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STUD TIRE EFFECTS ON PAVEMENT OVERLAYS

- Preliminary Report -

by

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ABSTRACT

This report presents some data obtained from testing twenty-two different types of overlays on three concentric tracks at the G.A. Riedesel Pavement Testing Facility at Washington State University. Six different passenger winter tires were tested, including unstudded, a garnet dust snow retread, and four different types of studs. The data represents a testing period from November 20, 1972 to February 20, 1973 and a total 300,000 revolutions, that is 900,000 wheel applications on the inside track and 300,000 wheel applications on the outside track.

The results reveal that the different polymer concretes show the least wear, and that rubber additives improved the performance of some of the asphalt concrete overlays. The type #2 stud continually showed less wear than the other types of studs. Comparisons with the previous ring reveals that the present ring overlays showed less wear, and that stud protrusions are much less. A comparison and discussion of the results from both rings at this wheel application range is presented. The results from the present data are also discussed. The results are tentative and may change as the present test continues.

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INTRODUCTION

This preliminary report presents results from some of the data obtaining from testing on Ring #6 at the G. A. Riedesel Pavement Testing Facility at Washington State University, Pullman, Washington, during the period from November 20, 1972 to February 20, 1973. At this time 300,000 revolutions had been applied to the tracks; that is, 900,000 wheel passes to the inside and center tracks and 300,000 wheel passes to the outside track. At this point of the test, the initial set of stud tires were removed and a new set of studded tires was installed.

The purpose of this second half of the project was threefold: 1) to determine pavement surface wear caused by studded tires; 2) to evaluate the resistance of different pavement overlays used in the states of Washington and Idaho to wear caused by studded tires; and 3) to test new pavement surface materials, finishes, and overlays to reduce tire stud damage.

This project, Y-1439, was initiated by the Transportation Systems Section of the Department of Civil Engineering, College of Engineering Research Division, Washington State University and is financed by the Washington State Highway Commission, Department of Highways; the Federal Highway Administration of the U.S. Department of Transportation as an HPR federal aid research project; and the Idaho Department of Highways.

Project Y-1439 is divided into three phases: the first phase was testing of current pavements and textures in use in the state of Washington on the effect of various stud tires; the second phase was to evaluate different overlays and materials to stud tire effects; and third phase is to compare both tests to the real world and to analyze the results. The results from the first phase has been published in a series of reports and papers (1,2,3). The second phase is still in progress and this report partially summarizes the results to date.

The data has not been analyzed. This report summarizes the results with respect to pavement surface wear, skid resistance and stud protrusion. A comparison with Ring 5 for that amount of wheel loads is made but this is not final. The final report results may modify analytically the findings presented here. These results were obtained and measured under WSU Test Track conditions and conclusions may not be valid elsewhere.

DESCRIPTION

This test track ring consists of three concentric tracks numbered consecutively, inside, center and outside, #1, #2, and #3; the inside, center and outside widths are 3.5 feet, 3.0 feet and 4.0 feet, respectively. The ring was divided into 12 sections, each 21.5 feet in length, which were further subdivided into subsections.

The old existing pavements from Ring #5 were used as a base and were overlaid with different materials of thicknesses varying from 0.75 inches to 2.0 inches. The old existing portland cement concrete and polymer concrete pavement wheel path grooves were filled in with different patching materials, which were high alumina cement, polymer cement concrete, polymer concrete and portland cement-sand mix. The wheel path grooves on the asphalt pavements were not patched before an overlay was put over them.

This time the inside, center and outside tracks were overlaid with the same overlay material in the same section. This is in contrast to what occurred in Ring #5 where each track had different materials in the same section. A total of 22 different types of overlays were put on the old Ring #5. Figure 1 shows the arrangement of sections of test track Ring #6 and Table 1 shows the types of materials and their lengths and widths.

The sections were patched and built during the months of July, August, September and October. Most were put in under ideal weather conditions. Although some premature failures have occurred; these have been in the bauxite asphalt epoxy surfacings on top of an overlay and has been due to a loss of bond between epoxy and the surface. The description of the materials and their design mixes will be included in the final report.

APPARATUS

The G. A. Riedesel Pavement Testing Apparatus consists of three arms supporting a water tank. These arms revolve in a circle on three sets of truck dual tires. A 60 h.p. D.C. electric motor on each arm provides the motive power. An eccentric mechanism enables the apparatus to move so that a considerable width of pavement can be covered by the test wheels.

The apparatus was extensively modified for Ring #5 so that more tires could be used in the tests. This same modification was continued in Ring #6, which allowed the placing of two sets of passenger tires inside the truck duals so that these tires could run on the inside track (track #1) and in wheel paths #1 and #2. The truck dual tires run on the center track (track #2) and in wheel paths #3 and 4. On the outside track (track #3) two passenger tires were hung on each of the two arms so as to travel in four separate wheel paths numberd #5, #6, #7 and #8. A total of 16 tires were mounted on the apparatus. The passenger car tires carried 1,000 pound loads, applied via air load cells, and the truck dual tires each carried 6,600 pounds. The only modification done for Ring #6 was to change the air load cells using a new system.

