WASHINGTON STATE HIGHWAY DEPARTMENT RESEARCH PROGRAM REPORT **9.2**

STUDDED TIRE PAVEMENT WEAR REDUCTION & REPAIR

PHASE 2

RESEARCH PROJECT

Y-1439

JULY 1973

PREPARED FOR
WASHINGTON STATE HIGHWAY COMMISSION
IN COOPERATION WITH
U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
AND IDAHO DEPARTMENT OF HIGHWAYS

MILAN KRUKAR
JOHN C. COOK
TRANSPORTATION SYSTEMS SECTION
RESEARCH DIVISION
COLLEGE OF ENGINEERING
WASHINGTON STATE UNIVERSITY

COLLEGE OF ENGINEERING
RESEARCH DIVISION
TRANSPORTATION SYSTEMS SECTION

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STUDDED TIRE PAVEMENT WEAR REDUCTION AND REPAIR - PHASE II

-Final Draft-

By Milan Krukar and John C. Cook

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Milan Krukar, P.E.
Associate Civil Engineer

John C. Cook, P.E.
Research Engineer & Head

Prepared for the Washington State Highway Commission, Department of Highways in cooperation with U.S. Department of Transportation, Federal Highway Administration and Idaho Department of Highways.

Engineering Lab Building 103
Pullman, Washington

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16. Abstract

This report presents results obtained from testing at the G. A. Riedesel Pavement Testing Facility at Washington State University during the period of November 20, 1972 to May 1, 1973. The purpose of this project was three-fold: 1) to determine pavement 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 tire studs; and 3) to test pavement materials and overlays to reduce tire stud damage.

Ring #6 and Phase II of this project consisted of three concentric tracks on which 16 tires traveled in eight wheel paths. Four types of studs in passenger snow tires two types of passenger tires, and unstudded truck tires, and 22 sections of various types of pavement overlays and surfacings were tested. Four different stripes were also tested. The results are based on wear in terms of rate of wear, area removed, maximum and average rut depths using the WSU profilometer and the camera wire shadow box apparatus. Skid resistance values were measured using the California Skid Tester and the English Portable Skid Tester. The results are valid only under WSU testing conditions.

The findings indicate that some pavement overlays are resistant to the effect of studded tires than others. All types of studded tires tested caused some pavement wear and this affected skid resistance values. Some of the newer types of studs reduced wear of various pavement overlays. The pavements having the most wear resistance conversely had the lowest skid resistance retention characteristics. Additives to asphalt concrete helped wear resistance characteristics but lowered skid resistance retention characteristics.

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PAVEMENT RESEARCH
AT THE
WASHINGTON STATE UNIVERSITY
TEST TRACK

STUDDED TIRE PAVEMENT WEAR REDUCTION AND REPAIR

PHASE II

Report to the Washington State Department of Highways
on Research Project Y-1439

by

Milan Krukar and John C. Cook

Transportation Systems Section
Department of Civil and Environmental Engineering
College of Engineering
Washington State University
Pullman, Washington
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Prepared for the
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Thanks go to Robert Bureau, Leadman with the Electrical Engineering Section, who designed and built the original WSU Profilometer and then re-designed it and Wayne E. Clayton, assistant mechanical engineer with the Applied Mechanics Section, who built it. Dave Heinen, Electrical Engineer student, with the assistance of Jim Logan, assistant engineer with the Electrical Engineering Section, deserve credit for designing and building the digitizer for automated profilometer readings and for developing the computer programs. Norm Shoup, Mechanical Engineer, designed and supervised the modifications to the G. A. Riedesel Pavement Testing Facility.

Max E. Huffaker and Dr. R. A. V. Raff, of the Polymer Materials Section, worked on the polymer concrete design. The construction was done by Max Huffaker and Walt Long.

Photographs were taken and printed by the Engineering Photographic Laboratory's staff - Herb Howard, William Hawkins and Glenn Sprouse.

Words of appreciation go to the secretary, Cheryl Caraher, who typed and also helped in editing this report. The list of WSU students who worked on this report is too lengthy for inclusion, but their help was necessary and and greatly appreciated. However, a special thanks and credit go to Rich Stager and Chuck West, Civil Engineering students, who did most of the figures and graphs calculation, and to Barbara J. Krukar, who worked on converting the profilometer and other data on to punch cards. Much credit must go to Leonard Hansen, Laboratory Mechanic, who worked on the construction of the pavements, ran the testing and took data measurements. Many suggestions on the text, figures and tables were made by Dr. Harold C. Sorensen, Assistant Civil Engineering Professor,and were incorporated into this report. His aid is sincerely appreciated.

We also express our thanks to the different organizations who contributed free material for testing in this project and also for their technical help. A list of companies and advisory personnel is included at the end of the report.

United Paving, Inc., did all of the asphalt concrete pavement construction and was most cooperative and helpful.

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STUDDED TIRE PAVEMENT WEAR REDUCTION AND REPAIR - PHASE II

SUMMARY OF RESULTS

1. Twenty-two different overlays were tested in this Phase II of the Studded Tire project at the WSU Test Track. This study was sponsored by the Washington State Highway Department in cooperation with the Federal Highway Administration, U.S. Department of Transportation, and the Idaho Highway Department.

   The overlays of 0.75 inch thickness were constructed during August, September and October of 1972. Testing started on November 20, 1972, and ended on May 1, 1973. There were three concentric tracks - inside, center and outside. On the inside track, there were three sets of passenger tires running in two wheel paths - in wheel path #1, three passenger snow tires and in wheel path #2, three passenger snow tires with controlled protrusion studs (type #1). On the center track, there were two wheel paths, #3 and #4, traveled by three sets of dual unstudded truck tires. Three studded tires and a garnet dust retread tire were run on the outside track which had four wheel paths, #5-#8, with one passenger tire traveling in each wheel path. The three types of studs tested on the outside track were the conventional stud (type #3) in wheel path #5, the Perma-T-Gripper (type #2) in wheel path #6, and the Finnstop stud (type #4) in wheel path #7. All of the passenger tires were free-wheeling.

   At the end of the test 2,151,306 wheel applications had been applied on the inside and center tracks; 717,102 wheel applications had been applied on the outside track.

   The types of overlays and surfacings tested are shown in Table I.

Measurements of wear were made with the WSU profilometer which was digitized and automatically recorded on paper tape and strip charts. Skid resistance values were measured with the California Skid Tester and the English Portable Skid Tester.

2. Comparisons of materials based on results of the tests should be made with care and judgement. The WSU testing conditions may make comparisons with results obtained elsewhere difficult. All testing was done under local environmental conditions. The only variable which was controlled was the speed. Even here, the inside wheels were traveling at lower speeds than the outside wheels, thus perhaps affecting wear and wear rates.

3. The bauxite aggregate asphalt extended epoxy surfacing on the high alumina cement concrete (010) for the group of six different surfacings had the most resistance to wear caused by the different types of studs. This is shown in Table IV and Figure I. Similar surfacing on class "G" asphalt concrete overlay (100% passing 5/8 inch sieve) showed high wear but also high skid resistance retention characteristics (Table III). The Idaho Chip Seal, which showed the most wear, had the highest skid resistance retention characteristics in this group. The other aggregates tested were of poorer quality in resisting the effects of studded tires with respect to wear and skid resistance characteristics.

4. The polymer concrete section (031) for the group of the eight portland cement concrete and polymer concrete sections had the best resistance to wear caused by the different types of studs. This is shown in Table IV and Figure II. Table III shows that this section had the lowest skid

resistance; the S.R.N.* was below 25 before the test started. The most wear occurred in the portland cement concrete section (122) followed by the rubber-sand polymer concrete section (034). These two sections had the highest skid resistance retention characteristics. The sections with the different aggregates (023, 032 and 033) had various wear resistances and poor skid resistance retention characteristics. The polymer steel fibrous concrete (022) had average wear and skid resistance characteristics. This group had the best overall wear resistant characteristics and the poorest skid resistance retention characteristics.

5. The mastic asphalt concrete (Gussasphalt) section (123) for the group of eight asphalt concrete sections had the best resistance to wear caused by the different type of studs. This is shown in Table II and Figure III. The class "B" asphalt concrete section (100% passing the 5/8 inch sieve) had the next highest wear resistance. The lowest wear resistance to studded tires was shown by the class "D" asphalt concrete (100% passing the 1/2 inch sieve). This was the coarse open graded hot-mix asphalt concrete. The different additives to the various class "G" asphalt concrete (100% passing 1/2 inch sieve) increased wear resistance compared to the regular class "G" asphalt concrete. The sections with the highest wear resistance conversely had the lowest skid resistance retention characteristics as shown in Table III. The poor skid resistance of the mastic asphalt concrete was due to the failure of the aggregate chips to adhere to the mastic asphalt concrete and was a construction failure.

6. All of the studded tires caused measurable wear on all surfaces of the test track. Comparative wear ratios shown in Table IV and calculated only for

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* S.R.N. is Skid Resistance Number.

the inside and outside tracks for 717,102 wheel applications, show that the type #2 studs caused less wear than the other three types of studs. The type #1 stud generally caused less wear than the type #3 or type #4 stud. The type #4 stud generally caused the most pavement wear. The unstudded passenger snow tires and the garnet dust retread tires caused the least amount of wear. The unstudded truck tires caused pavement wear but less than the studded tires.

7. The different additives to the class "G" asphalt concrete did increase the wear resistance to studded tires but they also lowered the skid resistance retention characteristics. This is compared to the regular class "G" asphalt extended epoxy concrete showed the most wear resistance to studded tires of the additives.

8. The surfacings with the largest size of aggregates had the highest skid resistance values and best skid resistance retention characteristics. It is possible that if larger sized garnet and mineral slag aggregates had been used, they would have compared favorably with the bauxite aggregate sections with respect to wear and skid resistance.

9. The initial rate of wear was in most cases higher than the medium, final and overall rates for almost all overlays. This indicates that there would be high initial wear which would slow down as the stud protrusion pins and tires wear down. In the real world, one might expect high wear rates at the beginning of the winter when many tires and studs are new and progressively slower wear with time.

10. Skid resistance values dropped with wear caused by the studded tires (Table III). Under the WSU test conditions, the studded tires had a polishing

effect especially on the portland cement concrete and polymer concrete groups and hence, on the different surfacings.

11. Comparison of wheel path measurements with different methods and procedures show that the results were quite comparable.

12. Construction problems with the mixing and placing of the mastic asphalt concrete (Gussasphalt) resulted in poor skid resistance values due to failure of retaining the aggregate chips. This was due to inability to keep the mix hot because of lack of proper equipment and cold weather.

13. Four different types of traffic stripings were tested. The thermoplastic striping was superior in resisting the effect of studded tires and was primarily due to its thickness.

14. No extensive comparisons of wear were made with the Phase I part of this project. However, the wear in similar types of pavements appears to have been greater for the Phase I of this study and may have been due to (1) different environmental conditions, (2) better pavement in Phase II due to better construction conditions, and (3) different surface textures. These comparisons are part of Phase III of this project.

TABLE I

RING #6 - TYPES OF OVERLAYS AS BUILT

SECTION	TRACK	TYPE OF OVERLAY	LENGTH[1]
010	1,2,3	Bauxite Asphalt Epoxy Surfacing/High Alumina Cement Concrete	21.5 Feet
021	1,2,3	Polymer Cement Concrete	16.5
022	1,2,3	Polymer Steel Fibrous Concrete	3.0
023	1,2,3	Garnet Surfacing on Polymer Cement Concrete	2.0
031	1,2,3	Polymer Concrete	15.5
032	1,2,3	Garnet Surfacing on Polymer Concrete	2.0
033	1,2,3	Mineral Slag-Sand on Polymer Concrete	2.0
034	1,2,3	Rubber-Sand on Polymer Concrete	2.0
041	1,2,3	Mineral Slag Asphalt Epoxy Surfacing/Portland Cement Sand Mix	2.0
042	1,2,3	Garnet Asphalt Epoxy Surfacing/Portland Cement Sand Mix	2.0
043	1,2,3	Bauxite Asphalt Epoxy Surfacing/Portland Cement Sand Mix	17.5
050	1,2,3	Bauxite Asphalt Epoxy Surfacing/Class "G" Asphalt Concrete	21.5
061	1,2,3	Class "D" Asphalt Concrete	16.5
062	1,2,3	Class "D" Asphalt Concrete with Petroset AT	5.0
070	1,2,3	Class "G" Asphalt Concrete with Pliopave	21.5
080	1,2,3	Class "G" Asphalt Extended Epoxy Concrete	21.5
090	1,2,3	Class "G" Asphalt Concrete	21.5
100	1,2,3	Class "G" Asphalt Concrete with Petroset AT	21.5
110	1,2,3	Idaho Chip Seal on Class "B" Asphalt Concrete	21.5
121	1,2,3	Class "B" Asphalt Concrete	14.5
122	1,2,3	Portland Cement Concrete	5.0
123	1,3	Mastic Asphalt (Gussasphalt)	2.0

[1] Measured in the direction of wheel travel at 41.5 foot radius line. The width for all of the sections was 10.5 feet.

TABLE II

COMPARISON OF AVERAGE RUT DEPTHS OF 717,102 WHEEL APPLICATIONS

SECTION	TYPE OF OVERLAY	AVERAGE RUT DEPTHS - INCHES					
		NO STUDS		STUD TYPE			
		U.S.[1]	GST	#1	#2	#3	#4
010	Bauxite Asphalt Epoxy/High Alumina C.C.	.010	.020	.047	.063	.095	.111
041	Mineral Slag Asphalt Epoxy Surfacing/ P.C. Sand Mix	.009	.022	.109	.085	.105	.140
042	Garnet Asphalt Epoxy Surfacing/ P.C. Sand Mix	.011	.003	.039	.064	.046	.076
043	Bauxite Asphalt Epoxy Surfacing/ P.C. Sand Mix	.015	.030	.090	.110	.127	.138
050	Bauxite Asphalt Epoxy Surfacing/ Class "B" Asphalt Concrete	.015	.046	.078	.096	.105	.131
110	Idaho Chip Seal on Class "G" A.C.	.036	.029	.092	.095	.239	.148
122	Portland Cement Concrete	.005	.013	.065	.031	.051	.048
021	Polymer Cement Concrete	.008	.002	.021	.027	.025	.014
022	Polymer Steel Fibrous Concrete	.003	.006	.028	.033	.036	.016
023	Garnet Surfacing on Polymer Cement Concrete	.005	.016	.021	.030	.014	.025
031	Polymer Concrete	.004	.004	.009	.009	.005	.009
032	Garnet Surfacing on Polymer Concrete	.006	.004	.009	.040	.027	.024
033	Mineral Slag-Sand on Polymer Concrete	.002	.001	.008	.012	.011	.007
034	Rubber-Sand on Polymer concrete	.001	.007	.042	.054	.040	.104

[1] These average rut depths were interpolated from the data obtained with the WSU Profilometer on the inside track.

TABLE II (Continued)

COMPARISON OF AVERAGE RUT DEPTHS OF 717,102 WHEEL APPLICATIONS

SECTION	TYPE OF OVERLAY	AVERAGE RUT DEPTHS - INCHES					
		NO STUDS		STUD TYPE			
		U.S.[1]	GST	#1	#2	#3	#4
061	Class "D" Asphalt Concrete	.013	.062	.301	.183	.461	.293
062	Class "D" Asphalt Concrete with Petroset AT	.010	.049	.408	.060	.407[2]	.748
070	Class "G" Asphalt Concrete with Pliopave	.010	.024	.159	.125	.259	.236
080	Class "G" Asphalt Extended Epoxy Concrete	.002	.002	.236	.085	.121	.159
090	Class "G" Asphalt Concrete	.007	.031	.295	.123	.267	.360
100	Class "G" Asphalt Concrete with Petroset AT	.006	.035	.240	.146	.281	.350
121	Class "B" Asphalt Concrete	.007	.020	.141	.099	.115	.117
123	Mastic Asphalt Concrete (Gussasphalt)	.010	.021	.089	.057	.080	.091

1 These average rut depths were interpolated from the data obtained with the WSU Profilometer on the inside track.

2 Calculated from the rate of wear since these ruts were filled after 500,000 wheel applications.

TABLE III

NUMBER OF WHEEL APPLICATIONS TO REACH SKID RESISTANCE NUMBER[1] OF 25[2]

PAVEMENT TYPES[4]	SECTION	TIRE & STUD TYPES					
		US	#1	#2	#3	#4	GST
		WHEEL PATHS					
		#1	#2	#6	#5	#7	#8
DIFFERENT SURFACINGS	010	--[3]	145,000	280,000	200,000	250,000	--[3]
	041	--[3]	90,000	65,000	90,000	200,000	--[3]
	042	--[3]	60,000	45,000	38,000	55,000	550,000
	043	--[3]	200,000	180,000	200,000	175,000	--[3]
	050	--[3]	300,000	312,500	185,000	195,000	--[3]
	110	--[3]	230,000	230,000	280,000	300,000	440,000
DIFFERENT PORTLAND CEMENT AND POLYMER CONCRETES	122	--[3]	120,000	50,000	20,000	65,000	--[3]
	021	1,000,000	10,000	26,000	25,000	24,000	180,000
	022	770,000	220,000	55,000	25,500	50,000	195,000
	023	--[3]	20,000	26,000	15,000	55,000	425,000
	031	0	0	0	0	0	0
	032	--[3]	35,000	35,000	30,000	115,000	260,000
	033	1,170,000	50,000	20,000	23,000	10,000	10,000
	034	950,000	120,000	180,000	150,000	200,000	340,000
DIFFERENT ASPHALT CONCRETES	061	2,151,000	580,000	355,000	355,000	665,000	--[3]
	062	2,151,000	540,000	250,000	470,000	560,000	--[3]
	070	2,151,000	770,000	175,000	250,000	265,000	--[3]
	080	2,050,000	540,000	180,000	160,000	190,000	--[3]
	090	1,380,000	530,000	200,000	350,000	340,000	530,000
	100	--[3]	530,000	175,000	250,000	275,000	--[3]
	121	550,000	320,000	175,000	190,000	160,000	--[3]
	123	--[3]	350,000	60,000	50,000	105,000	660,000

[1] California Skid Tester

[2] The Washington State Highway Department considers pavements having skid resistance values of 25 or less as being dangerous.

[3] Skid resistance number was above 25 at the end of the test.

[4] Refer to Table I for specific pavement overlays.

TABLE IV

COMPARATIVE PAVEMENT WEAR[1]

SECTION	TYPE OF OVERLAY	WEAR RATIO[2] WITH RESPECT TO TYPE #3 STUD					
		NO STUDS		STUD TYPE			
		U.S.[1]	GST	#1	#2	#3	#4
010	Bauxite Asphalt Epoxy/High Alumina C.C.	9.50	4.75	2.02	1.51	1.00	.86
041	Mineral Slag Asphalt Epoxy Surfacing/ P.C. Sand Mix	11.67	4.77	.96	1.24	1.00	.75
042	Garnet Asphalt Epoxy Surfacing/P.C. Sand Mix	4.18	15.3	1.18	.72	1.00	.61
043	Bauxite Asphalt Epoxy Surfacing/P.C. Sand Mix	8.47	4.23	1.41	1.15	1.00	.92
050	Bauxite Asphalt Epoxy Surfacing/Class "G" A.C.	6.8	2.28	1.31	1.09	1.00	.80
110	Idaho Chip Seal on Class "B" A.C.	6.64	8.24	2.60	2.52	1.00	1.62
122	Portland Cement Concrete	10.20	3.92	.79	1.65	1.00	1.06
021	Polymer Cement Concrete	3.13	12.5	1.19	.93	1.00	1.79
022	Polymer Steel Fibrous Concrete	12.0	6.0	1.29	1.09	1.00	2.25
023	Garnet Surfacing on Polymer Cement Concrete	2.8	.88	.67	.47	1.00	.56
031	Polymer Concrete	1.25	1.25	.56	.56	1.00	.56
032	Garnet Surfacing on Polymer Concrete	4.5	6.75	3.0	.68	1.00	1.13
033	Mineral Slag-Sand on Polymer Concrete	5.5	11.0	1.38	.92	1.00	1.57
034	Rubber-Sand on Polymer Concrete	40.0	5.7	.95	.74	1.00	.38

[1] Passenger tires, inside and outside tracks only, and at 717,102 Wheel Applications.

[2] Wear Ratio (W.R.) $= \frac{\text{Stud Type \#3 Average Rut Depth}}{\text{Stud Type \#Y Average Rut Depth}}$

TABLE IV (Continued)

COMPARATIVE PAVEMENT WEAR[1]

SECTION	TYPE OF OVERLAY	WEAR RATIO[2] WITH RESPECT TO TYPE #3 STUD					
		NO STUDS		STUD TYPE			
		U.S.[1]	GST	#1	#2	#3	#4
061	Class "D" Asphalt Concrete	35.46	7.44	1.53	2.52	1.00	1.57
062	Class "D" Asphalt Concrete with Petroset AT	40.90	8.31	1.00	6.78	1.00	.54
070	Class "G" Asphalt Concrete with Pliopave	25.90	10.79	1.63	2.07	1.00	1.10
080	Class "G" Asphalt Extended Epoxy Concrete	60.5	60.5	.51	1.42	1.00	.76
090	Class "G" Asphalt Concrete	38.14	8.61	.91	2.17	1.00	.74
100	Class "G" Asphalt Concrete with Petroset AT	46.83	8.03	1.17	1.92	1.00	.80
121	Class "B" Asphalt Concrete	16.43	5.75	.82	1.16	1.00	.98
123	Mastic Asphalt Concrete (Gussasphalt)	8.0	3.81	.90	1.40	1.00	.88

[1] Passenger tires, inside and outside tracks only, and at 717,102 Wheel Applications.

[2] $\text{Wear Ratio (W.R.)} = \frac{\text{Stud Type \#3 Average Rut Depth}}{\text{Stud Type \#Y Average Rut Depth}}$

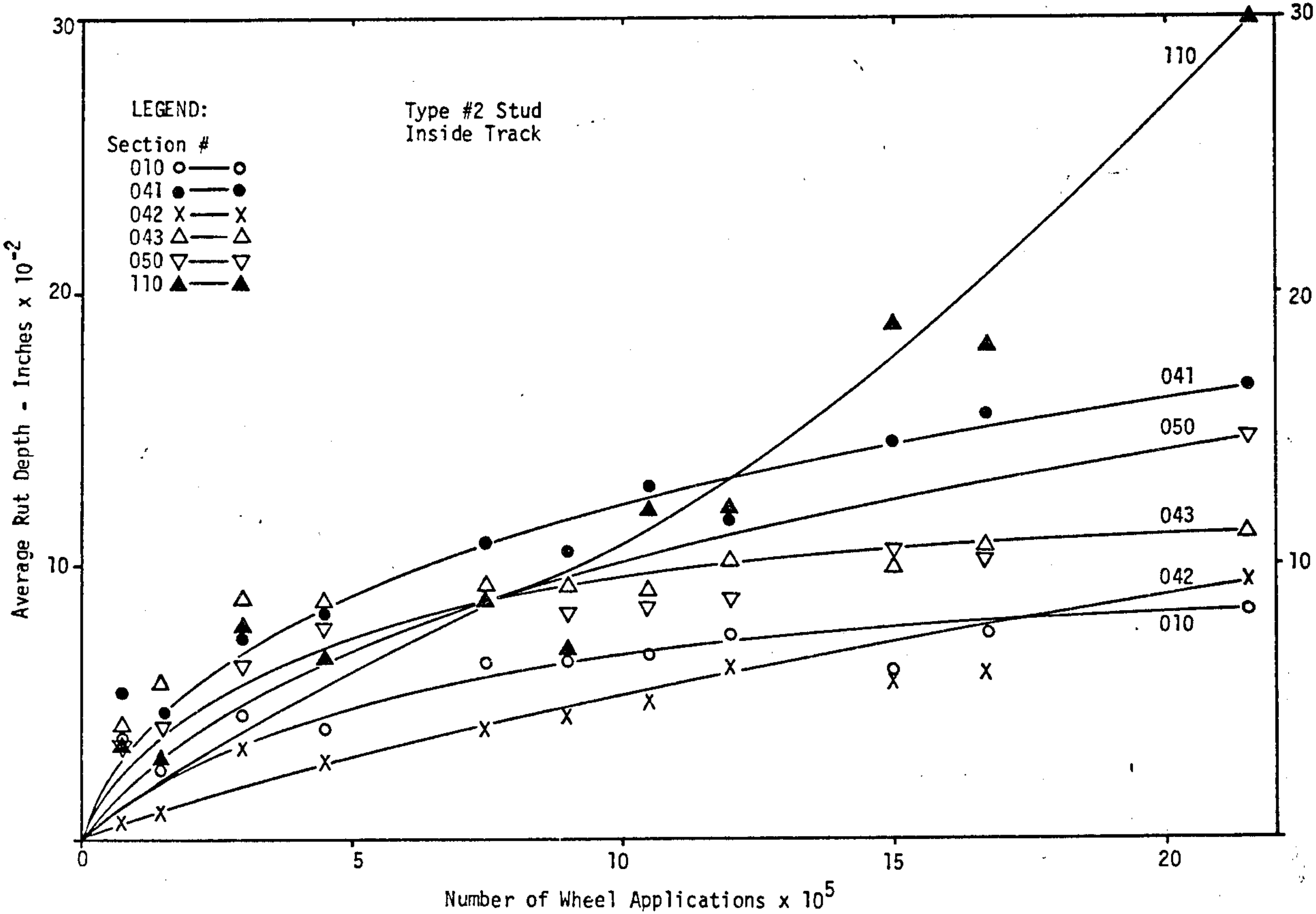

FIGURE I: Average Rut Depth with Wheel Applications for the Various Surfacings

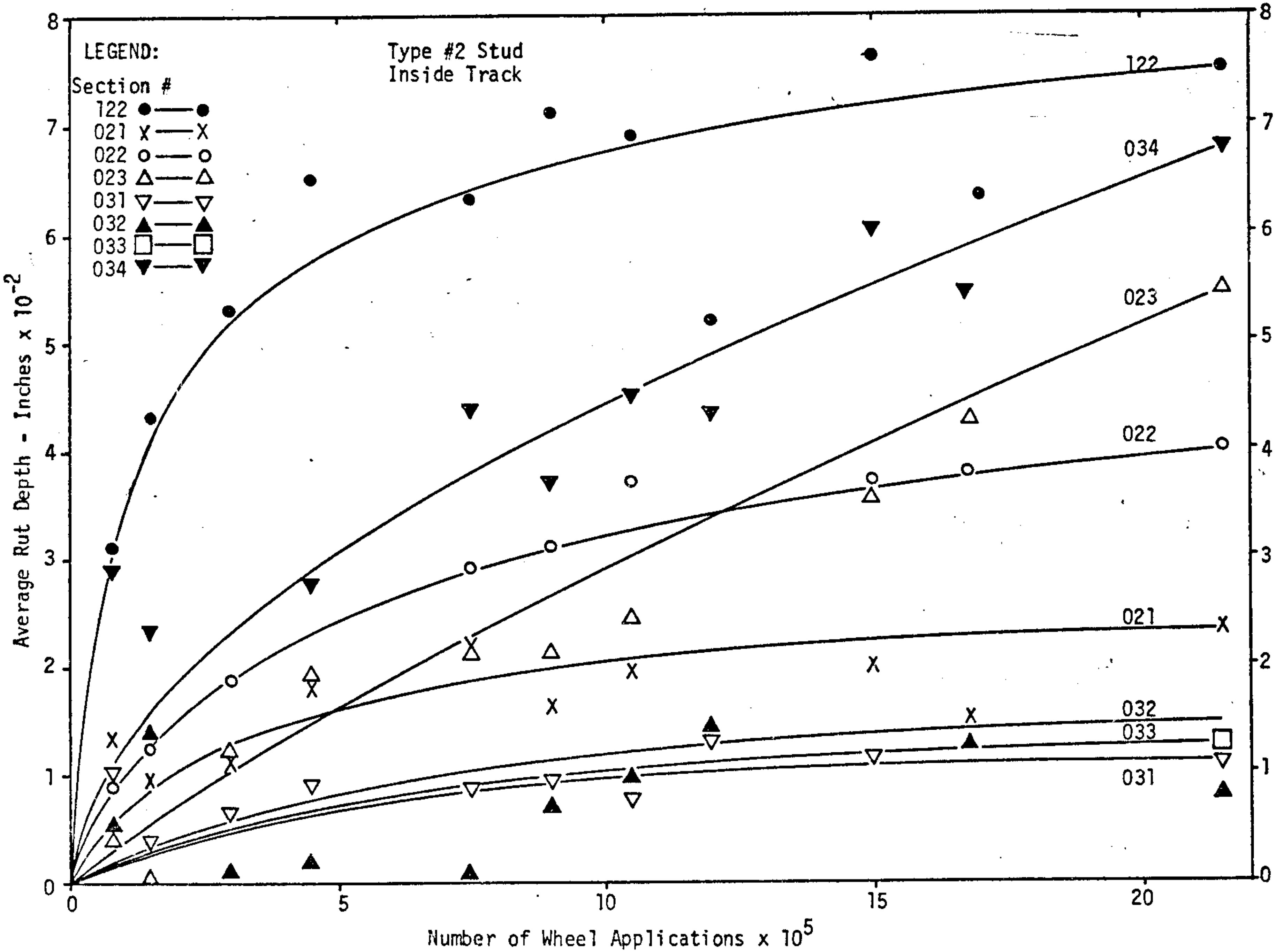

FIGURE II: Average Rut Depth with Wheel Applications for the PCC and Polymer Concrete Group

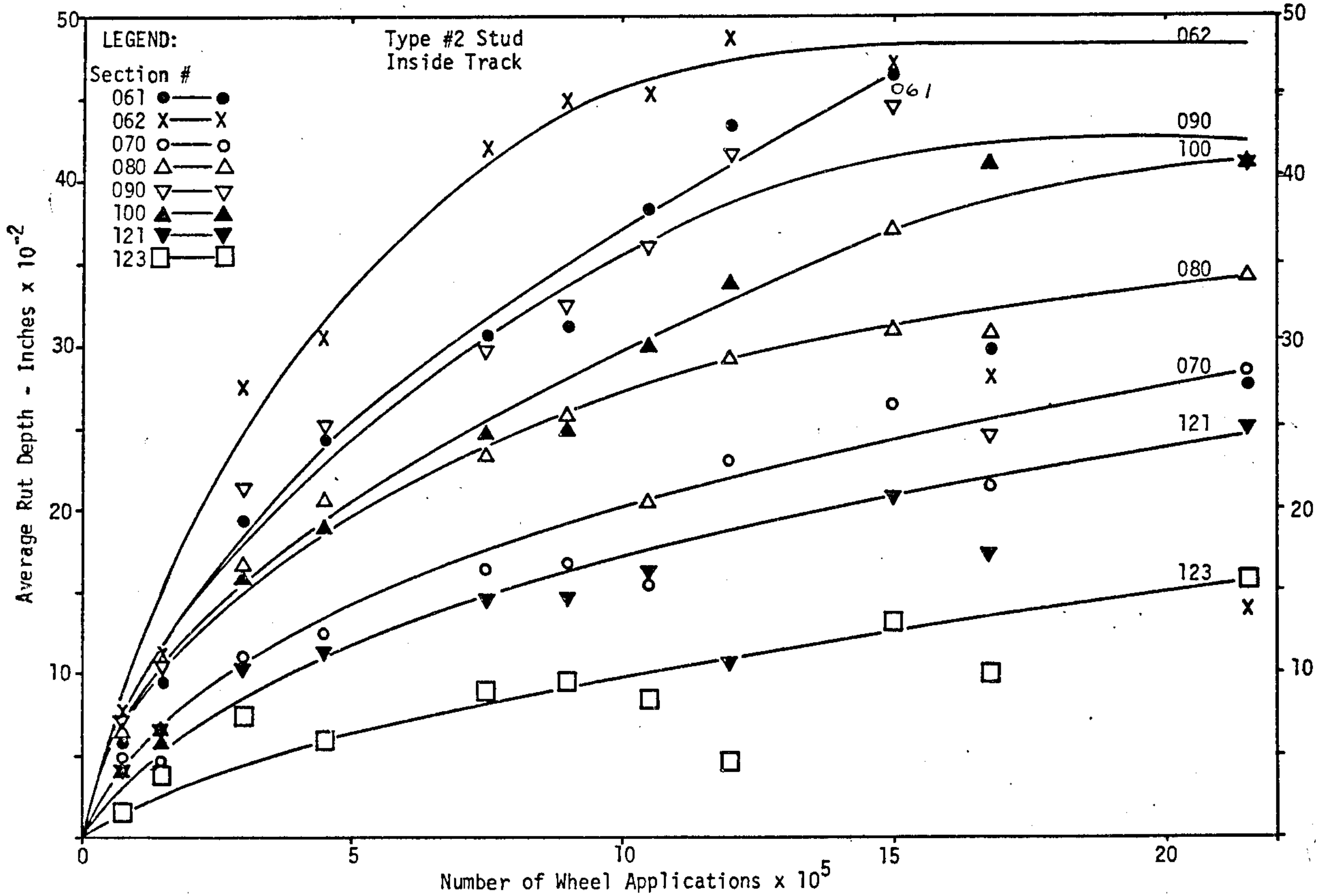

FIGURE III: Average Rut Depths with Wheel Applications for the Different Asphalt Concrete Group

STUDDED TIRE

PAVEMENT WEAR REDUCTION AND REPAIR - PHASE II

INTRODUCTION

This project, Y-1439, was initiated by the Transportation Systems Section, Department of Civil and Environmental 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, U.S. Department of Transportation, as a HPR Federal Aid research project; and the Idaho Department of Highways.

