure 10. Average skid number-speed gradient curves for sprinkle mixes.

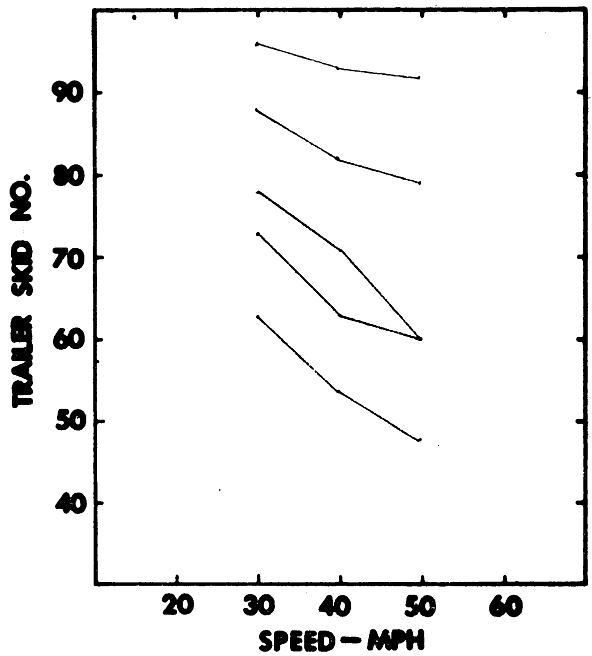

Figure 11. Average skid number-speed gradient curves for weblite mixes.

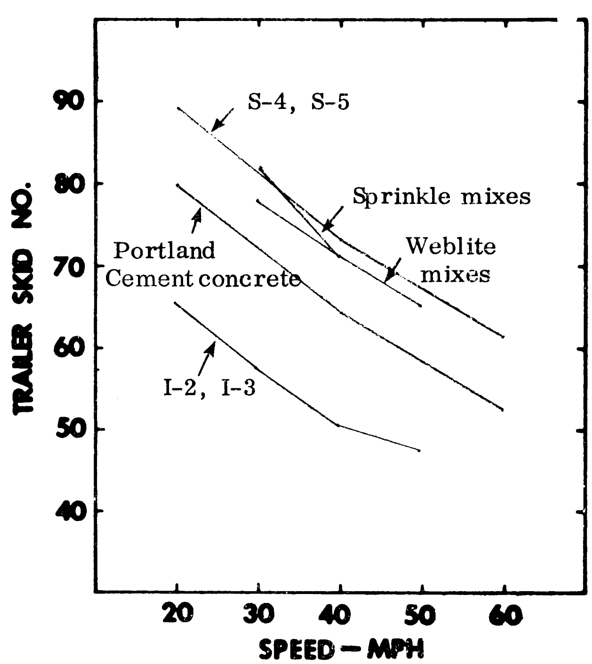

Figure 12. Average skid number-speed gradient curves for all mixes.

TABLE VI

REGRESSION ANALYSES GROUPED
BY TIME PERIODS

Group	Sites	Time Tested	Regression Analysis Trailer (x)	Car (y)	Equation	N	R	Std. Error
1	1 - 6	April - May, 1968	30 mph	40 mph	y = 0.89x - 7.7	10	0.93	2.52
			40 mph	40 mph	y = 0.81x + 2.7	12	0.83	3.51
			50 mph	40 mph	y = 0.40x + 26.6	12	0.61	4.15
2	7 - 15	August - Sept., 1968	30 mph	40 mph	y = 0.58x + 10.7	12	0.91	3.52
			40 mph	40 mph	y = 0.66x + 9.1	12	0.91	3.64
			50 mph	40 mph	y = 0.54x + 20.7	7	0.89	3.70
3	16 - 25	Sept., 1968	30 mph	40 mph	y = 0.65x + 6.0	16	0.97	2.59
			40 mph	40 mph	y = 0.67x + 10.7	16	0.94	3.57
4	26 - 30	May, 1969	30 mph	40 mph	y = 0.72x - 2.9	5	0.99	1.12
			40 mph	40 mph	y = 0.62x + 9.6	5	0.99	0.52
			50 mph	40 mph	y = 0.40x + 28.7	5	0.94	3.10
5	31 - 51	March, 1970	20 mph	40 mph	y = 0.63x + 2.04	25	0.87	3.12
			40 mph	40 mph	y = 0.75x + 2.9	25	0.85	3.29
			60 mph	40 mph	y = 0.76x + 12.4	25	0.64	4.83
6	52 - 62	April - May, 1970	20 mph	40 mph	y = 0.64x - 0.5	15	0.94	1.92
			40 mph	40 mph	y = 0.58x + 13.4	15	0.96	1.55
			60 mph	40 mph	y = 0.57x + 2.0	15	0.95	1.88
1 - 4	1 - 30		30 mph	40 mph	y = 0.62x + 7.9	43	0.95	2.96
			40 mph	40 mph	y = 0.63x + 11.6	45	0.92	3.56
			50 mph	40 mph	y = 0.47x + 2.4	43	0.88	3.64
1 - 6	1 - 62		20 mph	40 mph	y = 0.68x - 2.0	40	0.91	2.82
			40 mph	40 mph	y = 0.63x + 11.2	112	0.92	3.01
			60 mph	40 mph	y = 0.70x + 1.5	40	0.79	4.11

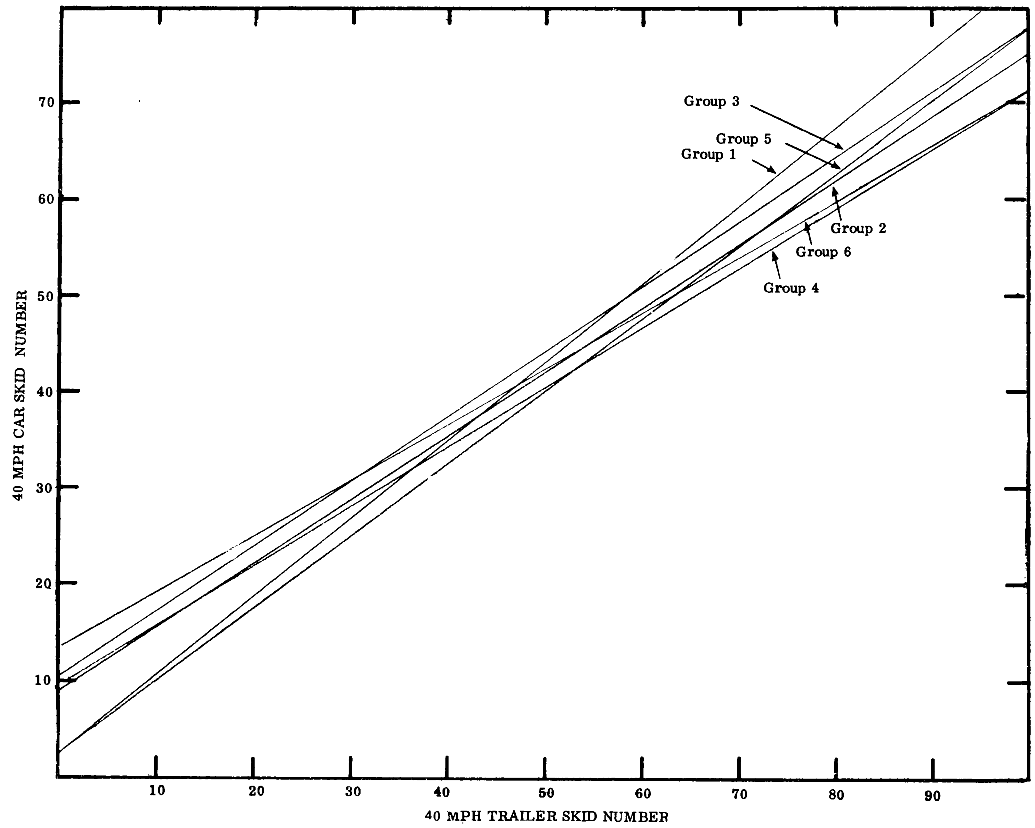

Figure 13. Car-trailer regression curves — trailer 40 mph vs. car 40 mph.

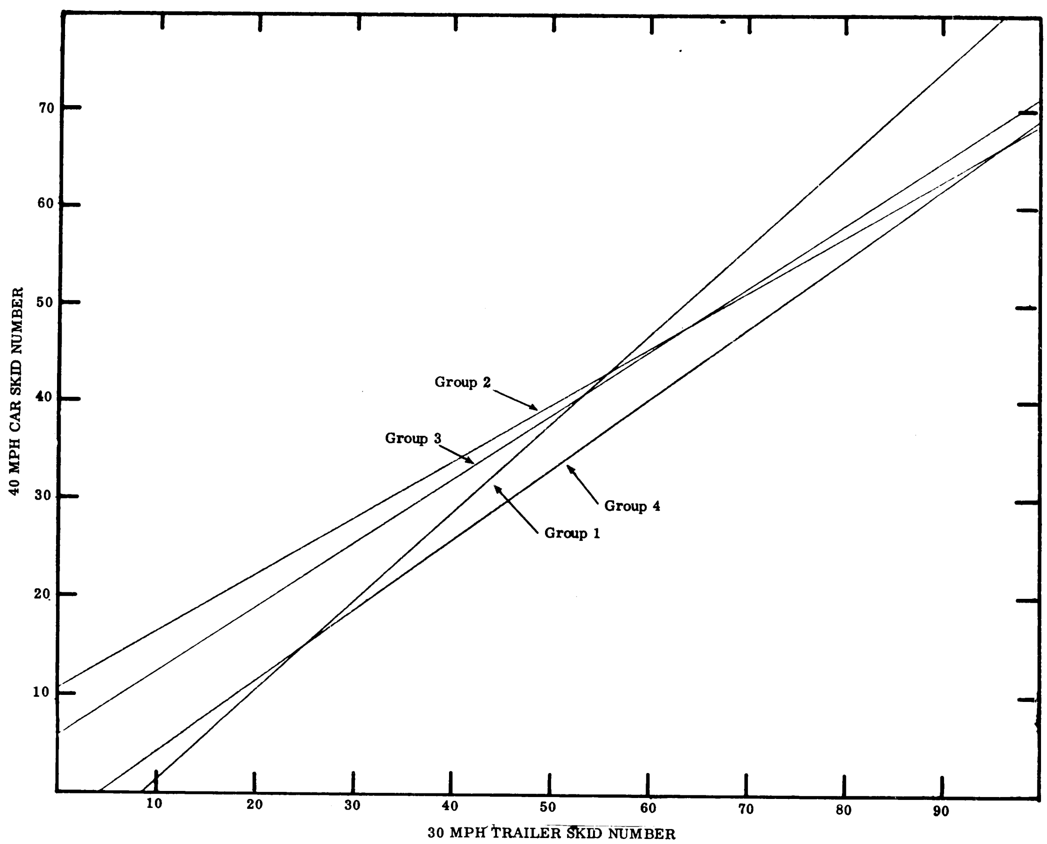

Figure 14. Car-trailer regression curves — trailer 30 mph vs. car 40 mph.

Traffic Volume — PSDN (40 mph) Relationship

The relationships for accumulated traffic volume versus PSDN (40 mph) were determined for S-4 and S-5 mixes composed of non-polishing aggregate, portland cement concrete composed of non-polishing aggregate, and I-2 and I-3 mixes of 100% limestone. The data for the S-4, S-5, and portland cement concrete mixes are shown in Tables VII and VIII. The I-2 and I-3 mixes are the same as shown in Table I and II, except that sites 4 and 25 were omitted since they incorporated a highly polish susceptible limestone no longer used in Virginia.

A computer program was written for the purpose of determining the accumulated traffic volume by lane, in which the lane volume breakdown was based on information contained in the highway capacity manual developed by HRB Committee TO-4. In this program, the authors considered trucks to be 2.5 automobiles.