Although a hydraulic braking system was installed on two of the arms on the inside tires for Ring #5, continuing problems with it precluded its use on this ring.

TIRES AND STUD TYPES

A total of 16 tires were used at any one time; 6 truck tires, all unstudded; and 10 passenger winter snow tires. The truck tires used in the center track were size 11 x 22.5, inflated to 80 psi air pressure; the inside tire was the driving tire while the outside tire was free-wheeling. The center track had three passes per revolution.

The passenger tires were all G 78x14 with winter snow tread, free-wheeling, and consisted of three unstudded, three with 112 type #1 studs, one with 112 type #2 studs, one with 112 type #3 studs and one with 112 type #4 studs. The remaining tire was a retread with garnet dust, similar to the old sawdust and walnut shell retread tires. Each tire was inflated to 28 psi and carried a 1,000 pound load.

Four types of studs were tested in this second phase. The Type #1 stud is the controlled protrusion stud or CP stud. The Type #2 stud is the perma-t-gripper type or PT stud. The Type #3 stud is the conventional type or the CV stud. The Type #4 is the plastic encased Norfin stud or the Finnish stud. The unstudded tires are designated as US tires and the garnet snow tire is designated as GST. These are symbols which will hereafter be used in tables, charts, and figures.

Track #1 (inside) had three US and three Type #1 studded tires traveling in wheel paths #1 and #2, respectively. The inside track has three wheel passes per revolution. On track #3 (outside), the four passenger car tires were used in four different wheel paths. The Type #3, Type #2, Type #4 studded tires, and the GST tire traveled in wheel paths #5, #6, #7, and #8, respectively. Each revolution represented one wheel pass.

TRAFFIC PAINTS

Four different types of traffic striping were tested to study their resistance to wear due to studded tires; three were paints applied with a constant thickness paint applicator and the other was a thermoplastic white tape. The tests were made on sections 021 and 100, the polymer cement concrete and the Class "G" A.C. with Petroset AT. The initial measured thicknesses of the three paints averaged 22 mils; while that of the thermoplastic white tape averaged 95 mils. At this time, the thermoplastic white tape withstood the stud tire effects better than the paints. A full report on the paints is in Reference 4.

MEASUREMENTS

Eighty-four sets of reference pins were installed in the sections so that transverse profile measurements could be taken with both the WSU profilometer and the camera box-wire technique. The WSU profilometer replaced the camera box-wire technique as the principal method for measuring transverse pavement wear. It was determined from Ring #5 that the profilometer was easier to handle, operate and to measure data.

The WSU profilometer was greatly modified so that the readings could be digitized and automatically put on punch tape, and on a strip chart recorder. The tape is then fed on IBM cards in a programmed form. Data then can be obtained from the computer within 48 hours compared to the old hand method which took two or more weeks for one set of measurements. Unfortunately all this automatic equipment was not ready when the test started and some data still has to be hand processed.

The camera box-wire method is presently being used as back-up equipment for the profilometer even though the measurements take such a long time to be processed from the photographs.

Depth measurements with a straight-edge were also taken.

Temperature measurements using iron-constantan thermocouples were used for measuring the overlay top and bottom temperatures on a 48 point Honeywell recorder. A Belfort thermograph was also used to monitor ambient and surface overlay temperatures. High and low daily air temperatures and daily precipitation amounts were obtained from the Palouse Soil Conservation Station. The temperature data from both the thermograph and the conservation station has been condensed into average weekly maximum and minimum ambient and surface temperatures in Tables 2 and 3, respectively.

Tire tread depth measurements and stud protrusions were also taken at the same time intervals as the transverse depths and skid resistance values. Table 4 shows the stud protrusion lengths for the different type studs and the corresponding tire tread depth.

The California Skid Tester, courtesy of the Washington Highway Department, was used to measure the skid resistance of the various sections and wheel paths. A British Portable Skid Tester was loaned to the researchers by Prismo Corporation. Unfortunately it was lost in transit for about a month and readings are incomplete for the test to date. Only some of the skid resistance values measured with the California Skid Tester are shown in Table 5 and 6.

CONDITIONS OF TEST

TIME PERIOD. Testing started on November 20, 1972 and will be terminated by May 1, 1973. This report covers only the period from November 20, 1972 to February 20, 1973 at which time 300,000 revolutions had been recorded. This means that 900,000, 900,000 and 300,000 wheel passes had been applied on the inside, center and outside tracks, respectively. The track was shut down only for maintenance, measurements or lack of operating personnel for certain shifts.

SPEED. The speed of the apparatus was kept between 20-25 mph. The variations in wear occurring on the various pavement surfaces prevented higher speeds.