Project Y-1439 is divided into three phases: Phase I - to evaluate the different pavement overlays and surface textures in use in the state of Washington with respect to studded tires during 1971-72; Phase II - to evaluate different overlays and materials with respect to studded tire effects during 1972-73; and Phase III - to compare data obtained from Phase I and Phase II to the real world and to analyze the results during 1973-74.

This final report presents results from data obtained 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 May 1, 1973. The purpose of the three-phased three-year project was fourfold: 1) to determine pavement surface wear caused by studded tires; 2) to evaluate the resistance of different pavement materials, overlays, and textures used in the states of Washington and Idaho to wear caused by studded tires; 3) to test new pavement surface materials, finishes, and overlays which hopefully will better resist effects of studs; and 4) to study the effect of studded truck tires on pavements.

The purpose of Phase II of this 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 which hopefully will better resist effects of studs. As can be seen, the purpose of Phase II is similar to that of the first three objectives in the overall purpose of the project.

The results from Phase I have been published in a series of reports and papers (1, 2, 3, 4). This report on Phase II presents results obtained from the data obtained from Ring #6. A preliminary report on Phase II (5) was published after about one half of the test was completed. It should be remembered that these results were obtained and measured under WSU test track conditions which may not make the conclusions valid elsewhere.

BACKGROUND

Previous studies on studded tire performance and effects have been extensively covered in the Phase I final report (4). Since that time, there have been relatively few significant studies published. The Washington State Highway Department in 1972 published a report (6) on the effectiveness of the use of studded tires. This provoked a rebuttal by the studded tire industry (7). Peterson and Blake (8) of the Utah State Department of Highways wrote a synthesis on studded tires, concerning both performance and effects. The organization for Economic Co-operation and Development studied the overall problem of winter damage as experienced in Europe and in North America (9). All these studies show that there is damage caused to pavements by studs, but most of these studies were made when the conventional type stud was prevalent and the new improved type studs presently available were non-existent.

There are studies concerning the development of new types of pavements which are hoped to be more resistant to the effects of studded tires. Most of these studies have been mentioned in the Phase I final report (4). One significant item is that in 1972 two states, Pennsylvania and Michigan, have put down experimental strips of mastic asphalt (Gussasphalt) (10). German experience has shown that this material has long service life, a highly skid-resistant surface, lower maintenance costs and is resistant to the effects of studded tires. These experimental pavements are still being studied, and it will be several years before any results will be available.

Recent studies have concentrated mainly on the safety effectiveness of studded tires. Two recent papers on this subject were written by Smith (11) and Preus (12). The National Cooperative Highway Research Program (NCHRP) is presently sponsoring three studies, two on evaluation of studded tires (13, 14) and one on winter traction aids (15). One study is being conducted by the University of Michigan Highway Safety Research Institute concerning the "effects of studded tires on highway safety" under non-winter driving conditions. The second study is being conducted by the Cornell Aeronautical Laboratory on the "effects of studded tires on highway safety" pertaining to accident incidence and severity. Neither study has been completed. The NCHRP study entitled "Evaluation of Winter-Driving Traction Aids" is in the process of being awarded. These studies should clear up some of the unanswered questions pertaining to the safety aspects of studded tires.

The state of Washington has been concerned with the effects of studded tires on mountain pass highways, on bridge decks, and on other highways since the use of the studs was legalized in 1969 (6). The State Highway Department decided to study different studded tire wear effects a) on aggregates in Washington, which are generally harder than those used in previous studies elsewhere, b) on their present pavements and surface textures in use, c) to obtain data on new types of pavements and surface textures, and d) to obtain data on new types of studs that are presently being developed and introduced. This report is only concerned with items (a), (c) and (d) as item (b) was part of Phase I of this research project. Washington State University was chosen because of its location and because of the G. A. Riedesel Pavement Testing Facility. The safety aspects of studded tires were not studied and not considered, except for skid resistance measurements. An interim report for Phase II has been submitted (5); the complete findings are presented in this Phase II final report.

DESCRIPTION OF TEST

G. A. RIEDESEL PAVEMENT TESTING FACILITY

The G. A. Riedesel Pavement Testing Facility consists of an apparatus with three loading arms supporting a water tank. These arms revolve in a circle on three sets of 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 specified width of the pavement can be covered by the test wheels.

The apparatus was extensively modified in 1972 for Phase I (Ring #5) of this study. One small modification of the apparatus was made for Phase II (Ring #6). The present facility has two sets of passenger tires inside the dual truck tires running on the inside track (track #1) and in wheel paths #1 and #2. The dual truck tires run on the center track (track #2) and in wheel paths #3 and #4. On the outside track (track #3), two passenger tires are attached to each of two arms so as to travel in four separate wheel paths, namely #5, #6, #7 and #8. A total of 16 tires are mounted on the apparatus.

Each passenger car tire carried a 1,000 pound load, applied via individual air load cells, and each set of the dual truck tires carried 6,600 pounds. The only modification done for Ring #6 was to change the type of air load cells. Figure 1 (p. 6) shows a view of the present G. A. Riedesel Pavement Testing Facility; Figure 2 (p. 7) shows a close-up view of the modification and the position of some of the tires.

Continued problems with the hydraulic braking systems, which were installed on two of the arms for the inside tires for Ring #5, precluded its use on Ring #6.

In December, 1972, a control tower was built above the entrance tunnel, and the controls were moved into it. This was done for reasons of safety and noise. The operators can now continually observe the apparatus and the track. In the past, the operator ran the test track blind from within the tunnel. The control tower is shown in Figure 1 (p. 6).

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, 4 unstudded and 6 with different types of studs. The truck tires used on 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 as 3 tires travelled in the same wheel path.

The passenger tires were all G78 x 14 with winter snow tread design made with oil-extended synthetic rubber; and consisted of three unstudded, three with 112 type #3 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

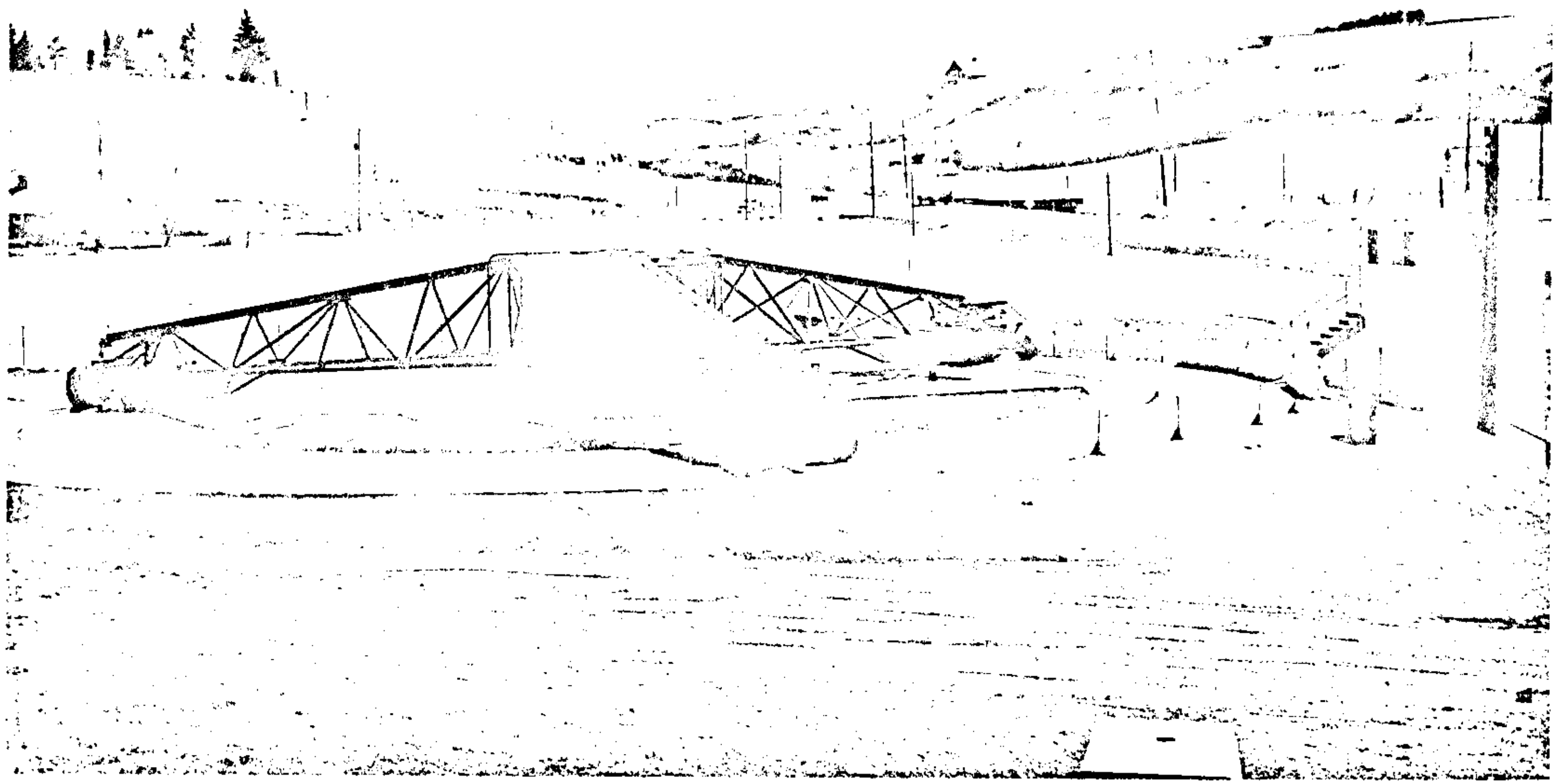

Figure 1: A view of the present G. A. Riedesel Pavement Testing Facility. Note the control tower on the right.

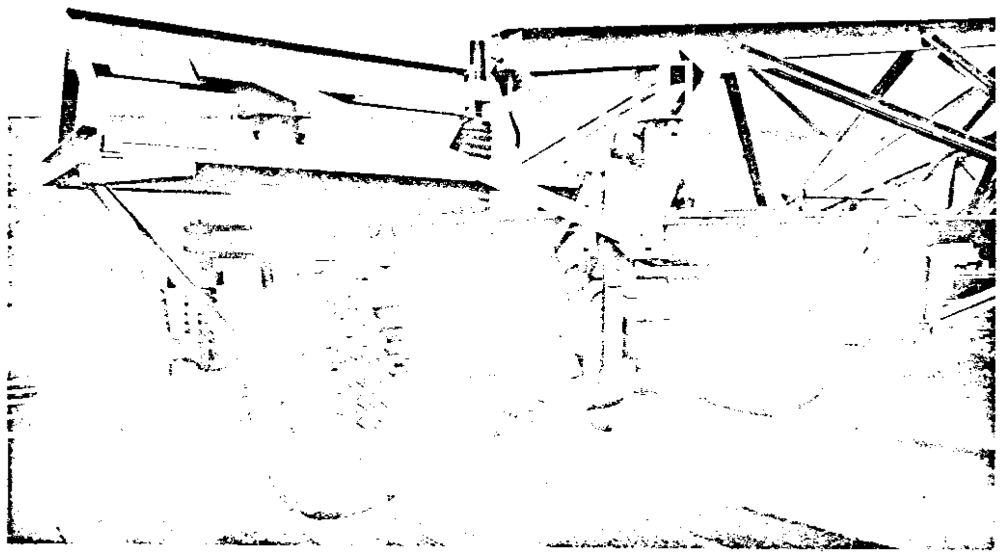

Figure 2: A view of the modifications and placing of the tires on Arm #1 on the three tracks.

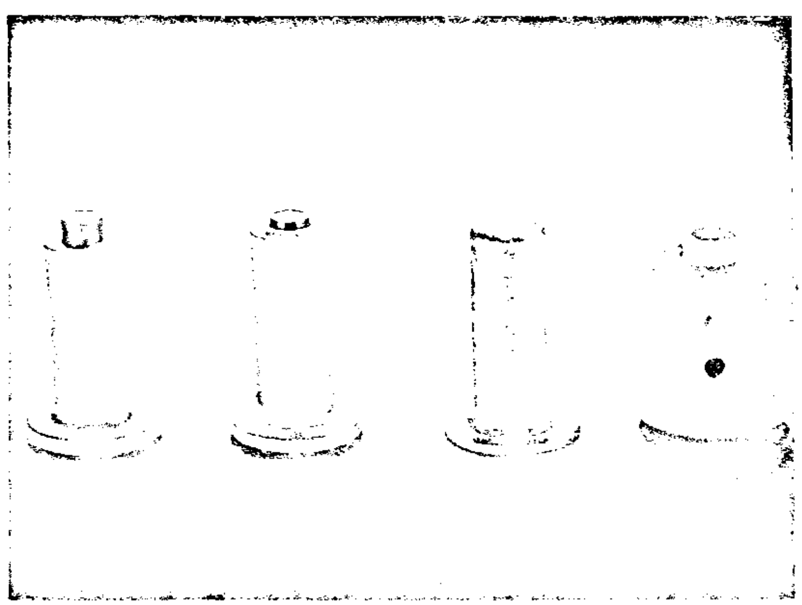

Figure 3: The appearance of 4 different types of studs tested. Left to right: Type #3 or CV stud; Type #1 or CP stud; Type #2 or PT stud; Type #4 or FS stud.

was inflated to 28 psi and carried a 1,000 pound load. All the passenger tires were free-wheeling.

Four different types of studs were tested in this second phase - two of them were supplied by the Kennametal, Inc.,* of Latrobe, Pennsylvania. These were the conventional type stud, hereby designated as type #3 or CV stud, and the controlled protrusion stud, hereby designated as type #1 or CP stud. The latter stud has been designed so that the carbide pin will move further into the stud body if, at any time, the protrusion of the stud from the tire exceeds a critical limit. These studs (type #1) are supposed to maintain nearly uniform protrusion throughout their lifetime. To maintain this critical protrusion length and pin movement, certain dynamic impact limits have to be attained (16). These studs as compared to the type #3 stud are 18 percent lighter and have a 5 percent small flange. The type #1 stud is designed to replace the type #3 stud on the market.

The conventional stud, type #3, has a tungsten carbide pin in a stud body. The pin does not move with impact and wears away less rapidly than the tire tread; hence, the stud protrusion increases with use. This is the only type of stud that was on the market before the winter of 1973.

Another type of stud tested was the Perma-T-Gripper supplied by the Permanence Corporation*, of Detroit, Michigan, and developed by the Townsend/TRS Division*, of Ellwood City, Pennsylvania. Here after, it will be designated as type #2 or PT stud. The tungsten carbide pin found in other studs has been replaced with a composite material consisting of relatively small tungsten carbide chips in a soft bonding matrix and is enclosed in a steel jacket. This composite core wears off and is purported to maintain a minimal

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*Addresses are listed on page 131.

particulate protrusion of approximately 0.020 inches or less according to the manufacturer (17). It is supposed to wear as it is used, thus always exposing a consistent, fresh, rough, short, stable surface.

The final type of stud tested was the Finnstop stud which may be manufactured by the Norfin, Inc.*, of Seattle, Washington. Hereafter, it will be designated as type #4 or FS stud. This stud was developed in Finaldn and is a composite stud, consisting of a light plastic casing with a tungsten carbide pin. The advantages of this type of stud, according to the manufacturer, are that the composite stud can be adjusted close to the tread rubber, no oscillation of the stud, the pin angle contact with the road varies very little with speed and the plastic housing tends to reduce the effect of the centrifugal force and heat build-up between the rubber and the stud. An air cushion can be left under the composite stud which results in a reduction of stiffness and causes it to float in the stud hole (18).

Figure 3 (p. 7) shows the four types of studs tested and shows the relative differences between them. Table 1 (p. 10) shows the types of tires, studs, wheel paths and symbols.

The unstudded tires are designated as US tires and the garnet snow tire is designated as GST. The unstudded tires are regular winter snow tires which can be bought anywhere, while the garnet snow tire is an experimental retread tire developed and manufactured locally by Marketing Industries*, of Coeur d'Alene, Idaho. Garnet dust has been mixed with a rubber retread compound and then used for retreading old tires. The principle is supposed to be similar to that of the old-type sawdust and walnut shell retread winter tires.

Track #1 (inside) has three US tires and three type #1 studded tires traveling in wheel paths #1 and #2, respectively. The inside track had three

*Addresses are listed on page 131.

TABLE 1: TYPES OF TIRES AND STUDS

WHEEL PATH	TIRE TYPE		STUD TYPE	SYMBOL
1	Passenger Winter Tread	G78 x 14	No studs	US
2	Passenger Winter Tread	G78 x 14	Controlled Protrusion	#1
3	Truck	11 x 22.5	No studs	UST
4	Truck	11 x 22.5	No studs	UST
5	Passenger Winter Tread	G78 x 14	Conventional Type	#3
6	Passenger Winter Tread	G78 x 14	Perma-t-Gripper	#2
7	Passenger Winter Tread	G78 x 14	Finnstop	#4
8	Passenger Retread	G78 x 14	Garnet Dust Retread, No studs	GST

wheel passes per revolution. On track #3 (outside), the four passenger 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. On track #2 (center), the two unstudded truck tires traveled in wheel paths #4 and #5. Each revolution represented three wheel passes.

TEST PAVEMENT CONCENTRIC TRACKS

Ring #6 consisted of three concentric tracks numbered consecutively, inside, center and outside, #1, #2 and #3; the inside, center and outside widths were 3.5 feet, 3.0 feet and 4.0 feet, respectively. The ring was divided into 12 sections, each 21.5 feet in length, at the 41.5 foot radius line, which were further divided 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; namely, high alumina cement and polymer cement-sand mix. The wheel path grooves on the asphalt pavements were not patched before an overlay was put over them.

The inside, center and outside tracks were overlaid with the same overlay material in the same section. A total of 22 different types of overlays were put on top of the old Ring #5. Figure 4 (p. 12) shows the arrangement of the sections of the test track for Ring #6, and Table 2 (p. 13) shows the types of overlays and the lengths and widths of the appropriate test sections.

The sections were patched and built during the months of July, August, September and October. Most were placed under ideal weather conditions. A

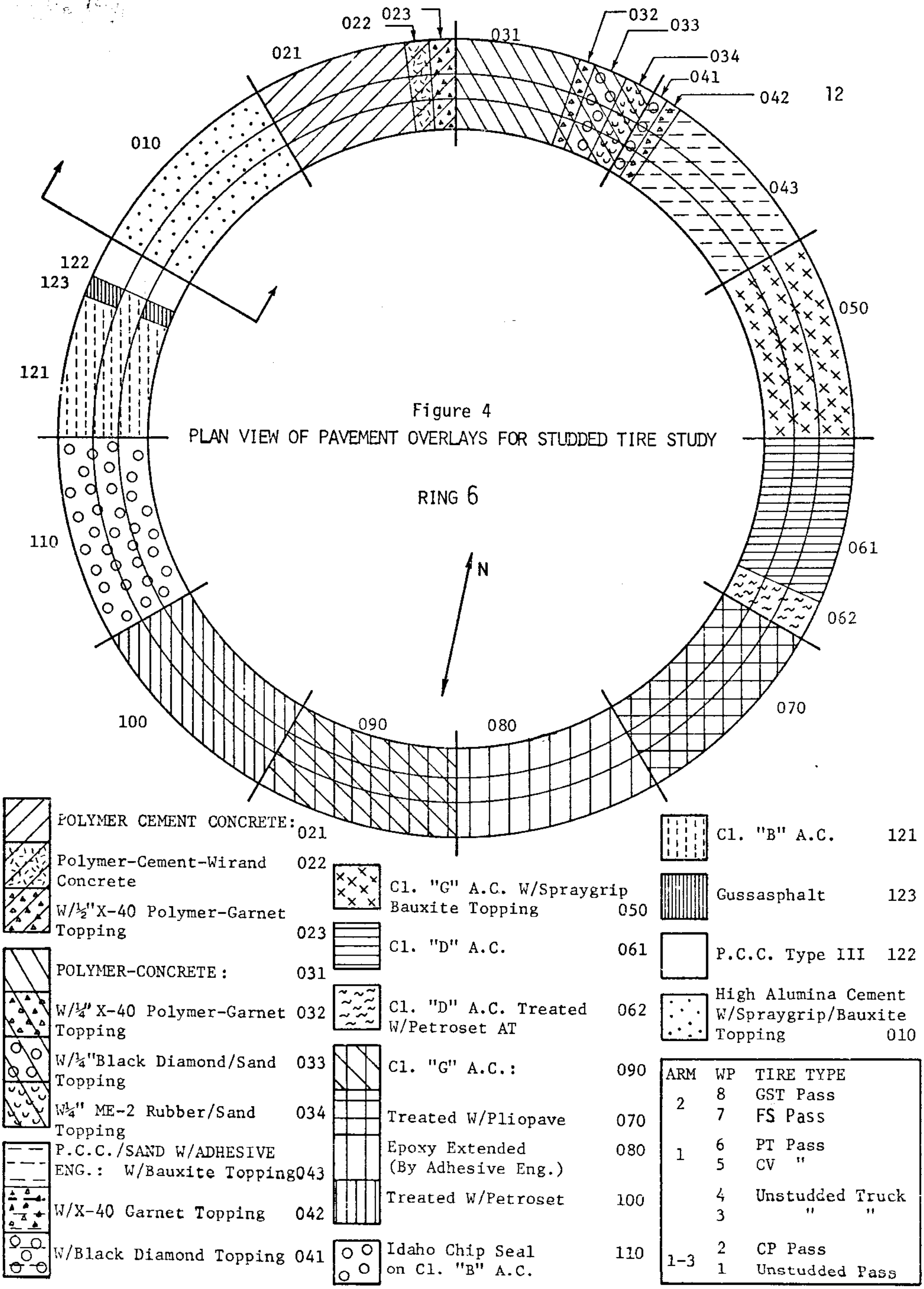

Figure 4
PLAN VIEW OF PAVEMENT OVERLAYS FOR STUDDED TIRE STUDY

RING 6

TABLE 2

RING #6 - TYPES OF OVERLAYS AS BUILT

SECTION	TRACK	TYPE OF OVERLAY	LENGTH[1]
010	1,2,3	Bauxite Asphalt Epoxy Surfacing/High Alumina Cement Concrete	21.5 Feet
021	1,2,3	Polymer Cement Concrete	16.5
022	1,2,3	Polymer Steel Fibrous Concrete	3.0
023	1,2,3	Garnet Surfacing on Polymer Cement Concrete	2.0
031	1,2,3	Polymer Concrete	15.5
032	1,2,3	Garnet Surfacing on Polymer Concrete	2.0
033	1,2,3	Mineral Slag-Sand on Polymer Concrete	2.0
034	1,2,3	Rubber-Sand on Polymer Concrete	2.0
041	1,2,3	Mineral Slag Asphalt Epoxy Surfacing/Portland Cement Sand Mix	2.0
042	1,2,3	Garnet Asphalt Epoxy Surfacing/Portland Cement Sand Mix	2.0
043	1,2,3	Bauxite Asphalt Epoxy Surfacing/Portland Cement Sand Mix	17.5
050	1,2,3	Bauxite Asphalt Epoxy Surfacing/Class "G" Asphalt Concrete	21.5
061	1,2,3	Class "D" Asphalt Concrete	16.5
062	1,2,3	Class "D" Asphalt Concrete with Petroset AT	5.0
070	1,2,3	Class "G" Asphalt Concrete with Pliopave	21.5
080	1,2,3	Class "G" Asphalt Extended Epoxy Concrete	21.5
090	1,2,3	Class "G" Asphalt Concrete	21.5
100	1,2,3	Class "G" Asphalt Concrete with Petroset AT	21.5
110	1,2,3	Idaho Chip Seal on Class "B" Asphalt Concrete	21.5
121	1,2,3	Class "B" Asphalt Concrete	14.5
122	1,2,3	Portland Cement Concrete	5.0
123	1,3	Mastic Asphalt (Gussasphalt)	2.0

[1] Measured in the direction of wheel travel at 41.5 foot radius line. The width for all of the sections was 10.5 feet.

premature failure occurred; this was in one of the bauxite asphalt epoxy surfacings which were placed on top of certain overlays and was due to a loss of bond between the epoxy and the base surface. The description of the pavements and their design mixes is included in Appendix A.

TRAFFIC PAINTS

Four different types of traffic striping were tested to determine their resistance to wear from 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 (the polymer cement concrete) and 100 (the class "G" asphalt concrete with Petroset AT). The initial measured thicknesses of the three paint stripes averaged 22 mils; while that of the thermoplastic white tape averaged 95 mils.

Kennametal, Inc., of Latrobe, Pennsylvania, supplied the paints. The company does not manufacture paint but was interested in determining the effect of their tire studs on the life of pavement traffic striping. Table 3 (p. 15) shows the brands of paint which were tested and their corresponding code numbers. A full report on the paints is given in Reference 19.

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 wire-box technique. The WSU profilometer was used as the principal method for taking these transverse measurements. It was determined on the basis of experience from Ring #5 that the profilometer was easier to handle, to operate and to use in obtaining data than the camera wire-box technique.

TABLE 3: TYPES OF TRAFFIC STRIPING PAINTS

BRAND OF PAINT	CODE NO.
Prismo Universal[1]	#1
Merkin Mastercraft Heavy Duty Traffic Paint-350 White[2]	#2
Gleem Zone Marking Paint - Instant Dry White[3]	#3
Thermoplastic Striping Tape - Prismo[1]	#4

[1] Manufactured by Prismo Corporation

[2] Merkin Paint Company,
A Division of Baltimore Paint & Chemical Corporation
2325 Hollins Ferry Road
Baltimore, Maryland

[3] Gleem Division
Baltimore Paint and Chemical Corporation

The measurements taken with the WSU profilometer were digitized and automatically put on paper tape and simultaneously recorded on a strip chart. The data on the paper tape were then transferred to IBM cards. Results could be obtained from the computer within 48 hours as 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 data up to 200,000 wheel passes had to be hand processed using the Benson-Lehner, Model F Decimal Converter, which is tied directly to an IBM 026 card punch. Figures 5, 6 and 7 (p. 17-18) show the modified WSU profilometer, a close-up of the scanning crosshead and the digitizer with mechanical tape punch.

The principle and design of the WSU profilometer is described in Appendix B. Several typical strip chart readouts are shown. A computer program was developed so that the data could be analyzed on the basis of rate of wear, average area removed, and average and maximum rut depths. A discussion of this program is in Appendix C.

The camera wire-box equipment was used primarily as back-up for the profilometer. The reason was that the measurements using the photographic technique took such a long time to obtain, to process and to transfer to IBM cards. Figure 8 (p. 18) shows a picture of the profilometer with the frame. The procedure and problems associated with this technique are in Appendix D.

Depth measurements with a straight-edge and a moving probe were also taken.

Temperature measurements using iron-constantan thermocouples were obtained at the top and bottom of the overlays and recorded on a 48-point Honeywell recorder. A Belfort Thermograph was also used to monitor ambient and surface overlay temperatures.

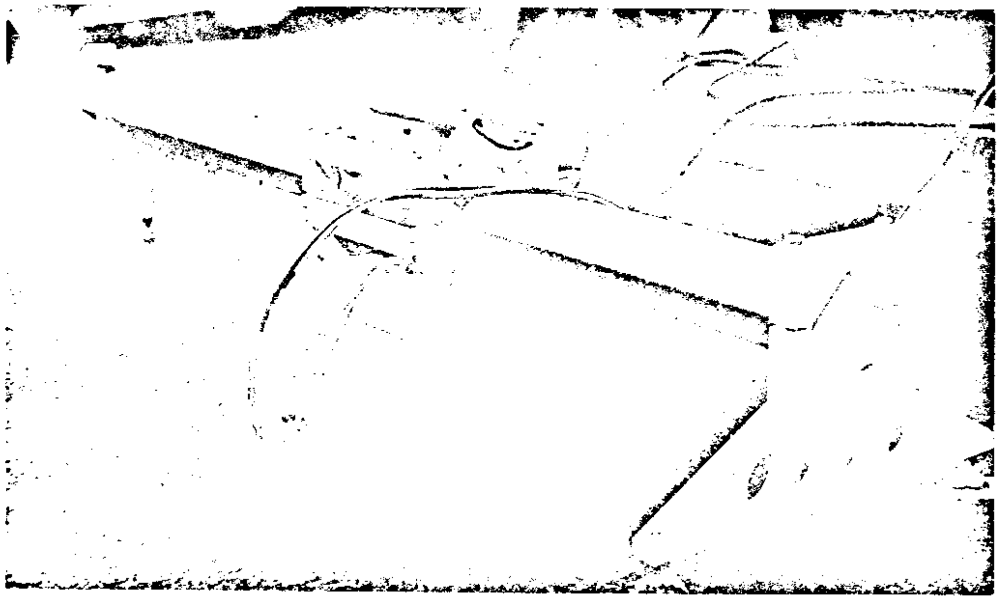

Figure 5: A view of the modified WSU Profilometer.

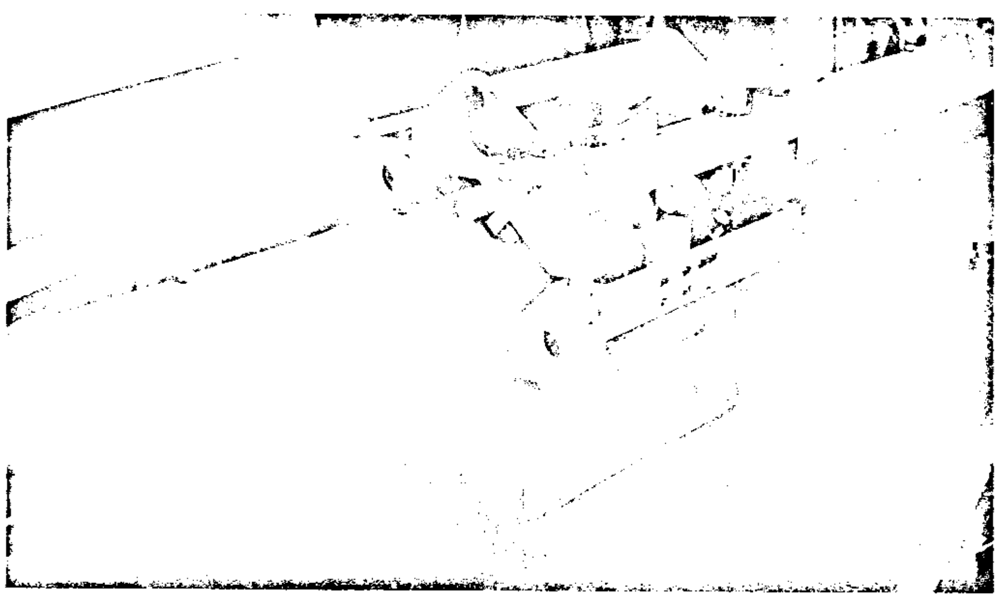

Figure 6: A close-up view of the WSU profilometer iron-head scanner.