The results of this analysis are shown graphically in Figure 15. For the portland cement concrete and the S-4 and S-5 mixes each point is an average of several sites within an accumulated traffic volume of 2.5 million. For the I-2 and I-3 mixes each point represents a single site. Also, for the I-2 and I-3 mixes the accumulated volume is plotted versus actual SDN's (40 mph) rather than PSDN's (40 mph).

As can be seen from Figure 16, the limestone mixes drop off most rapidly and reach stopping distance skid numbers in the low forties by an accumulated volume of 15 million. The portland cement concrete mixes stay at the same point as do the S-4 and S-5 mixes, but decrease more rapidly and reach values in the mid to low forties at between 20 to 25 million vehicle passes. The S-4 and S-5 mixes still retain predicted stopping distance skid numbers in the mid to high forties after 25 to 30 million vehicle passes.

TABLE VII

TRAFFIC VOLUME - PSDN (40mph) RELATIONSHIP
FOR S - 4 AND S - 5 MIXES

Site	Accumulated Traffic (Millions)	PSDN (40mph)
1	12.7	50
2	2.5	57
3	13.9	49
4	2.9	57
5	14.0	50
6	3.0	57
7	28.4	46
8	12.4	52
9	6.2	63
10	1.2	67
11	5.2	65
12	0.9	67
13	30.2	47
14	14.5	52
15	28.4	46
16	12.4	51
17	3.2	59
18	0.6	63
19	3.1	59
20	0.6	62
21	3.2	59
22	0.6	65
23	5.2	60
24	0.6	63
25	3.3	59
26	0.6	65
27	2.6	61
28	0.5	64
29	3.4	65
30	0.7	68
31	0.8	65
32	0.3	65
33	2.6	65
34	0.6	67
35	2.6	65
36	0.6	70
37	1.8	66
38	0.4	67
39	1.8	65
40	0.4	68
41	1.8	65
42	0.4	67
43	2.2	65
44	0.5	72
45	2.8	65
46	0.6	70
47	2.8	65
48	0.6	69
49	3.4	65
50	0.7	70

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TABLE VIII

TRAFFIC VOLUME - PSDN (40 mph) RELATIONSHIP
FOR PORTLAND CEMENT CONCRETE

Site	Accumulated Traffic (Millions)	PSDN (40mph)
1	10.9	52
2	2.2	61
3	12.4	48
4	2.5	63
5	14.7	48
6	2.9	65
7	15.5	48
8	3.1	63
9	24.6	45
10	9.0	50
11	24.3	42
12	8.8	45
13	24.5	43
14	8.9	47
15	24.1	43
16	8.6	50
17	21.4	44
18	8.1	53
19	21.8	42
20	8.5	50
21	21.8	42
22	8.5	49
23	21.9	44
24	8.6	49
25	21.9	42
26	8.6	48
27	21.9	42
28	8.6	50

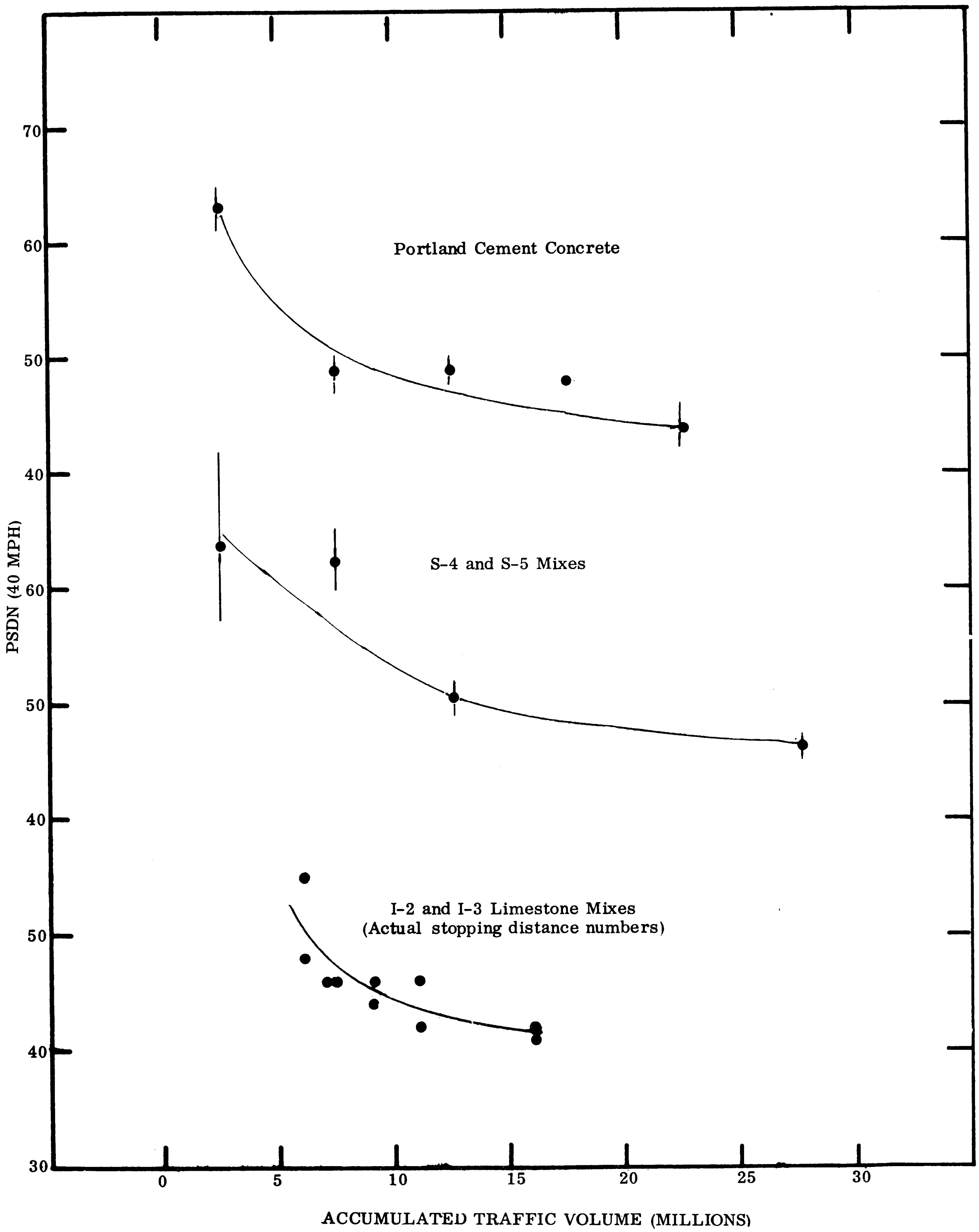

Figure 15. Traffic volume versus PSDN (40 mph).

PERIODIC TEST SITES

One of the goals set forth in the working plan for this study was to initiate a testing program that would lead to a clearer understanding of the effects of natural elements on skid resistance. To accomplish this goal thirty test sections representative of pavements of various ages and types in Virginia have been selected. Table X gives descriptive data for these sections. Two of the sites have not been tested, eleven have been tested once, eleven have been tested twice, and six have been tested three times. The intent is to retest each site four times each year, as near as possible to the beginning of each season. In addition to skid data to be recorded, the surface and air temperatures and weather conditions will be recorded at the time of test. At present the data are insufficient to permit an analysis; however, over several years of testing this program should provide some insight into seasonal effects. Also, the program will provide detailed data regarding the effects of accumulated traffic volumes on skid resistance. The continuation of this test program will be financed under state funds.

TABLE IX

DATA FOR PERIODIC TEST SITES

Route	County	Site	Mix Type	Location	Times Tested	Dates Tested	Temperature		Trailer Skid Number and (Predicted Stopping Distance Number)									
							Air	Surface	EBTL	WBTL	NBTL	SBTL	EBPL	NBPL	NBPL	SBPL	NCL	EBCL
1	Caroline		Coarse Surface Treatment	MP 6.86-8.86	None													
2	Spotsylvania		Coarse Surface Treatment	MP 7.01-9.01	None													
11	Augusta		Slurry Seal	MP 0.0-1.45	1	5-2-69	60	71			74(58)	90(69)						
I-81	Rockbridge		Slurry Seal	MP	2	11-27-68 1-24-69					70(55) 75(59)	72(57) 77(60)			91(70) 86(66)	92(70) 85(65)		
340	Rockingham	1	Sprinkle Mix	MP 1.5-6.0	2	10-19-69 4-8-70	69 69	79 78			76(52) 86(67)	79(59) 79(62)						
340	Rockingham	1R	Sprinkle Mix	MP 1.5-6.0	2	10-19-69 4-8-70	69 69	79 78			79(57) 85(66)							
340	Rockingham	2	Sprinkle Mix	MP 1.5-6.0	2	10-19-69 4-8-70	69 69	79 78			86(62) 82(64)							
340	Rockingham	3	Sprinkle Mix	MP 1.5-6.0	2	10-19-69 4-8-70	69 69	79 78			104(73) 77(60)	89(67) 85(66)						
I-95	Caroline		PCC - Old and Smooth	MP 10.26-14.16	1	10-2-69	87	104			55(45)	56(46)			64(51)	62(50)		
I-95	Spotsylvania		PCC - Old and Smooth	MP 5.0-9.70	1	10-2-69	87	104			54(44)	56(46)			60(48)	61(49)		
I-95	Prince William		PCC Grooved Concrete	MP 11.2-12.0	2	12-20-68 1-23-69	46 50	49 51			57(45) 55(44)		73(55) 73(55)				62(48) 62(48)	
I-64	Henrico		PCC Grooved Concrete	MP 8.0-8.4	1	6-2-70	68	69	57(46)				66(53)					51(42)
I-64	Albemarle		PCC Heavy Burlap	MP 21.2-22.2	1	11-16-70	58	63		58(47)				63(50)				
I-64	Louisa		PCC Light Burlap	MP 4.9-5.4	1	11-16-70	58	63	56(46)				56(46)					
I-64	Louisa		S - 5	MP 5.4-6.4	1	11-16-70	58	63	63(50)				63(50)					
I-64	Goochland		S - 5	MP 28.9	2	10-29-69 11-16-70	 58	 63	49(49) 67(53)									
11	Augusta		S - 5 Blended	MP 17.96-20.46	1	5-2-69	60	71			82(63)	79(61)						
I-95	Caroline		S - 5 New	MP 3.46 - 6.87	1	10-15-69	86	101			59(48)	55(45)						
55	Shenandoah	1	I - 2	MP 2.70	3	4-30-68 10-4-68 5-14-70	60 84	64 90	55(46) 52(42) 57(47)	55(45) 52(43) 55(45)								
55	Shenandoah	2	I - 3	MP 3.70	3	4-30-68 10-4-68 5-14-70	60 84	64 90	50(41) 48(40) 54(44)	55(45) 53(41) 56(46)								

TABLE IX (continued)

Route	County	Site	Mix Type	Location	Times Tested	Dates Tested	Temperature		Trailer Skid Number and (Predicted Stopping Distance Number)									
							Air	Surface	EBTL	WBTL	NBTL	SBTL	EBPL	NBPL	NBPL	SBPL	NCL	EBCL
55	Shenandoah	3	I - 2	MP 4.50	3	4-30-68 10-4-68 5-14-70	60 84	64 90	54(48) 54(46) 58(49)	54(49) 53(45) 56(46)								
55	Shenandoah	4	I - 3	MP 7.70	3	4-30-68 10-4-68 5-14-70	60 84	64 90	53(49) 61(50) 62(51)	49(44) 60(50) 67(51)								
55	Shenandoah	5	I - 2	MP 8.95	3	4-30-68 10-4-68 5-14-70	60 84	64 90	61(54) 63(56) 67(53)	60(51) 62(51) 64(52)								
55	Shenandoah	6	I - 3	MP 11.00	3	4-30-68 10-4-68 5-14-70	60 84	64 90	38(34) 40(36) 47(40)	43(40) 42(38) 46(38)								
460	Bedford	1	Weblite	MP 21.53	2	5-26-69 4-7-70	75 60	85 64					93(67) 92(70)					
460	Bedford	2	Weblite	MP 21.73	2	5-26-69 4-7-70	75 60	85 64	56(43) 59(48)				80(59) 86(67)					
460	Bedford	3	Weblite	MP 21.63	2	5-26-69 4-7-70	75 60	85 64	70(53) 68(55)									
460	Bedford	4	Weblite	MP 21.33	2	5-26-69 4-7-70	75 60	85 64	73(55) 71(57)									
340	Augusta		S - 1	MP 0.1-MP 4.14	1	4-22-69	56	62			87(67)	83(64)						
250	Augusta		S - 1	MP 8.9-9.7	1	2-11-69	40	54	71(56)		78(61)							

* See Appendix — for Virginia mix designations

PERCENT WET ACCIDENT — FRICTION RELATIONSHIP

Only the interstate system was included in the analysis of the relationship between wet pavement accidents and friction levels. Some limited data were collected on the primary system, but they were not sufficient to permit any analysis.