ECCENTRICITY. The eccentricity was fixed at 3.50 inches total thus making each passenger tire wheel path 9.5 inches wide and the truck tire wheel path 11.12 inches wide. This is the maximum eccentricity that could be used without the tire paths overlapping.

ENVIRONMENT. The WSU Test Track was operated in all weather conditions that occurred during the testing period. The only abnormal condition was that the track was kept clear of snow at all times.

TIRES. The studded tires were changed after each had 300,000 revolutions, approximately equivalent to 15,000 miles. In the previous test, the tires were kept on until some 25,000 miles had been realized. It was decided to change them on the basis that 1) tire edge wear on both sides due to the constant rotation caused extreme edge wear and caused the studs to loosen and come out and 2) the studs had become quite worn down. The GST tire experienced rapid wear, some of it was due to improper camber and toe-in, and the nature of the retread rubber.

RESULTS

TEMPERATURE. The air and surface temperatures at the WSU Test Track from the Belfort Thermograph were averaged by the week and are shown in Table 2.

They are shown as maximum and values. The maximum and minimum ambient temperatures and daily precipitation amounts were obtained from the Palouse Conservation Station and summarized on a weekly average and maximums and minimums for the week in Table 3.

STUD PROTRUSION AND TREAD DEPTH. The stud protrusions varied with the different types and with the length of test. Tread depth measurements also showed variation. Table 4 shows the initial and average stud protrusions and the corresponding tread depths during the test period covered in this report.

SKID RESISTANCE VALUES. These measurements were taken by the California Skid Tester in each of the wheel paths and were taken quite frequently even though testing time was lost. This winter was also dryer than the previous winter, which allowed taking readings at more frequent intervals. Only the initial and the 300,000 wheel pass skid resistance value are shown in Table 5.

OVERLAY WEAR. The readings shown in Tables 6,7,8,9 and 10 are taken off the computer readout obtained from data taken with the WSU profilometer. The results presented in Table 6-8 are average rate of wear in inches per million wheel applications, the maximum depth and the average depth. The readings have been put onto tables from which comparisons can be drawn as to overlay material and the effect of the various studs.

The Tables are so made so that similar materials can be compared. Table 6 has all the toppings and chipseals grouped together. Table 7 has the portland cement concrete and the different polymer concretes grouped; while Table 8 shows all the different asphalt concretes together.

Table 9 and 10 show the maximum and average depths obtained after 900,000 wheel applications. These were measured on the inside track and in wheel paths #1 and 2.

COMPARISON WITH PREVIOUS TEST. A series of tables were compiled to compare the similar types of studs and tires and also comparative pavements. The stud protrusion lengths and tread depths are compared in Table 11 Tables 12,13 and 14 show the comparison of the maximum and average depths for a few similar pavements and for similar stud types. Table 12 was for 900,000 wheel applications while Tables 13 and 14 were for 300,000 wheel applications.

DISCUSSION OF THE TWO TESTS

It should be noted that comparisons of materials and tests should be made with care and judgment. There are enough differences in both tests, that in some cases, direct comparisons cannot be made. The two tests were run at different times and were constructed at different times. This could have affected the pavements and their wear.

The present test ring sections were constructed during ideal weather conditions most of the time; the exception being the mastic asphalt, section 123. The testing was done during a longer time period and perhaps colder but dryer weather conditions than the previous ring. Tables 2 and 3 show the temperatures that prevailed during this test to date.

Comparing the stud protrusions and tread depths with the previous test, it is obvious that the previous tests had greater stud protrusion lengths which may have increased the pavement wear. Table 4 shows the present stud protrusions and tread depths and Table 11 shows the comparison between this ring and the previous one. The differences appear to be significant.

Tables 12, 13 and 14 show that for similar pavements and stud types, the maximum and average depths in most cases were deeper in Ring 5 than in Ring 6.

Some of the reasons which may have caused greater stud protrusions and greater wear in Ring 5 than Ring 6 may be 1) the pavements in Ring 6 were built under ideal weather conditions than those in Ring 5 and hence may be better pavements; 2) the temperatures for testing of Ring 6 pavements have been colder thus making the pavements harder and more resistant to stud wear; 3) the eccentricity was gradually introduced in Ring 5 as compared to Ring 6 where it was immediately applied and the ridges may have acted to force the studs to protrude more; and 4) the stud manufacturer claims that their experience shows that rough pavements (e.g., grooving, heavy brooming, etc.) as found in Ring 5 cause studs to protrude out faster and uneven wear of studs occurs. All these factors may have contributed to higher pavement wear and greater stud protrusions in Ring 5 than in Ring 6.

DISCUSSION OF RING 6 RESULTS

Although the wear rates were lower than for Ring 5, all studded tires caused wear on all surfaces of the test track. Skid resistance values as shown in Table 5 were lower in the different stud tire wheel paths. It can be said that with exception of the Class "D" asphalt pavements, all skid resistance values in the stud tire wheel paths were below minimum skid resistance value of 25 after 300,000 wheel applications. Once the various toppings were worn off, the skid resistance values went down rapidly.