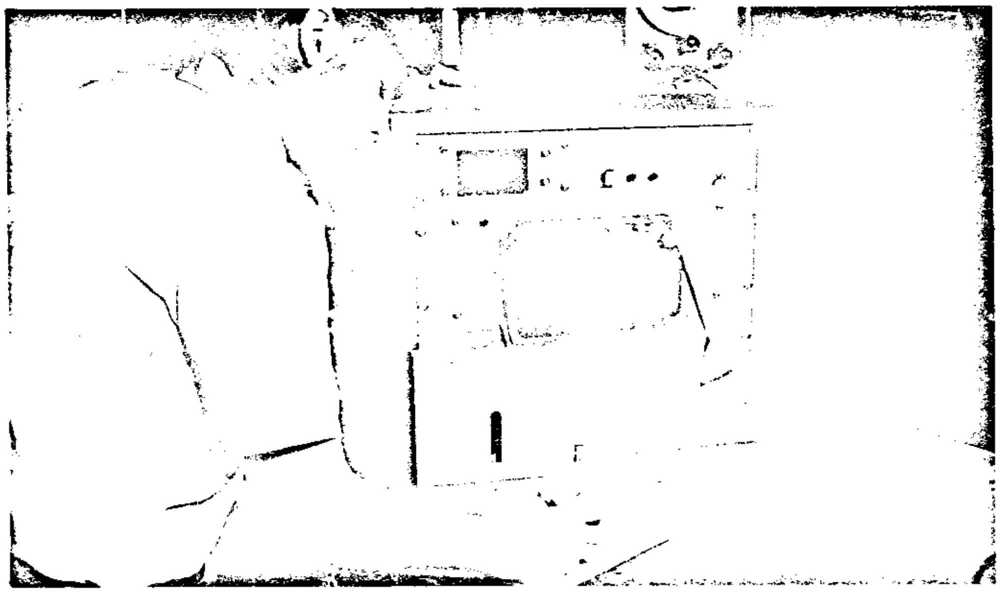

Figure 7: The digitizer with mechanical tape punch being checked out in the laboratory.

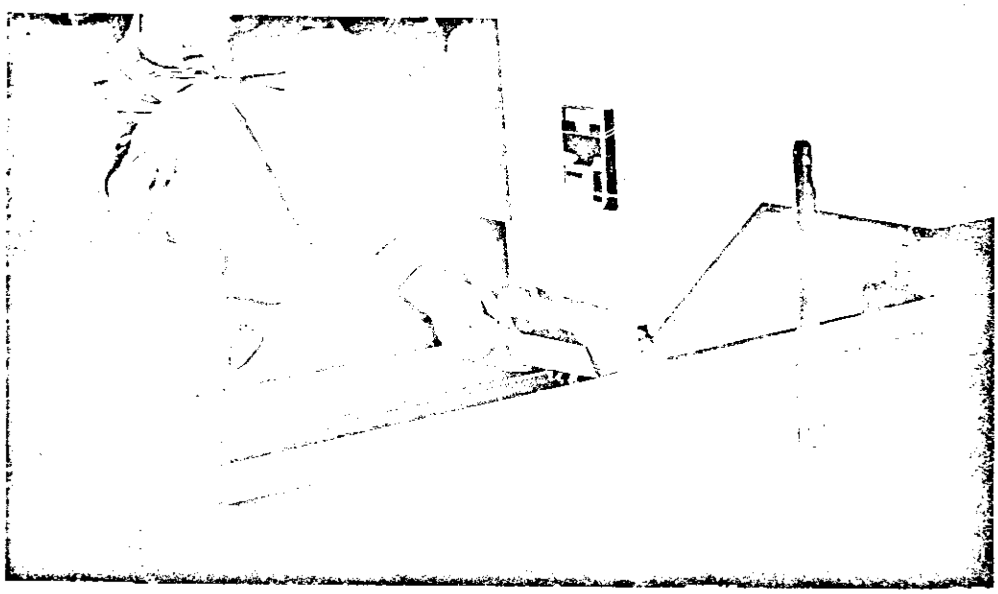

Figure 8: A view of the camera wire box with leveling frame.

Tire tread depth measurements and stud protrusion lengths were taken at the same time intervals as the transverse depths and skid resistance values.

The California Skid Tester, courtesy of the Washington State Highway Department, was used to measure the skid resistance of the various sections in the wheel paths. Figure 9 (p. 20) shows the California Skid Tester. A British Portable Skid Tester was loaned to the researchers by Prismo Corporation. Unfortunately, it was lost in transit for about a month and data are incomplete for the test. Figure 10 (p. 20) shows the British Portable Skid Tester.

Photographs of the paints and pavements were taken periodically. A procedure for showing pavement wear in reference to the straight-edge method was developed by the College of Engineering Research Division Photographic Laboratory staff and is presented in Appendix E.

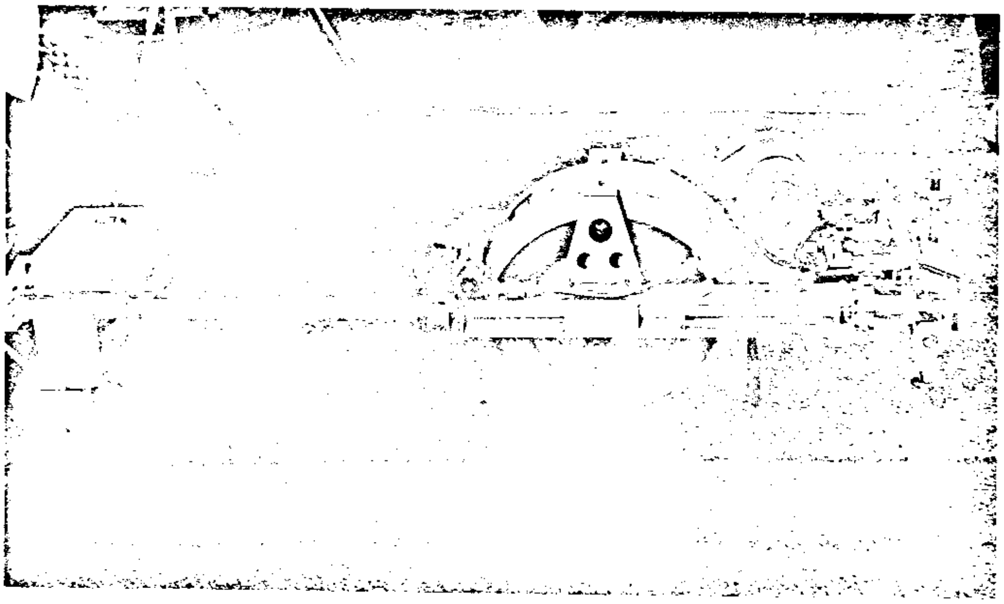

Figure 9: The California Skid Tester

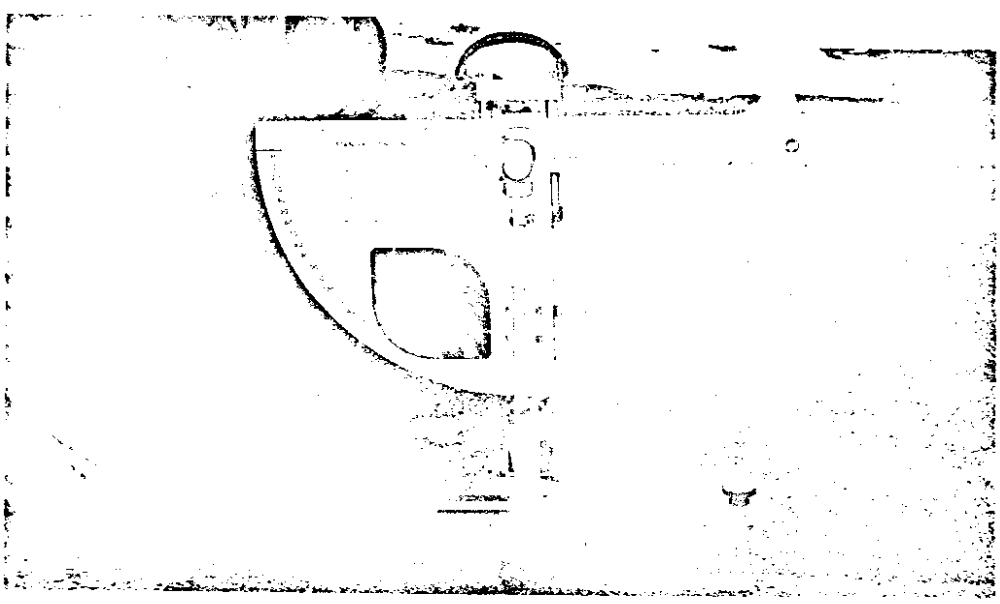

Figure 10: The English Portable Skid Tester

CONDITIONS AND LIMITATIONS OF THE TEST

TIME PERIOD

Testing started on November 20, 1972, and continued until May 1, 1973. A total of 717,102 revolutions had been applied. This meant that 717,102; 2,151,306; and 2,151,306 wheel passes had been applied on the outside, center and inside tracks, respectively.

The apparatus was in operation for a total of 1,896 hours and 43 minutes, which is approximately 79 twenty-four hour days. The rest of the time was used for taking measurements and performing maintenance and repairs. More than two weeks was lost in late December when the control tower was being built and the controls were being transferred. Figure 11 (p. 22) shows the time the apparatus was in operation. An abbreviated log of operations is shown in Appendix F.

SPEED

The speed of the apparatus was maintained between 20-25 m.p.h. as shown in Figure 12 (p. 22) and in Appendix F. The differences in wear occurring on the various pavement overlay surfaces prevented higher speeds. This limit on speed was one of the real limitations of this test. This meant that the dynamic effect needed to obtain pin movement in the type #1 stud to control protrusion length was not achieved. Although the low speed is probably the speed that is common on many city streets during the winter, it is much less than what can be expected on highways, even in the winter. Higher speeds, producing greater stud impact forces, may cause different wear patterns.

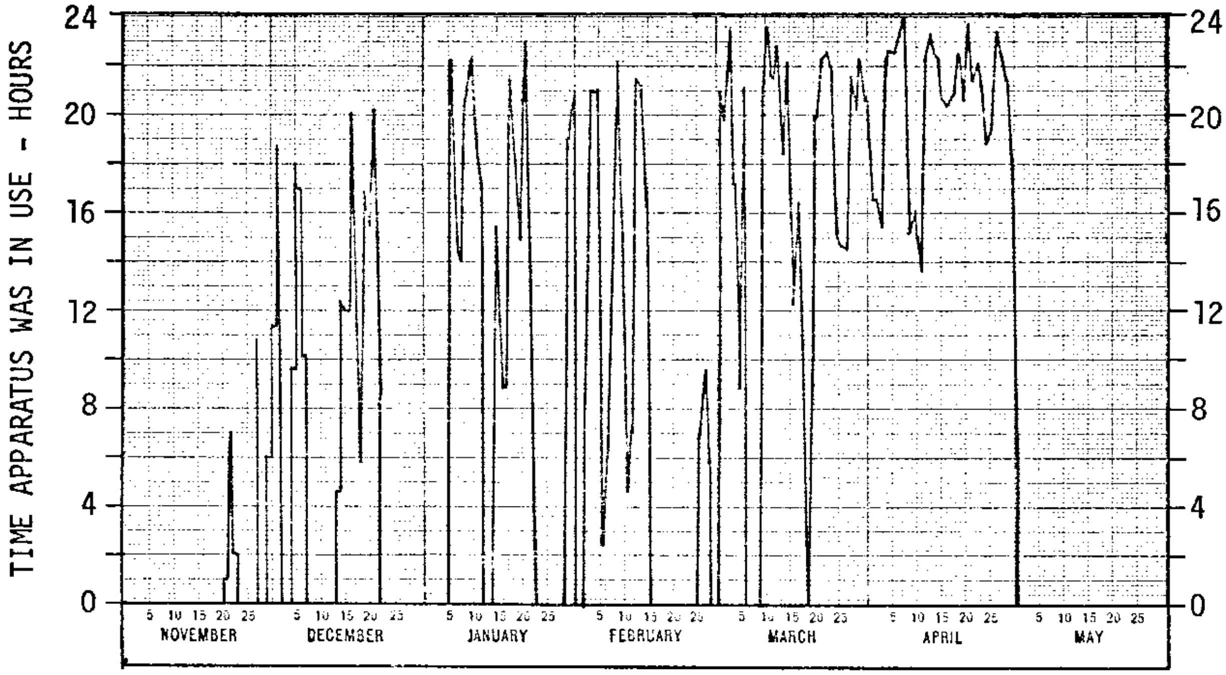

Figure 11: The time the apparatus was in operation during Phase II test.

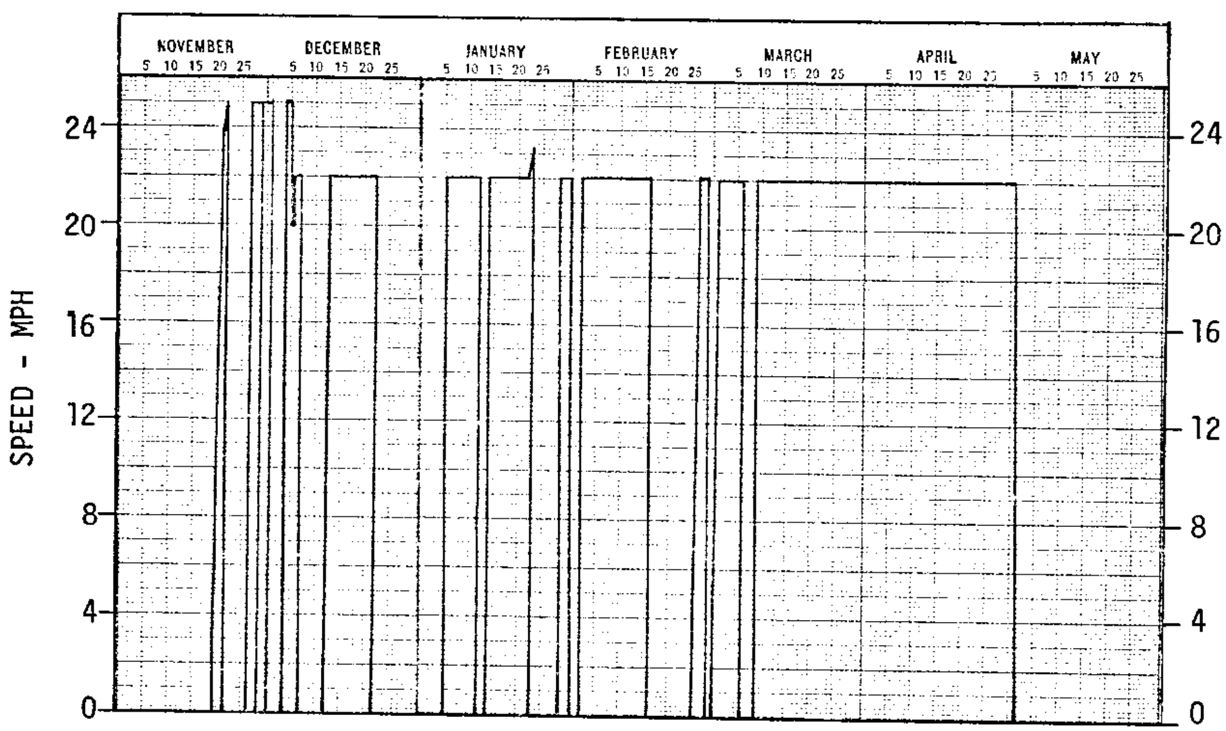

Figure 12: Speed of Apparatus during the test.

ECCENTRICITY

The eccentricity radius was fixed at 1.75 inches, thus making the eccentricity a total of 3.50 inches. This is the maximum eccentricity that could be used without the tire paths overlapping. The wheel paths for the individual tires are shown in Appendix G.

ENVIRONMENT AND TEMPERATURE

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. This was done to make sure that the snow would not pack and enhance the possibility of irregular wear on some of the pavements, e.g., snow may pack on one of the sections, hence the tires would be running on packed snow while elsewhere the tires would be running on bare pavement. This would cause irregular wear and make comparisons difficult.

Since the track was open to the elements, there was no control on the temperatures. The temperature range is quite representative of the temperatures that are found in southeastern Washington during this time period (less than a normal amount of precipitation occurred this winter). Figure 13 (p. 24) shows the maximum and minimum daily air temperatures and the amount of daily precipitation for the Pullman area. Table 4 (p. 25) shows the high, low and average ambient temperatures and total monthly precipitation for the testing months. Table 5 (p. 26) shows weekly maximum, minimum and average temperatures and weekly precipitation amounts. Table 6 (p. 27) shows the weekly average air and surface temperatures as measured at the test track with the Belfort Thermograph. The daily temperatures measured at the Palouse Conservation Field Station and the test track are shown in Appendix H.

(Palouse Conservation Field Station)
(Pullman 2NW)

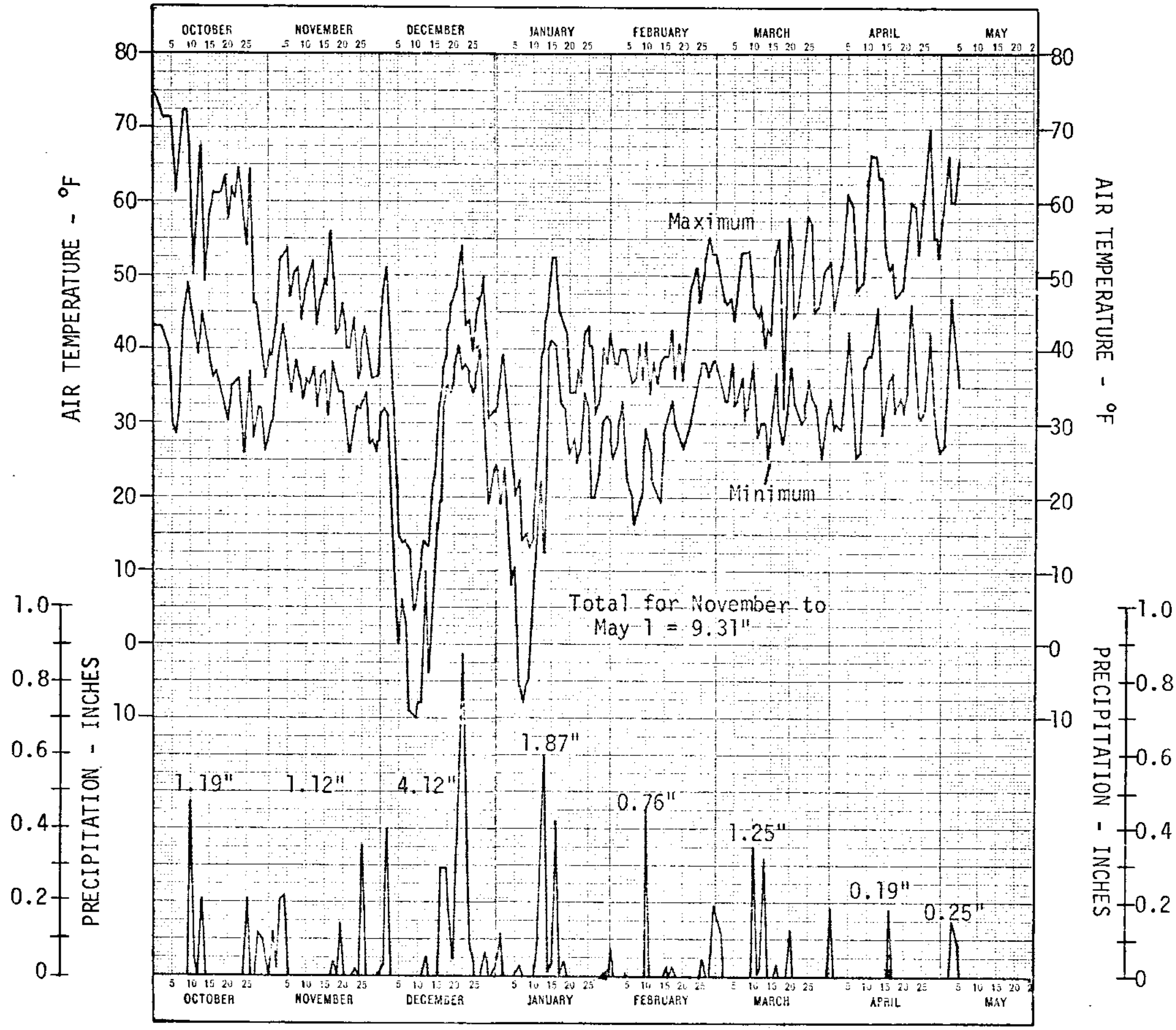

Figure 13: Daily Maximum-Minimum Air Temperatures and Daily Precipitation

TABLE 4

HIGH, LOW AND AVERAGE AMBIENT TEMPERATURES AND TOTAL PRECIPITATION[1]

Year	Month	Ambient[2] Temperature °F		Average[3] Ambient Temperature		Total Precipitation Inches
		Maximum	Minimum	Maximum	Minimum	
1972	October	74	26	59.7	36.3	1.19
	November	56	26	44.9	33.9	1.12
	December	54	-10	31.5	19.4	4.12
1973	January	52	- 8	34.4	20.9	1.87
	February	55	16	41.4	27.9	0.76
	March	58	25	48.3	31.9	1.25
	April	70	25	55.9	34.1	0.19
	May	86	27	67.7	41.8	1.68

[1] Palouse Conservation Field Station - Pullman 2NW

[2] Total Month

[3] Monthly Average of Daily Maximums-Minimums

TABLE 5

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

Year	Weekly Period	Max.	Min.	Average Air Temperature		Precipitation[2]
				Max.	Min.	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	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
	02/25 - 03/03	55	33	48.9	35.9	0.21 R,S
	03/04 - 03/10	53	30	48.9	34.7	0.35 R
	03/11 - 03/17	55	25	46.0	29.9	0.43 R
	03/18 - 03/24	57	27	46.9	32.3	0.13 R
	03/25 - 03/31	58	25	51.0	30.9	0.21 R
	04/01 - 04/07	61	25	52.6	31.7	0.00
	04/08 - 04/14	66	26	60.7	36.6	0.00
	04/15 - 04/21	56	31	50.9	33.7	0.19 R
	04/22 - 04/28	70	30	59.9	36.4	0.00
	04/29 - 05/05	66	26	60.6	34.0	0.25

[1]Data from Palouse Conservation Station - Pullman 2NW

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

[3]T means Trace Quantity.

TABLE 6

WEEKLY AVERAGE AIR AND PAVEMENT TEMPERATURES[1]

IN °F RECORDED AT THE TEST TRACK

Year	Weekly Period	Air		Pavement	
		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
	02/25 - 03/03	51.3	35.9	43.4	30.0
	03/04 - 03/10	50.3	33.3	46.9	31.7
	03/11 - 03/17[3]	47.4	30.6	42.4	28.1
	03/18 - 03/24[3]	53.0	28.0	48.0	32.7
	03/25 - 03/31[3]	50.2	32.8	52.3	31.3
	04/01 - 04/07	54.6	29.7	52.3	29.4
	04/08 - 04/14	62.9	34.3	65.0	36.3
	04/15 - 04/21	51.6	31.7	53.0	32.0
	04/22 - 04/28	60.0	36.0	68.0	39.3
	04/29 - 05/01	62.6	33.0	69.1	38.0

[1] Air and pavement temperatures recorded with Belfort Thermograph.

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

[3] Based on incomplete data as Belfort Thermograph was not operating properly.

Thermocouples were used to measure the temperatures at the top and bottom of the pavement overlays at various positions around the track. Data was taken around the clock at every hour. This data will be included in a future report.

TIRES

Most of the studded tires were changed after each tire had run 300,000 revolutions, which is approximately equivalent to 15,000 miles. The snow tire with the type #2 studs was changed after 550,000 revolutions or about 25,000 miles. For Ring #5, the tires were kept on until about 25,000 miles had elapsed. The tires were changed on the basis that 1) tire edge wear on both sides of the tire caused the studs to loosen and come out and 2) the studs had become worn down. Rapid tread wear occurred on the GST tire. Although some of it was due to improper camber and toe-in (which was corrected), the rapid wear on this tire continued throughout the test.

When 10,000 revolutions had been reached, the Washington State Highway Department had a request to test the FS stud which may be manufactured by a Seattle, Washington, firm. The tire with the type #1 stud originally in wheel path #7 was removed at 10,000 revolutions, and the test continued without a tire in wheel path #7 until the tire with the type #4 studs arrived, which was at 25,000 revolutions. Table 7 (p. 29) shows the tire changes and the number of revolutions that had elapsed before the changes.

TABLE 7: THE REVOLUTIONS AND MILES TRAVELLED BEFORE TIRE CHANGE

Track	Tire Type	Loading Arm	Wheel Path	1st Change		2nd Change	
				Number of Revolutions	Number of Miles	Number of Revolutions	Number of Miles
1	U.S.	1	1	717,102	31,274	---	---
	U.S.	2	1	717,102	31,274	---	---
	U.S.	3	1	717,102	31,274	---	---
	CP/#1	1	2	300,000	13,388	417,102	18,612
	CP/#1	2	2	300,000	13,388	417,102	18,612
	CP/#1	3	2	300,000	13,388	417,102	18,612
2	U.S. Truck	1	3	717,102	34,760	---	---
	"	2	3	717,102	34,760	---	---
	"	3	3	717,102	34,760	---	---
	U.S. Truck	1	4	717,102	35,694	---	---
	"	2	4	717,102	35,694	---	---
	"	3	4	717,102	35,694	---	---
3	CV/#3	1	5	300,000	15,470	417,102	21,511
	PT/#2	1	6	551,000	28,954	166,102	8,728
	CP/#2	2	7	10,000	535.5	---	---
	FS/#4	2	7	275,000	14,739	417,102	22,341
	GST	2	8	202,642	11,025	514,460	28,067

RESULTS AND ANALYSIS

STUD PROTRUSION AND TREAD DEPTH

Stud protrusion lengths varied within each set of measurements for each different type of stud and also over the duration of the test. Tread depths also varied. The results of the analyses for the stud protrusion lengths and the tread depths are summarized in Table 8 (p. 31), and in Figures 14-17 (p. 32-35). It should be noted that each tire has different mileage; this is because each tire was a different radial distance from the center of rotation. Appendix I gives the mileage for the tires.

It can be seen from Table 8 (p. 31) and Figures 16 (p. 34) and 17 (p. 35) that there was a considerable amount of tire tread remaining while the stud protrusion lengths were quite low with miles travelled, and were rather evenly worn down. This was quite different than that experienced in Phase I (4) where the stud protrusion lengths were greater.

In normal road use, a winter tire will usually last about 10,000 miles before it has to be discarded.[1] One of the limitations of the test track is that normal tire use could not be duplicated; the fast starts and sudden stops

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[1] Measurements made in 1972 on winter studded tires used on Washington State University motor pool cars indicate that the average miles travelled were 7329 and 6107 for glass belted and nylon tires, respectively. The average tread depth was 8.6 and 6.5 (x 1/32 inches), respectively. The final average stud protrusion length, with type #3 studs, were 0.074 and 0.083 inches for the glass belted and nylon tires, respectively.

In 1973, measurements were taken on several tires with different types of studs. Measurements on the Transportation Systems Section state vehicle which had four studded tires with type #3 studs yielded final average stud protrusion lengths for the two front and two rear tires of 0.092 and 0.069 inches, respectively. Measurements on a private car which had rear tires with type #2 studs yielded an average final stud protrusion length of 0.077 inches. On another car which had two type #3 studded tires on the front and two type #4 studded tires on the rear, the average stud protrusion lengths were found to be 0.073 and 0.047 inches on the front and rear, respectively. It was noted that many studs were missing from all of the tires. This research was conducted by the Transportation Systems Section staff.

TABLE 8

STUD PROTRUSIONS FOR DIFFERENT STUDS AND CORRESPONDING TREAD DEPTH

Miles Travelled[3]	STUD PROTRUSION[1] - INCH x 10^{-3}				TREAD DEPTH[2] - 1/32 INCH					
	WP #2[2] Type #1	WP #5 Type #3	WP #6 Type #2	WP #7 Type #4	WP #1[2] U.S.	WP #2[2] Type #1	WP #5 Type #3	WP #6 Type #2	WP #7 Type #4	WP #8 GST
0	41.5	64.0	22.5	41.5[6]	15.8	16.6	15.5	15.6	15.5[6]	13.9
5,000	19.0	23.5	12.0	21.0	13.7	14.0	13.4	14.5	14.3	5.3
10,000	13.2	14.0	7.5	12.0	13.5	13.7	13.2	13.2	13.8	4.5[7]
15,000	12.5	9.0	5.7	10.0	13.4	13.5	13.0	13.0	12.9	11.6
15,000	28.5[4]	68.0[4]	--	70.0[4]	--	15.1[4]	15.7[4]	--	15.7[4]	9.6
20,000	18.0	39.5	4.8	41.4	13.0	14.7	13.3	12.7	14.9	8.1
25,000	17.8	33.5	5.5	32.0	12.6	14.2	13.2	12.1	14.4	7.0
30,000	20.5	31.0	5.0	28.0	12.0	13.4	13.1	11.5	13.9	6.1
30,000	--	--	33.5[5]	--	--	--	--	18.1[8]	--	--
35,000	--	32.0	30.0[5]	27.0	--	--	13.0	17.2	13.3	4.9
Final	23.0	33.0	29.0	27.0	11.8	13.0	13.0	16.4	12.7	3.3

1 Average Values

2 Based on averaging the results from three tires.

3 This is approximate as each tire travelling in a certain wheel path radius will have travelled more or less than the indicated miles. See Appendix F.