Five hundred and twenty-one sections on Virginia's interstate system, totaling 312.8 miles, were studied to determine the relationship between the percent of wet accidents and predicted stopping distance skid numbers. In the final analysis the sites were separated into four categories: open roadway (level and tangent areas not at interchanges), non-open roadway (vertical and/or horizontal curves not at interchanges), open interchanges (level and tangent areas at interchanges), and non-open interchanges (vertical and/or horizontal curves at interchanges). Initially, many more detailed categories were considered, but because of the difficulty in classifying sites it was decided to use the broad ones outlined above. Classifying a site as open or non-open was very difficult. Geometric data were not readily available, so the authors drove over each site and classified it according to their combined judgement. Sight distance was considered of prime importance. Therefore, areas with gentle horizontal and/or vertical curves affording good sight distance were classified as open roadway.

Sites not at interchange areas generally were one-half mile in length. Sites at interchange areas were usually longer, generally about one mile in length, and were determined by starting one-tenth of a mile before the exit ramp and ending one-tenth mile beyond the entrance ramps. In both cases the sites were classified as open or non-open, depending on which description most generally was applicable.

Percent of wet accidents was selected as one factor for analysis for two reasons. First, it was the only meaningful wet accident figure easily obtainable since wet accident rates were almost impossible to compute. Second, it was hoped that by selecting percent wet accidents the effect of traffic volume would be reduced. It is pointed out that one basic assumption was made in this analysis, i.e., the amount of time the pavement was wet was essentially equal for all sections tested.

The possible effects of traffic volume were also taken into account by subdividing each classification into four lane-traffic volume groups: 0 to 3,999 AVD (average vehicles daily) per lane, 4,000 to 7,999 AVD per lane, 8,000 to 11,999 AVD per lane, and 12,000 to 15,999 AVD per lane.

After each site was selected and classified, a weighted predicted stopping distance skid number was obtained for it. Trailer skid tests were taken at 40 mph in each lane (generally a site consisted of two passing and two traffic lanes) and averages were obtained for the traffic and passing lanes. A weighted trailer skid number was then usually obtained by summing 80% of the average traffic lane's skid number and 20% of the average passing lane's skid number. These factors were used since the normal traffic for the sites was 80% in the traffic lanes and 20% in the passing lanes. Other weighting factors based on traffic volume and number of lanes were used when appropriate. The general 40 mph regression equation discussed earlier in the report was then used to predict the weighted 40 mph stopping distance skid number for the site.

After weighted stopping distance skid numbers were obtained for each site, the 1969 accident data were used to determine percent wet accidents for each site. These data were summarized as shown in Tables X - XIII. Figures 16 - 19 present the data graphically in a more summarized form where percent wet accidents for the skid number groups 40 to 44, 45 to 49, 50 to 54, and 55 and above are plotted versus the average group skid number. It should be pointed out that for sites at interchanges the accident data included only those accidents occurring on the main road.

Notice in Tables X - XIII that in effect only three lane — AVD groups were applicable for each classification since very few data fell in the highest lane — AVD group. Also, the data were not balanced between traffic volume groups and skid number groups, obviously because the higher volume sites usually had more accumulated traffic and therefore a lower skid number.

Two things are evident from the data shown in Tables X - XIII, and Figures 16 - 19. First, in most cases there was a definite negative slope; i.e., the percent of wet accidents decreased as the PSDN increased; and second, if volume was a factor it appears that on the average the percent of wet accidents was lower with volume. In many cases the data are erratic, probably because of the small number of accidents the percentages were based on. The authors feel that certainly at least fifty, and preferably one hundred or more, total accidents per skid number group (such as 40-44) would be necessary to provide results which could be used with confidence that they are fairly accurate. It is obvious in looking at Tables X - XIII that many skid number groups have less than fifty, and far less than one hundred, total accidents. However, the consistency of the negative slope and the smaller percent wet accidents with higher volume for each of the classifications indicate that these are defensible results based on the data available.

The decrease in percent wet accidents with an increase in the PSDN was, of course, expected by the authors. However, the lower percent of wet accidents associated with the higher volumes of traffic was not expected. This perhaps can be explained by the fact that the roads with the lowest traffic volumes had less traffic than they were designed for, thus drivers could make errors without becoming involved in accidents. This, of course, would hold the total number of accidents to a minimum, which in turn might make the wet to dry ratio high, even with a few wet accidents.

TABLE X

SKID NUMBER - PERCENT NET ACCIDENT ANALYSIS OPEN ROADWAY

Weighted Skid Number	0 - 3999					4000 - 7999					8000 - 11,999					12,000 - 15,999				
	Secs	Mi.	Tot.	Wet	%	Secs.	Mi.	Tot.	Wet	%	Secs.	Mi	Tot.	Wet	%	Secs.	Mi.	Tot.	Wet	%
41											4	2.4	29	9	31					
42						5	2.6	39	20	51	5	2.5	9	0	0	4	1.9	8	1	12
43						16	8.5	48	14	29										
44	2	1.0	3	1	33	13	6.4	41	8	20	1	0.7	13	2	15	2	0.8	16	0	0
45						12	7.9	49	6	14	3	1.5	9	1	11					
46	4	2.0	4	1	25	20	11.1	102	10	10	3	1.3	8	0	0					
47	2	1.0	9	3	33	21	10.9	75	8	11	9	1.9	35	11	32					
48	3	1.3	5	1	20	11	5.4	40	4	10	8	3.8	44	6	13					
49	2	1.1	2	0	0	6	3.2	13	1	8										
50	11	6.0	15	3	20	4	1.8	6	2	33										
51	8	4.3	10	0	0															
52	6	3.0	4	1	25	5	3.7	42	9	21	9	2.0	35	3	8					
53	12	5.8	30	6	20															
57	27	15.0	19	0	0															
62	36	18.5	34	5	15															
63	35	20.4	36	2	6															

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TABLE XI

SKID NUMBER — PERCENT WET ACCIDENT ANALYSIS
NON - OPEN ROADWAY

Weighted Skid Number	0 - 3999					4000 - 7999					8000 - 11,999					12,000 - 15,999				
	Secs.	Mi.	Tot.	Wet	%	Secs.	Mi.	Tot.	Wet	%	Secs.	Mi.	Tot.	Wet	%	Secs.	Mi.	Tot.	Wet	%
40											3	1.5	18	8	44					
41											12	6.6	96	42	44					
42						4	2.1	42	14	33										
43	1	0.4	2	0	0	1	0.5	1	0	0										
44						9	5.2	82	22	27	4	2.0	25	8	33	3	2.0	21	3	14
45						3	1.6	25	5	20	5	3.1	27	3	11					
46	1	0.5	1	0	0	7	3.8	67	19	28	6	3.5	56	9	16					
47	3	1.6	7	3	43	8	7.9	45	13	29	6	1.2	45	10	22					
48						4	2.3	10	4	40	2	1.3	18	0	0					
49						1	0.7	3	0	0										
50	4	2.2	14	3	21	2	1.2	4	0	0	3	1.5	26	3	12					
52	1	0.5	4	2	50															
53	2	1.1	7	2	29															
57	3	2.1	6	0	0															
62	3	2.0	3	1	33															
63	11	5.1	7	2	29															

TABLE XII

SKID NUMBER — PERCENT WET ACCIDENT ANALYSIS
OPEN INTERSECTIONS

Weighted	0 - 3999					4000 - 7999					8000 - 11,999					12,000 - 15,999				
Skid Number	Secs.	Mi.	Tot.	Wet	%	Secs.	Mi.	Tot.	Wet	%	Secs.	Mi.	Tot.	Wet	%	Secs.	Mi.	Tot.	Wet	%
41											2	1.1	47	21	45					
42						1	0.8	10	1	10	1	1.0	7	3	43					
43						3	2.3	22	2	9										
44											1	0.5	2	1	50					
45						2	1.3	17.	1	6										
46						4	3.2	38	5	13										
47	1	0.6	9	1	11	6	4.9	51	8	16	2	1.6	32	5	16					
48	1	0.5	2	0	0	3	1.9	23	2	9										
49	2	1.5	16	5	31	1	0.4	3	1	33										
50	5	3.4	26	6	23	1	0.8	2	0	0	1	0.8	19	2	11					
51	2	1.3	19	5	26															
52	2	1.0	7	3	43	2	0.9	5	2	40	1	0.7	18	5	28					
53																				
57	6	4.0	7	0	0															
62	5	2.8	9	2	22															
63	6	4.6	15	6	40															

TABLE XIII

SKID NUMBER — PERCENT WET ACCIDENT ANALYSIS
NON — OPEN INTERSECTIONS

Weighted Skid Number	0 - 3999					4000 - 7999					8000 - 11,999					12,000 - 15,999				
	Secs.	Mi.	Tot.	Wet	%	Secs.	Mi.	Tot.	Wet	%	Secs.	Mi.	Tot.	Wet	%	Secs.	Mi.	Tot.	Wet	%
41											1	0.7	11	6	54					
42																2	0.7	18	1	5
43						4	3.9	137	63	46										
44						5	6.1	158	47	30	1	1.1	28	7	25	1	0.8	20	6	30
45	1	0.7	12	6	50	2	1.6	19	4	21										
46						3	2.0	27	3	11	3	2.4	47	11	23	1	0.8	21	1	5
47						3	3.0	12	0	0	4	3.6	109	34	31					
48	2	1.6	29	9	31	3	2.4	28	8	29	1	1.0	9	3	33					
49	1	0.6	4	1	25	1	0.5	3	1	33	1	6.8	189	52	28					
51	1	1.0	3	0	0	1	0.8	12	2	17										
52	2	1.8	11	1	9						1	0.5	9	0	0					
53																				
57	5	3.3	15	6	40															
62	3	2.5	13	2	15															

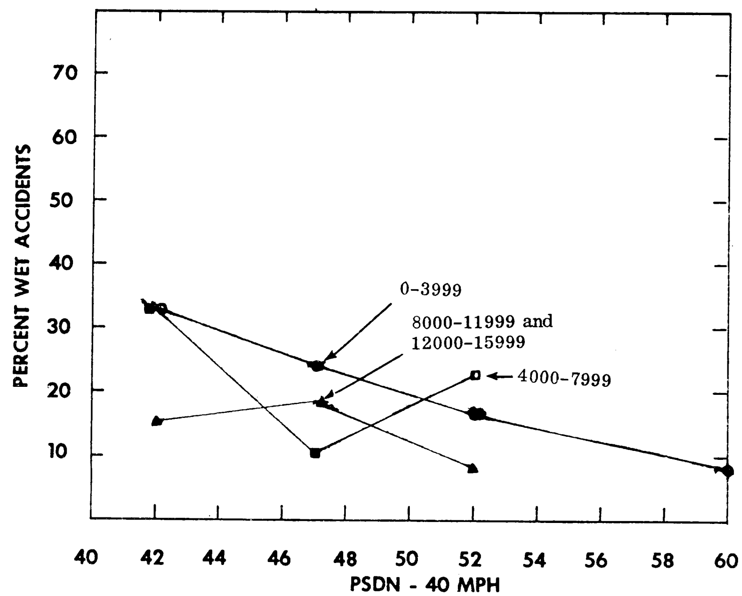

Figure 16. Skid number — percent wet accident analysis for open roadway.