The materials were grouped in tables according to similarities; e.g., construction and materials. Table 6, which compares the various toppings, the sections with bauxite asphalt epoxy on high-alumina cement concrete (section 010) and on the Class "G" asphalt concrete (section 050) seem to be inferior to other types. The bauxite asphalt epoxy topping on portland cement sand mix had some premature failure in bond with the concrete. This material was applied by hand. The Idaho Chipseal on Class "B" asphalt concrete (section 110) seems to have done well as far as skid resistance and its wear resistance was quite good as shown in Tables 6 and 10. According to Table 6, the type 2 stud seems to have caused the least wear. The GST and US tires seem to be performing similarly as to wear.

A study of the wear comparison of the different portland cement and polymer concretes in Table 7, 9 and 10 again shows the superiority of the polymer concrete and polymer cement concretes over the portland cement concrete. However all these materials had low skid resistance values with the exception of the rubber-sand polymer concrete (section 034) which seems to show promise. The polymer Wirand® concrete seems to have performed as well as most of the other sections as far as wear is concerned. The wear differences at 300,000 wheel applications were so slight that it is difficult to tell which pavement is superior but at 900,000 wheel applications, some differences in wear are showing. According to Table 7, the type #2 stud caused the least amount of wear, followed by the type #1, #4 and #3 studs, respectively.

The addition of garnet and mineral slag to improve the skid resistance values of the polymer concretes seem to be of little value. Only one screen size of these materials were used; however a more variable size mix may help improve skid resistance and resist stud effects. The addition of reclaimed rubber seems to act similarly as a sawdust tire, except that the effect is in the pavement, and seems to improve skid resistance. This warrants more study.

Table 8, on wear comparisons for the different asphalt concrete types with and without additives, shows that the Class "E" asphalt extended epoxy concrete pavement (section 080) has the best resistance to stud wear at 300,000 wheel applications. However, at 900,000 wheel applications, this pavement as shown in Table 10 was not that much superior to stud wear than Class "G" asphalt concretes with Petroset AT and Pliopave. Tables 8 and 10 also shows that the Class "G" asphalt pavements with Petroset AT (section 100) and Pliopave (section 070) seem to show less wear than the Class "G" asphalt concrete pavement (section 090). The Class "D" asphalt concrete (section 061) seems to show the least resistance to stud tire effects. The addition of Petroset AT (section 062) did not seem to help, but it should be noted that parts of the Class "D" asphalt concrete seem to lose bond and come loose. The Class "B" asphalt concrete (section 121) and the mastic asphalt (section 123) seem to show the least wear of all the asphalt concrete pavements, at 300,000 and 900,000 wheel applications.

The asphalt concrete pavement skid resistance values, although higher than those for the various polymer concretes and portland cement concrete, were also lowered by stud tire wear. The type #2 stud caused the least amount of wear, followed by the type #4, type #3 and type #1 studs, respectively.

It should be remembered and emphasized that results shown in this report have not been completely processed,analyzed and evaluated and hence may be subject to change. It should be used with care. The findings from the WSU test track may not be valid elsewhere due to different conditions. The continuation of the test may modify somewhat the present findings.

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3. Krukar, M. and Cook, J.C. "Experimental Ring No. 5: Studded Tire Pavement Wear Reduction and Repair," Research Report No. 73/8-2, College of Engineering Research Division, Washington State University, Pullman, Washington, December 30, 1972, 160 pages.

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TABLE 1: RING #6 - TYPES OF OVERLAYS AS BUILT

SECTION	SUBSECTION	TRACK	TYPE	DIMENSIONS-FT	
				LENGTH	WIDTH
01	0	1,2,3	Bauxite Asphalt Epoxy Surfacing/High Alumina Cement Concrete	21.5	10.5
02	1	1,2,3	Polymer Cement Concrete	16.5	10.5
	2	1,2,3	Polymer Steel Fibers Concrete	3.0	10.5
	3	1,2,3	Garnet Surfacing on Polymer Cement Concrete	2.0	10.5
03	1	1,2,3	Polymer Concrete	15.5	10.5
	2	1,2,3	Garnet Surfacing on Polymer Concrete	2.0	10.5
	3	1,2,3	Mineral Slag-Sand on Polymer Concrete	2.0	10.5
	4	1,2,3	Rubber-Sand on Polymer Concrete	2.0	10.5
04	1	1,2,3	Mineral Slag Asphalt Epoxy Surfacing/Portland Cement Sand Mx	2.0	10.5
	2	1,2,3	Garnet Asphalt Epoxy Surfacing/Portland Cement Sand Mix	2.0	10.5
	3	1,2,3	Bauxite Asphalt Epoxy Surfacing/Portland Cement Sand Mix	17.5	10.5
05	0	1,2,3	Bauxite Asphalt Epoxy Surfacing/Class "G" A.C.	21.5	10.5
06	1	1,2,3	Class "D" A.C.	16.5	10.5
	2	1,2,3	Class "D" A.C. with Petroset AT	5.0	10.5
07	0	1,2,3	Class "G" A.C. with Pliopave	21.5	10.5
08	0	1,2,3	Class "G" Asphalt Extended Epoxy Concrete	21.5	10.5
09	0	1,2,3	Class "G" A.C.	21.5	10.5
10	0	1,2,3	Class "G" A.C. with Petroset AT	21.5	10.5
11	0	1,2,3	Idaho Chip Seal on Class "B" A.C.	21.5	10.5
12	1	1,2,3	Class "B" A.C.	14.5	10.5
	2	1,2,3	Portland Cement Concrete	5.0	10.5
	3	1,3	Mastic Asphalt (Gussasphalt)	2.0	10.5