4 These tires were changed at approximately 15,000 miles of travel.

5 This tire was changed at approximately 29,000 miles of travel.

6 This tire was put on after 25,000 revolutions had been applied.

7 This tire was replaced with a new one after 11,000 miles of travel due to rapid wear.

8 This new tire with type #2 studs had a deeper tread than the original tire. It was a different tire brand.

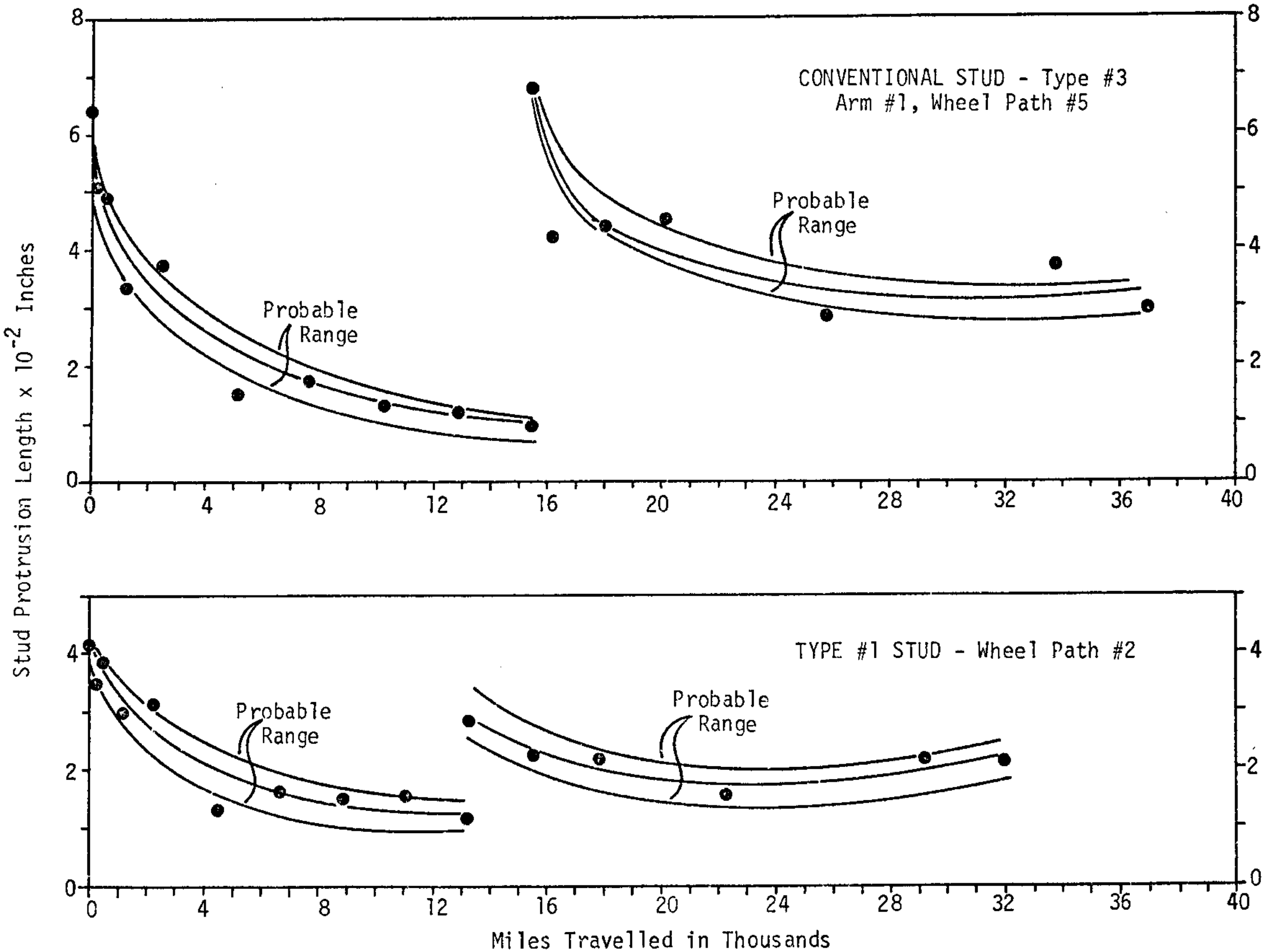


Figure 14: Stud Protrusion Lengths with Wheel Applications

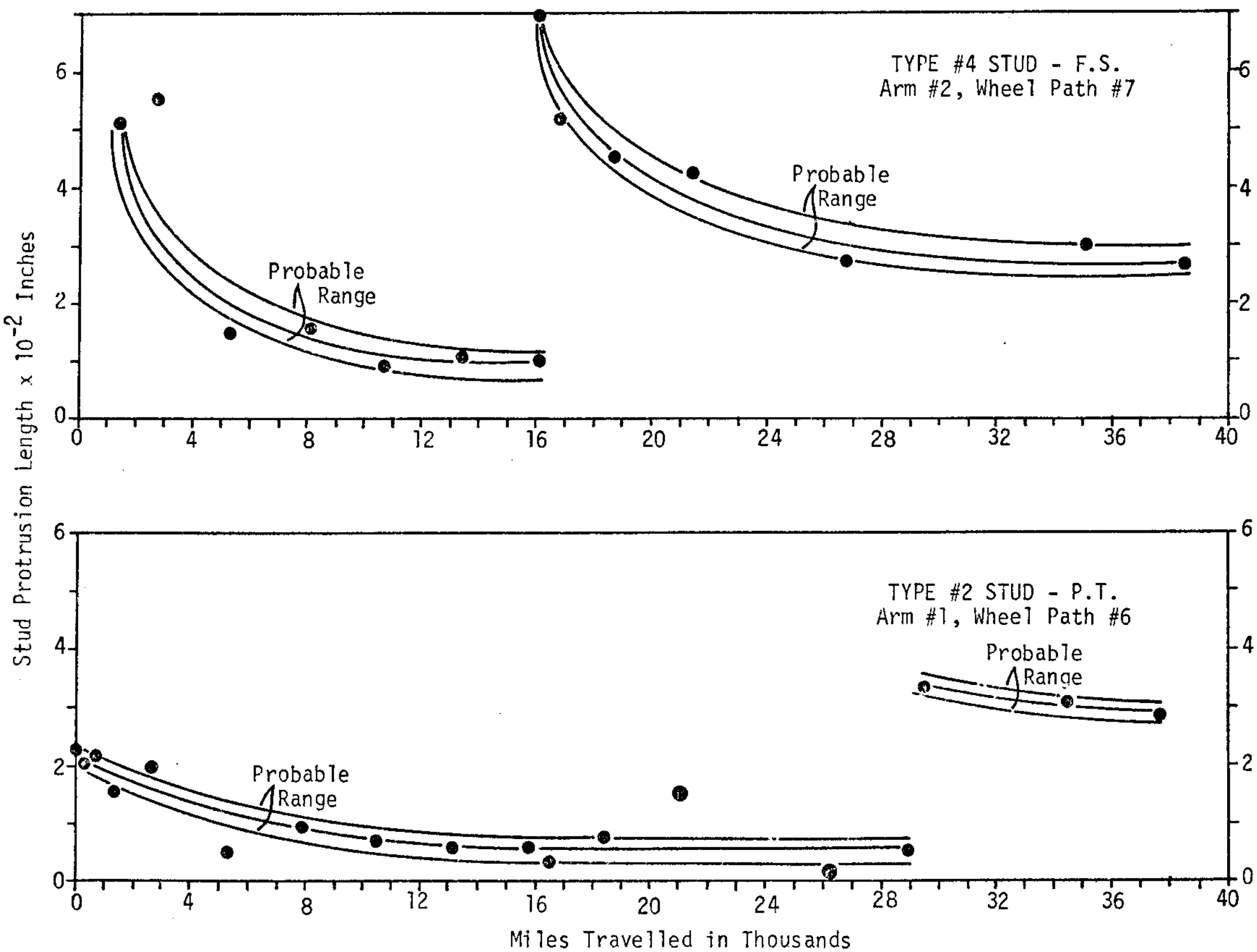


Figure 15: Stud Protrusion Lengths with Wheel Applications

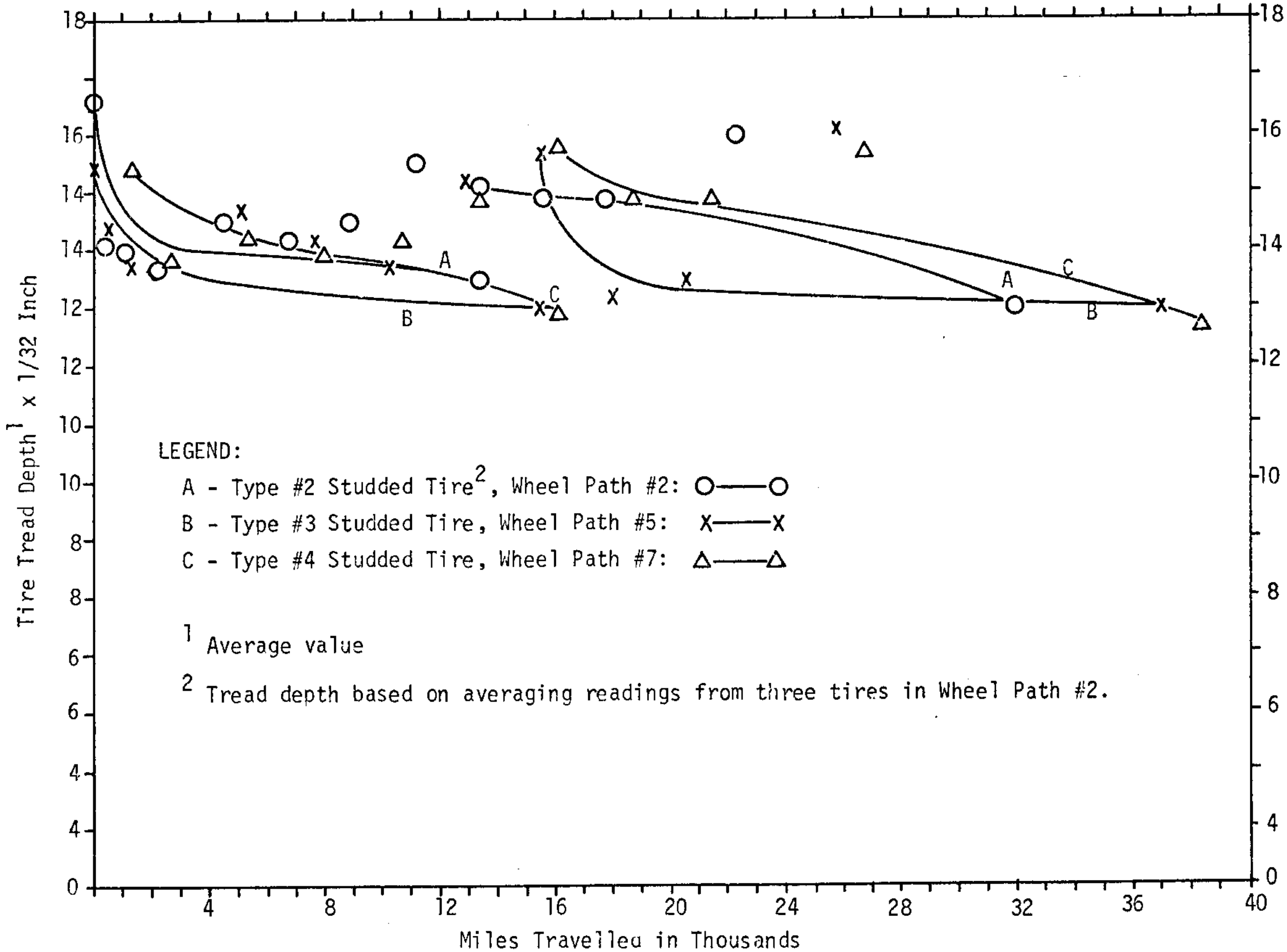


Figure 15: Tread Depth Versus Miles Travelled

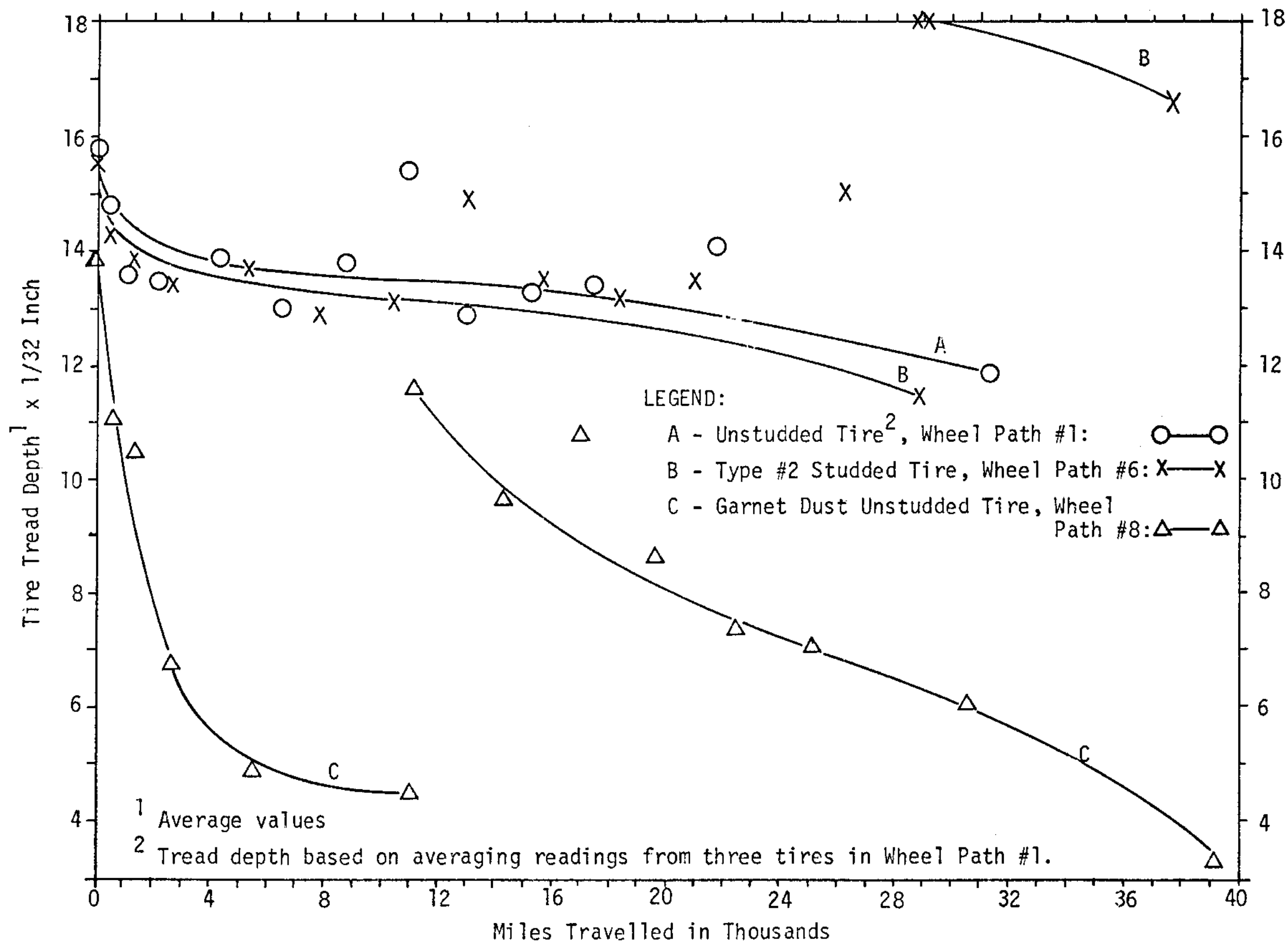


Figure 17: Tread Depth Versus Miles Travelled

at various speeds could not be duplicated; this influenced the tire life. All of the tires on the test track were free-rolling, except for the driving truck tire in wheel path #3. This type of action could have also influenced the life of the tires.

The tread depths of the truck tires were also measured, but the data is not included in this report.

Figures 14 (p. 32) and 15 (p. 33) and Tables 8 (p. 31) and 9 (p. 37) show that the tire with the type #2 studs had consistantly lower protrusions than the type #1, type #4 or type #3 studs for the duration of the test and for both sets of tires. It should be noted that the stud protrusion lengths for the different stud types were plotted as a probable range of values. It was found that the values varied considerably and the distribution of the values was large. Hence, a stud protrusion length range is more indicative of the data.

Figures 18A and 18B (p. 38) show the appearance of the different studs after 300,000 revolutions and at the end of the test, respectively. Figures 19A and 19B (p. 39) show the appearance of the six passenger tires after approximately 15,000 miles and 23,000 miles, respectively. It can be seen that the tread edges of the studded tires, especially those on the tire with the type #2 studs, had excessive wear. The tire manufacturer and the stud manufacturer claimed that the wheel path rut caused this wear and abused the tire causing longer than normal stud protrusion, especially on the outside rows of studs. Hence, the tires were changed to minimize these effects. Note the two GST tires and their extreme tread wear in Figure 19C (p. 39).

TABLE 9

AVERAGE STUD PROTRUSIONS FOR DIFFERENT STUDS

Range of Miles Travelled	WP #2[1] Type #1 Inch x 10^{-3}	WP #5 Type #3 Inch x 10^{-3}	WP #6 Type #2 Inch x 10^{-3}	WP #7 Type #4 Inch x 10^{-3}
0 - 5,000	30.25	43.75	17.25	31.25
5,000 - 10,000	16.1	18.75	9.75	16.5
10,000 - 15,000	12.85	11.5	6.6	11.0
15,000 - 20,000	23.25	53.75	5.25	55.7
20,000 - 25,000	17.9	36.5	5.15	36.7
25,000 - 30,000	19.15	32.25	5.25	30.0
30,000 - 35,000	21.75[2]	31.5	31.75	27.5
35,000 - Final		32.5[3]	29.5[4]	27.0[5]

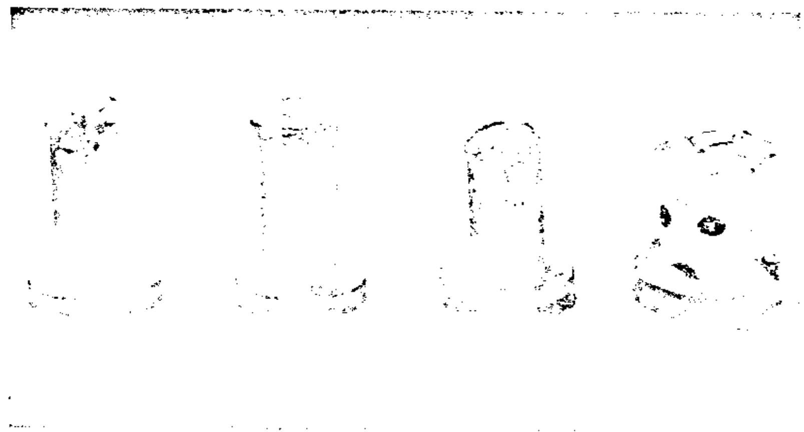
1 Data taken from three tires, and then averaged.

2 Although 717,102 revolutions had been applied, due to the inside radius, the final mileage was 31,999.0 at 717,102 revolutions.

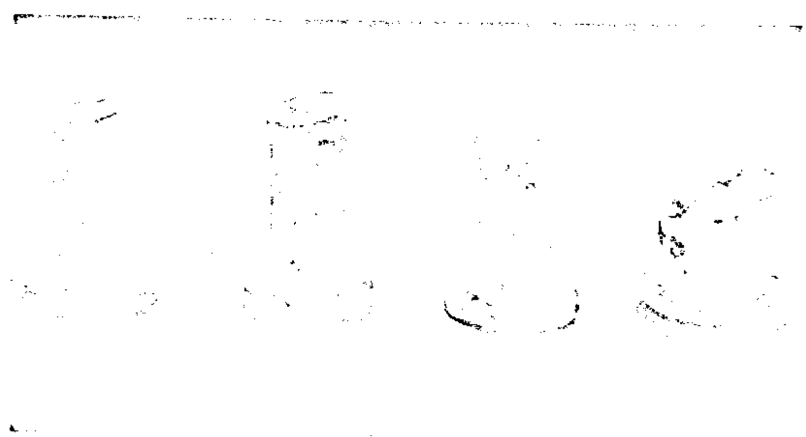
3 Final mileage was 36,983 at 717,102 revolutions.

4 Final mileage was 37,688 at 717,102 revolutions.

5 Final mileage was 38,409 at 717,102 revolutions; correct mileage with this tire was 37,758 at 692,102 revolutions.

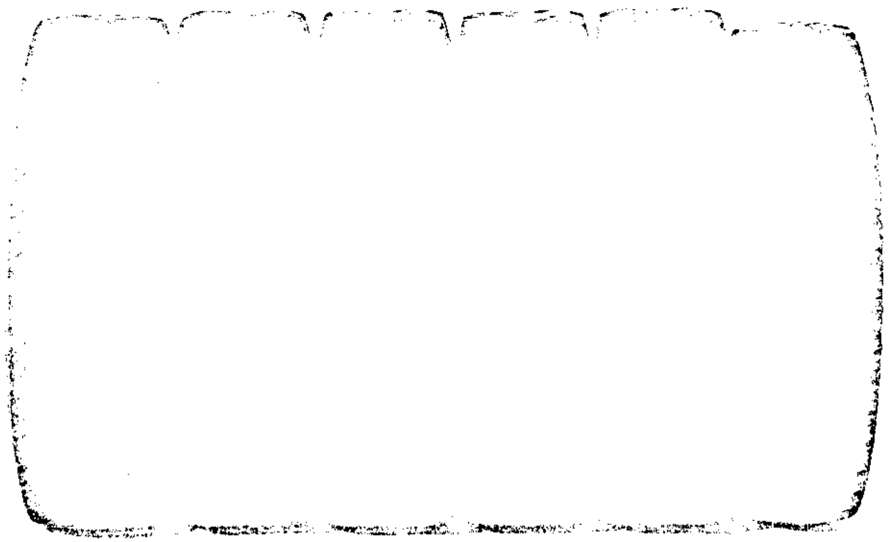


(a) After 300,000 revolutions



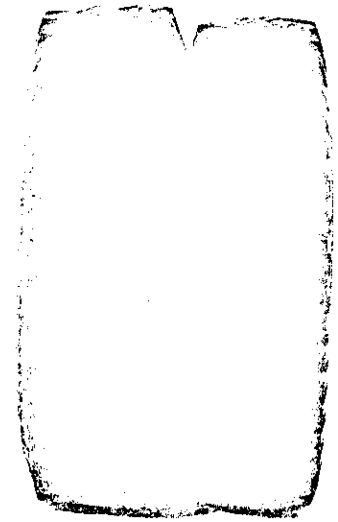
(b) After 417,102 revolutions

Figure 18: The worn appearance of the different studs after 300,000 and 417,102 revolutions. From left to right - the CV stud (#3), the CP stud (#1), the PT stud (#2) and the FS stud (#4). The PT stud in Figure (a) had 551,000 revolutions and the FS stud had 275 revolutions. In Figure (b) the PT stud had 168,102 revolutions.



(a) After 15,000 miles (300,000 revolutions)

(b) After 23,000 miles (417,102 revolutions)



(c) The GST tires

Figure 19: The three photographs show the appearance of the tires after being removed at 300,000 and 417,102 revolutions. From left to right the tires are - unstudded, type #1 stud, type #3 stud, type #2 stud, type #1 stud and the GST tires, respectively. Note that the tire tread edges are worn. Note the appearance of the GST tires in Figure (c). There were two different tread designs. Left to right - GST with 202,642 revolutions and GST with 567,102 revolutions. The one on the left had uneven garnet distribution with most of the garnet being in the right half of the tire.

SKID RESISTANCE VALUES

Skid resistance measurements with both the California Skid Tester and the English Portable Skid Tester were taken in each of the wheel paths. The length of time needed to take these readings along with the need for dry pavement surfaces for measurement precluded their desired frequency, especially near the end of the test. The series of skid resistance values taken at specific wheel applications using the California Skid Tester are shown in Appendix J.

Skid resistance values obtained with the California Skid Tester are summarized for 300,000; 717,102; and 2,151,306 wheel applications in Tables 10-12 (p. 41-43). Only Table 12 shows the values obtained in the dual truck tire wheel paths. All of these tables show that the skid resistance values were reduced from their initial values by the different studded tires.

Table 13 (p. 44) shows the skid resistance values obtained with the English Portable Skid Tester after 717,102 wheel applications. The results tend to verify the California skid resistance values. It is difficult to compare the English Portable Skid resistance values with the California Skid Tester values. The two instruments are different in principle and operation. Their measurement paths are different; the English Portable Skid Tester measures over a consistant length of 4.875 inches, while the California Skid Tester measures over a range of lengths from 0-18 inches. The former is sensitive to water and pavement temperatures. It was found that the English Skid Tester measurements were very susceptible to human error because the instrument required constant positioning. The California Skid Tester was easier to operate and required less time.

TABLE 10

SKID RESISTANCE VALUES[1] AFTER 300,000 WHEEL APPLICATIONS

SECTION	0[2]	TIRE & STUD TYPES					
		US	#1	#3	#2	#4	GST
		WHEEL PATHS					
	INITIAL	#1	#2	#5	#6	#7	#8
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	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] California Skid Tester

[2] No traffic and for the entire section

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

TABLE 11

SKID RESISTANCE VALUES[1] AFTER 717,102 WHEEL APPLICATIONS

SECTION	0[2]	TIRE & STUD TYPES					
		US[3]	#1[3]	#3	#2	#4	GST
		WHEEL PATHS					
	INITIAL	#1	#2	#5	#6	#7	#8
010	50	44	18	21	21	22	47
021	29	34	17.5	16	14.5	15.5	16
022	37.5	31	18	16	15	16	15
023	37	34	17	20	19	20	21
031	24	23	17	13.5	14	15	15
032	33.5	38	17	17	18	15.5	20
033	35	30	18	17.5	16.5	15	15
034	32.5	32	23	25	19	24.5	23.5
041	45	42	21	18.5[4]	14[5]	19[4]	34
042	46	42	17.5	31	27	16	21
043	47.7	44	19	27.5	20	19	40.5
050	46.2	47	22	27	17.5	16	38
061	37.7	31	25	20	17	25	27
062	37	35	20	16	14.5	19	29
070	43.7	40	21	15.5	14.5	17.5	28.5
080	34.3	28	18	14.5	14	14	21.5
090	39.7	33	19	16	14	14	29.5
100	39	33	17	15.5	14.5	17	24.5
110	37	32	21	17	15	20	28.5
121	36	24	18	15[5]	16[5]	15	21
123	47.5	35	23	23[5]	18[5]	21	30
122	47.5	33	18	15.5[5]	15[5]	14	28

[1] California Skid Tester

[2] No traffic and for the entire section

[3] These values were interpolated for the inside track.

[4] These values obtained at 500,000 wheel applications.

[5] These values obtained at 350,000 wheel applications.

TABLE 12

SKID RESISTANCE VALUES[1] AFTER 2,151,306 WHEEL APPLICATIONS

SECTION	0[2] INITIAL	TIRE & STUD TYPES US	#1	UST	UST
		WHEEL PATHS #1	#2	#3	#4
010	50	40.5	14.5	34	40
021	29	20.5	13	16	23
022	37.5	18.5	14.5	14	16.5
023	37	27	13.5	16	16
031	24	15.5	14	14.5	15
032	33.5	25.5	12.5	14	28
033	35	15.5	14	15	21
034	32.5	22	15	14	20
041	45	38.5	--	16	34
042	46	35	--	23	30
043	47.7	38.5	14.5	31	38
050	46.2	36	14	35	36
061	37.7	25	14	19.5	24
062	37	25	15	23	26.5
070	43.7	25	14	21	25.5
080	34.3	27	13.5	19	22
090	39.7	26	17	22	26
100	39	26	15	18	24
110	37	24	17	19	22
121	36	22	13.5	18	23.5
123	47.5	26	13.5	--	--
122	47.5	31	14	19.5	25

[1] California Skid Tester

[2] No traffic and for the entire section

TABLE 13

ENGLISH PORTABLE SKID RESISTANCE VALUES AFTER 717,102 WHEEL APPLICATIONS

SECTION	0[1]	TIRE & STUD TYPES					
		US[2]	#1[2]	#3	#2	#4	GST
		WHEEL PATHS					
	INITIAL	#1	#2	#5	#6	#7	#8
010	82	84	39	60	64	59	68
021	64	48	32	40	57	42	37
022	61	51	43	50	54	56	55
023	60	59	47	63	78	67	50
031	58	37	27	41	54	49	32
032	64	57	32	44	68	50	47
033	56	38	27	43	53	40	24
034	66	53	54	58	63	65	45
041	55	45	46	--	70	--	40
042	71	60	34	69	78	--	49
043	98	79	47	53	63	56	55
050	90	82	38	62	58	56	54
061	65	48	63	48	45	59	40
062	65	53	62	57	55	57	36
070	70	58	53	55	55	49	45
080	68	55	51	54	58	63	40
090	66	50	55	53	53	50	41
100	65	47	59	47	52	71	35
110	62	52	51	51	50	50	34
121	62	52	47	48	51	48	39
123	79	60	40	54	65	55	44
122	72	68	40	62	55	58	44

[1]No traffic and for entire section

[2]These values were interpolated for the inside track.

Table 14 (p. 46) and Figures 20-22 (p. 47-49) compare the relative percent reduction in the skid resistance values on the basis of similar types of pavement materials and the different types of studs.

As seen from Figure 20 (p. 47) and Table 14 (p. 46), which pertain to the different surfacings, the unstudded tires and garnet dust retread tires reduced the skid resistance numbers (values) less than any of the studded tires. On the average, the skid resistance numbers were reduced by the stud types in the following order: type #2 (most reduction), type #3, type #4 and type #1 (least reduction). The section with the bauxite asphalt epoxy surfacing on high alumina cement concrete overlay (010) and the section with the bauxite asphalt epoxy surfacing on class "G" asphalt concrete (050) had the best skid resistance and the least reduction in skid resistance values. The Idaho Chip Seal surfacing (110), although its initial skid resistance value is lower than those for the other types of surfacings, displayed a lesser total reduction in skid resistance value. The remaining three sections (mineral slag asphalt epoxy surfacing (041), garnet asphalt epoxy surfacing (042) and bauxite asphalt epoxy surfacing (043), all on portland cement sand mix overlay) may have had improper bond between the asphalt epoxy and the portland cement sand mix overlay. As a result, the surfacings stripped off very rapidly and reduced skid resistance values of the three sections accordingly. The garnet surfaced section (042) and the mineral slag surfaced section (041) appear to polish once the original mineral aggregates were worn off.

Table 14 (p. 46) and Figure 21 (p. 48) show that the portland cement and polymer concrete sections reached lower skid resistance values than the other group of sections, especially under the action of the different studded tires. The garnet dust retread reduced skid resistance values as much as the studded tires for these groups of pavement materials. The section with the

TABLE 14

COMPARISON OF PERCENT REDUCTION[1] IN SKID RESISTANCE NUMBERS[2] AFTER 717,102 WHEEL APPLICATIONS

SECTION	TIRE & STUD TYPES					
	US	#1	#3	#2	#4	GST
	WHEEL PATHS					
	#1	#2	#5	#6	#7	#8
010	12	64	58	58	56	6
021	+17	40	45	50	55.6	45
022	17	52	57	60	57	60
023	8	54	46	48	46	43
031	4	29	44	42	37.5	37.5
032	+13	49	49	46	54	40
033	14	49	50	53	57	57
034	2	29	23	42	25	28
041	7	53	59	69	58	24
042	9	62	36	41	65	54
043	8	60	42	58	60	15
050	+ 1	52	42	62	65	18
061	18	33	47	55	33	28
062	5	43	57	61	49	22
070	8.5	52	65	67	60	35
080	18	52	58	59	59	37
090	17	52	60	65	65	26
100	15	56	60	63	55	37
110	13.5	43	54	59.5	46	33
121	33	50	58	56	58	42
123	26	52	51	61	56	37
122	30.5	62	67	68	70.5	41

[1] Minus values except where noted.