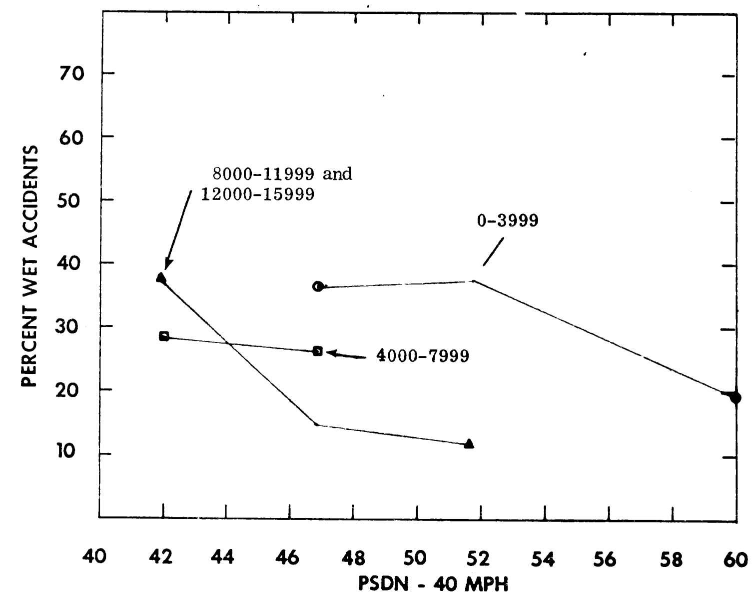

Figure 17. Skid number — percent wet accident analysis for non-open roadway.

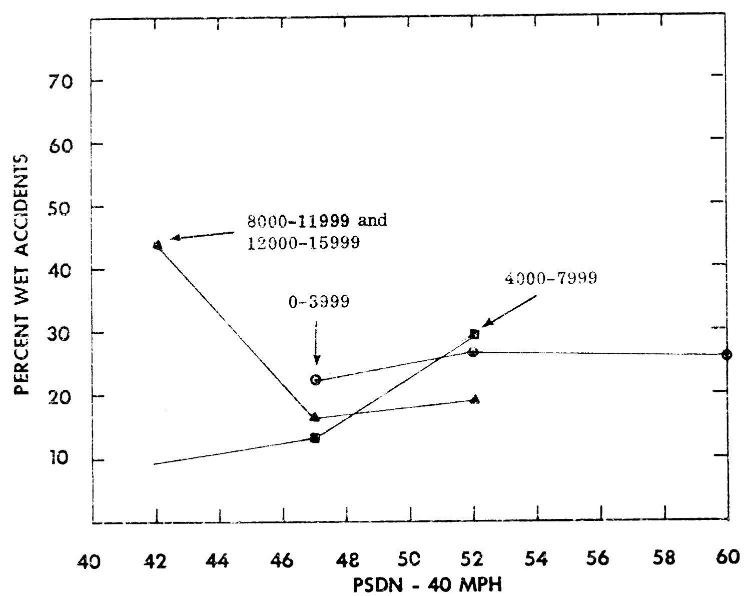

Figure 18. Skid number — percent wet accident analysis for open intersections.

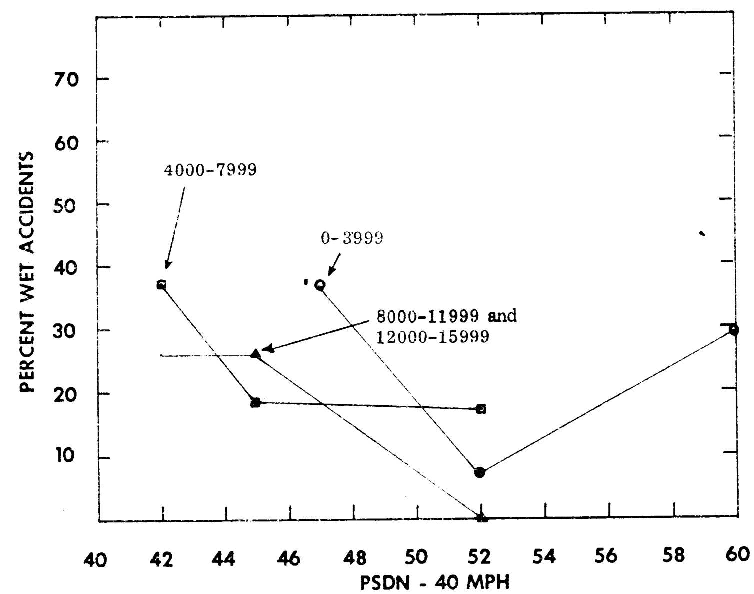

Figure 19. Skid number — percent wet accident analysis for non-open intersections.

In order to make a better estimate of what the percent wet accident — PSDN curve looks like for each classification, the data in all volume groups for the four classifications were combined as shown in Table XIV and Figure 20.

In this analysis the curves shown in Figure 20 were developed by starting at the lowest PSDN for each classification and adding PSDN's until at least fifty total accidents were available to compute percent wet accidents. This percentage was then plotted versus the average PSDN of the group from which the percentage was computed. It was felt by the authors that the possible effect of volume on percent wet accidents shown previously should not prevent the combining of data in the manner described since the vast majority of data fell in the two middle volume groups.

In studying Figure 20 it appears the following conclusions can be drawn:

1. There is very little difference in the shapes and locations of the four curves. There does, however, seem to be some tendency for the curves to move up and to the right with the complexity of the roadway situation; i.e., the percent wet accidents is usually at least slightly lower at any given PSDN for the open roadway condition than for the other conditions. The order of complexity in this case would be open roadway, non-open roadway and open-interchange about equal, and non-open interchange.

2. The "breaking point" for all four curves, i.e., the point with the greatest change in slope, appears to be about a PSDN of 45. Again the curve seems to increase slightly with the complexity as ordered above in number 1. This point, that at which be greatest change in slope occurrs, should be selected as a guideline for a minimum PSDN.

Obviously, these results are averages, and to apply them to a particular existing roadway situation as a general remedy for areas having a high percentage of wet accidents would not always be appropriate without considering factors such as the total and wet accident history. However, it is felt that the results could be used in the development of general design guidelines for the PSDN's needed on new construction. Also, they could be incorporated in a general policy regarding resurfacing or other corrective action when a site has a PSDN lower than the guideline and a history of a high percent of wet accidents, particularly if it is an accident-prone location in terms of the total number of accidents and/or the accident rate.

In using these findings as guidelines it should be remembered that the PSDN's shown are weighted. Actually, in a guideline for the design and/or for the maintenance of skid resistance the traffic lane skid numbers would be of prime importance. Actually, since the traffic lanes generally were weighted very heavily in relation to the passing lanes, the weighted average PSDN would be on the average only about 2-3 PSDN's above the

TABLE XIV

SKID NUMBER — PERCENT WET ACCIDENT
ANALYSIS SUMMARY

Weighted Skid Number	Secs.	Mi.	Tot.	Wet	%	Secs.	Mi.	Tot.	Wet	%	Secs.	Mi.	Tot.	Wet	%	Secs.	Mi.	Tot.	Wet	%
40						3	1.5	18	8	44										
41	4	2.4	29	9	31	12	6.6	96	42	44	2	1.1	47	21	45	1	0.7	11	6	54
42	14	7.0	56	21	38	4	2.1	42	14	33	2	1.8	17	4	24	2	0.7	18	1	5
43	16	8.5	48	14	29	2	0.9	1	0	0	3	2.3	22	2	9	4	3.9	137	63	46
44	13	8.9	73	27	37	16	9.4	128	33	26	1	0.5	2	1	50	7	8.0	206	60	29
45	15	9.9	58	7	12	8	4.7	52	8	15	2	1.3	17	1	6	3	2.3	31	10	32
46	27	14.4	114	11	10	14	7.8	124	28	23	4	3.2	38	5	13	7	5.2	95	15	16
47	27	13.3	114	22	18	13	10.7	97	26	27	9	7.1	92	14	15	7	6.6	121	34	28
48	22	8.5	89	11	12	6	3.6	18	4	22	4	2.4	25	2	8	6	5.0	66	20	30
49	8	4.3	15	1	7	1	0.7	3	0	0	3	1.9	19	6	32	3	7.9	196	54	28
50	15	7.8	21	5	24	9	4.9	44	6	14	7	5.0	47	8	17					
51	8	4.3	10	0	0	1	0.5	4	2	50	2	1.3	19	5	26	2	1.8	15	2	13
52	15	8.7	81	13	16	2	1.1	7	2	29	5	2.6	30	10	33	3	2.3	20	1	5
53	12	5.8	30	6	20															
54																				
55																				
57	27	15.0	19	0	0	3	2.1	6	0	0	6	4.0	7	0	0	5	3.3	15	6	40
62	36	18.5	34	5	15	3	2.0	3	1	33	5	2.8	9	2	22	3	2.5	13	2	15
63	35	20.4	36	2	6	11	5.1	7	2	29	6	4.6	15	6	40					

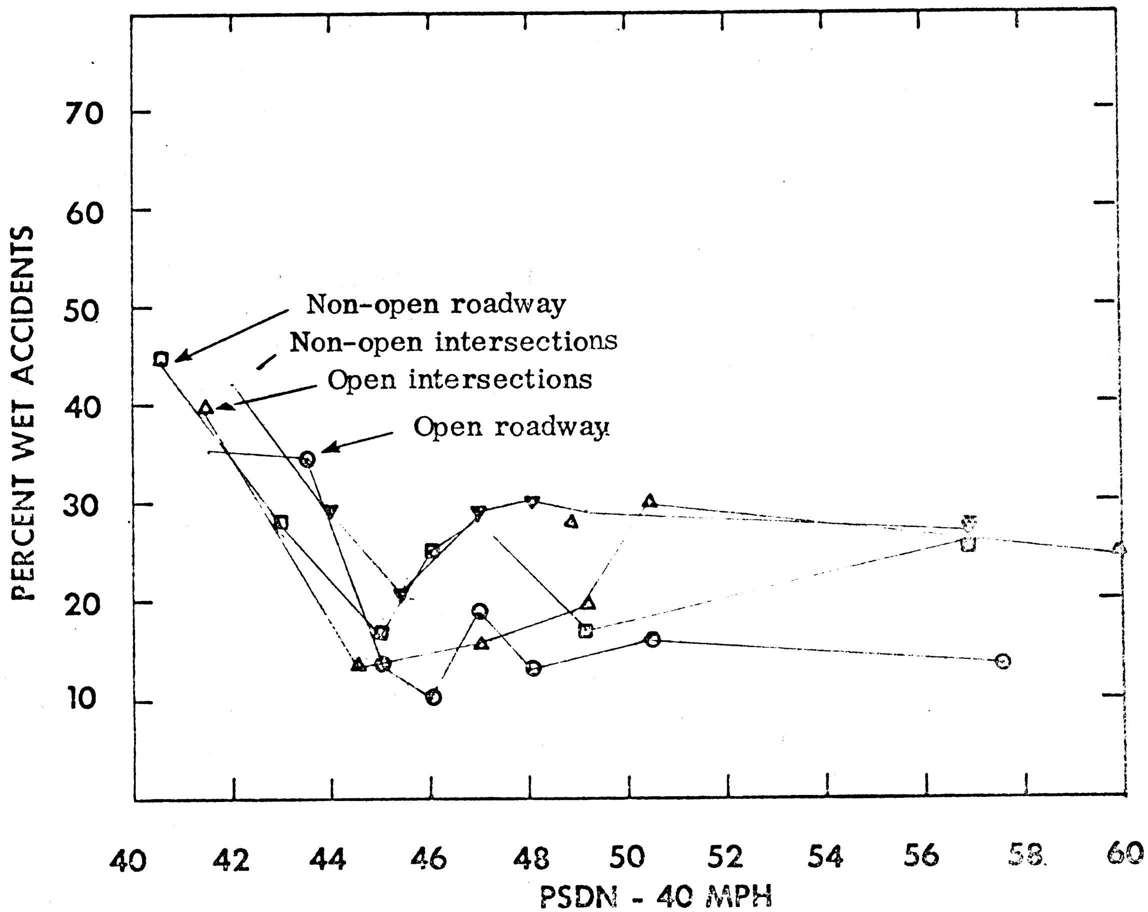

Figure 20. Skid number — percent wet accident analysis — summary four classifications.

average PSDN for the traffic lanes. This is demonstrated in Figure 21 where the total (including all classifications) skid number percent wet accident relationships for the weighted and non-weighted conditions are shown. The breaking point is 45 PSDN for the weighted condition and 42 PSDN for the non-weighted condition.