TABLE 2

WEEKLY AVERAGE AIR AND SURFACE TEMPERATURES[1] IN °F

RECORDED AT THE TEST TRACK

YEAR	WEEKLY PERIOD	AIR		SURFACE[2]	
		MAX.	MIN.	MAX.	MIN.
1972	11/19-11/25	40.4	27.4	37.4	27.4
	11/26-12/02	39.3	26.7	34.9	25.0
	12/03-12/09	11.6	-0.4	18.4	7.9
	12/10-12/16	19.9	4.7	16.4	9.0
	12/17-12/23	44.6	36.7	31.9	27.4
	12/24-12/30	38.6	28.6	31.1	25.4
1973	12/31-01/06	22.6	9.9	22.1	17.9
	01/07-01/13	28.0	10.7	19.7	17.9
	01/14-01/20	42.6	32.4	29.9	24.1
	01/21-01/27	36.7	25.1	28.1	21.6
	01/28-02/03	40.0	29.4	30.7	24.3
	02/04-02/10	38.1	19.6	31.7	21.3
	02/11-02/17	41.4	24.7	32.7	23.3
	02/18-02/24	49.0	29.7	41.6	24.4

[1] Air and Surface Temperatures recorded with Belfort Thermograph

[2] Surface Temperatures measured in Class "G" A.C. at an average depth of 0.40 inches

TABLE 3

MAXIMUM, MINIMUM AND AVERAGE AMBIENT WEEKLY TEMPERATURES INCLUDING PRECIPITATION[1]

YEAR	WEEKLY PERIOD	MAX.	MIN.	AVG AIR TEMP MAX.	AVG AIR TEMP MIN.	PRECIP.[2] INCHES
1972	11/19-11/25	46	26	41.3	31.1	0.51 R,S
	11/26-12/02	51	26	41.3	29.9	0.43 R,S
	12/03-12/09	35	-10	17.0	2.4	T[3] S
	12/10-12/16	32	- 8	17.0	4.0	.34 R,S
	12/17-12/23	54	32	45.1	36.3	3.18 R
	12/24-12/30	50	19	41.4	30.9	0.17 R,S
1973	12/31-01/06	39	- 6	29.4	14.3	0.16 R,S
	01/07-01/13	42	- 8	23.6	4.1	1.14 R,S
	01/14-01/20	52	26	45.3	34.6	0.49 R
	01/21-01/27	43	20	36.9	26.6	T[3] R
	01/28-02/03	42	23	38.4	28.6	0.08 S
	02/04-02/10	41	16	38.1	22.1	0.46 R,S
	02/11-02/17	43	19	38.0	25.6	0.06 R
	02/18-02/24	51	26	43.6	30.1	0.00

[1] Data from Palouse Conservation Station

[2] S means precipitation was in form of snow, R for rain

[3] Trace Quantity

TABLE 4

STUD PROTRUSIONS FOR DIFFERENT STUDS AND CORRESPONDING TREAD DEPTH[1]

ARM	WHEEL PATH	TYPE		STUD PROTRUSION IN. $X10^{-3}$		TREAD DEPTH-1/32 IN.	
		TIRE	STUD	INITIAL	FINAL	INITIAL	FINAL
1	1	Pass.	US	--	--	15.6	14.0
	2	Pass.	#1	43.7	12.6	15.9	13.8
	5	Pass.	#3	64.2	9.7	15.5	13.0
	6	Pass.	#2	22.7	6.0	15.6	13.5
2	1	Pass.	US	--	--	16.0	12.7
	2	Pass	#1	41.0	9.9	17.5	13.7
	7	Pass	#4	51.1	6.7	15.5	12.9
	8	Pass.	GST	--	--	13.9	8.7
3	1	Pass.	US	--	--	15.9	12.1
	2	Pass.	#1	40.7	12.9	16.3	9.4
Average	2[2]	Pass.	#1	41.8	11.8	15.8	12.9