[2] California Skid Tester

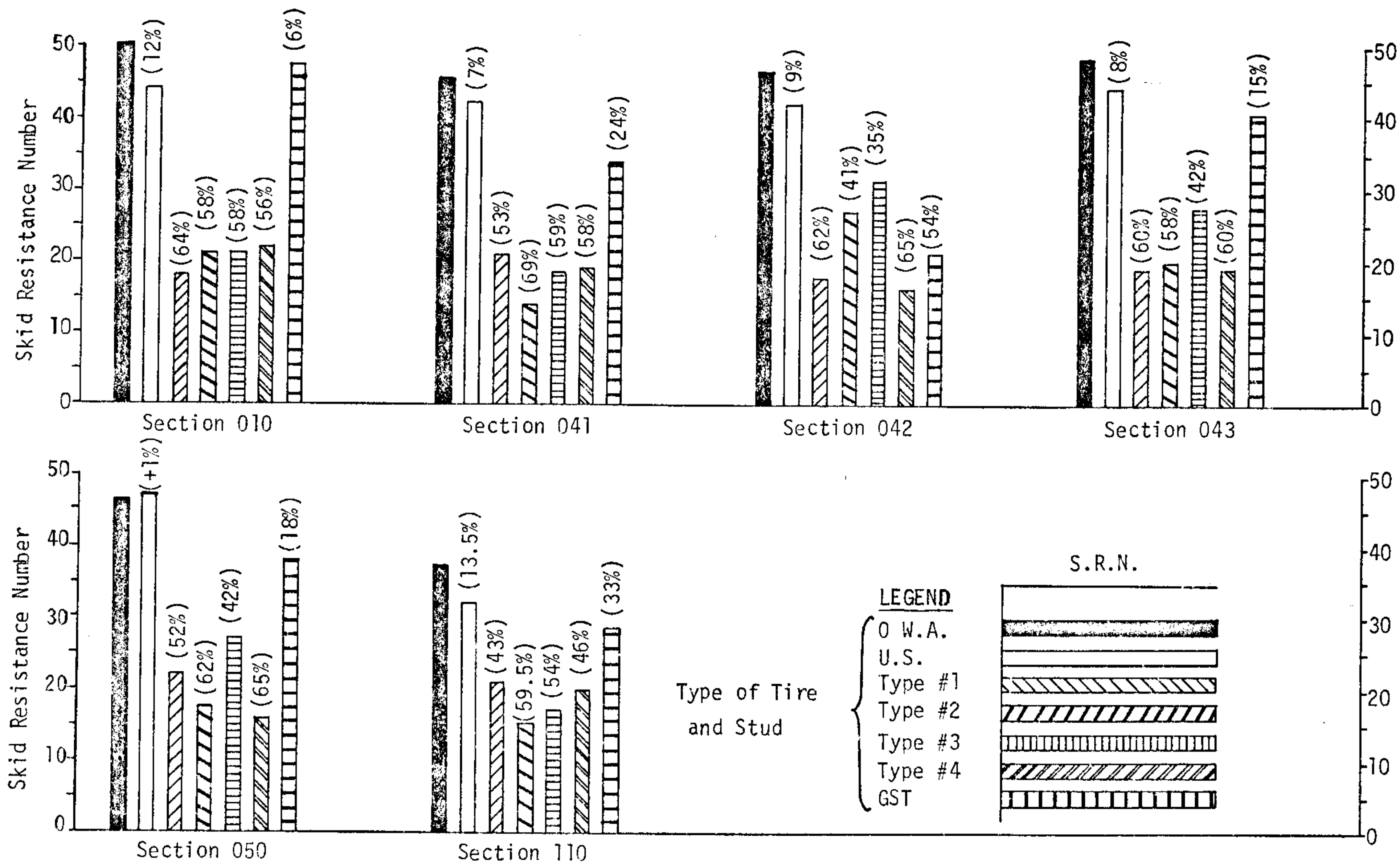


Figure 20: Comparison of Skid Resistance Numbers for 0 W.A. and 717,102 W.A. for the Different Surfacings.

Note: The number in parenthesis indicates percent reduction in skid resistance from the initial S.R.N.

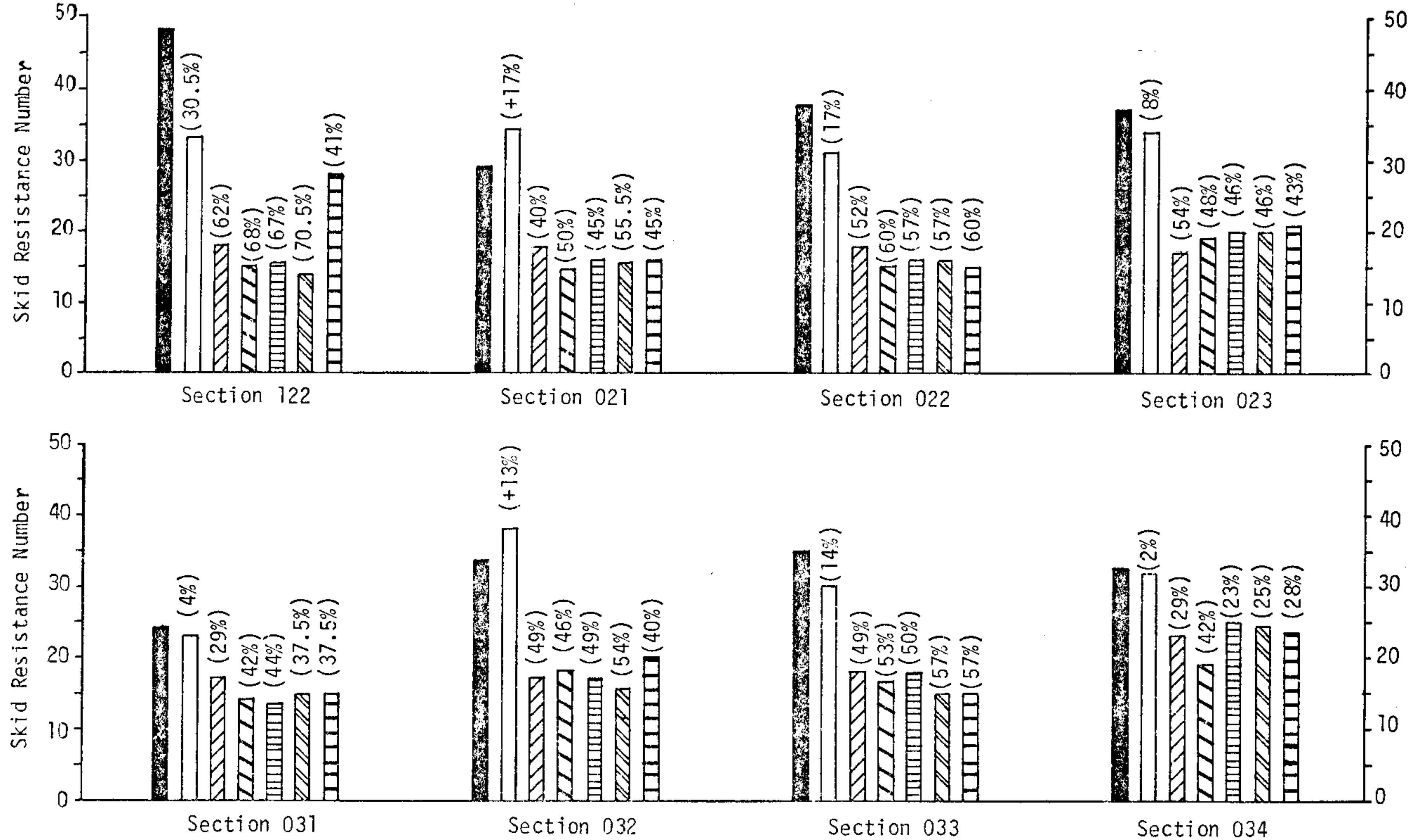


Figure 21: Comparison of Skid Resistance Numbers for 0 W.A. and 717,102 W.A. for the Different Portland Cement and Polymer Concretes.

Note: The legend is the same as that for Figure 20. The number in parenthesis indicates percent reduction in skid resistance from initial S.R.N.

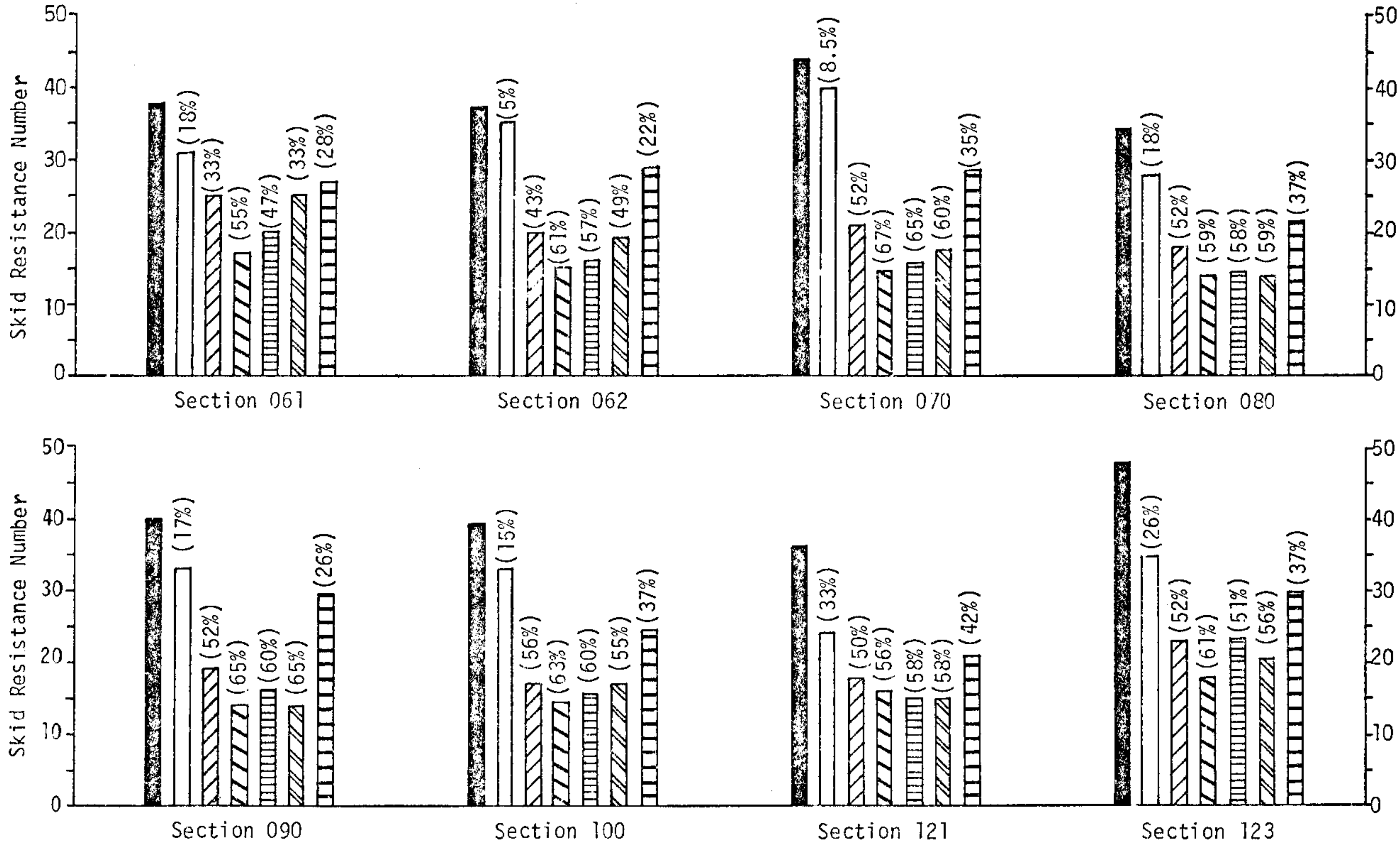


Figure 22: Comparison of Skid Resistance Numbers for 0 W.A. and 717,102 W.A. for the Different Asphalt Concretes.

Note: The legend is the same as that for Figure 20. The number in parenthesis indicates percent reduction in skid resistance from initial S.R.N.

rubber-sand on polymer concrete (034) had the highest skid resistance values compared to the other seven sections in this group. However, the sections in this group did not retain their skid resistance values in the studded tire wheel paths as well as the other groups. As for the sections with the garnet surfacing (023, 032) and the mineral slag surfacing section (033), some of the low skid resistance values may be due to the fine gradation of the aggregates (-40 mesh). (The steel fibers in the polymer steel fibrous concrete (022) did not appreciably affect the skid resistance values.) The type #2 stud reduced the skid resistance values more than any of the other three types of studs.

Table 14 (p. 46) and Figure 22 (p. 49) show that the group containing the eight different asphalt concrete sections also had their skid resistance values reduced, especially in the studded tire wheel paths. The class "D" asphalt concrete sections (061 and 062) had the least reduction in skid resistance values. The mastic asphalt section (123) was second in reduction of skid resistance values. The class "G" A.C. with Pliopave (070), the class "G" A.C. (090), the class "G" A.C. with Petroset AT (100), and the class "B" A.C. (121) displayed similar skid resistance values, and it is difficult to choose which one is the best in retaining their original skid resistance characteristics. The class "G" asphalt extended epoxy concrete section (080) had the highest overall reduction in skid resistance values for this group. The skid resistance values were reduced by the stud types in the following order: type #2 (most reduction), type #3, type #4 and type #1 (least reduction). The unstudded tire reduced the skid resistance values less than the garnet dust retread tire and the tires with the four different types of studs for this group.

Since the Washington State Highway Department considers pavements having California Skid Resistance values of 25 or less as being dangerous, and since at the end of the the test most of the sections had reached this value of 25 or lower, it was desirable to determine the number of wheel applications at which the pavements under the action of the different tires and studs reached this number. Table 15 (p. 52) displays these numbers which were obtained from figures similar to Figures 23-28 (p. 53-58).

Table 15 (p. 52) shows for the group of sections containing the six different surfacings that the sections with the bauxite aggregates (010, 050) and the section with the Idaho Chip Seal (110) appeared superior to the other three sections. Type #2 and #3 studs caused the quickest reduction in skid resistance values as compared to the type #1 and #4 studs. The section with the mineral slag aggregates (041) and the section with the garnet aggregates (042) reached the S.R.N.* of 25 more rapidly than the other sections. This is probably due to the relatively small size of the aggregates used in these sections as contrasted to the larger bauxite aggregates and Idaho Chip aggregates used in other sections in this group.

The rubber-sand on polymer concrete section (034) displays the best skid resistance characteristics in the portland cement and polymer concrete group as shown in Table 15 (p. 52). The portland cement concrete section (122) was a distant second. The type #2 and type #3 studs caused the S.R.N. of the pavement to reduce to 25 faster than either the type #4 or type #1 studs. The garnet dust retread tire also reduced the skid resistance values to 25 while the unstudded tire rarely reduced the S.R.N. to this value for this group.

The class "D" asphalt concrete sections (061 and 062) in these eight different asphalt concretes required the most wheel applications to reach the

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* Skid Resistance Number

TABLE 15

NUMBER OF WHEEL APPLICATIONS TO REACH SKID RESISTANCE NUMBER[1] OF 25[2]

PAVEMENT TYPES[4]	SECTION	TIRE & STUD TYPES: US	#1	#2	#3	#4	GST
		WHEEL PATHS: #1	#2	#6	#5	#7	#8
DIFFERENT SURFACINGS	010	--[3]	145,000	280,000	200,000	250,000	--[3]
	041	--[3]	90,000	65,000	90,000	200,000	--[3]
	042	--[3]	60,000	45,000	38,000	55,000	550,000
	043	--[3]	200,000	180,000	200,000	175,000	--[3]
	050	--[3]	300,000	312,500	185,000	195,000	--[3]
	110	--[3]	230,000	230,000	280,000	300,000	440,000
DIFFERENT PORTLAND CEMENT AND POLYMER CONCRETES	122	--[3]	120,000	50,000	20,000	65,000	--[3]
	021	1,000,000	10,000	26,000	25,000	24,000	180,000
	022	770,000	220,000	55,000	25,500	50,000	195,000
	023	--[3]	20,000	26,000	15,000	55,000	425,000
	031	0	0	0	0	0	0
	032	--[3]	35,000	35,000	30,000	115,000	260,000
	033	1,170,000	50,000	20,000	23,000	10,000	10,000
	034	950,000	120,000	180,000	150,000	200,000	340,000
DIFFERENT ASPHALT CONCRETES	061	2,151,000	580,000	355,000	355,000	665,000	--[3]
	062	2,151,000	540,000	250,000	470,000	560,000	--[3]
	070	2,151,000	770,000	175,000	250,000	265,000	--[3]
	080	2,050,000	540,000	180,000	160,000	190,000	--[3]
	090	1,380,000	530,000	200,000	350,000	340,000	530,000
	100	--[3]	530,000	175,000	250,000	275,000	--[3]
	121	550,000	320,000	175,000	190,000	160,000	--[3]
	123	--[3]	350,000	60,000	50,000	105,000	660,000

[1] California Skid Tester

[2] The Washington State Highway Department considers pavements having skid resistance values of 25 or less as being dangerous.

[3] Skid resistance number was above 25 at the end of the test.

[4] Refer to Table I for specific pavement overlays.

RING 6 - SECTION 122; Inside Track, Portland Cement Concrete

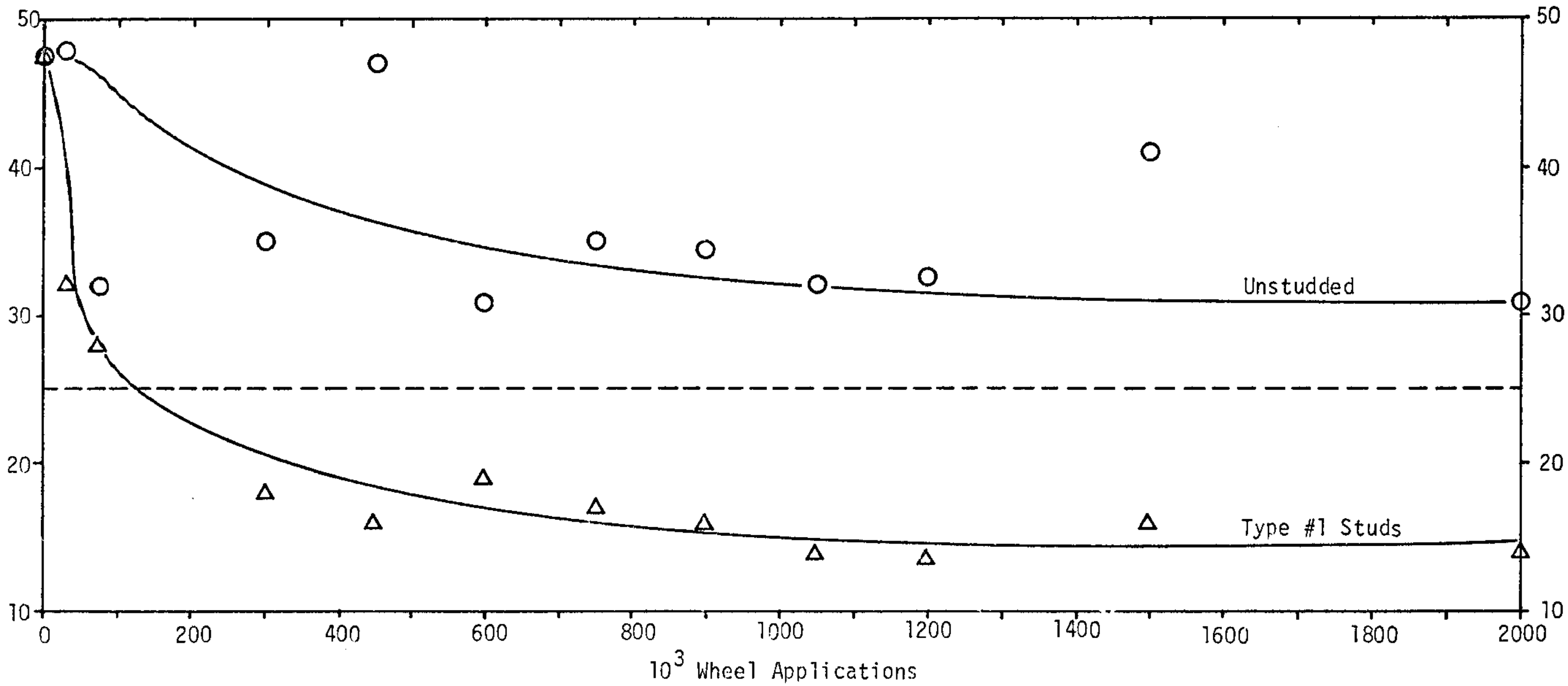


Figure 23: California Skid Resistance Number vs W.A.-Portland Cement Concrete

RING 6 - SECTION 122; Outside Track, Portland Cement Concrete

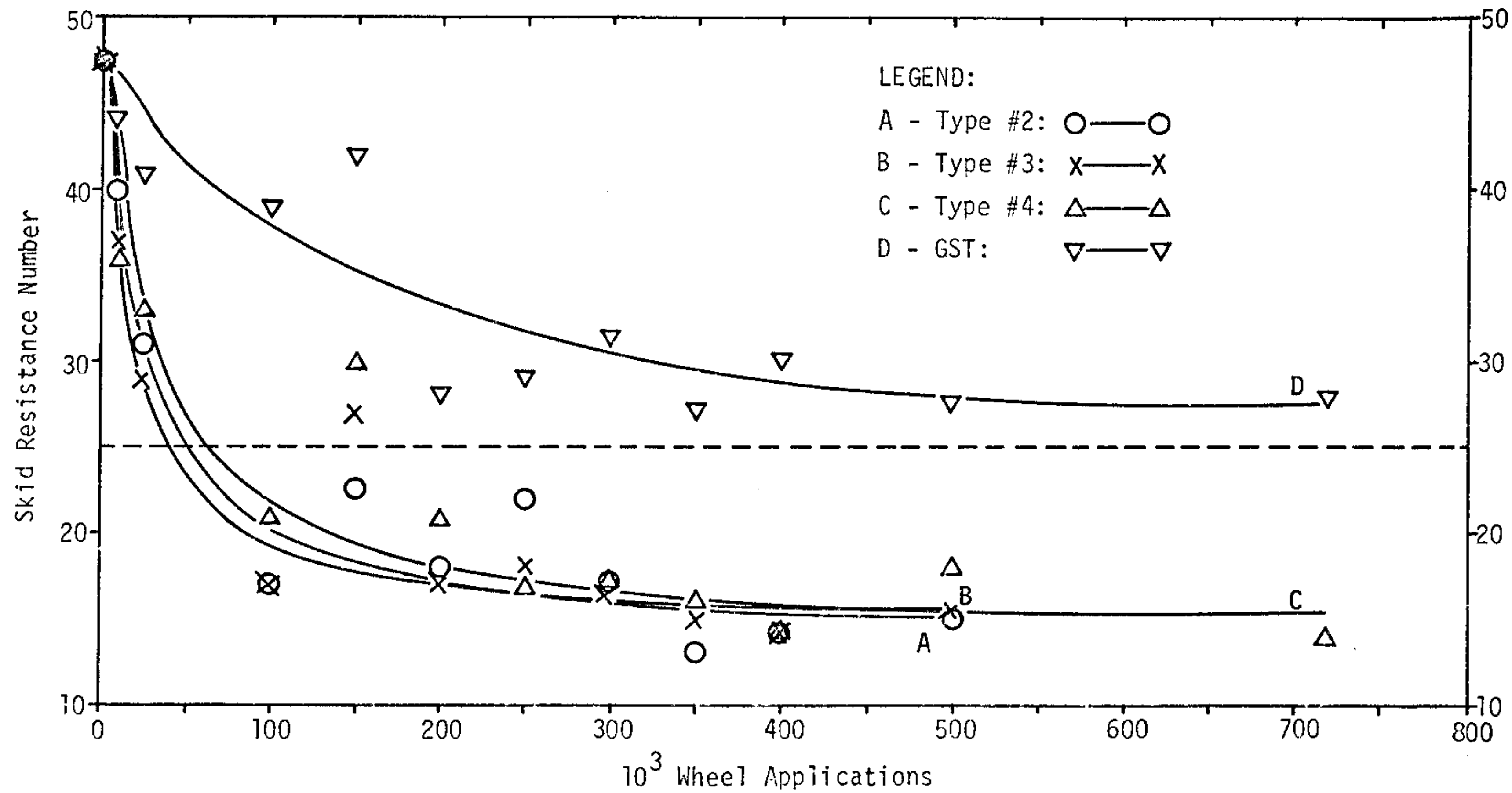


Figure 24: California Skid Resistance Number vs W.A.-Portland Cement Concrete

RING 6 - SECTION 041; Inside Track,
Mineral Slag Asphalt Epoxy Surfacing on Portland Cement Sand Mix Overlay

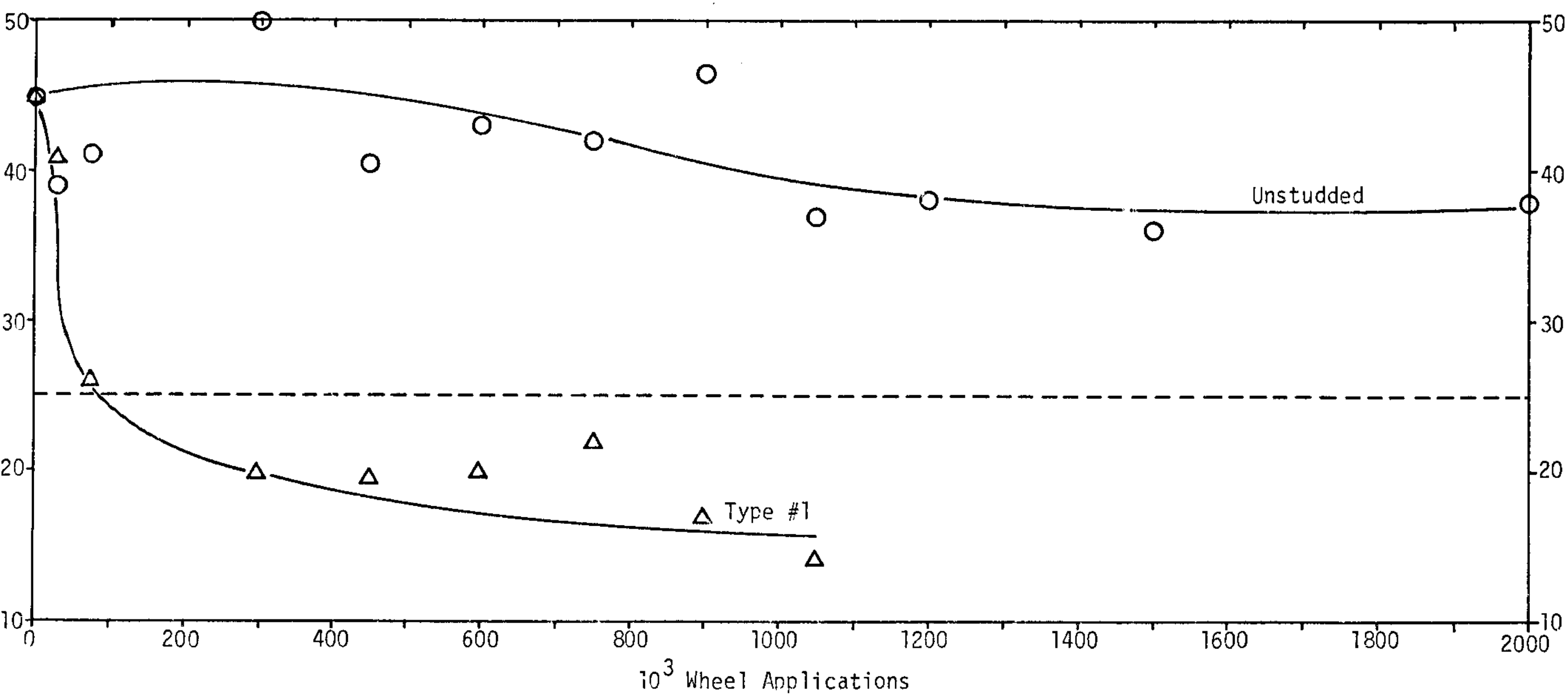


Figure 25: California Skid Resistance Number vs W.A.- Mineral Slag Asphalt Epoxy Surfacing on Portland Cement Sand Mix Overlay.

RING 6 - SECTION 041; Outside Track, Mineral Slag Aggregate Asphalt Extended Epoxy Surfacing

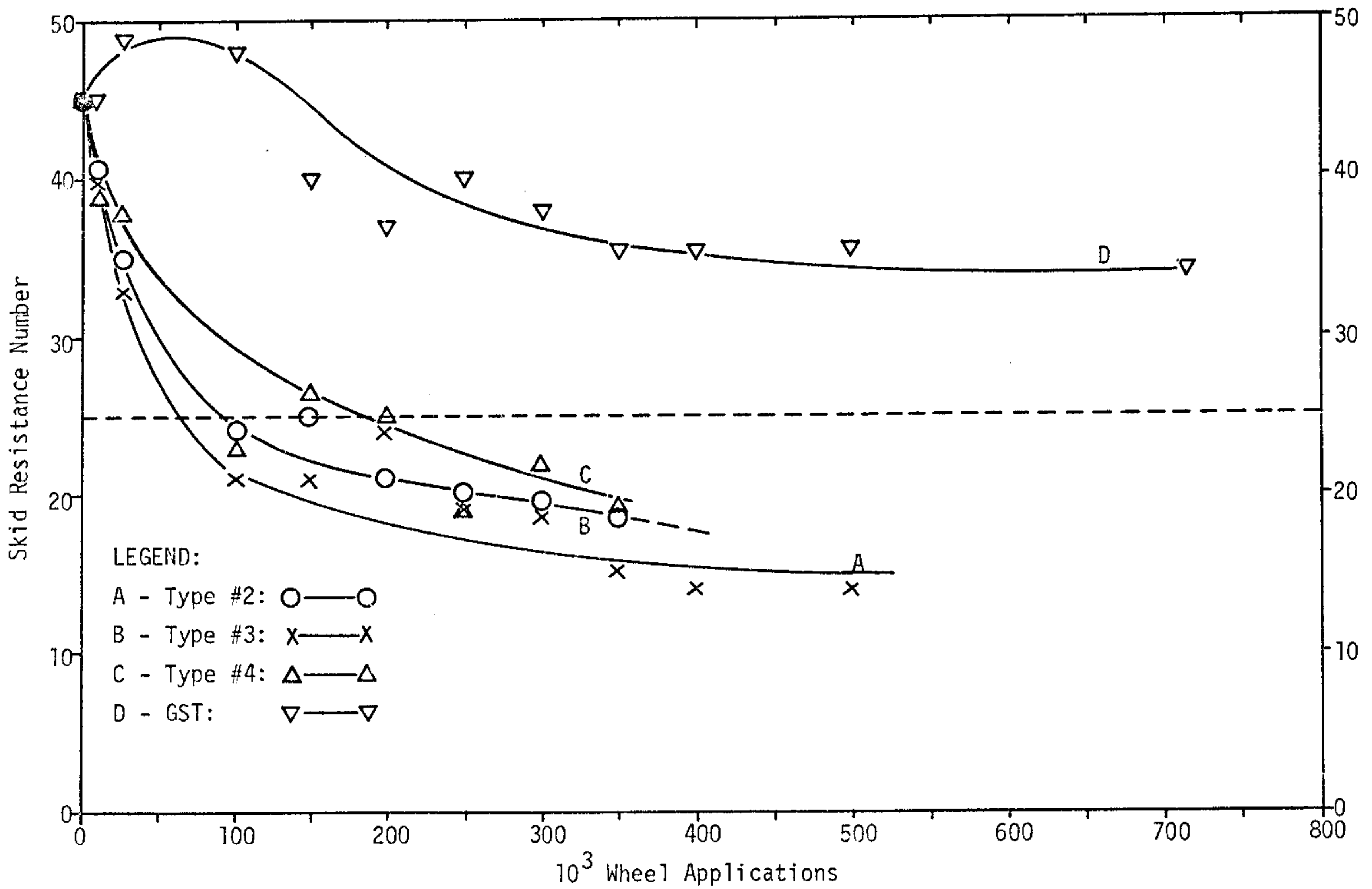


Figure 26: California Skid Resistance vs W.A.-Number of Wheel Applications

RING 6 - SECTION 070; Inside Track, Class "G" A.C. with Pliopave

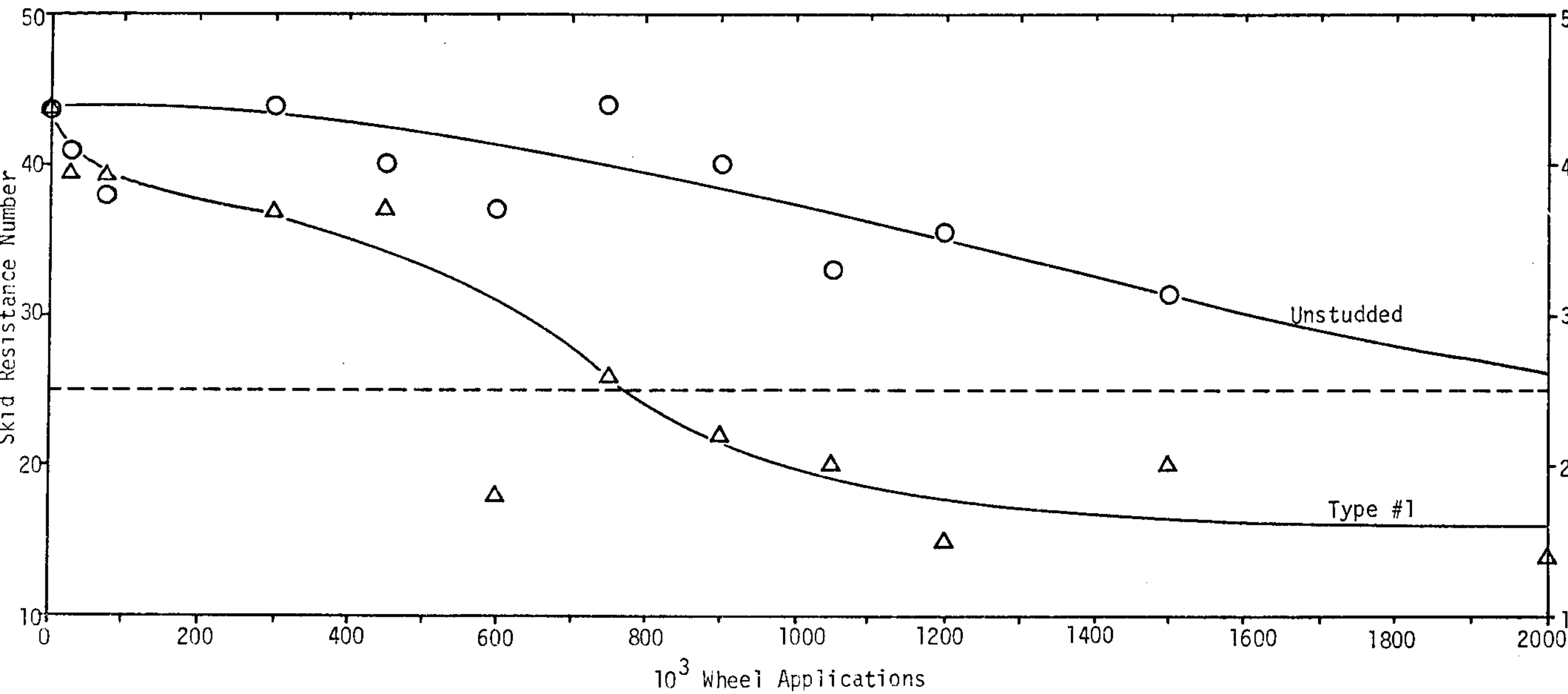


Figure 27: California Skid Resistance Number vs W.A.-Class "G" A.C. with Pliopave