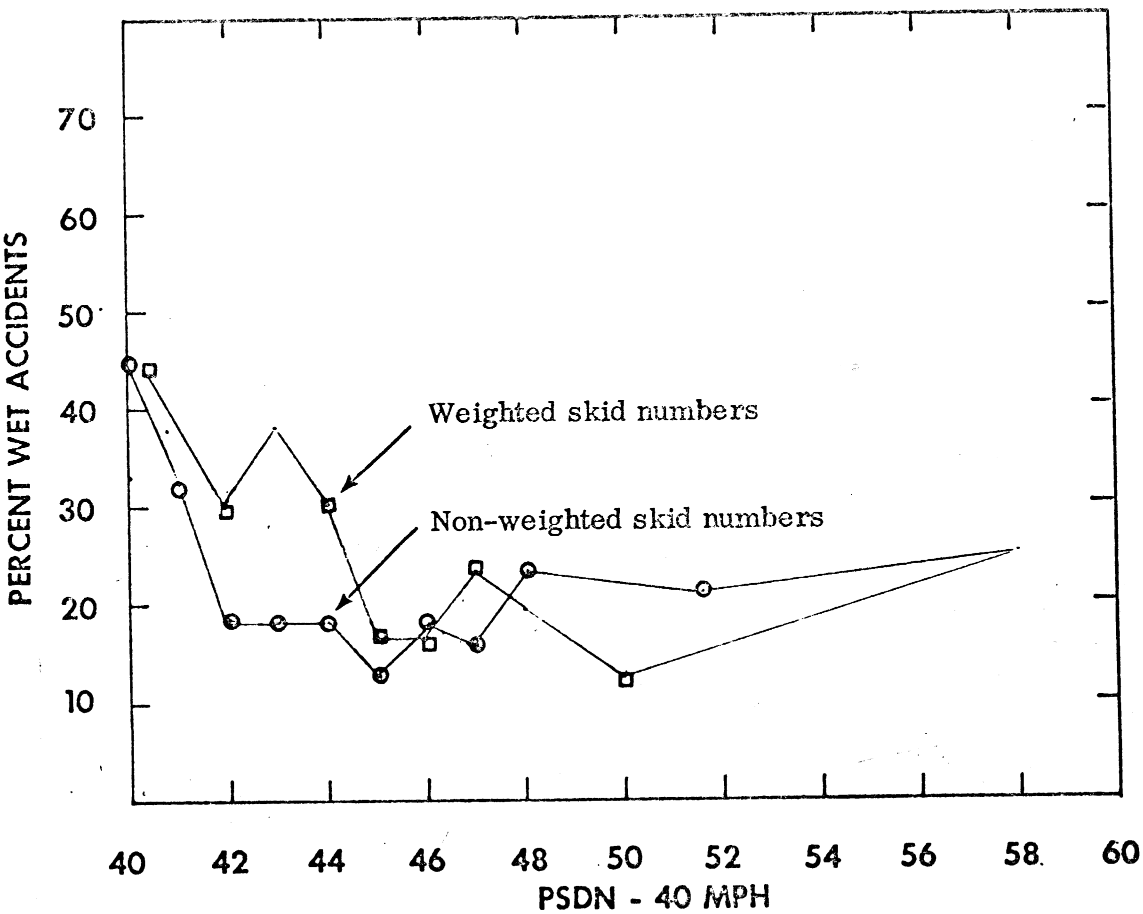

Figure 21. Comparison of weighted and non-weighted PSDN vs. percent wet accidents.

It is obvious that additional work is needed with more definitive geometric data describing each site. It is felt by the authors that one possible reason the curves did not differ more was the very general way in which the site classifications were derived.

A comparison of the 45 PSDN (40 mph) found in this study with the recommended minimum interim stopping distance skid number requirements shown in Table 19 of NCHRP Report 37 by Kummer and Meyers seems to indicate a discrepancy(5). The 45 PSDN applies to the Virginia interstate system, which is designed for a 70 mph traffic speed.

Also, unpublished data available from other researchers at the Virginia Highway Research Council indicate average speeds on many of the sites included in the study to be between 65 and 70 mph. Based on the mean traffic speed, the stopping distance number proposed by Kummer and Meyers would be about 55-57, or 10 to 12 numbers higher than the number established in this study.

The authors feel that this apparent discrepancy is due in great part to the relationship between the trailer and stopping distance methods used by Kummer and Meyers to obtain the stopping numbers. The relationship used was based on research results presented in a paper entitled "Correlation Study—Comparison of Several Methods of Measuring Road Surface Friction" by Dillard and Allen in 1958, and none of the trailers used in that study are still in existence[6]. Also, tires other than the E-17 test tire were used in the Dillard and Allen study.

Correlation studies undertaken since 1965 indicate a somewhat different relationship. Data taken from Figure 17 of a report by Dillard and Mahone, and from Figure 8 of a report by Rizenbergs are shown in Figure 21[7,8]. These data indicate an approximate 1:1 relationship.

Based on the data shown in Figure 22, the minimum stopping distance number required for a mean speed of 70 mph would be 47 instead of 57. This, of course, would bring the findings of this study into aggrement with those in NCHRP Report 37, as well as with the recent guidelines set forth by the U. S. Department of Transportation in Volume 12 of the Highway Safety Program Manual, which were extracted from NCHRP Report 37[9].

If Kummer and Meyers' work in developing the minimum acceptable trailer skid numbers as measured at 40 mph is sound, and if the average relationship between trailer skid numbers and stopping distance skid numbers is as shown in Figure 22, then the desired mimimum SN (40 mph) for roadways which carry 70 mph traffic is 42 rather than the 37 or 40 so often used as a guideline.

This value of 42 is also in disagreement with the findings of McCullough and Hankins[10], which indicate a SN(20 mph) of 40 and a SN (50 mph) of 30 as desirable. The SN (40 mph) by extrapolation could be about 35, which is much lower than the 42 indicated as desirable above. Of course, there is no way of knowing how the Texas skid trailer might relate to those used in the Tappahanock[7] and Florida[8] correlation studies. This uncertainty is one reason that the authors feel it is very important to develop regression equations for individual skid trailer skid numbers versus stopping distance skid numbers, particularly since data from the Florida correlation study indicate that the variability between skid numbers obtained by several stopping distance cars was much less than that obtained by the trailers.

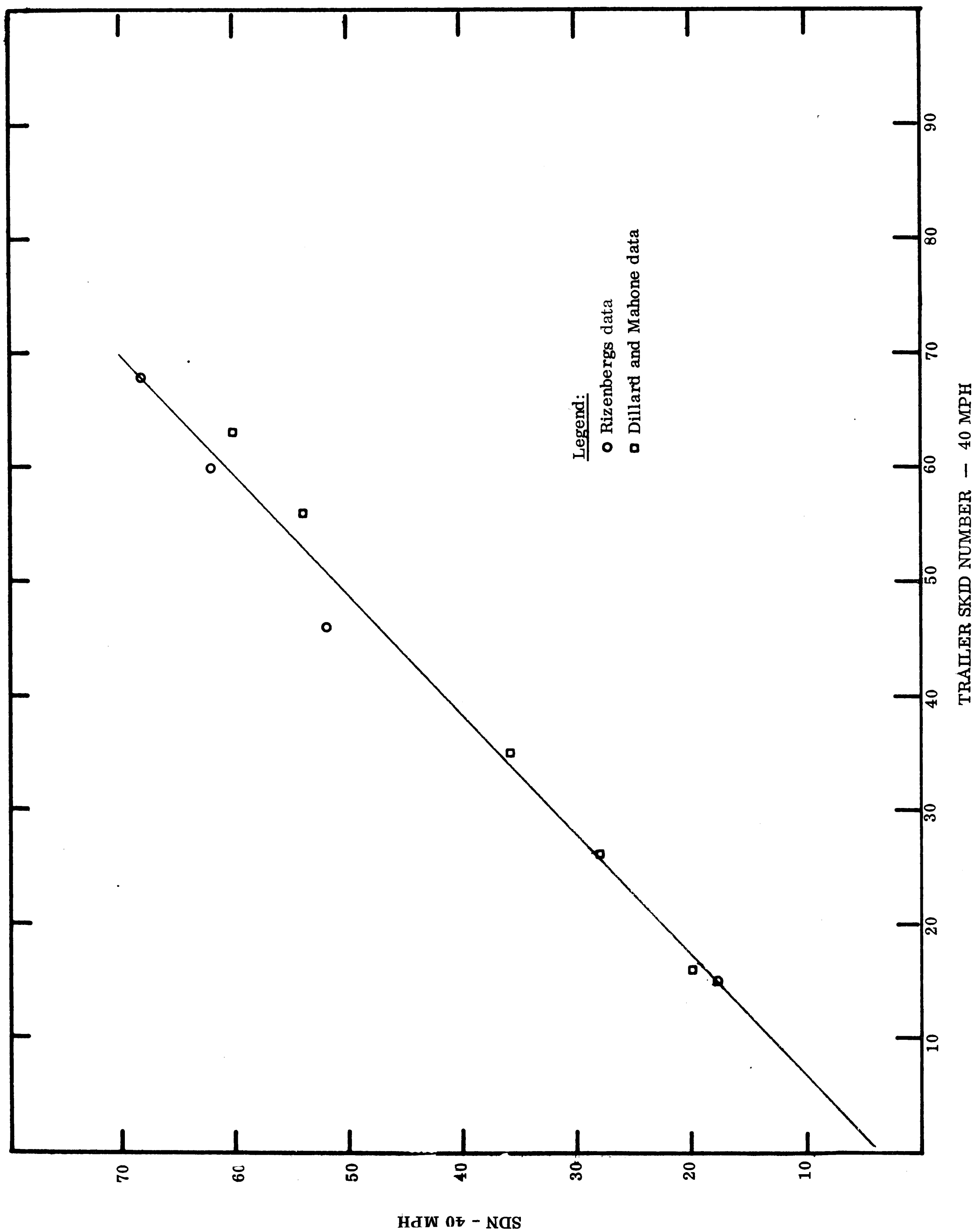

Figure 22. Stopping distance skid number — trailer skid number relationship.

CONCLUSIONS

1. Speed gradients were not found to be different for any of the paving mixes normally used in Virginia, and the average gradient was about 0.7. This conclusion is drawn within the limits for which the data were obtained, and would not necessarily remain the same for varying water and tire tread depths.