1 For 300,000 revolutions and approximately 15,000 miles of travel

2 Average for the three type #1 studs in wheel path #2

TABLE 5

SKID RESISTANCE VALUES AFTER 300,000 WHEEL PASSES

SECTION	INITIAL (0[1])	US (#1)	#1 (#2)	#3 (#5)	#2 (#6)	#4 (#7)	GST (#8)
		TIRE & STUD TYPES / WHEEL PATHS					
010	50	47	21	20.5	26	22	35.5
021	29	36	16	16	16.5	16.5	17.5
022	37.5	34	24	16.5	16.5	16.5	20
023	37	48	15	17.5	17	18.5	26.5
031	24	23	16	14.5	15	16.5	15.5
032	33.5	39	17	16	16.5	16	28.5
033	35	30	16	15.5	16	16.5	20
034	32.5	21	23	22	24	20	29
041	45	50	20	19.5	18	22	38
042	46	47	16	17.5	17.5	17.5	36
043	47.7	50	22	18	19.5	18	43
050	46.2	50	25	24	31.5	19.5	48
061	37.7	42	44	29.5	27	32	35
062	37	34	33	31.5	27	30.5	28
070	43.7	44	37	23	17	23	29
080	34.3	41	34	18	18	14.5	31
090	39.7	38	42	27	25.5	27	32.5
100	39	37	32	23	18	23	32
110	37	39	17	25.5	22.5	23	25
121	36	27	26	15.5	16.5	16	31
123	47.5	41	17	17	15	17.5	30
122	47.5	35	18	16.5	17	17	31.5

1 No traffic

NOTE: The Washington State Highway Department considers pavements having skid resistance values of less than 25 to be dangerous.

TABLE 6: WEAR COMPARISONS[1] OF THE DIFFERENTS TOPPINGS

SECTION	PARAMETERS	UNITS	TYPE OF STUDS & TIRES US	#1	#3	#2	#4	GST
010	Ave. Rate of Wear/10^6 w.a.	in. x10^{-3}	2.4	167.4	212.5	179.0	221.0	59.7
	Maximum Depth	inches	.032	.090	.103	.093	.108	.056
	Average Depth	inches	.008	.050	.064	.054	.066	.018
041	Ave. Rate of Wear/10^6 w.a.	in. x10^{-3}	9.3	302.4	130.1	165.6	233.8	24.6
	Maximum Depth	inches	.041	.150	.091	.088	.127	.039
	Average Depth	inches	.003	.091	.039	.050	.070	.007
042	Ave. Rate of Wear/10^6 w.a.	in. x10^{-3}	7.0	83.2	98.1	112.0	106.3	44.9
	Maximum Depth	inches	.029	.067	.068	.071	.075	.036
	Average Depth	inches	.002	.025	.029	.033	.032	.013
043[2]	Ave. Rate of Wear/10^6 w.a.	in. x10^{-3}	43.4	267.4	246.7	186.4	267.2	40.7
	Maximum Depth	inches	.043	.136	.131	.106	.125	.064
	Average Depth	inches	.013	.080	.074	.056	.080	.012
050	Ave. Rate of Wear/10^6 w.a.	in. x10^{-3}	56.5	217.4	222.4	193.9	231.8	34.6
	Maximum Depth	inches	.077q	.119	.107	.109	.114	.054
	Average Depth	inches	.017	.065	.067	.058	.070	.010
110	Ave. Rate of Wear/10^6 w.a.	in. x10^{-3}	[3]85.1	[3]166.9	181.6	170.8	223.3	145.3
	Maximum Depth	inches	.088	.127	.156	.185	.199	.151
	Average Depth	inches	.026	.050	.054	.051	.067	.044

1 Wear measurement at 300,000 wheel applications (w.a.)
2 Some premature failure was noted in failure of epoxy bond to base
3 Estimated to be 65% of wear at 900,000 wheel applications (w.a.)