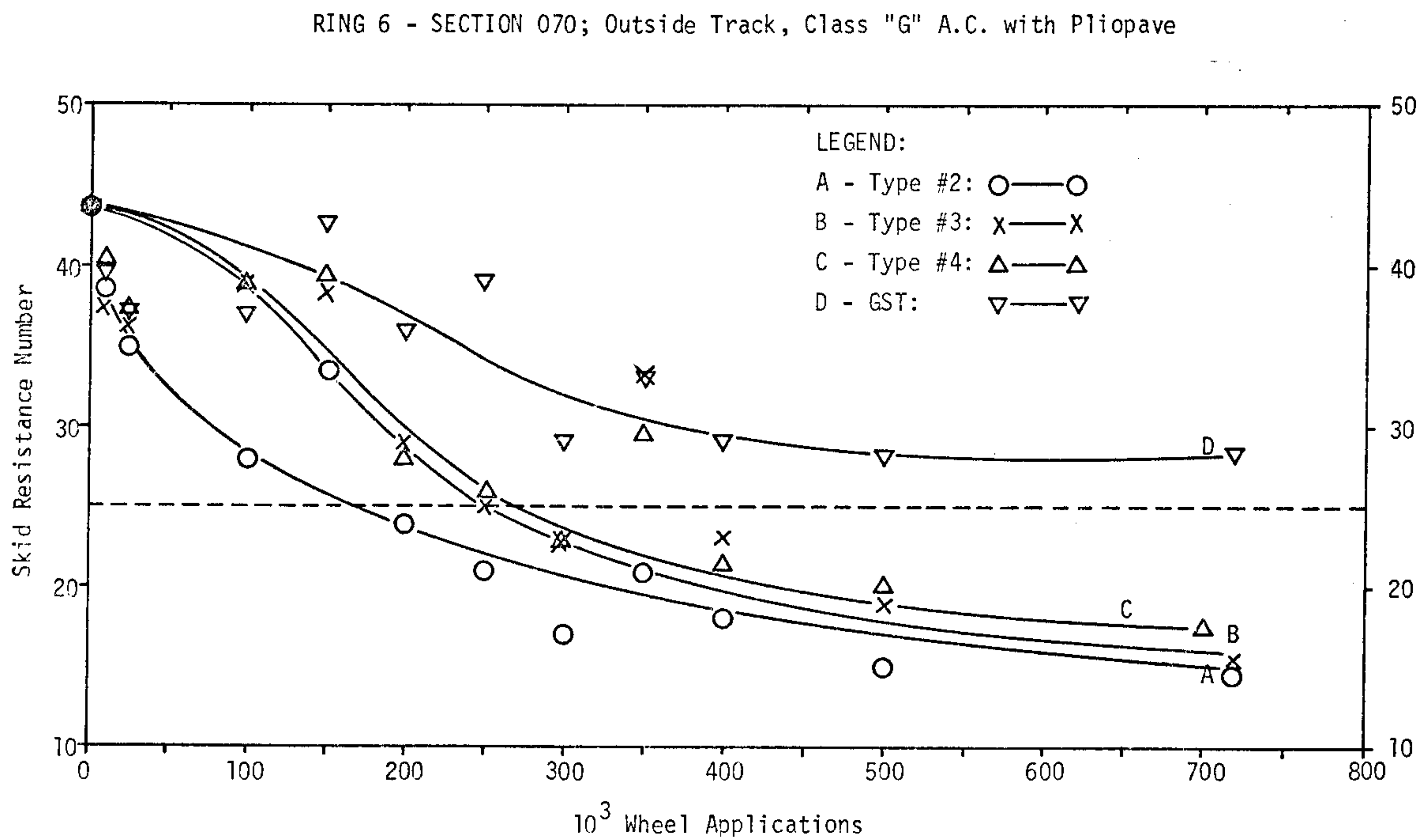


Figure 28: California Skid Resistance Number vs W.A.-Class "G" A.C. with Pliopave

S.R.N. of 25. The mastic asphalt section (123) was the poorest of the asphalt sections, but this may be due to the loss of the surface aggregates which is attributed to construction difficulties. Types #2 and #3 studs caused the asphalt pavements to give a S.R.N. of 25 more rapidly than type #4 and type #1 studs. Both the unstudded tire and the garnet dust retread tire did not lower the skid resistance values to 25 except in the class "G" A.C. section (090) and the mastic asphalt section (123) where the S.R.N. was reduced to 25 by the GST tire.

Referring to Table 12 (p. 43), the dual truck tires, which were unstudded, reduced the skid resistance values of all the pavements appreciably except in the bauxite asphalt epoxy sections (010 and 050). One reason for this is that some oil leakage occurred from the driving tire mechanism which may have slickened both wheel paths. The wheel path of the driving tire displayed a lower S.R.N. than the wheel path of the free-wheeling tire.

The tables and graphs show that many of the pavement sections exhibited skid resistance values of less than 25 at the end of the test in the paths of the studded tires. The unstudded tire and the garnet dust retread tire did reduce skid resistance values, but not as much as the studded tires. The type #2 and type #3 studs seem to have reduced skid resistance values in their respective wheel paths more than either the type #4 or type #1 studs. The test shows that all pavements under all types of tires (unstudded and studded) will have reduction in skid resistance values, but these values are reduced more rapidly by studded tires.

TRAFFIC STRIPES

No quantitative measurements were made of the wear of the traffic stripes. Rather, visual observations were made and the stripes were ranked according to appearance on the basis of whiteness and adherence. The rankings were made on the stripes relative to the different studs; e.g., each stripe was ranked versus the stud or tire type. The purpose of the test was to determine which stripe would have the most resistance to the various studs and tires. The rankings are more subjective than objective.

The rankings are presented in Tables 16-23 (p. 61 -64) for the polymer cement concrete section (021) and the class "G" A.C. with Petroset AT section (100) determined at wheel applications of 10,000; 25,000; 50,000; and 150,000+. A series of pictures were taken but only those taken at 50,000 wheel applications are included in this report as Figures 29 (p. 65) and 30 (p. 66). These figures show the appearance of the stripes. Rankings were based on such appearances.

One can see from Tables 16-23 (p. 61-64) that striping material no. 4 was the outstanding performer. This material consistantly showed better adherence than the other three stripes.

The traffic striping materials performed differently on the polymer cement concrete than on the asphalt concrete. The stripes wore off more rapidly on the polymer cement concrete. As can be seen from Tables 16 (p. 61), 18 (p. 62), 20 (p. 63) and 22 (p. 64), stripe no. 4 was superior to the other three stripes followed by no. 1, no. 2 and no. 3 in that order. After 50,000 wheel applications most of these stripes were worn off. The type #3 stud caused the most damage followed by types #4, #1, #2, the GST, US and UST, respectively.

The traffic striping materials performed differently on the asphalt concrete section as shown in Tables 17 (p. 61), 19 (p. 62), 21 (p. 63) and 23 (p. 64), respectively. The no. 4 striping was again number one in ranking.

TABLE 16: RANKING OF STRIPES ACCORDING TO WEAR - SECTION 021 - 10,000 W.A.[1]

STRIPE NO.	WHEEL PATHS							
	1	2	3	4	5	6	7	8
	TYPE OF STUDS AND TIRES							
	US	#1	UST	UST	#3	#2	#4	GST
1	2	2	2	2	2	2	3	3
2	3	3	3	3	--[2]	4	4	2
3	4	4	4	4	--[2]	3	2	4
4	1	1	1	1	1	1	1	1

[1] Wheel Applications

[2] Stripe completely worn off

TABLE 17: RANKING OF STRIPES ACCORDING TO WEAR - SECTION 100 - 10,000 W.A.[1]

STRIPE NO.	WHEEL PATHS							
	1	2	3	4	5	6	7	8
	TYPE OF STUDS AND TIRES							
	US	#1	UST	UST	#3	#2	#4	GST
1	2	2	4	4	4	4	4	4
2	3	3	3	3	3	3	3	3
3	4	4	2	2	2	2	2	2
4	1	1	1	1	1	1	1	1

[1] Wheel Applications

TABLE 18: RANKING OF STRIPES ACCORDING TO WEAR - SECTION 021 - 25,000 W.A.[1]

STRIPE NO.	WHEEL PATHS							
	1	2	3	4	5	6	7	8
	TYPE OF STUDS AND TIRES							
	US	#1	UST	UST	#3	#2	#4	GST
1	2	2	2	2	2	2	3	3
2	3	4	3	3	--[2]	4	4	2
3	4	3	4	4	--[2]	3	2	4
4	1	1	1	1	1	1	1	1

[1] Wheel Applications

[2] Stripe completely worn off

TABLE 19: RANKING OF STRIPES ACCORDING TO WEAR - SECTION 100 - 25,000 W.A.[1]

STRIPE NO.	WHEEL PATHS							
	1	2	3	4	5	6	7	8
	TYPE OF STUDS AND TIRES							
	US	#1	UST	UST	#3	#2	#4	GST
1	4	4	4	4	2	2	3	3
2	3	3	2	2	3	4	2	4
3	2	2	3	3	4	3	4	2
4	1	1	1	1	1	1	1	1

[1] Wheel Applications

TABLE 20: RANKING OF STRIPES ACCORDING TO WEAR - SECTION 021 - 50,000 W.A.[1]

STRIPE NO.	WHEEL PATHS 1	2	3	4	5	6	7	8
	TYPES OF STUDS AND TIRES							
	US	#1	UST	UST	#3	#2	#4	GST
1	2	2	2	2	--[2]	--[2]	--[2]	--[2]
2	3	3	3	3	--[2]	--[2]	--[2]	--[2]
3	4	3	4	4	--[2]	2	2	2
4	1	1	1	1	1	1	1	1

[1] Wheel Applications [2] Stripe completely worn off

TABLE 21: RANKING OF STRIPES ACCORDING TO WEAR - SECTION 100 - 50,000 W.A.[1]

STRIPE NO.	WHEEL PATHS 1	2	3	4	5	6	7	8
	TYPES OF STUDS AND TIRES							
	US	#1	UST	UST	#3	#2	#4	GST
1	4	--[2]	4	4	4	3	3	3
2	3	--[2]	2	2	3	4	4	4
3	2	2	3	3	2	2	2	2
4	1	1	1	1	1	1	1	1

[1] Wheel Applications [2] Stripe completely worn off

TABLE 22: RANKING OF STRIPES ACCORDING TO WEAR - SECTION 021 - 150,000+ W.A.[1]

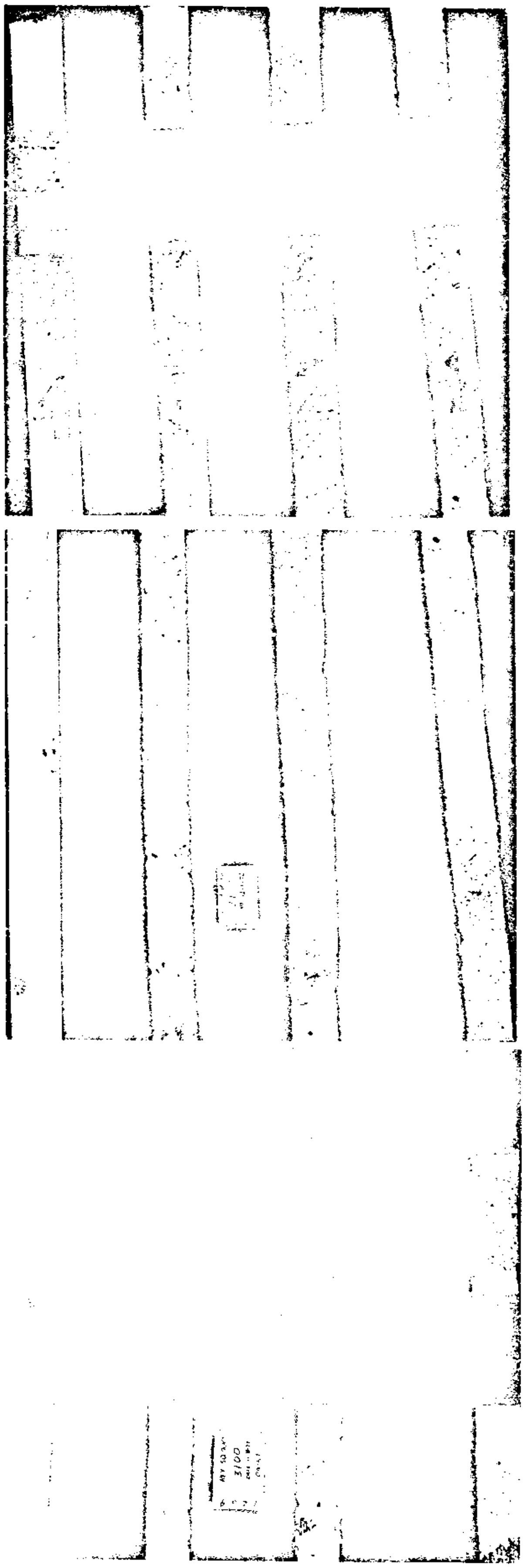
STRIPE NO.	WHEEL PATHS							
	1	2	3	4	5	6	7	8
	TYPE OF STUDS AND TIRES							
	US	#1	UST	UST	#3	#2	#4	GST
1	3	--[2]	2	2	--[2]	--[2]	--[2]	--[2]
2	2	--[2]	3	3	--[2]	--[2]	--[2]	--[2]
3	4	2	4	4	--[2]	2	--[2]	--[2]
4	1	1	1	1	1	1	1	1

[1] Wheel Applications [2] Stripe completely worn off

TABLE 23: RANKING OF STRIPES ACCORDING TO WEAR - SECTION 100 - 150,000+ W.A.[1]

STRIPE NO.	WHEEL PATHS							
	1	2	3	4	5	6	7	8
	TYPE OF STUDS AND TIRES							
	US	#1	UST	UST	#3	#2	#4	GST
1	2	--[2]	4	4	2	2	2	2
2	3	--[2]	3	3	4	4	4	4
3	4	--[2]	2	2	3	3	3	3
4	1	1	1	1	1	1	1	1

[1] Wheel Applications [2] Stripe completely worn off

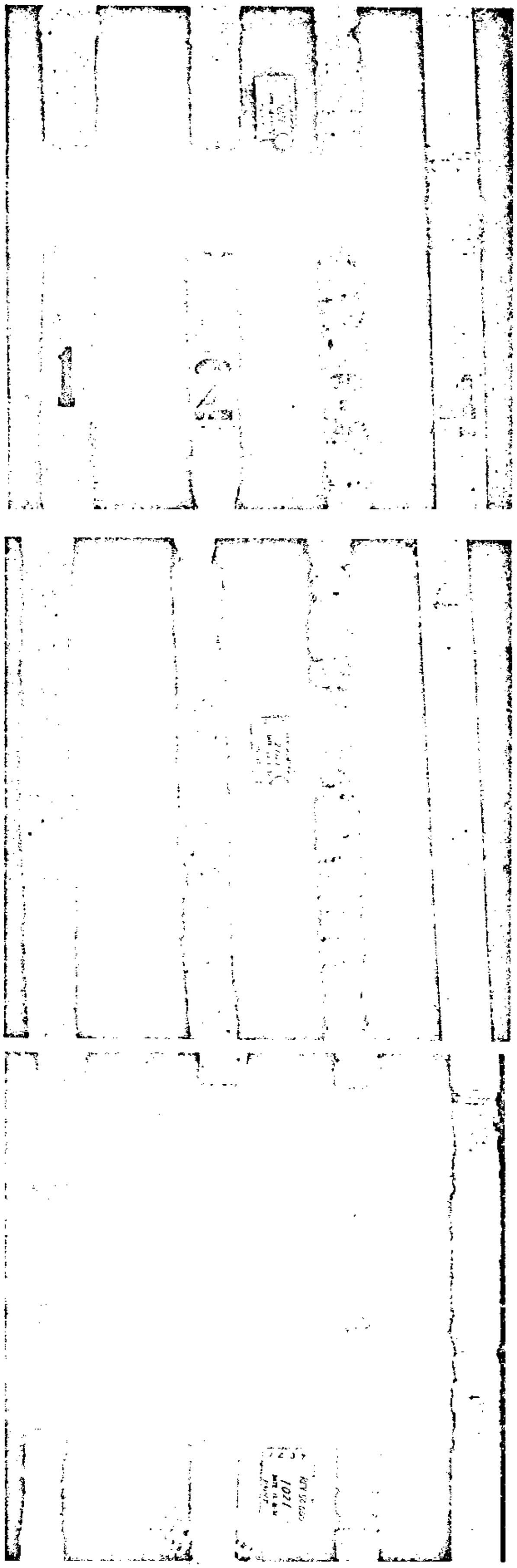


(a) 1100 - wheel paths 1 and 2

(b) 2100 - wheel paths 3 and 4

(c) 3100 - wheel paths 5 - 8

FIGURE 29: The appearance of the traffic stripesin Section 100 after 50,000 wheel applications.



(a) 1021 - wheel paths 1 and 2

(b) 2021 - wheel paths 3 and 4

(c) 3021 - wheel paths 5 to 8

FIGURE 30: The appearance of the Traffic paints in Section 021 after 50,000 wheel applications.

The rankings of the remaining stripes varied with the number of wheel applications. Stripes no. 1 and no. 3 consistently vied for the number two ranking; stripe no. 2 was almost always ranked third or fourth. Stud type #3 caused the most wear followed by types #4, #2, #1, GST, US and UST, respectively.

After 150,000 wheel applications, almost all of the stripes were worn off in the polymer concrete section (021) while some stripes still remained in the class "G" A.C. with Petroset AT section (100).

The reason for the phenomenal success of the striping tape in regard to its resistance to wear is its thickness and its composition; it was four times as thick as the paint stripes and it had an asphalt base. A disadvantage of this type of stripe is its bond with the pavement. The stripe may become loose, which happened during the test. Another disadvantage is that snow plows may tear it off because of its thickness. One solution to the latter problem may be to apply this material into pre-recessed grooves to make it flush with the pavement.

MEASUREMENTS OF WHEEL PATHS

a) WSU Profilometer Measurements

The results from the WSU profilometer were obtained from computer readout sheets such as shown in Appendix K. Three typical formats are included for the three tracks and one for the 22 sections. The computer also plotted typical cross-sections for each of the tracks, the wheel paths and for the number of wheel passes; three samples of typical cross-section plots are included in Appendix K. The final results from the profilometer data are summarized in Tables 24-32 (p. 68-76).

Tables 24-26 (p. 68-70) summarize the profilometer data for this group of six different surfacings for the outside, center and inside tracks,

TABLE 24

PROFILOMETER DATA SUMMARY FOR OUTSIDE TRACK - FOR GROUP OF DIFFERENT SURFACINGS

Tire or Stud Type	Parameters	Units	Bauxite Asphalt Epoxy	Mineral Slag Asphalt Epoxy	Garnet Asphalt Epoxy	Bauxite Asphalt Epoxy	Bauxite Asphalt Epoxy	Idaho Chip Seal
			High Alumina Cement Concrete Overlay	Portland Cement Sand Mix Overlay			Class "G" AC Overlay	Class "B" AC Overlay
			010	041	042	043	050	110
GST	Area Removed	sq. inches	.1889	.2116	.0013	.2821	.3631	.2717
	Rate of Wear	in./10^6 W.A.	.02747	.03078	.00363	.04131	.05314	.04007
	Maximum Depth	inches	.061	.075	.039	.074	.086	.104
	Average Depth	inches	.020	.022	.003	.030	.038	.029
#2	Area Removed	sq. inches	.6063	.8125	.6144	1.0512	.8680	.9199
	Rate of Wear	in./10^6 W.A.	.08796	.11833	.08926	.15334	.12623	.13308
	Maximum Depth	inches	.107	.130	.102	.163	.138	.275
	Average Depth	inches	.063	.085	.064	.110	.091	.095
#3	Area Removed	sq. inches	.9103	1.0120	.4416	1.2132	.9714	2.2846
	Rate of Wear	in./10^6 W.A.	.13209	.14672	.06400	.17715	.15932	.33348
	Maximum Depth	inches	.173	.196	.095	.186	.144	.364
	Average Depth	inches	.095	.105	.046	.127	.102	.239
#4	Area Removed	sq. inches	1.0625	.1341	.7321	1.3158	1.1724	1.4203
	Rate of Wear	in./10^6 W.A.	.15456	.19529	.10620	.19176	.17069	.20744
	Maximum Depth	inches	.178	.209	.125	.187	.174	.311
	Average Depth	inches	.111	.140	.076	.138	.122	.148

TABLE 25

PROFILOMETER DATA SUMMARY FOR CENTER - FOR GROUP OF DIFFERENT SURFACINGS

Tire or Stud Type	Parameters	Units	Bauxite Asphalt Epoxy	Mineral Slag Asphalt Epoxy	Garnet Asphalt Epoxy	Bauxite Asphalt Epoxy	Bauxite Asphalt Epoxy	Idaho Chip Seal
			High Alumina Cement Concrete Overlay	Portland Cement Sand Mix Overlay			Class "G" AC Overlay	Class "B" AC Overlay
			010	041	042	043	050	110
Driving UST	Area Removed	sq. inches	.0977	.8477	.5886	.5552	.5409	1.6230
	Rate of Wear	in./10^6 W.A.	.00581	.03340	.02307	.02194	.03200	.06393
	Maximum Depth	inches	.049	.136	.120	.105	.109	.222
	Average Depth	inches	.008	.072	.050	.048	.046	.138
Free Wheeling UST	Area Removed	sq. inches	.1199	.2484	.1625	.3506	.2618	1.5089
	Rate of Wear	in./10^6 W.A.	.00478	.00993	.00651	.01398	.01041	.05904
	Maximum Depth	inches	.049	.072	.053	.090	.070	.232
	Average Depth	inches	.010	.021	.014	.030	.022	.127

TABLE 26

PROFILOMETER DATA SUMMARY FOR INSIDE TRACK - FOR GROUP OF DIFFERENT SURFACINGS

Tire or Stud Type	Parameters	Units	Bauxite Asphalt Epoxy	Mineral Slag Asphalt Epoxy	Garnet Asphalt Epoxy	Bauxite Asphalt Epoxy	Bauxite Asphalt Epoxy	Idaho Chip Seal
			High Alumina Cement Concrete Overlay	Portland Cement Sand Mix Overlay			Class "G" AC Overlay	Class "B" AC Overlay
			010	041	042	043	050	110
#1	Area Removed	sq. inches	.8022	1.5755	.8889	1.1829	1.2938	2.8652
	Rate of Wear	in./10^6 W.A.	.03876	.07740	.04351	.05761	.06393	.140117
	Maximum Depth	inches	.128	.252	.147	.187	.208	.510
	Average Depth	inches	.083	.167	.094	.124	.138	.302
U.S.	Area Removed	sq. inches	.1509	.2511	.1173	.1745	.2702	.8587
	Rate of Wear	in./10^6 W.A.	.00498	.01214	.00567	.00846	.01505	.04298
	Maximum Depth	inches	.037	.065	.041	.070	.067	.301
	Average Depth	inches	.011	.026	.012	.018	.028	.092

TABLE 27

PROFILOMETER DATA SUMMARY FOR OUTSIDE TRACK - P.C.C. AND POLYMER CONCRETE GROUP

Tire or Stud Type	Parameters	Units	Portland Cement Concrete	Plain	Steel Fibers	Garnet Surfacing	Plain	Garnet Surfacing	Mineral Slag Surfacing	Rubber-Sand
				Polymer Cement Concrete			Polymer Concrete			
			122	021	022	023	031	032	033	034
GST	Area Removed	sq. inches	.1284	.0183	.0078	.1481	.0347	.0380	.1202	.0659
	Rate of Wear	in./10^6 WA	.01874	.00432	.00849	.02173	.00518	.00560	.01784	.00969
	Maximum Depth	inches	.052	.036	.028	.043	.030	.030	.010	.034
	Average Depth	inches	.013	.002	.006	.016	.004	.004	.001	.007
#2	Area Removed	sq. inches	.2984	.2590	.3199	.2861	.0845	.3817	.1139	.5142
	Rate of Wear	in./10^6 WA	.04303	.03758	.04655	.04155	.02182	.05593	.01652	.07480
	Maximum Depth	inches	.070	.053	.059	.073	.037	.097	.055	.089
	Average Depth	inches	.031	.027	.033	.030	.009	.040	.012	.054
#3	Area Removed	sq. inches	.4881	.2377	.3486	.1384	.0420	.2543	.1094	.3838
	Rate of Wear	in./10^6 WA	.07157	.03450	.05079	.02554	.00641	.04782	.01585	.05597
	Maximum Depth	inches	.093	.057	.065	.046	.031	.057	.036	.100
	Average Depth	inches	.051	.025	.036	.014	.005	.027	.011	.040
#4	Area Removed	sq. inches	.4636	.1390	.1558	.2359	.0845	.2254	.0136	.9880
	Rate of Wear	in./10^6 WA	.06743	.02016	.02238	.03431	.02182	.03276	.01263	.14347
	Maximum Depth	inches	.095	.049	.043	.066	.037	.078	.035	.183
	Average Depth	inches	.048	.014	.016	.025	.009	.024	.007	.104

TABLE 28

PROFILOMETER DATA SUMMARY FOR CENTER TRACK - P.C.C. AND POLYMER CONCRETE GROUP

Tire or Stud Type	Parameters	Units	Portland Cement Concrete	Plain	Steel Fibers	Garnet Surfacing	Plain	Garnet Surfacing	Mineral Slag Surfacing	Rubber-Sand
				Polymer Cement Concrete			Polymer Concrete			
			122	021	022	023	031	032	033	034
Driving UST	Area Removed	sq. inches	.0469	.0319	.0594	.0597	.1176	.1729	.0426	.0397
	Rate of Wear	in./10^6 WA	.00187	.00125	.00232	.00238	.00466	.00683	.00164	.00157
	Maximum Depth	inches	.051	.023	.031	.020	.014	.040	.031	.042
	Average Depth	inches	.004	.003	.005	.005	.010	.015	.004	.003
Free-Wheeling UST	Area Removed	sq. inches	.0603	.1416	.0782	.0166	.0244	.1819	.0595	.1130
	Rate of Wear	in./10^6 WA	.00234	.00565	.00305	.00064	.00097	.00721	.00247	.00454
	Maximum Depth	inches	.048	.033	.030	.025	.026	.047	.043	.117
	Average Depth	inches	.005	.012	.007	.001	.002	.016	.005	.010

TABLE 29

PROFILOMETER DATA SUMMARY FOR INSIDE TRACK - P.C.C. AND POLYMER CONCRETE GROUP

Tire or Stud Type	Parameters	Units	Portland Cement Concrete	Plain	Steel Fibers	Garnet Surfacing	Plain	Garnet Surfacing	Mineral Slag Surfacing	Rubber-Sand
				Polymer Cement Concrete			Polymer Concrete			
			122	021	022	023	031	032	033	034
#1	Area Removed	sq. inches	.7232	.2247	.3831	.5257	.1623	.1343	.1211	.6415
	Rate of Wear	in./10^6 WA	.03509	.01088	.01864	.02547	.00793	.00663	.00539	.03105
	Maximum Depth	inches	.116	.055	.078	.117	.044	.046	.065	.107
	Average Depth	inches	.076	.023	.040	.055	.017	.014	.012	.067
US	Area Removed	sq. inches	.0814	.1245	.0618	.0763	.0547	.0786	.0760	.03141
	Rate of Wear	in./10^6 WA	.00508	.00603	.002993	.00369	.00265	.00380	.00372	.00142
	Maximum Depth	inches	.047	.036	.016	.027	.030	.028	.016	.045
	Average Depth	inches	.008	.013	.006	.008	.006	.008	.008	.003

TABLE 30

PROFILOMETER DATA SUMMARY FOR OUTSIDE TRACK - ASPHALT CONCRETE GROUP

Tire or Stud Type	Parameters	Units	Class "D" A.C.	Class "D" A.C. with Petroset A.T.	Class "G" A.C. with Pliopave	Class "G" Asphalt Extended Epoxy Concrete	Class "G" A.C.	Class "G" A.C. with Petroset A.T.	Class "B" A.C.	Mastic Asphalt Concrete
			061	062	070	080	090	100	121	123
GST	Area Removed	sq. inches	.5911	.4647	.2336	.0198	.2901	.3286	.1988	.1983
	Rate of Wear	in./10^6 WA	.08648	.06788	.03403	.00271	.04236	.04825	.12867	.02879
	Maximum Depth	inches	.125	.124	.060	.034	.077	.080	.055	.069
	Average Depth	inches	.062	.049	.024	.002	.031	.035	.020	.021
#2	Area Removed	sq. inches	1.7536	.5705	1.2006	.8135	1.8431	1.4009	.9474	.5531
	Rate of Wear	in./10^6 WA	.25477	.08355	.17493	.11802	.17147	.20376	.13755	.08006
	Maximum Depth	inches	.246	.152	.176	.134	.192	.215	.153	.117
	Average Depth	inches	.183	.060	.125	.085	.123	.146	.099	.057
#3	Area Removed	sq. inches	4.4180	2.71784[1]	2.1689	1.1612	2.5659	2.6765	1.1018	.7723
	Rate of Wear	in./10^6 WA	.64300	.56721	.31491	.16892	.37292	.39070	.16000	.11201
	Maximum Denth	inches	.576	.390	.336	.197	.369	.400	.171	.148
	Average Depth	inches	.461	.284	.259	.121	.267	.281	.115	.080
#4	Area Removed	sq. inches	2.80291	5.0040[1]	2.2556	1.5255	3.4521	3.3448	1.1280	.8764
	Rate of Wear	in./10^6 WA	.40850	1.04351	.32922	.22190	.50232	.48774	.16377	.12753
	Maximum Depth	inches	.398	.667	.310	.237	.462	.446	.170	.149
	Average Depth	inches	.293	.522	.236	.159	.360	.350	.117	.091

[1] Based on 500,000 wheel applications. These ruts were filled because of their extreme depths.