2. The regression analyses performed between the stopping distance car data and the trailer data indicate that the best predicting equations for stopping distance numbers occur when the trailer tests at 30 mph. Also, it appears that the relationships did not change in any orderly fashion with time.

3. The accumulated traffic — PSDN relationships indicate that non-polishing S-4 and S-5 mixes retain an average PSDN of 48 after 25-30 million vehicle passes. Non-polishing portland cement concrete mixes lose resistance more rapidly than do non-polishing S-4 and S-5 mixes, and on the average have a PSDN of about 44 after 20 to 25 million vehicle passes. The PSDN's for I-2 and I-3 limestone mixes decrease more rapidly than those for S-4 and S-5, and portland cement mixes reach an average of 42 after 16 million vehicle passes.

4. Based on the percent wet accident — PSDN analysis, it appears that a minimum weighted PSDN of 45, or non-weighted traffic lane PSDN of 42, is desirable for interstate roads with a mean traffic speed of about 65 or 70 mph. It can be demonstrated that these values probably are about the same as those recommended by Kummer and Meyers in NCHRP Report 37, assuming that a different relationship exists between skid trailers and the stopping distance method than the one they used.

REFERENCES

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2. Cook, L. M., and W. H. Dancy, Jr., "Development and Fabrication of the Virginia Skid-Resistance Measurement Vehicle (Model 2)", Virginia Highway Research Council, VHRC 70-R15, October 1970.

3. Giles, C. G., and Barbara E. Sabey, "A Note on the Problem of Seasonal Variation in Skidding Resistance", Proceedings, First International Skid Prevention Conference, Part II, Virginia Highway Research Council (1959).

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5. Kummer, H. W., and W. E. Meyer, "Tentative Skid-Resistance Requirements for Main Rural Highways", National Cooperative Highway Research Program Report No. 37, Highway Research Board, Washington, D. C. 1967.

6. Dillard, J. H., and Dr. Terrence M. Allen, "Correlation Study — Comparison of Several Methods of Measuring Road Surface Friction", Proceedings, First International Skid Prevention Conference, Part II, Virginia Council of Highway Investigation and Research, August 1959.

7. Dillard, J. H., and D. C. Mahone, "Measuring Road Surface Slipperiness", ASTM STP No. 366, 1965.

8. Rizenbergs, R. L., "Florida Skid Correlation Study of 1967 — Skid Testing with Automobiles", ASTM STP No. 456, 1968.

9. Highway Safety Program Manual, Volume 12 "Highway Design, Construction and Maintenance, U. S. Department of Transportation, Federal Highway Administration, March 1971.

10. McCullough, F. B., and K. D. Hankins, "Skid Resistance Guidelines for Surface Improvements on Texas Highways", Departmental Research Report No. 45 - 2, Texas Highway Department, May 1965.

APPENDICES

COUNTY STAFFORD

ROUTE 95

LANE	MILE POST	DATE	WEATHER	AIR TEMP	SUR TEMP	SPEED	LWSN	LWGD	BRIDGE	PCSN
NBPL	12.60	9-16-69	CLEAR	81	101	41.4	62	.32		50
	12.80	9-17-69		71	89	40.8	62			50
	12.80	9-16-69		81	101	42.0	59			48
	13.00	9-17-69		71	89	39.6	57			47
	13.00	9-16-69		81	101	41.4	53		*	44
	13.00	9-17-69		80	91	40.8	57		*	47
	13.00	9-18-69	CLOUDY	70	81	40.8	57		*	47
	13.00					40.8	59		*	48
	13.00	9-16-69	CLEAR	81	101	40.8	72			56
	13.20	9-17-69		71	89	39.6	59			48
	13.20	9-16-69		81	101	40.2	64			51
	13.40	9-17-69		71	89	39.6	59			48
	13.40	9-16-69		81	101	39.6	64			51
	13.60	9-17-69		71	89	39.6	59			48
	13.60	9-16-69		81	101	40.2	64			51
	13.80	9-17-69		71	89	40.8	62			50
	13.80	9-16-69		81	101	40.8	67			53
	14.00	9-17-69		71	89	40.8	62			50
	14.00	9-16-69		81	101	40.8	62			50
	14.20	9-17-69		71	89	40.8	59			48
	14.20	9-16-69		81	101	43.2	64			51
	14.40	9-17-69		71	89	42.0	62			50
	14.40	9-16-69		81	101	40.8	64			51
	14.60	9-17-69		71	89	40.8	62			50
	14.60	9-16-69		81	101	39.0	67			53
	14.80	9-17-69		71	89	40.8	57			47
	14.80	9-16-69		81	101	40.8	64			51
	15.00	9-17-69		71	89	40.8	52			43
	15.00	9-16-69		81	101	42.6	62			50
	15.20	9-17-69		71	89	40.8	53			44
	15.20	9-16-69		81	101	42.6	64			51
	15.30					39.6	64			51
	15.40	9-17-69		71	89	40.8	57			47
	15.50					40.8	52			43
	15.50	9-16-69		81	101	39.6	64			51
	15.60	9-17-69		71	89	40.8	53			44
	15.70					40.8	59			48
	15.70	9-18-69	CLOUDY	70	81	40.8	82		*	62
	15.70	9-17-69	CLEAR	80	91	39.6	57		*	47
	15.70	9-16-69		81	101	40.8	67		*	53
	15.70	9-18-69	CLOUDY	70	81	40.8	78		*	60
	15.70	9-16-69	CLEAR	81	101	39.6	64			51

COUNTY FREDERICK

ROUTE 81

DATE 7-69

		NBTL						NBPL						NBCL					
MILE	TEST SPEED	AVG SN	AVG SPEED	N	STD DEV SN	STD DEV SPD	PCSN	AVG SN	AVG SPEED	N	STD DEV SN	STD DEV SPD	PCSN	AVG SN	AVG SPEED	N	STD DEV SN	STD DEV SPD	PCSN
0- 1	40	70	40.3	10	3.5	.4	55	78	40.9	10	1.1	1.2	61						
1- 2	40	72	40.0	5	3.1	.3	56	83	40.4	5	1.6	.7	64						
2- 3	40	75	39.0	5	4.9	.4	59	82	40.6	5	2.7	.5	63						
3- 4	40	76	40.0	5	3.3	.5	59	79	41.2	5	1.6	.3	61						
4- 5	40	75	40.4	10	4.5	1.1	59	80	41.3	10	2.4	.8	61						
5- 6	40	74	40.3	10	3.7	.8	58	80	41.5	8	4.1	1.1	62						
	50							82	49.2	1			62						
6- 7	40	76	39.1	10	1.5	.7	59	83	40.7	7	1.6	.5	63						
7- 8	40	76	38.4	5	3.6	.7	59	85	39.7	5		.5	64						
8- 9	40	78	40.2	5	4.6	.9	60	85	39.2	5		.8	64						
9-10	40	76	40.6	5	2.5	.5	59	83	40.6	5	1.6	.3	64						
10-11	40	77	40.4	5	1.3	.7	60	84	40.4	5	1.3	.5	64						
11-12	40	76	39.7	5	2.7	.5	59	84	39.5	5	1.3	.0	64						
12-13	40	77	39.4	5	1.6	1.5	60	83	41.2	5	2.9	1.0	63						
13-14	40	77	40.7	10	3.2	.9	60	80	41.5	10	3.1	.5	61						
14-15	40	78	41.2	5	2.3	.3	60	79	42.1	5	1.6	.8	61						
15-16	40	79	39.7	5	4.2	.7	61	79	40.9	5	2.8	.8	61						
16-17	40	78	38.9	5	2.3	.7	60	83	40.3	5	1.6	.3	63						
17-18	40	77	39.8	5	4.7	.9	60	83	39.8	5	2.9	.5	63						
18-19	40	77	41.3	10	2.0	.7	60	80	40.1	10	2.3	1.8	62						
19-20	40	78	40.7	6	2.9	1.6	60	85	41.6	5		1.1	64						
20-21	40	77	40.4	5	1.3	.5	60	82	41.8	8	1.1	1.0	63						

APPENDIX B

The following is a copy of the manual for the codes and data structures for skid test data, site descriptive data, and site materials data.

The basic roadway identification unit for the above data files is the milepost, which will enable these data files to be used in conjunction with the traffic volume and accident data files maintained by the Virginia Department of Highways.

CODES AND DATA STRUCTURES FOR SKID TEST DATA, SITE DESCRIPTION DATA, AND MATERIALS DATA

SECTION I

CARD FORMATS

SKID TEST DATA CARD

Column	Information	Coded	Reference Page
1-2	County	Yes	B-7
3-5	Route Number	No	B-8
6	Route Alpha Code	Yes	B-8
7	Direction	Yes	B-8
8	Lane	Yes	B-8
9-12	Milepost (implied decimal between columns 10 and 11)	No	B-8
13	Data Type	Yes	B-9
14-19	Date (as MMDDYY)	No	B-9
20-23	Military Time	No	B-10
24-25	Operator	Yes	B-10
26	Weather	Yes	B-11
27-29	Air Temperature (°F)	No	B-11
30-32	Surface Temperature (°F)	No	B-11
33	Test Vehicle	Yes	B-11
34-36	Speed (MPH) (implied decimal between columns 35 and 36)	No	B-11
37-40	Left Wheel Skid Number (implied decimal between cols. 39 and 40)	No	B-11
41-44	Right Wheel Skid Number (implied decimal between cols. 43 and 44)	No	B-11
45-47	Calibration	Yes	B-12
48-50	Gain	No	B-12
51-52	Left Wheel Groove Depth (implied decimal between cols. 50 and 51)	No	B-12
53-54	Right Wheel Groove Depth (implied decimal between cols. 52 and 53)	No	B-12

Note: All items are to be right justified in their respective fields and filled with leading zeros.

SITE DESCRIPTIVE DATA CARD[1]

Columns	Information	Coded	Reference Page
1-2	County	Yes	B-7
3-5	Route Number	No	B-8
6	Route Alpha Code	Yes	B-8
7	Direction	Yes	B-8
8	Lane(s)	Yes	B-8
9-12	Beginning Milepost (implied decimal between columns 10 and 11)	No	B-8
13	Data Type	Yes	B-9
14-17	Ending Milepost (implied decimal between columns 15 and 16)	No	B-8
18	New Construction or Maintenance Schedule	Yes	B-12
19-21	Construction or Schedule Number	No	B-12
22-27	Date of Completion (as MMDDYY)	No	B-9
28-29	Highway Type	Yes	B-12
30-31	Speed Limit	No	B-13
32-33	Speical Features	Yes	B-13
34-35	Mix Type	Yes	B-14
36	Asphalt Type	Yes	B-14
37	Curing Method	Yes	B-15
38	Texturing Method	Yes	B-15
39-40	Asphalt GSY (implied decimal before column 39)	No	B-14
41-42	Aggregate Size	No	B-15
43-44	Aggregate Geological Type	Yes	B-15
45-47	Aggregate Source	Yes	B-16
48-49	Aggregate lb./sq.yd.	No	B-17
50	Number of Aggregate Types in Mix	No	

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(1) See page B-17 for instructions regarding how a site is defined.