TABLE 7: WEAR[1] COMPARISONS OF THE DIFFERENT PORTLAND CEMENT & POLYMER CONCRETES

SECTION	PARAMETERS	UNITS	TYPE OF STUDS & TIRES: US	#1	#3	#2	#4	GST
122	Ave. Rate of Wear/10^6 w.a.	in. $x10^{-3}$	[2]39.7	[2]173.8	110.2	88.5	114.2	35.5
	Maximum Depth	inches	.026	.085	.064	.060	.068	.056
	Average Depth	inches	.011	.052	.033	.027	.034	.011
021	Ave. Rate of Wear/10^6 w.a.	in. $x10^{-3}$	9.9	56.3	68.7	49.5	27.3	17.2
	Maximum Depth	inches	.020	.045	.049	.042	.034	.024
	Average Depth	inches	.006	.017	.021	.015	.008	.005
022	Ave. Rate of Wear/10^6 w.a.	in. $x10^{-3}$	49.0	67.3	57.0	56.3	10.0	6.7
	Maximum Depth	inches	.056	.060	.043	.049	.038	.036
	Average Depth	inches	.015	.020	.017	.017	.003	.002
023	Ave. Rate of Wear/10^6 w.a.	in. $x10^{-3}$	3.3	21.2	62.5	31.0	30.9	10.3
	Maximum Depth	inches	.021	.032	.042	.038	.044	.029
	Average Depth	inches	.001	.006	.019	.009	.009	.003
031	Ave. Rate of Wear/10^6 w.a.	in. $x10^{-3}$	27.6	15.6	24.5	8.3	14.6	16.1
	Maximum Depth	inches	.027	.019	.041	.033	.030	.028
	Average Depth	inches	.008	.005	.007	.002	.004	.005
032	Ave. Rate of Wear/10^6 w.a.	in. $x10^{-3}$	[2]39.3	[2]60.4	82.8	112.1	124.5	47.3
	Maximum Depth	inches	.017	.036	.063	.068	.072	.043
	Average Depth	inches	.011	.018	.025	.034	.037	.014
033	Ave. Rate of Wear/10^6 w.a.	in. $x10^{-3}$	19.1	81.6	61.4	31.3	52.7	13.2
	Maximum Depth	inches	.037	.063	.050	.042	.047	.030
	Average Depth	inches	.006	.024	.018	.009	.016	.004
034	Ave. Rate of Wear/10^6 w.a.	in. $x10^{-3}$	[2]5.6	[2]78.6	85.8	91.9	94.5	9.9
	Maximum Depth	inches	.022	.051	.059	.056	.077	.037
	Average Depth	inches	.002	.023	.026	.028	..028	.009

1 Wear measured at 300,000 wheel applications (w.a.)

2 Estimated to be 65% of wear at 900,000 wheel applications (w.a.)

TABLE 8: WEAR[1] COMPARISONS OF THE DIFFERENT ASPHALT CONCRETES

SECTION	PARAMETERS	UNITS	TYPE OF STUDS & TIRES					
			US	#1	#3	#2	#4	GST
061	Average Rate of Wear/10^6 w.a.	in. $x10^{-3}$	56.8	917.0	580.5	233.8	395.7	280.8
	Maximum Depth	inches	.041	.407	.246	.121	.178	.197
	Average Depth	inches	.017	.275	.174	.070	.119	.084
062	Average Rate of Wear 10^6 w.a.	in. $x10^{-3}$	45.4	919.2	522.3	259.2	862.7	58.0
	Maximum Depth	inches	.126	.440	.264	.238	.372	.069
	Average Depth	inches	.014	.276	.157	.078	.259	.017
070	Average Rate of Wear/10^6 w.a.	in. $x10^{-3}$	44.2	359.8	469.7	260.9	402.4	64.0
	Maximum Depth	inches	.081	.175	.205	.124	.188	.060
	Average Depth	inches	.013	.108	.141	.078	.121	.019
080	Average Rate of Wear/10^6 w.a.	in. $x10^{-3}$	36.3	548.6	160.1	186.7	205.0	104.0
	Maximum Depth	inches	.160	.270	.098	.090	.103	.057
	Average Depth	inches	.011	.165	.048	.056	.061	.031
090	Average Rate of Wear/10^6 w.a.	in. $x10^{-3}$	[2]32.2	[2]697.8	396.4	228.6	536.3	37.5
	Maximum Depth	inches	.049	.307	.176	.132	.237	.055
	Average Depth	inches	.010	.209	.119	.069	.161	.011
100	Average Rate of Wear/10^6 w.a.	in. $x10^{-3}$	[2]19.4	[2]557.3	112.6	235.5	441.3	43.3
	Maximum Depth	inches	.045	.250	.169	.116	.187	.038
	Average Depth	inches	.006	.167	.101	.071	.132	.013
121	Average Rate of Wear/10^6 w.a.	in. $x10^{-3}$	[2]67.6	[2]272.5	195.1	204.4	220.3	41.6
	Maximum Depth	inches	.039	.143	.109	.105	.107	.069
	Average Depth	inches	.020	.082	.059	.061	.066	.013
123	Average Rate of Wear/10^6 w.a.	in. $x10^{-3}$	[2]76.4	[2]247.1	210.6	154.3	176.6	42.2
	Maximum Depth	inches	.052	.129	.124	.121	.106	.054
	Average Depth	inches	.023	.074	.063	.046	.054	.013

1 Wear measured at 300,000 wheel applications (w.a)
2 Estimated to be 65% wear at 900,000 wheel applications (w.a.)

TABLE 9

COMPARISON OF MAXIMUM & AVERAGE DEPTHS AT 900,000 WHEEL APPLICATIONS

SECTION	WHEEL PATH #1		WHEEL PATH #2	
	US		TYPE #1	STUDS
	MAXIMUM DEPTH-IN.	AVERAGE DEPTH-IN.	MAXIMUM DEPTH-IN.	AVERAGE DEPTH-IN.
010	.077	.009	.111	.068
021	.021	.006	.054	.024
022	.021	.001	.060	.032
023	.039	.005	.080	.036
031	.042	.018	.035	.011
032	.022	.013	.048	.024
033	.045	.011	.068	.039
034	.034	.002	.074	.036
041	.040	.003	.190	.119
042	.037	.003	.089	.044
043	.047	.019	.146	.090
050	.074	.019	.138	.081