TABLE 31

PROFILOMETER DATA SUMMARY FOR CENTER TRACK - ASPHALT CONCRETE GROUP

Tire or Stud Type	Parameters	Units	Class "D" A.C.	Class "D" A.C. with Petroset A.T.	Class "G" A.C. with Pliopave	Class "G" Asphalt Extended Epoxy Concrete	Class "G" A.C.	Class "G" A.C. with Petroset A.T.	Class "B" A.C.	Mastic Asphalt Concrete
			061	062	070	080	090	100	121	123
Driving UST	Area Removed	sq. inches	1.1072	.9644	.6524	.1072	1.1240	1.4292	1.5121	---
	Rate of Wear	in./10 WA	.0438	.0382	.0259	.0042	.0446	.0568	.0599	---
	Maximum Depth	inches	.150	.128	.108	.052	.144	.170	.181	---
	Average Depth	inches	.094	.082	.056	.009	.096	.123	.075	---
Free Wheeling UST	Area Removed	sq. inches	.7915	.5952	.7167	.1860	1.0445	1.1004	---	---
	Rate of Wear	in./10 WA	.0315	.0239	.0286	.0075	.0416	.0440	---	---
	Maximum Depth	inches	.125	.116	.111	.052	.141	.140	.175	---
	Average Depth	inches	.069	.051	.062	.016	.090	.095	---	---

TABLE 32

PROFILOMETER DATA SUMMARY FOR INSIDE TRACK - ASPHALT CONCRETE GROUP

Tire or Stud Type	Parameters	Units	Class "D" A.C.	Class "D" A.C. with Petroset A.T.	Class "G" A.C. with Pliopave	Class "G" Asphalt Extended Epoxy Concrete	Class "G" A.C.	Class "G" A.C. with Petroset A.T.	Class "B" A.C.	Mastic Asphalt Concrete
			061	062	070	080	090	100	121	123
#1	Area Removed	sq. inches	4.3845	4.66133	2.7178	3.3680	4.1762	3.8464	2.3739	1.4924
	Rate of Wear	in./10^6 WA	.31243	.404697	.13118	.16150	.20373	.18958	.11577	.07241
	Maximum Depth	inches	.599	.565	.389	.492	.622	.561	.364	.270
	Average Depth	inches	.469	.486	.282	.347	.438	.408	.249	.156
U.S.	Area Removed	sq. inches	.1921	.2473	.1841	.0968	.1036	.1547	.1519	.2278
	Rate of Wear	in./10^6 WA	.00940	.01222	.00894	.00464	.00538	.00733	.00733	.01103
	Maximum Depth	inches	.053	.081	.066	.044	.056	.052	.052	.095
	Average Depth	inches	.020	.026	.019	.010	.012	.016	.016	.024

respectively. The two types of asphalt extended epoxy surfacings with their various mineral aggregates on different overlays can be compared to the Idaho Chip Seal rubberized asphalt surfacing in these three tables. The bauxite aggregate extended epoxy surfacing (010) on the high alumina cement concrete overlay was superior with respect to wear to the other five sections for all three tracks. The garnet aggregate asphalt extended epoxy surfacing on portland cement sand mix overlay (042) was superior to the other two surfacings (042 and 043) on similar overlays with respect to wear. Some of the wear in section 043 probably was due to premature failure of bond between the surfacing and the overlay. The bauxite aggregate asphalt extended epoxy surfacing on class "G" asphalt concrete overlay showed more wear than the other bauxite sections (010 and 043).

Tables 27-29 (p. 71-73) summerize the profilometer data for this group of eight portland cement concrete and polymer concrete sections for the outside, center and inside tracks, respectively. The polymer concrete section (031) was almost always superior with respect to wear resistance than the other sections in this group. The portland cement concrete section (122) usually showed the most wear with the rubber-sand polymer concrete section (034) next in ranking. The data shows that the wear was quite small compared to the other two groups.

Tables 30-32 (p. 74-76) summarize the profilometer data for the group of eight asphalt concrete sections for the outside, center and inside tracks, respectively. The mastic asphalt concrete (Gussasphalt) section (123) was almost always superior in resisting wear to the other sections in this group. The class "B" A.C. section (121) was second best in resisting wear with the class "G" asphalt extended epoxy concrete section (080) being third best. The worst were the class "D" A.C. sections (061 and 062).

Tables 25 (p. 69), 28 (p. 72) and 31 (p. 75) for the center track show that the unstudded truck tires also caused wear on the different pavements. The amount of wear was greater than in the unstudded passenger snow or in the garnet dust retread passenger tire wheel paths. The driving truck tire wheel path usually showed more wear than the free-wheeling truck tire wheel path. The wear, especially for the different surfacings and asphalt concrete groups, was appreciable, although not as severe as that caused by the studded tires.

Tables 33-35 (p. 79-81) show the maximum rut depth values obtained using four different measurement methods. Methods #1 and #2 were obtained using profilometer charts and data; and it can be seen that the values were quite similar to the other two methods, the photo-wire measurements and straight-edge profilometer.

The WSU profilometer has some limitations. The maximum depth that the profilometer could measure was 1.00 inch with ±1% error. This was frequently limited to about 0.75 inches on the recorder chart. However, as this was also recorded on paper tape, the true depth could be obtained. Reference pins did not limit the amount of vertical and horizontal adjustments necessary by the analyst to obtain accurate results from the computer. Some human error occurred because the instrument was more sensitive to weather and temperature than the previous model. More care was needed to take these measurements. However, the profilometer proved to be the most reliable and quickest method of measuring transverse wear and almost all of the results came from this method.

b) Photo-wire Picture Measurements

Since this technique was used to check the WSU profilometer measurements, only an initial and a final series of photographs were taken and analyzed. A

TABLE 33

COMPARISON OF FINAL MAXIMUM RUT DEPTHS USING DIFFERENT METHODS

INSIDE TRACK - INCHES

SECTION	UNSTUDDED - WHEEL PATH #1				STUD TYPE #1 - WHEEL PATH #2			
	MEASURING METHODS[1]							
	#1	#2	#3	#4	#1	#2	#3	#4
010	.040	.037	.042	.052	.130	.128	.106	.146
021[2]	.035	.036	.048	.062	.075	.055	.077	.073
022[3]	.010	.016	.000	.031	.080	.078	.083	.188
023[3]	.005	.027	.008	.031	.140	.117	.079	.188
031[2]	.045	.030	.000	.047	.065	.044	.013	.047
032[3]	.020	.028	.023	0	.100	.046	.090	.098
033[3]	.040	.008	.011	.031	.080	.065	.063	.098
034[3]	.020	.045	.035	.062	.010	.107	.080	.098
041[3]	.040	.065	.042	.098	.270	.252	.232	.281
042[3]	.030	.041	.005	.062	.140	.147	.119	.125
043	.057	.066	----[4]	.083	.147	.173	----[4]	.219
050	.045	.067	----[4]	.031	.187	.208	----[4]	.271
061[2]	.070	.053	.095	.063	.360	.599	.379	.328
062[3]	.110	.081	.044	.062	.360	.565	.224	.406
070	.070	.066	----[4]	.062	.433	.389	----[4]	.427
080	.027	.044	.076	.042	.487	.492	.477	.458
090	.043	.056	.076	.125	.620	.622	.527	.583
100	.060	.052	.095	.135	.590	.561	.447	.521
110	.210	.301	----[4]	.198	.400	.510	----[4]	.438
121[2]	.032	.052	.085	.078	.350	.364	.198	.375
123[3]	.070	.095	.042	.188	.280	.270	.194	.438
122[3]	.010	.047	.083	0	.150	.116	.125	.188

[1] Method #1: Measured from Profilometer charts.

Method #2: Computed by computer from WSU Profilometer paper tape.

Method #3: Computed by computer from Photo-wire pictures.

Method #4: All are measured with the Straight-edge Profilometer. Average of 3 readings except where noted.

[2] From an average of 2 readings.

[3] From 1 reading.

[4] Data incomplete.

TABLE 34

COMPARISON OF FINAL MAXIMUM RUT DEPTHS USING DIFFERENT METHODS

CENTER TRACK - INCHES

SECTION	DRIVING TRUCK TIRE UNSTUDDED - WHEEL PATH #3				FREE-WHEELING TRUCK TIRE UNSTUDDED - WHEEL PATH #4			
	MEASURING METHODS[1]							
	#1	#2	#3	#4	#1	#2	#3	#4
010	.063	.049	----[5]	.115	.053	.049	----[5]	.125
021[2]	.035	.023	.033	.062	.030	.033	.000	.062
022[3]	.050	.031	.034	.062	.040	.030	.000	.125
023[3]	.010	.020	.021	0	.010	.025	.000	.031
031[2]	.055	.014	.025	.109	.035	.026	.000	.016
032[3]	.020	.040	.027	0	.060	.047	.000	.062
033[3]	.040	.031	.032	.062	.030	.043	.000	.062
034[3]	.040	.042	.027	.031	.040	.117	.000	.031
041[3]	.100	.136	.124	.156	.050	.072	.000	.125
042[3]	.100	.120	.104	.125	.040	.053	.000	.062
043	.093	.105	----[5]	.035	.067	.090	----[5]	.115
050	.080	.109	----[5]	.125	.057	.070	----[5]	.094
061[2]	.100	.150	.17811	.032	.120	.125	.000	.109
062[3]	.140	.128	----5	.125	.090	.116	----[5]	.098
070	.127	.108	.341	.083	.120	.111	.000	.115
080	.050	.052	.057	.125	.037	.052	.000	.115
090	.173	.144	.162	.188	.143	.141	.000	.125
100	.207	.170	.158	.188	.140	.140	.000	.156
110	.425	.222	----[5]	.333	.533	.232	----[5]	.292
121[2]	.150	.181	.187	.156	.100	.175	.000	.141
123[3]	---	---	----[5]	.312[4]	---	---	----[5]	.125[4]
122[3]	.060	.051	----[5]	.062	.060	.048	----[5]	.062

[1] Method #1: Measured from Profilometer charts.

Method #2: Computed by computer from WSU profilometer paper tape.

Method #3: Computed by computer from Photo-wire pictures.

Method #4: All are measured with the Straight-edge Profilometer. Average of 3 readings except where noted.

[2] From an average of 2 readings.

[3] From 1 reading.

[4] Class "B" A.C.

[5] Data incomplete.

TABLE 35

COMPARISON OF FINAL MAXIMUM RUT DEPTHS USING DIFFERENT METHODS - OUTSIDE TRACK - INCHES

SECTION	STUD TYPE #3 - W.P. #5				STUD TYPE #2 - W.P. #6				STUD TYPE #4 - W.P. #7				GARNET DUST RETREAD - W.P. #8			
	MEASURING METHODS[1]															
	#1	#2	#3	#4	#1	#2	#3	#4	#1	#2	#3	#4	#1	#2	#3	#4
010	.173	.173	.000	.208	.090	.107	.073	.127	.150	.178	.154	.188	.043	.061	.084	.063
021[2]	.060	.057	.000	.062	.065	.053	.046	.055	.030	.049	.037	.031	.025	.036	.020	.016
022[3]	.140	.065	.000	.098	.030	.059	.048	.062	.040	.043	.047	.031	.060	.028	.040	.125
023[3]	.080	.046	.000	.098	.100	.073	.028	.219	.080	.066	.043	.156	.040	.043	.071	.062
031[2]	.040	.031	---[4]	.016	.035	.037	---[4]	.078	.015	.037	---[4]	.047	.015	.030	---[4]	.047
032[3]	.040	.057	.000	.062	.080	.097	.045	.062	.070	.078	.013	.062	.030	.030	.051	0
033[3]	.050	.036	.000	.062	.020	.055	.077	.031	.020	.035	.052	.031	.010	.010	.034	.031
034[3]	.070	.100	.000	.098	.100	.089	.087	.056	.160	.183	.189	.188	.020	.034	.000	.250
041[3]	.190	.196	.000	.188	.170	.130	.113	.188	.210	.209	.236	.188	.070	.075	.000	.062
042[3]	.080	.095	.000	.062	.080	.102	.070	.098	.100	.125	.169	.125	.030	.039	.032	.031
043	.107	.186	.000	.219	.110	.163	.102	.188	.140	.187	.122	.250	.037	.074	.063	.115
050	.147	.160	.000	.198	.120	.142	.092	.156	.142	.190	.153	.177	.062	.092	.070	.094
061[2]	.545	.576	.000	.359	.130	.246	.150	.313	.475	.398	.577	.656	.155	.125	.137	.125
062[3]	.190	.133	.000	.156	.182	.152	.232	.188	.340	.348	.433	.625	.080	.124	.247	.062
070	.373	.336	.000	.260	.167	.176	.180	.156	.393	.310	.381	.344	.073	.060	.084	.083
080	.187	.197	.000	.198	.117	.134	.136	.146	.213	.237	.214	.177	.013	.034	.075	.021
090	.367	.369	.000	.354	.193	.192	.192	.208	.437	.462	.440	.479	.083	.077	.053	.094
100	.400	.400	.000	.396	.193	.215	.213	.208	.447	.446	.404	.417	.077	.080	.079	.104
110	.353	.364	---[4]	.542	.247	.275	---[4]	.458	.303	.311	---[4]	.458	.247	.104	---[4]	.333
121[2]	.195	.171	.000	.188	.125	.153	.155	.141	.175	.170	.179	.172	.060	.055	.100	.094
123[3]	.140	.148	.000	.156	.140	.117	.084	.125	.140	.149	.108	.156	.070	.069	.074	.062
122[3]	.090	.093	.000	.125	.110	.070	.063	.125	.090	.095	.064	.156	.030	.052	.014	.062

[1] Method #1: Measured from Profilometer charts.
Method #2: Computed by computer from WSU Profilometer paper tape.
Method #3: Computed by computer from Photo-Wire pictures.
(All methods are an average of 3 readings except where noted.)
Method #4: Measured with the Straight-edge Profilometer.

[2] From an average of 2 readings

[3] From 1 reading.

[4] Data incomplete.

typical strip of film for one of the sections is shown in Appendix L. The data were handled similarly to the initial series of profilometer readings; i.e., transferring to IBM cards to be analyzed by computer. Some of this data, concerning maximum rut depth, is shown in Tables 33, (p. 79), 34 (p. 80) and 35 (p. 81). The results indicate measuring method variability.

Reference pins were used for placing the camera box frame. In the field, it took more time and manpower to operate and take pictures of the sections. In the office, transferring the data onto IBM cards took longer than for the profilometer charts.

c) Straight-edge Profilometer Measurements

These measurements were taken only at the end of the test, mainly to check the measurements obtained by other means. A series of measurements were taken on each section and then averaged. The data is presented in Table 36 (p. 83). Comparison of this data, taken only in the reference pin area, with other methods is shown in Tables 33 (p. 79), 34 (p. 80) and 35 (p. 81). The values seem to be within reason and variations may be due to the limitations of this method.

The problems of using a straight-edge profilometer are 1) that a smooth transverse surface is assumed which may not be correct and 2) the tolerance of each measurement is ±1/16 of an inch. For these reasons, the use of a straight-edge was minimized and was used for comparison purposes only.

PHOTOGRAPH SERIES

The use of photographs can show up unusual features which data cannot adequately expose. Therefore, a series of photographs are included for comparison purposes. Before and after photographs of the different sections are shown in Figures 31-42 (p. 84-98). Figures 31a-31d (p. 84-85) show the

TABLE 36

FINAL MAXIMUM RUT DEPTHS BY STRAIGHT-EDGE PROFILOMETER

SECTION	TIRE & STUD TYPES							
	US[1]	#1[1]	UST[1]	UST[1]	#3[2]	#2[2]	#4[2]	GST[2]
	WHEEL PATHS							
	#1	#2	#3	#4	#4	#6	#7	#8
010[3]	.049	.143	.125	.080	.214	.138	.192	.067
021[4]	.056	.100	.038	.062	.050	.059	.088	.025
022[5]	.031	.188	.062	.125	.098	.062	.031	.125
023[5]	.031	.188	0	.031	.098	.219	.156	.062
031[6]	.055	.062	.062	.031	.023	.062	.047	.031
032[5]	0	.098	0	.062	.062	.062	.062	0
033[5]	.031	.098	.062	.062	.062	.031	.031	.031
034[5]	.062	.098	.031	.031	.098	.156	.188	.250
041[5]	.098	.281	.156	.125	.188	.188	.188	.062
042[5]	.062	.125	.125	.062	.062	.098	.125	.031
043[4]	.078	.198	.104	.125	.167	.151	.208	.104
050[3]	.058	.205	.121	.094	.192	.156	.183	.107
061[4]	.055	.414	.094	.119	.444	.275	.706	.125
062[5]	.062	.406	.125	.098	.156	.188	.625	.062
070[3]	.040	.496	.121	.098	.304	.174	.326	.112
080[7]	.022	.393	.089	.076	.192	.147	.170	.027
090[3]	.085	.562	.161	.143	.357	.223	.509	.103
100[3]	.112	.509	.156	.138	.375	.223	.375	.098
110[3]	.254	.571	.348	.348	.509	.402	.446	.250
121[4]	.094	.325	.188	.164	.212	.144	.219	.094
123[5]	.188	.438	.312	.125	.156	.125	.156	.062
122[5]	0	.188	.062	.062	.125	.125	.156	.062

[1] Measured after 2,151,306 wheel applications.

[2] Measured after 717,102 wheel applications.

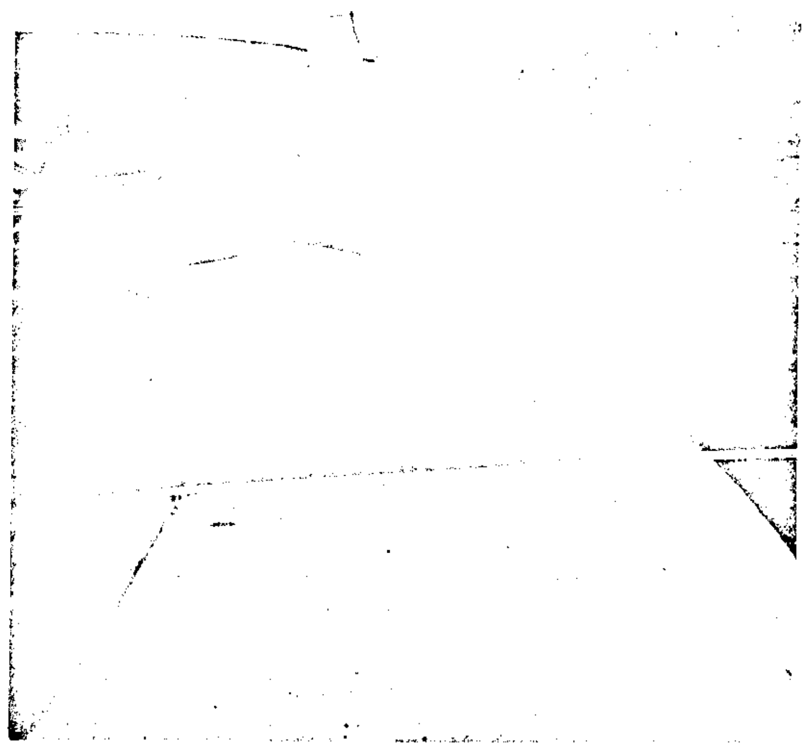
[3] Average of 7 readings over the length of section.

[4] Average of 5 readings over the length of section.

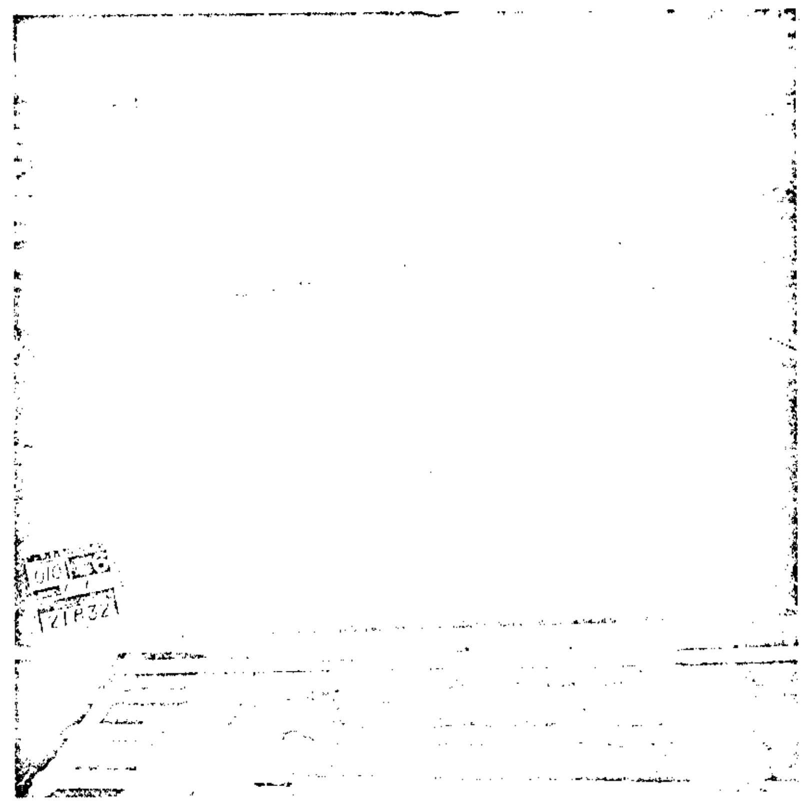
[5] From 1 reading.

[6] Average of 4 readings over the length of section.

[7] Average of 6 readings over the length of section.

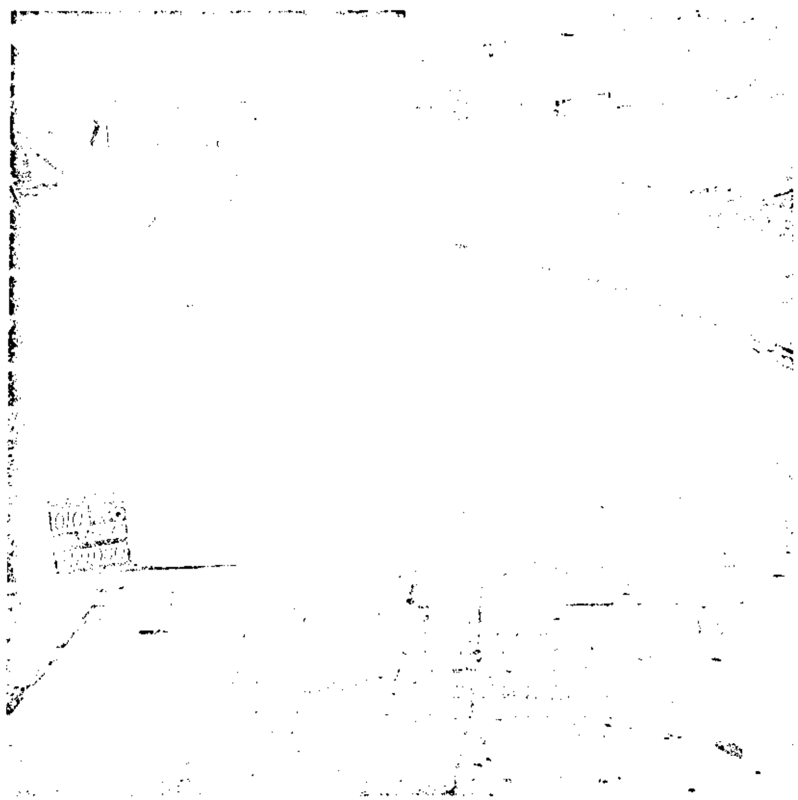


(a) Zero revolutions

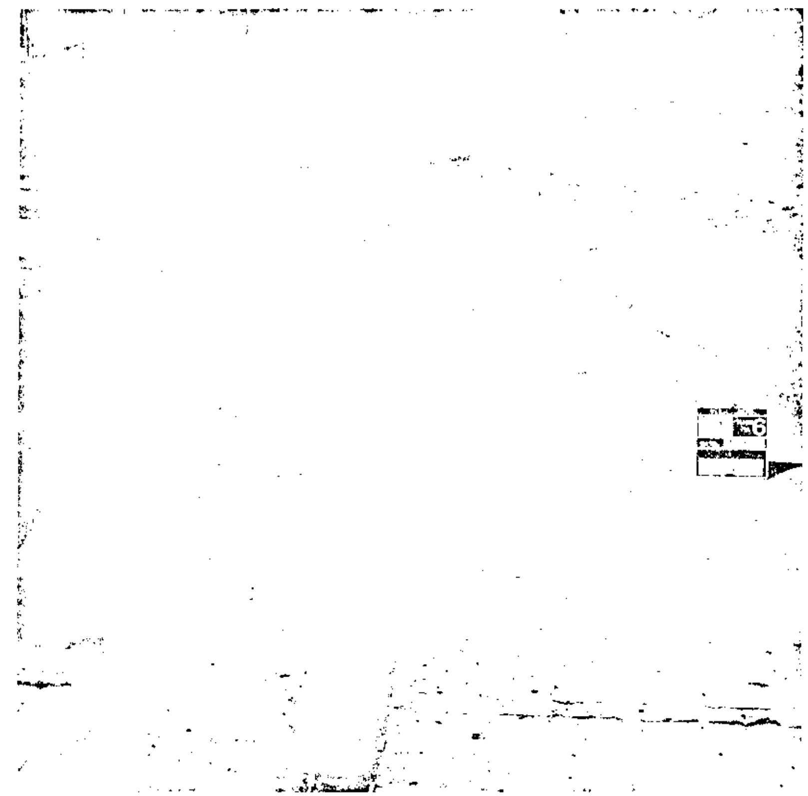


(b) After 21,832 revolutions

Figure 31: The overall appearance of bauxite asphalt epoxy surfacing on high alumina cement concrete section (010) before and after 21,832 revolutions. This is equivalent to 65,496; 65,496 and 21,832 wheel applications on the inside, center and outside tracks, respectively. Note the appearance of the paint stripes in section 021.

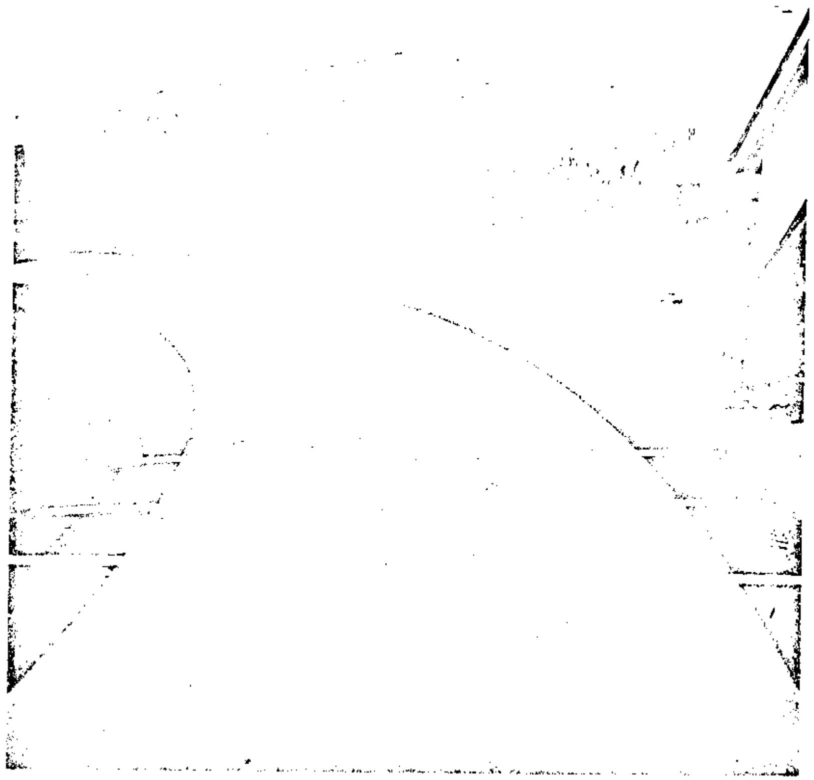


(c) After 250,000 revolutions

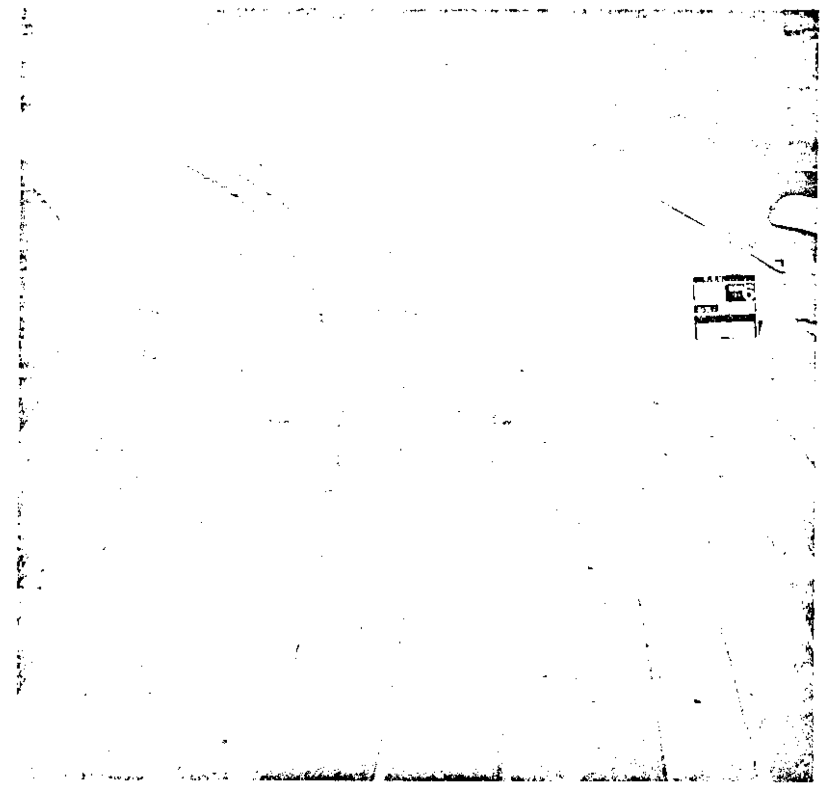


(d) After 717,102 revolutions

Figure 31: The overall appearance of Section 010 after 250,000 and 717,102 revolutions. The former is equivalent to 750,000; 750,000 and 250,000 wheel applications on the inside, center and outside tracks, respectively. The latter is equivalent to 2,151,306; 2,151,306 and 717,102 wheel applications on the inside, center and outside tracks, respectively. Note that some of the surfacing in Figure 31d stripped off of the concrete overlay in wheel paths #5 and #7.