AGGREGATE MATERIALS DATA CARD

Columns	Information		Coded	Reference Page
1-2	County		Yes	B-7
3-5	Route Number		No	B-8
6	Route Alpha Code		Yes	B-8
7	Direction		Yes	B-8
8	Lane(s)		Yes	B-8
9-12	Beginning Milepost (implied decimal between columns 10 and 11)		No	B-8
13	Data Type		Yes	B-9
14-17	Ending Milepost (implied decimal between columns 15 and 16)		No	B-8
18-19	Aggregate #1	Aggregate Size	Yes	B-15
20-21		Aggregate Geologic Type	Yes	B-15
22-23		Aggregate Source	Yes	B-16
24-26		Aggregate Percent	No	B-17
27-28	Aggregate #2	Aggregate Size	Yes	B-15
29-30		Aggregate Geologic Type	Yes	B-15
31-33		Aggregate Source	Yes	B-16
34-36		Aggregate Percent	No	B-17
37-38	Aggregate #3	Aggregate Size	Yes	B-15
39-40		Aggregate Geologic Type	Yes	B-15
41-43		Aggregate Source	Yes	B-16
44-46		Aggregate Percent	No	B-17
47-48	Aggregate #4	Aggregate Size	Yes	B-15
49-50		Aggregate Geologic Type	Yes	B-15
51-53		Aggregate Source	Yes	B-16
54-56		Aggregate Percent	No	B-17

CODES AND DATA STRUCTURES FOR SKID TEST DATA, SITE DESCRIPTION DATA, AND MATERIALS DATA

SECTION II

CODES AND DETAILS OF CARD PREPARATION

County Codes

Code	County	Code	County
00	Arlington	51	Lancaster
01	Accomac	52	Lee
02	Albemarle	53	Loudoun
03	Alleghany	54	Louisa
04	Amelia	55	Lunenburg
05	Amherst	56	Madison
06	Appomattox	57	Mathews
07	Augusta	58	Mecklenburg
08	Bath	59	Middlesex
09	Bedford	60	Montgomery
10	Bland	61	Nansemond
11	Botetourt	62	Nelson
12	Brunswick	63	New Kent
13	Buchanan	65	Northampton
14	Buckingham	66	Northumberland
15	Campbell	67	Nottoway
16	Caroline	68	Orange
17	Carroll	69	Page
18	Charles City	70	Patrick
19	Charlotte	71	Pittsylvania
20	Chesterfield	72	Powhatan
21	Clarke	73	Prince Edward
22	Craig	74	Prince George
23	Culpeper	76	Prince William
24	Cumberland	77	Pulaski
25	Dickenson	78	Rappahannock
26	Dinwiddie	79	Richmond
28	Essex	80	Roanoke
29	Fairfax	81	Rockbridge
30	Fauquier	82	Rockingham
31	Floyd	83	Russell
32	Fluvanna	84	Scott
33	Franklin	85	Shenandoah
34	Frederick	86	Smyth
35	Giles	87	Southampton
36	Gloucester	88	Spotsylvania
37	Goochland	89	Stafford
38	Grayson	90	Surry
39	Greene	91	Sussex
40	Greensville	92	Tazewell
41	Halifax	93	Warren
42	Hanover	95	Washington
43	Henrico	96	Westmoreland
44	Henry	97	Wise
45	Highland	98	Wythe
46	Isle of Wigh	99	York
47	James City		
48	King George		
49	King and Queen		
50	King William		

Route and Route Alpha Code

The route number is coded in a three column field followed by a single column field for the route alpha code.

The route alpha codes are:

Alpha Character	Code
None	0
A	1
B	2
C	3
Y	4
Z	5

Thus, route 250 bypass would be coded as 2502, and route 6 would be coded as 0060.

Direction and Lane

The codes are:

Direction	Lane
North-South or East-West	0
North	1
South	2
East	3
West	4

Lane	Code
All Lanes	0
Traffic	1
Passing	2
Center	3

Thus the NBTL would be coded as 11, the BBCL would be coded as 23, and the WBPL would be coded as 42.

Note: Often for descriptive and materials data, all lanes (in one or both directions) will have the same data. Thus both directions, all lanes would be coded as 04, northbound direction lanes would be coded as 10, and both directions passing lane would be coded as 02.

Milepost

The milepost location, recroded to the nearest hundredth of a mile, should be consistent with that shown for the same location in the graphic log. The milepost is coded in a four column field with an implied decimal point before the last two columns. Thus milepost 26.18 would be coded as 2618, and milepost 6.01 would be coded as 0601.

Data Type

The codes for data type are:

Data Type	Code
General skid data	0
Accident site skid data	1
Correlation skid data	2
Bridge surface skid data	3
Ramp surface skid data	4
Traffic data	7
Accident data	8

Date

The date is coded in a six column field. The first two columns contain the month code, the second two columns contain the day code, and the last two columns contain the year code.

The codes are:

Month	Code
January	01
February	02
March	03
April	04
May	05
June	06
July	07
August	08
September	09
October	10
November	11
December	12

Day	Code
First	01
Second	02
Third	03
etc.	etc.

Year	Code
	Last two digits of the year

Thus, May 9, 1970, would be coded as 050970; December 29, 1969, would be coded as 122969.

Military Time

Time should be recorded to the nearest minute. Military time is coded in a four column field. The first two columns contain the hour, and the last two columns contain the minutes.

Hour	Code
12 p.m.	00
1 a.m.	01
2 a.m.	02
3 a.m.	03
11 a.m.	11
12 N.	12
1 p.m.	13
2 p.m.	14
10 p.m.	22
11 p.m.	23

Minutes	Code
	Number of minutes past the hour

Thus, 10:30 a.m. would be coded as 1030, 2 p.m. would be coded as 0200, and 4:07 p.m. would be coded as 0407.

Operators

The equipment operators are coded in a two column field. The first column should contain a code for the driver, and the second column a code for the test operator. Codes are shown below for individuals who might use the test equipment.

Person	Code
Hill	0
Payne	1
Runkle	2
Dancy	3
Mahone	4

Thus the following examples would apply:

Driver	Operator	Code
Hill	Payne	01
Hill	Runkle	02
Payne	Runkle	12
Hill	Dancy	03
Payne	Dancy	13

Weather

Ambient weather conditions are coded in a one column field. The codes are:

Weather Condition	Code
Not specified	0
Clear	1
Cloudy	2
Fog	3
Mist	4
Raining	5
Snowing	6
Sleeting	7
Smoke-Dust	8

Air and Surface Temperatures

Air and surface temperatures, recorded in fahrenheit to the nearest degree, are each coded in three column fields. Thus, a temperature of 76°F would be coded as 076, and 105°F would be coded as 105.

Test Vehicle

The codes for test vehicles are:

Vehicle	Code
Skid Trailer	0
Skid Car	1
British Portable Tester (BPT)	2

Speed

Test vehicle speed, recorded in miles per hour to the nearest tenth, is coded in a three column field with an implied decimal point before the last column. Thus 39.7 mph would be coded as 379, and 35.0 mph would be coded as 350.

Left and Right Wheel Skid Numbers

Left and right wheel skid numbers, recorded to the nearest tenth, are each coded in four column fields with an implied decimal point before the last column. If only one wheel is being used in testing, the field for the other wheel should be filled with zeros. Thus a skid number of 96.3 would be coded as 963, a skid number of 106.0 would be coded as 1060, and no test would be coded as 0000.

Calibration

Calibration, referring to the calibration usedto reduce the skid data, is coded in a three column field. The first column contains the last digit of the year the calibration was performed, and the last two columns contain the number of the calibration for that year. Thus the first calibration for 1969 would be coded as 901, and the twelfth calibration for 1970 would be coded as 012.

Gain

The gain of the recorder (on the skid trailer) is coded in a three column field. If a vehcile other than the trailer is used, this field should be filled with zeros. Thus a gain of 48 would be coded as 048, and if the skid car is used, the gain would be coded as 000.

Left and Right Wheel Groove Depth

The average grooved depths for the left and right wheels, recorded to the nearest hundredth of an inch, are coded in two column fields with an implied leading decimal point. If only one wheel is being used in testing, the field for the other wheel should be filled with zeros. Thus a groove depth of 0.27 inch would be coded as 27, a groove depth of 0.09 inch would be coded as 09, and no test would be coded as 00.

New Construction or Maintenance Schedule

A one digit code should be used to indicate if the surface is new construction (coded as 1) or maintenance schedule work (code as 2). A code of 0 will indicate that this information is unknown.

Construction or Maintenance Schedule Number

The first three digits of the maintenance schedule number, or the fourth set of numbers in the project number, should be used in this three digit field.

Example: Maintenance schedule 104-67, coded 104;
project 7058-097-101, 0503, coded 503.

Highway Type

A two digit code as shown below should be used to identify highway type.

Code	Kind of Highway
10	One-way
20	Two-lane
30	Three-lane
40	Four-lane, undivided
41	Four-lane, divided, no control of access
42	Four-lane, divided, parital control of access
43	Four-lane, divided, full control of access
60	Six-lane, undivided
61	Six-lane, divided, no control of access
62	Six-lane, divided, parital control of access
63	Six-lane, divided, full control of access
80	Eight-lane, undivided
81	Eight-lane, divided, no control of access
82	Eight-lane, divided, parital control of access
83	Eight-lane, divided, full control of access
	Transition — when one kind of highway transitions into another kind of highway which is accompanied by a change in pavement width.
72	Transition from a two lane (20) highway to a higher kind of highway - 30-40 etc. or, transition from a higher kind of highway to a two lane (20) highway
73	Transition from a three lane (30) highway to a higher kind of highway - 40-60 etc. or, transition from a higher kind of highway to a three lane (30) highway
74	Transition from a four lane (40-41-42-43) highway to a higher kind of highway - 60-61-62-63) or, transition from a higher kind of highway to a four lane highway
76	Transition from a six lane (60-61-62-63) highway to a higher kind of highway - 80-81-82-83 or, transition from a higher kind of highway to a six lane highway
98	Service road on right
99	Service road on left.

Speed Limit

The posted speed limit should be coded directly.

Special Features

Special feature should be coded as shown below:

Special Feature	Code
None	00
Grooved	01
Limestone blend	02
Sprinkle mix	03
Lightweight aggregate mix	04

Mix Type

The type of mix of the road surface should be coded in the following manner.

Code	Mix Type
00	Unknown (Bituminous Concrete)
01	S-1
02	S-2
03	S-3
04	S-4
05	S-5
06	I-1
07	I-2
08	B-1
09	B-2
10	B-3
11	B-4
12	P-1
13	P-2
14	P-3
20	Surface Treatment
30	Slurry Seal
99	Portland Cement Concrete

Asphalt Type

The asphalt type should be coded as shown below:

Type	Code
Unknown or not applicable	00
AP-00	01
AP-1	02
AP-2	03
AP-3	04
CAE-2	05
RL-2	06

Asphalt GSY

The gallons per square yard should be coded directly as a two digit number with an implied decimal preceding the first digit.

Number of Aggregate Types in Mix

The number of aggregate types in the mix should be coded as a single digit number in column 50 of the site descriptive data card.