TABLE 10

COMPARISON OF MAXIMUM & AVERAGE DEPTHS AT 900,000 WHEEL APPLICATIONS

SECTION	WHEEL PATH #1		WHEEL PATH #2	
	US		TYPE #1	STUDS
	MAXIMUM DEPTH-IN.	AVERAGE DEPTH-IN.	MAXIMUM DEPTH-IN.	AVERAGE DEPTH-IN.
061	.044	.016	.458	.323
062	.294	.040	.591	.466
070	.117	.011	.250	.164
080	.190	.029	.344	.210
090	.100	.015	.473	.322
100	.086	.004	.385	.257
110	.128	.042	.169	.067
121	.078	.041	.220	.126
123	.103	.046	.198	.114
122	.052	.022	.130	.080

TABLE 11

STUD PROTRUSIONS AND TREAD DEPTH COMPARISONS BETWEEN BOTH RINGS AFTER 300,000 APPLICATIONS[1]

ARM	WHEEL PATH	STUD TYPE	STUD PROTRUSION $\times 10^{-3}$ INCH			TREAD DEPTH-1/32 INCH		
			RING #5	RING #6	DIFF.[3]	RING #5	RING #6	DIFF.[3]
1	1	US	--	--	--	15.5	14.0	+1.5
	2	#1	64.0	12.6	+51.4	15.3	13.8	+1.5
	5	#3	125.0	9.7	+115.3	12.5	13.0	-0.5
	6	#2	25.0	6.0	+19.0	14.1	13.5	+0.6
2	1	US	--	--	--	16.2	12.7	+3.5
	2	#1	88.0	9.9	+78.1	14.9	13.7	+1.2
	7	#1	115.0	--	--	12.0	--	--
3	1	US	--	--	--	15.3	12.1	+3.2
	2	#1	71.0	12.9	+58.1	15.0	9.4	+5.6
Average	#2[2]	#1	74.3	11.8	+62.5	15.0	12.9	+2.1

1 Approximately equivalent to 15,000 miles of travel
2 Average for the three type #1 studs in wheel path #2
3 Difference between Ring #5 and Ring #6

TABLE 12

COMPARISONS OF MAXIMUM AND AVERAGE DEPTHS
FOR COMPARABLE PAVEMENTS FROM BOTH TESTS [1]

Pavement Type	Maximum Depth-in.			Average Depth-in.		
	R #5	R #6	Diff.[2]	R #5	R #6	Diff.[2]
Polymer Cement Concrete	.113	.054	+.059	.062	.024	+.038
Polymer Concrete	.121	.034	+.087	.058	.011	+.047
Portland Cement Concrete	.196	.130	+.066	.108	.080	+.028
Class "B" Asphalt Concrete	.400	.220	+.180	.285	.126	+.159
Class "G" Asphalt Concrete	.489	.473	+.016	.355	.322	+.033

[1] For type #1 studs, wheel path #2 and 900,000 wheel applications.
[2] Difference between Ring #5 and Ring #6

TABLE 13

COMPARISON OF MAXIMUM DEPTH
FOR VARIOUS STUDS AND PAVEMENTS FROM BOTH TESTS[1]

Pavement Types	Stud #1			Stud #2			Stud #3		
	R #5	R #6	Diff.[2]	R #5	R #6	Diff.[2]	R #5	R #6	Diff.[2]
Polymer Cement Concrete	.190	.019	+.171	.204	.033	+.171	.173	.041	+.132
Portland Cement Concrete	.146	.085	+.061	.144	.060	+.084	.137	.064	+.073
Class "B" A.C.	.372	.143	+.229	.164	.105	+.059	.497	.109	+.388
Class "G" A.C.	.264	.307	-.043	.165	.132	+.033	.424	.176	+.248

[1] After 300,000 wheel applications.
[2] Difference between Ring #5 and Ring #6

TABLE 14

COMPARISON OF AVERAGE DEPTH FOR
VARIOUS STUDS AND PAVEMENTS FROM BOTH TESTS[1]

Pavement Types	Stud #1			Stud #2			Stud #3		
	R #5	R #6	Diff.[2]	R #5	R #6	Diff.[2]	R #5	R #6	Diff.[2]
Polymer Concrete	.070	.005	+.065	.111	.002	+.109	.088	.007	+.081
Portland Cement Concrete	.089	.052	+.037	.064	.027	+.037	.060	.033	+.027
Class "B" A.C.	.275	.082	+.193	.108	.061	+.047	.319	.059	+.260
Class "G" A.C.	.188	.209	-.021	.092	.069	+.023	.287	.119	+.168

[1]After 300,000 wheel applications.
[2]Difference between Ring #5 and Ring #6

FIGURE 1