Curing Method

The curing method should be coded as shown below:

Method	Code
Unknown or not applicable	00
Liquid Membrane	01
Polyethylene	02
Curing Paper	03

Texturing Method

The texturing method should be coded as shown below:

Method	Code
Unknown or not applicable	00
Burlap Drag	01

Aggregate Size

The aggregate size should be coded as shown below:

Size	Code	
Unknown or not applicable	00	For site descriptive data card
78	01	
68	02	
8	03	
Fine	04	For aggregate materials data card
Medium	05	
Coarse	06	
Filler	07	
#57	08	
#7	09	

Aggregate Geologic Type

The geologic type should be coded as shown below:

Geologic Type	Code	Geologic Type	Code
Unknown or not applicable	00	Sand	05
Limestone	01	Sandstone	06
Dolomite	02	Slag	07
Gravel	03	Traprock	08
Granite	04		

Aggregate Source

The aggregate source should be coded as shown below:

SUFFOLK DISTRICT

1. R. H. Baillo Sand Co.
Virginia Beach, Virginia
2. W. R. Bishop Sand
Handsom, Virginia
3. Melvin Mann Sand
Boykins, Virginia
4. Adams Construction Co.
Stony Creek, Virginia
5. Trego Stone Co.*
Skippers, Virginia

RICHMOND DISTRICT

6. Southern Materials Co., Inc.*
Rawlings, Virginia
7. Southern Materials Co., Inc.*
Alberta, Virginia
8. Vulcan Materials Co.*
Lawrenceville, Virginia
9. Dolphin Stone Co.*
Dolphin, Virginia
10. Friend and Co., Inc.
Petersburg, Virginia
11. Southern Materials Co., Inc.*
Petersburg, Virginia
12. Southern Materials Co., Inc.*
Jack, Virginia
13. Southern Materials Co., Inc.*
Chester, Virginia
14. Southern Materials Co., Inc.*
Kingsland Reach, Virginia
15. Tidewater Crushed Stone and Asphalt Co.*
Richmond, Virginia
16. Southern Materials Co., Inc.*
Richmond, Virginia
17. West Sand and Gravel Co., Inc.*
Richmond, Virginia
18. Carter Sand and Gravel Co. Inc.*
Richmond, Virginia
19. Commonwealth Sand and Gravel Corp.*
Richmond, Virginia
20. Rockville Stone Corp.*
Richmond, Virginia
21. Vulcan Materials Co.*
Richmond, Virginia
22. Boscobel Granite Corp.*
Richmond, Virginia
23. Sadler Materials Co.
Richmond, Virginia
24. Chickahominy Sand and Gravel Corp.
Williamsburg, Virginia
25. J. R. Parker and Co., Inc.*
Providence Forge, Virginia
26. Burkeville Stone Corp.*
Burkeville, Virginia
27. Richmond Crushed Stone Co.
Oilville, Virginia
28. Salem Stone Corp.*
Gum Springs, Virginia

FREDERICKSBURG DISTRICT

29. Fox Sand and Gravel Co.
Aylett, Virginia
30. Mattaponi Sand and Gravel Co., Inc.*
Aylett, Virginia
31. A & T Sand and Gravel Co.
Milford, Virginia
32. Port Royal Sand and Gravel
Woodford, Virginia
33. Solite Corp.*
Fredericksburg, Virginia
34. Fredericksburg Sand and Gravel Corp.*
Fredericksburg, Virginia
35. Fredericksburg Stone Co.*
Fredericksburg, Virginia
36. Massaponax Sand and Gravel Corp.*
Fredericksburg, Virginia
37. The General Crushed Stone Co.*
Doswell, Virginia

CULPEPER DISTRICT

38. Vulcan Materials Co.*
Occoquan, Virginia
39. Vulcan Materials Co.*
Manassas, Virginia
40. Sanders Quarry, Inc.*
Warrenton, Virginia
41. Fairfax Quarries, Inc.*
Centreville, Virginia
42. Chantilly Crushed Stone, Inc.*
Chantilly, Virginia
43. Virginia Trap Rock, Inc.*
Leesburg, Virginia
44. Arlington Stone Co.
Sterling, Virginia
45. Potomac Sand and Gravel Co.*
Washington, D.C.
46. Hilltop Sand and Gravel Co.
Alexandria, Virginia
47. Belvoir Sand and Gravel Co.
Accotink, Virginia
48. Modern Sand and Gravel Co.
Alexandria, Virginia
49. Virginia Sand and Gravel Co.*
Alexandria, Virginia
50. Bull Run Stone Co.
Catharpin, Virginia
51. Loudoun Quarries, Inc.*
Arcola, Virginia
52. Northern Virginia Construction Co.
Annandale, Virginia
53. Flint Hill Quarry*
Flint Hill, Virginia
54. Culpeper Stone Co.*
Culpeper, Virginia
55. Superior Stone Co.*
Gordonville, Virginia
56. Superior Stone Co.*
Rivanna River, Virginia
57. Superior Stone Co.*
North Garden, Virginia
58. Charlottesville Stone Corp.*
Shadwell, Virginia
59. A. H. Smith*
Louisa, Virginia
60. Vulcan Materials Co.*
Ferncliff, Virginia

STAUNTON DISTRICT

61. W. S. Frey Co.*
Clearbrook, Virginia
62. Stuart M. Perry, Inc.*
Winchester, Virginia
63. Stuart M. Perry, Inc.*
Berryville, Virginia
64. M. J. Grove Lime Co.*
Stephens City, Virginia
65. M. J. Grove Lime Co.*
Middletown, Virginia
66. Riverton Lime and Stone Co., Inc.*
Riverton, Virginia
67. Virginia Asphalt Paving Co.
Strasburg, Virginia
68. Chemstone Corp.*
Strasburg, Virginia
69. Riverton Lime and Stone Co., Inc.*
Luray, Virginia
70. C. S. Mundy Quarries, Inc.*
Forrestville, Virginia
71. C. S. Mundy Quarries, Inc.*
Singers Glen, Virginia
72. Fred K. Betts, III, Quarry, Inc.*
Harrisonburg, Virginia
73. The Frazier Quarry, Inc.*
Harrisonburg, Virginia
74. Shenandoah Sand and Gravel
Shenandoah, Virginia
75. Elkton Limestone Co.*
Elkton, Virginia
76. Grottoes Sand and Gravel Co.*
Grottoes, Virginia
77. Sidney Sattterfield
Elkton, Virginia
78. Augusta Stone Corp.*
Staunton, Virginia
79. Belmont Trap Rock Co., Inc.*
Staunton, Virginia
80. Vulcan Materials Co.*
Staunton, Virginia
81. Virginia Dept. of Agriculture
Staunton, Virginia
82. Vulcan Materials Co.*
Waynesboro, Virginia
83. Vulcan Materials Co.*
Lowmoor, Virginia
84. Charles W. Barger and Son Limestone Quarry, Inc.*
Lexington, Virginia
85. Lone Jack Limestone Co., Inc.*
Glasgow, Virginia
86. Beaver Dam Quarry
Callaghan, Virginia
87. Virginia Dept. of Highways
Hightown, Virginia
88. Eastside Quarries
Waynesboro, Virginia

LYNCHBURG DISTRICT

89. Rockydale Stone Service*
Lynchburg, Virginia
90. Blue Ridge Stone Corp.*
Lynchburg, Virginia
91. Solite Corp.*
Bremo Bluff, Virginia
92. Arvonia-Buckingham Slate Co.*
Arvonia, Virginia
93. Le Sueur Richmond Slate Co.
Arvonia, Virginia
94. Dominion Stone Co.
Piney River, Virginia
95. Vulcan Materials Co.*
South Boston, Virginia
96. Vulcan Materials Co.*
Chatham, Virginia
97. Vulcan Materials Co.*
Danville, Virginia

SALEM DISTRICT

98. Liberty Limestone Corp.
Rocky Point, Virginia
99. Liberty Limestone Corp.
Buchanan, Virginia
100. James River Limestone Co., Inc.*
Buchanan, Virginia
101. Blue Ridge Stone Corp.*
Blue Ridge, Virginia
102. Rockydale Quarries Corp.*
Roanoke, Virginia
103. Salem Stone Corp.*
Salem, Virginia
104. Castle Sand Corp.
New Castle, Virginia
105. Shawsville Stone Co.
Shawsville, Virginia
106. Ararat Rock Products Co.*
Blacksburg, Virginia
107. Montgomery Limestone Corp.*
Ellett, Virginia
108. Montgomery Limestone Corp.*
Shawsville, Virginia
109. Martinsville Stone Corp.*
Martinsville, Virginia
110. Wilson Quarries*
Horsepasture, Virginia
111. Wilson Quarries*
Patrick Springs, Virginia
112. Ararat Rock Products Co.*
Mount Airy, North Carolina
113. Newman Brothers Quarry, Inc.*
Floyd, Virginia
114. Virginian Limestone Corp.*
Ripplemead, Virginia
115. Radford Stone Corp.*
Radford, Virginia
116. Radford Stone Corp.*
Newbern, Virginia
117. Weblite Corp.*
Roanoke, Virginia

BRISTOL DISTRICT

118. Cardinal Stone Co.*
Independence, Virginia
119. Acme Stone Co.*
Bland, Virginia
120. Elkhorn Stone Co.*
Elkhorn City, Kentucky
121. Bland Correctional Farm
White Gate, Virginia
122. Newman Brothers Quarry, Inc.*
Sylvatus, Virginia
123. H. D. Crowder and Sons*
Poplar Camp, Virginia
124. The New Jersey Zinc Co.*
Ivanhoe, Virginia
125. Grayson Stone Co.*
Galax, Virginia
126. Paul E. Delp*
Elk Creek, Virginia
127. Pendleton Construction Corp.*
Wytheville, Virginia
128. Pounding Mill Quarry Corp.*
Bluefield, Virginia
129. Holston River Quarry
Marion, Virginia
130. Pounding Mill Quarry Corp.*
Pounding Mill, Virginia
131. James River Hydrate and Supply Co., Inc.*
Swords Creek, Virginia
132. Meadowview Lime and Stone Co.
Meadowview, Virginia
133. Washington County Stone Co.*
Glade Spring, Virginia
134. Acme Stone Co.*
Abingdon, Virginia
135. Vulcan Materials Co.*
Bristol, Virginia
136. Tri State Lime Co.
Blountville, Tennessee
137. Vulcan Materials Co.*
Kingsport, Tennessee
138. R. G. Pope Construction Co.
Dickensonville, Virginia
139. White Excavating Co.*
Castlewood, Virginia
140. Clinch River Quarries*
St. Paul, Virginia
141. Adams Stone Co.*
Burdine, Kentucky
142. Lonesome Pine Stone Co.*
East Stone Gap, Virginia
143. Southwest Quarries, Inc.
Big Stone Gap, Virginia
144. Natural Tunnel Stone Co.*
Clinchport, Virginia
145. Woodway Stone Co.*
Woodway, Virginia
146. Kentucky-Virginia Stone Co.
Gibson Station, Virginia
147. Southeastern Stone Co.
Gibson Station, Virginia

* Denotes Association Members

Aggregate lb./sq.yd.

The aggregate lb./sq.yd. should be coded directly as a two digit number. Code 00 indicates unknown or not applicable.

Aggregate Percent

The percent of the total mix represented by a given aggregate should be coded directly as a three digit number. Code 00 indicates unknown or not applicable.

Site Definitions

A site generally is defined by the beginning and ending mileposts of a given particular surface mix, i.e., a mix placed at the same time, with the same materials. etc., having one schedule or project number. However, it may be necessary at times to define smaller sites within a given mix type when:

(1) the highway type changes,
(2) the speed limit changes, and,
(3) when special features occur.

APPENDIX 3

BITUMINOUS CONCRETE MIXTURES

Type	Percentage by Weight Passing Square Mesh Sieves*										Percent Bituminous Materials	Mix Temperature (At Plant)
	1½	1	¾	½	⅜	No. 4	No. 8	No. 30	No. 50	No. 200		
S-1						100	95-100	50-95	25-65	0-8	8.5-10.5	225-300°F
S-2					100	95-100	60-85	20-40	10-30	2-10	9.5-12.0	225-300°F
S-3					100	90-100	70-95	25-55	15-35	2-12	6.5-10.5	200-240°F
S-4				100	90-100		60-80	25-45	10-30	2-10	5.5- 9.5	225-300°F
S-5				100	80-100		35-55	15-30	7-22	2-10	5.0- 8.5	225-300°F
I-1		100	90-100		85-100	75-100	60-95	25-60	12-35	2-12	5.0- 7.5	225-300°F
I-2		100	95-100		60-80	40-60	25-45		5-14	1-7	4.5- 8.0	225-300°F
B-1		100	90-100			70-100	55-95	25-65	12-40	0-10	3.0- 6.5	225-300°F
B-2	100		50-75			20-35	15-25			0-5	4.0- 6.0	200-240°F
B-3	100		72-87			35-50	28-38			2-6	4.0- 7.0	225-300°F
C-1				100	90-100	65-80	45-65	25-40	13-23	6-10	6.0- 9.0	305-345°F
S-6	Gradation determined by Marshall design—See Section 212.25.										7.5-11.5	225-300°F

*In inches except where otherwise indicated. Numbered Sieves are those of the U. S. Standard Sieve Series.