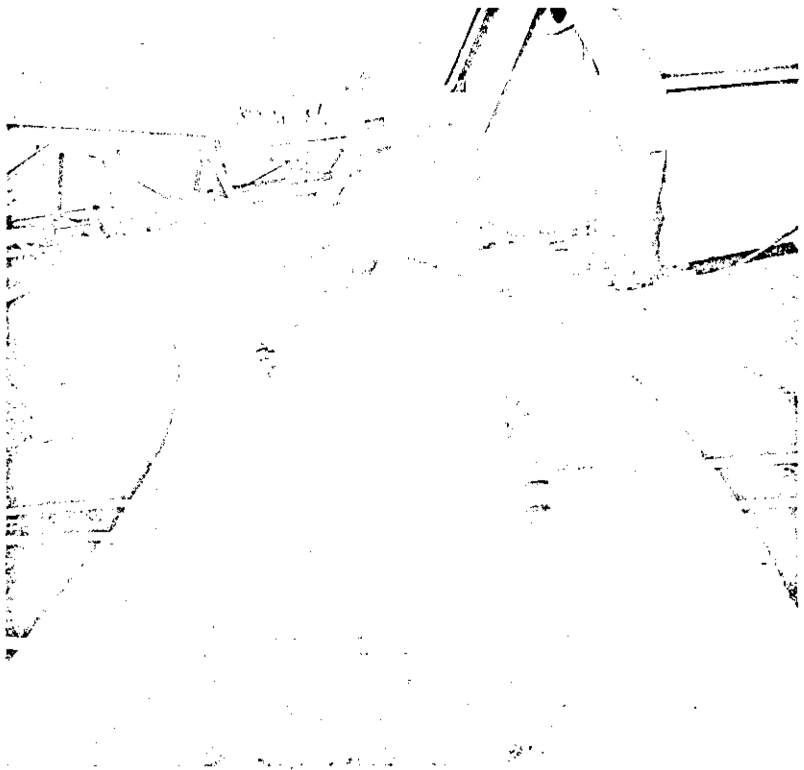


(a) Zero revolutions

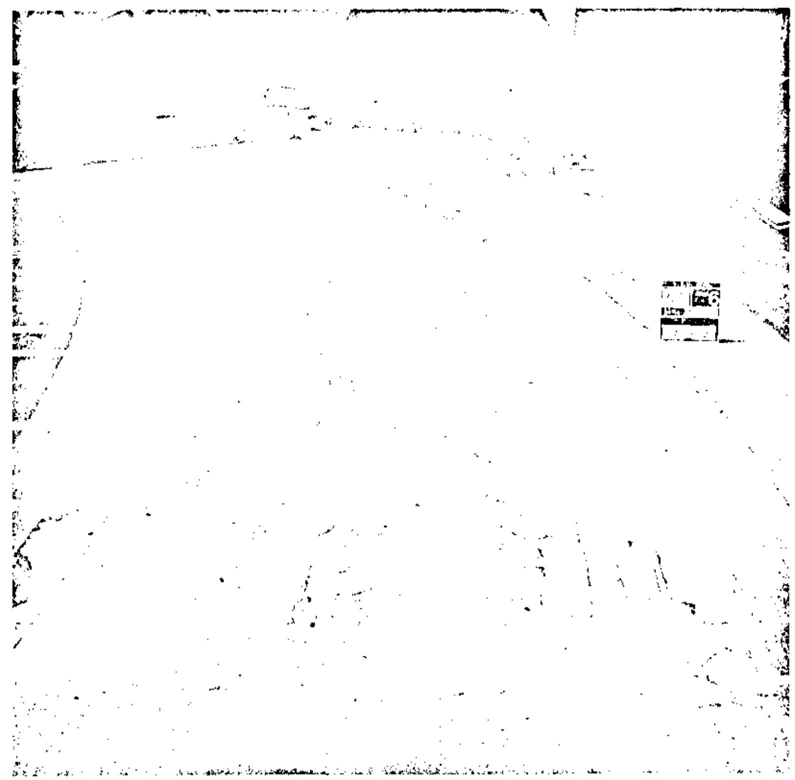


(b) After 717,102 revolutions

Figure 32: The overall appearance of the various polymer cement concrete sections (polymer cement concrete (021), polymer steel fiber concrete (022) and garnet surfacing on polymer cement concrete (023)) before and after 717,102 revolutions (2,151,300; 2,151,306 and 717,102 wheel applications on the inside, center and outside tracks, respectively).

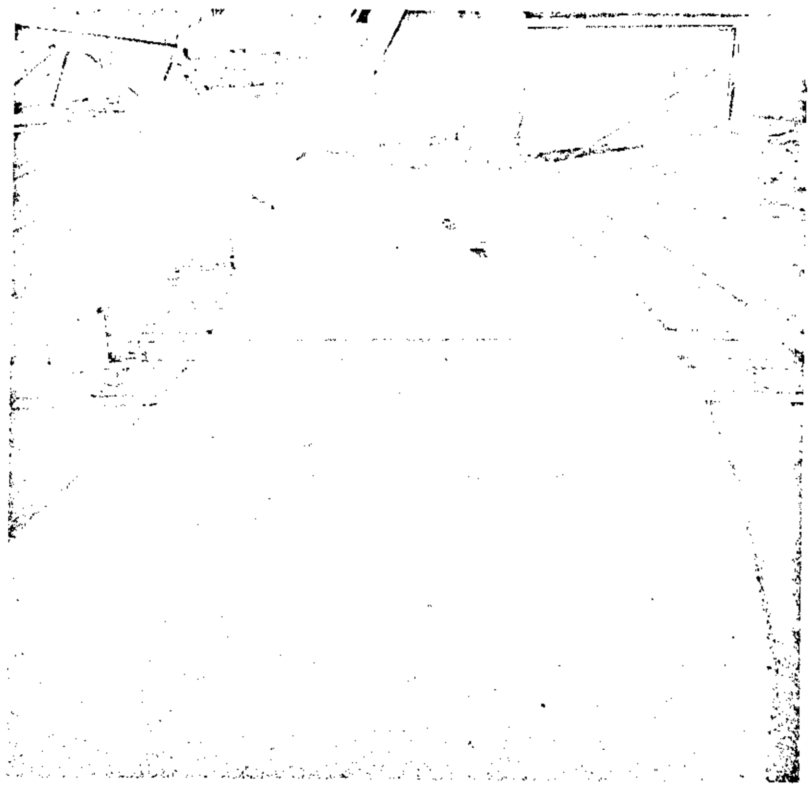


(a) Zero revolutions

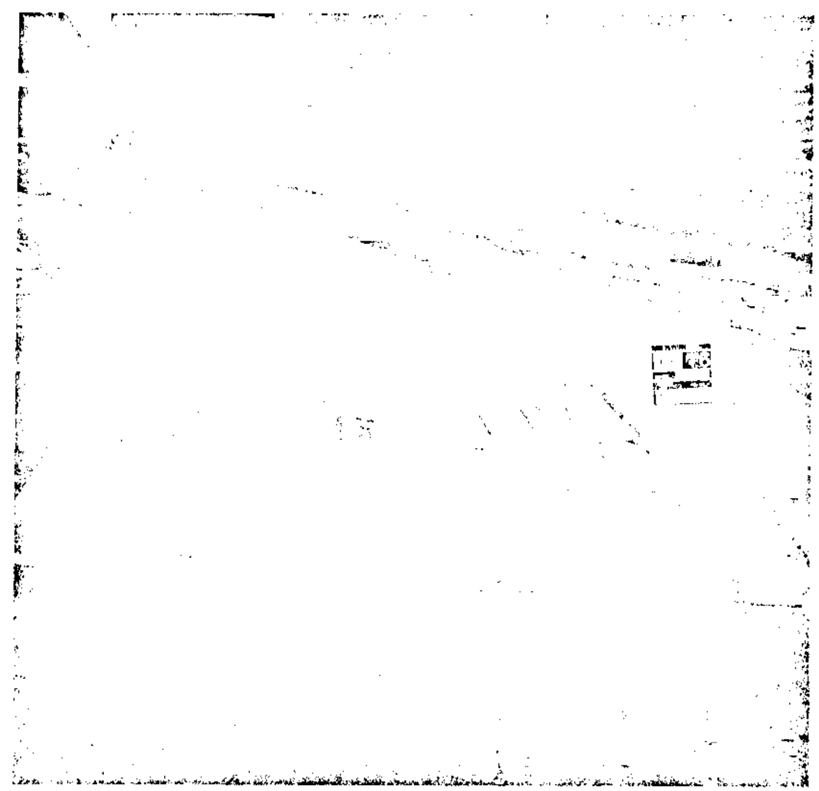


(b) After 717,102 revolutions

Figure 33: The overall appearance of the various polymer concrete sections (polymer concrete (031), garnet surfacing on polymer concrete (032), mineral slag-sand on polymer concrete (033) and rubber-sand on polymer concrete (034)) before and after 717,102 revolutions.

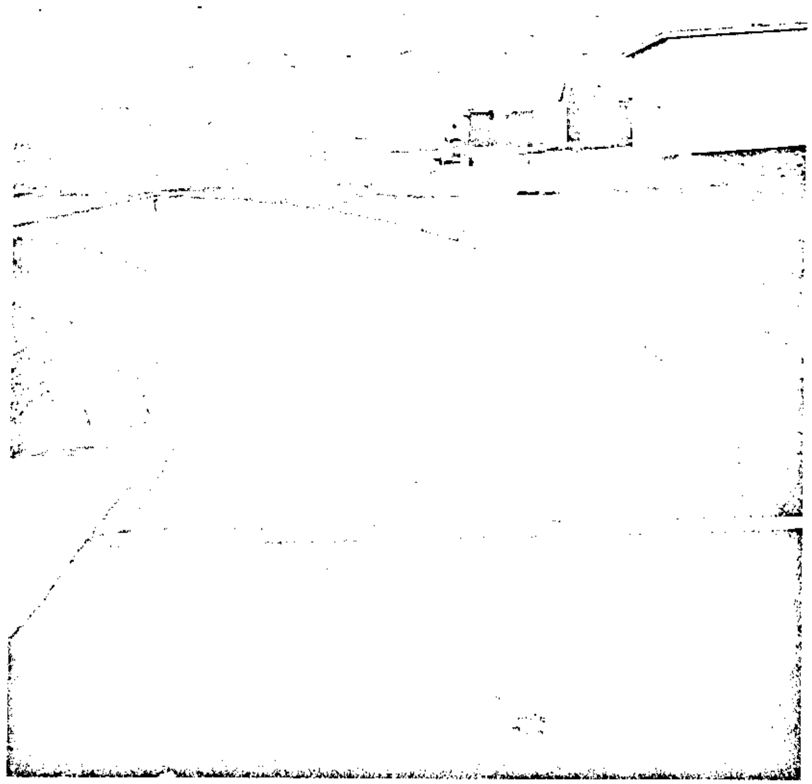


(a) Zero revolutions

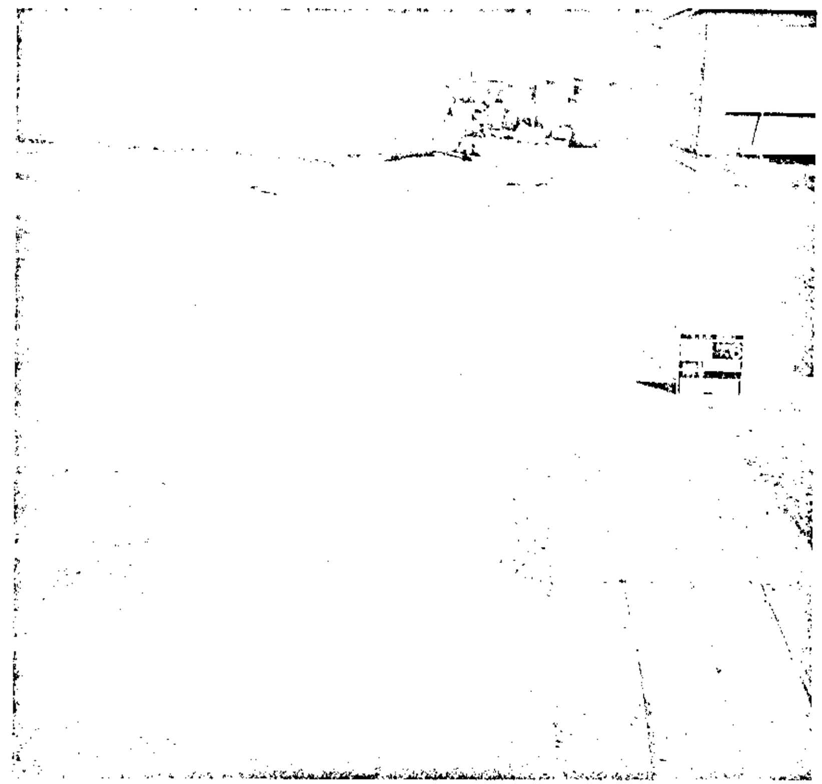


(b) After 500,000 revolutions

Figure 34: The overall appearance of the mineral slag asphalt epoxy surfacing (041), garnet asphalt epoxy surfacing (042) and bauxite asphalt epoxy surfacing (043), all on portland cement sand mix overlay, before and after 500,000 revolutions. Note that the surfacing has completely stripped off the overlay in several wheel paths.

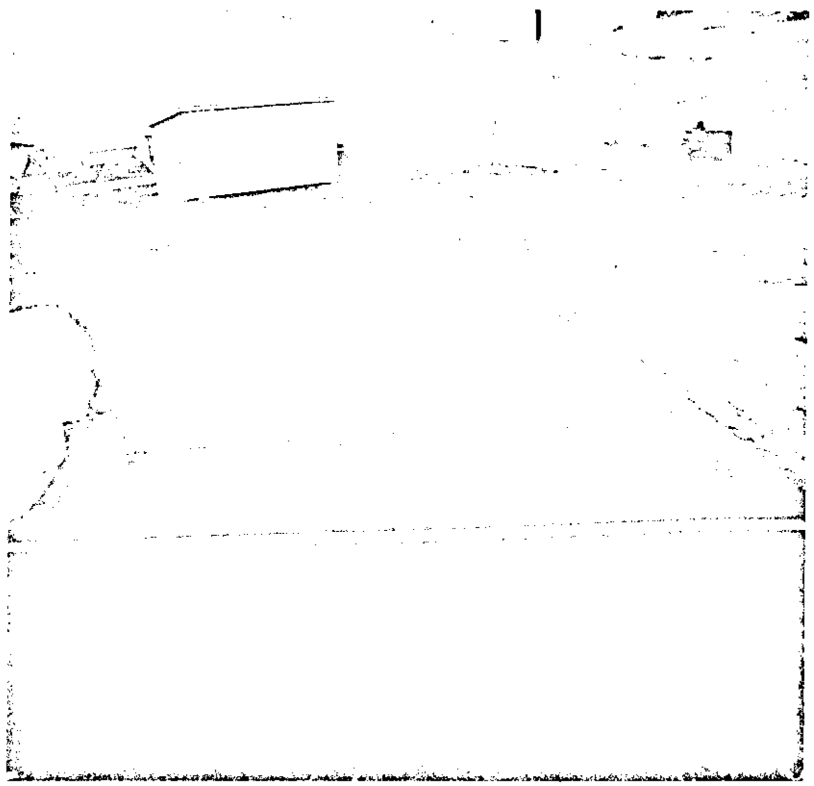


(a) Zero revolutions

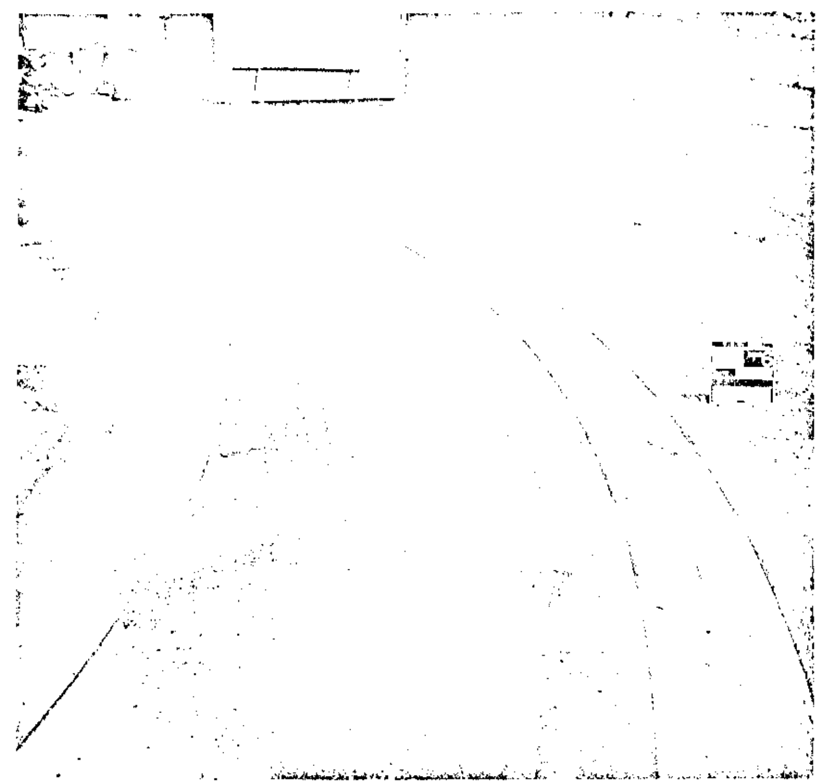


(b) After 717,102 revolutions

Figure 35: The overall appearance of the bauxite asphalt epoxy surfacing on Class "G" A.C. overlay (050) before and after 717,102 revolutions.

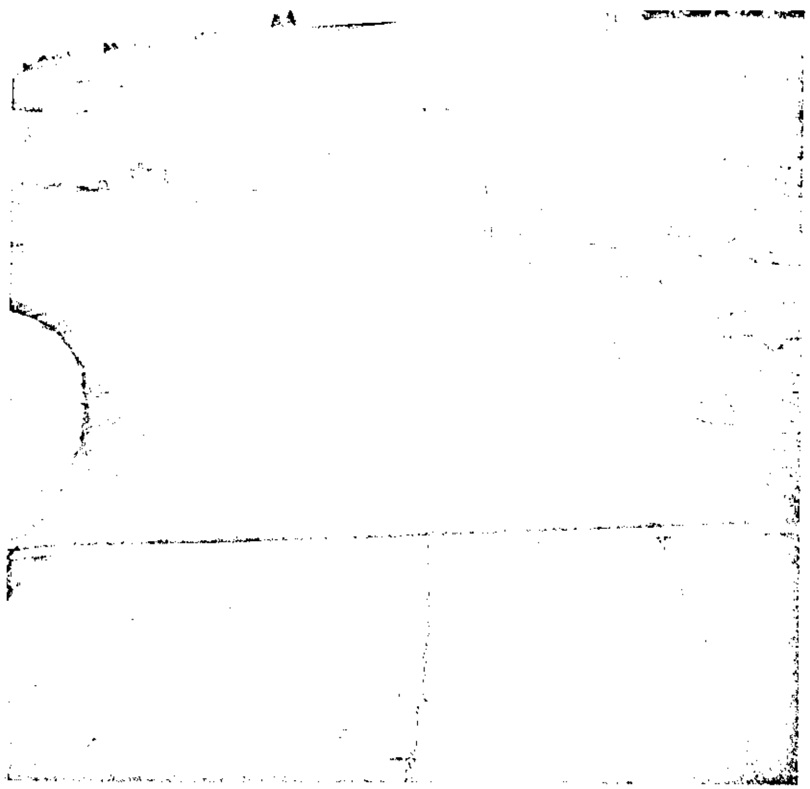


(a) Zero revolutions

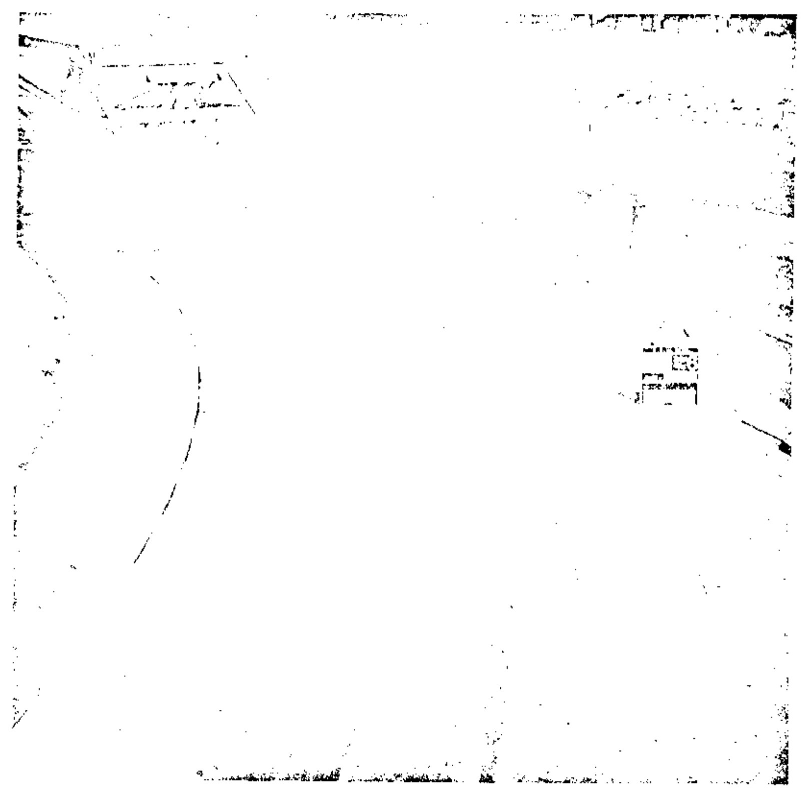


(b) After 717,102 revolutions

Figure 36: The overall appearance of the Class "D" A.C. (061) and the Class "D" A.C. with Petroset A.T. (062) overlays before and after 717,102 revolutions. Note that some of the wheel paths had to be patched because of deep rut depths.

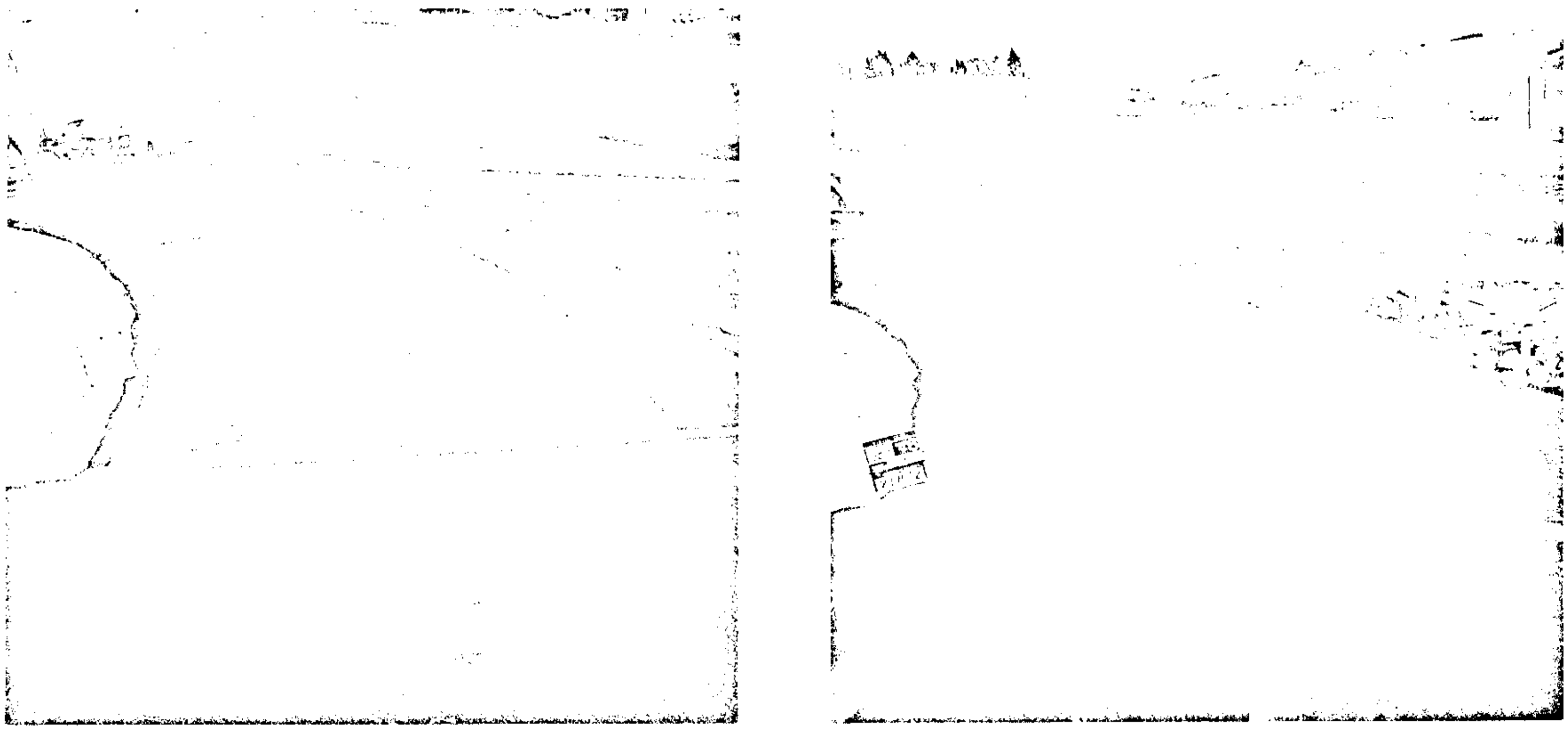


(a) Zero revolutions



(b) After 717,102 revolutions

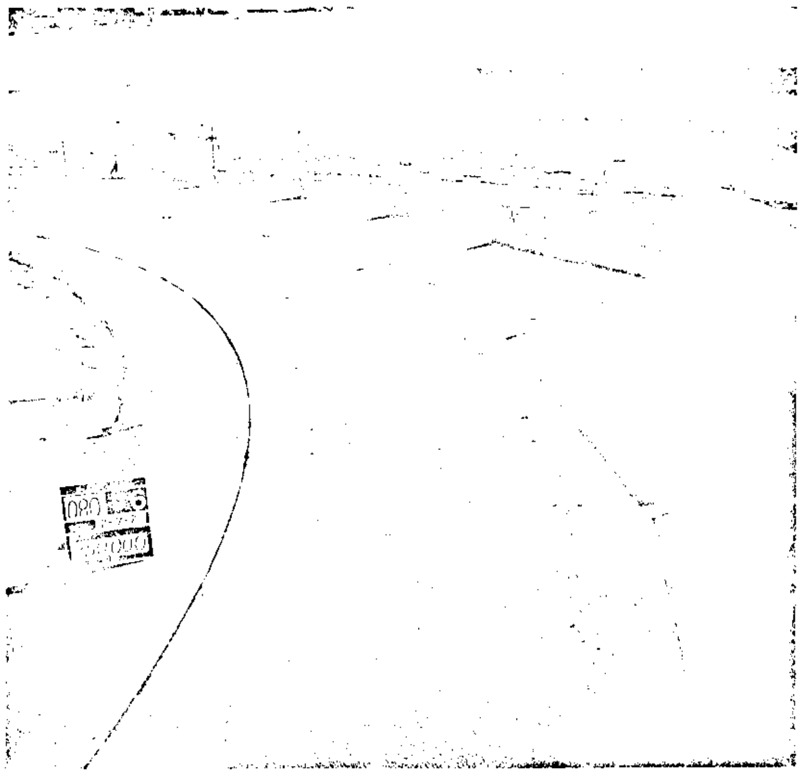
Figure 37: The overall appearance of the Class "G" A.C. overlay with Pliopave (070) before and after 717,102 revolutions.



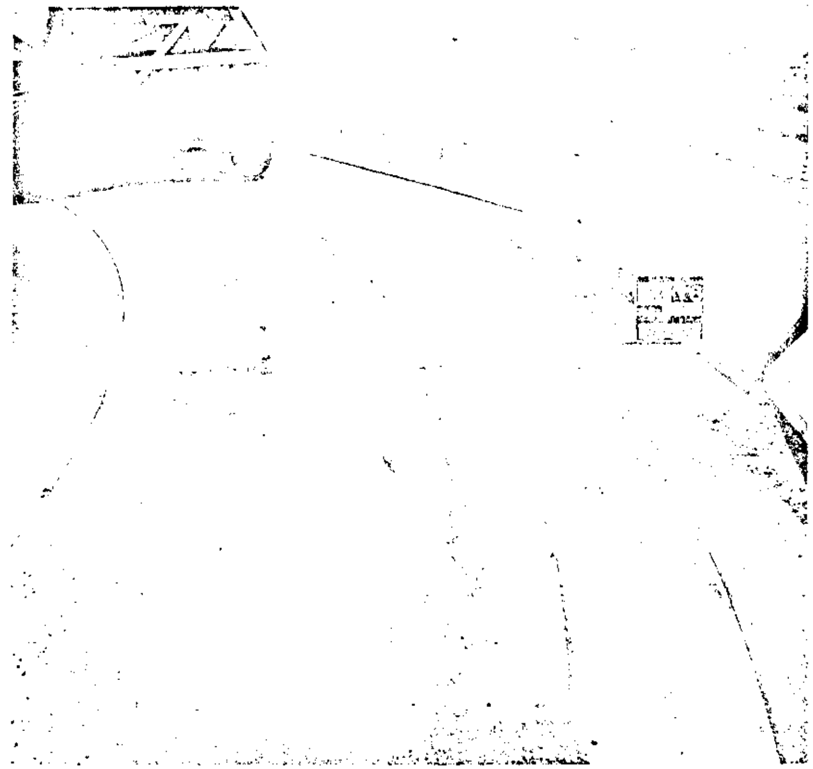
(a) Zero revolutions

(b) After 21,832 revolutions

Figure 38: The overall appearance of the Class "G" asphalt extended epoxy concrete (080) overlay before and after 21,832 revolutions.

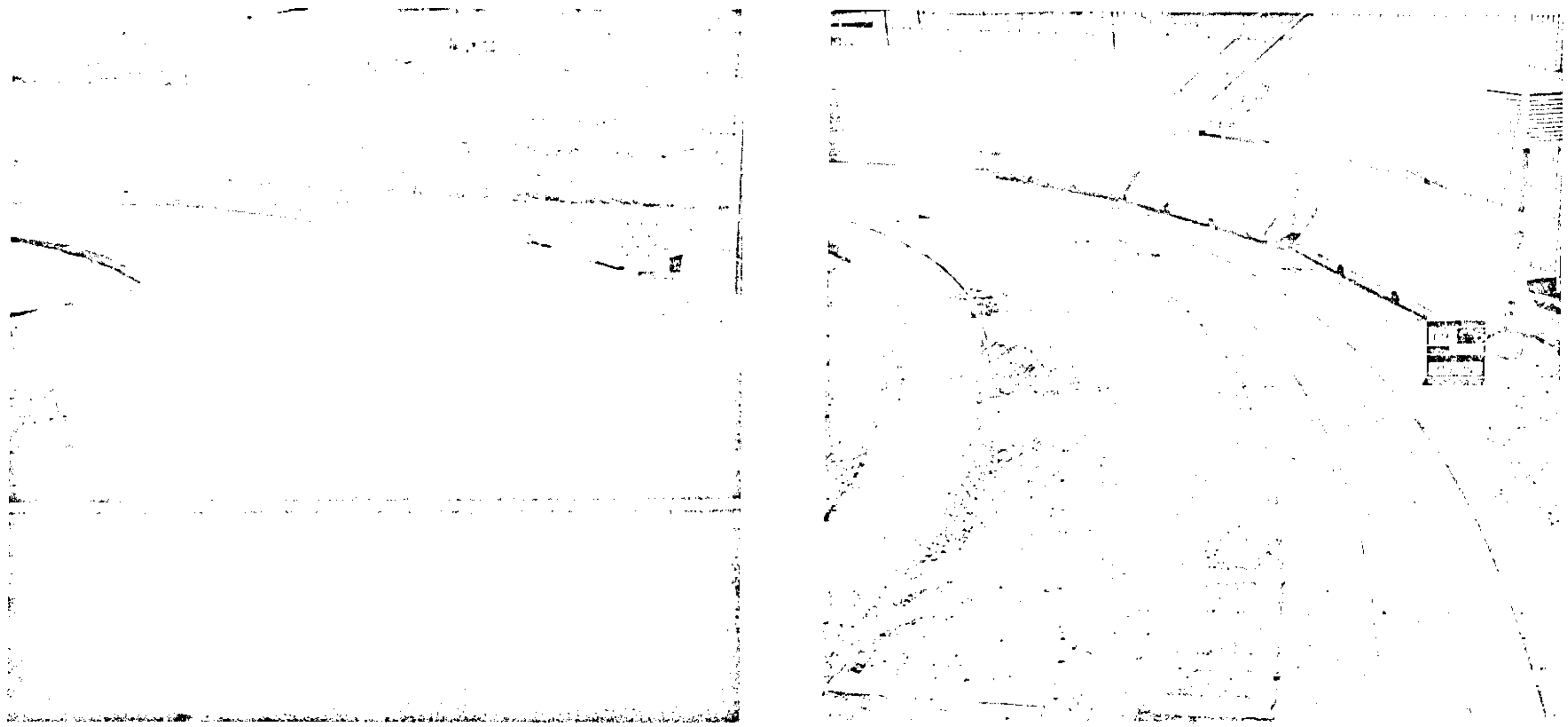


(c) After 250,000 revolutions



(d) After 717,102 revolutions

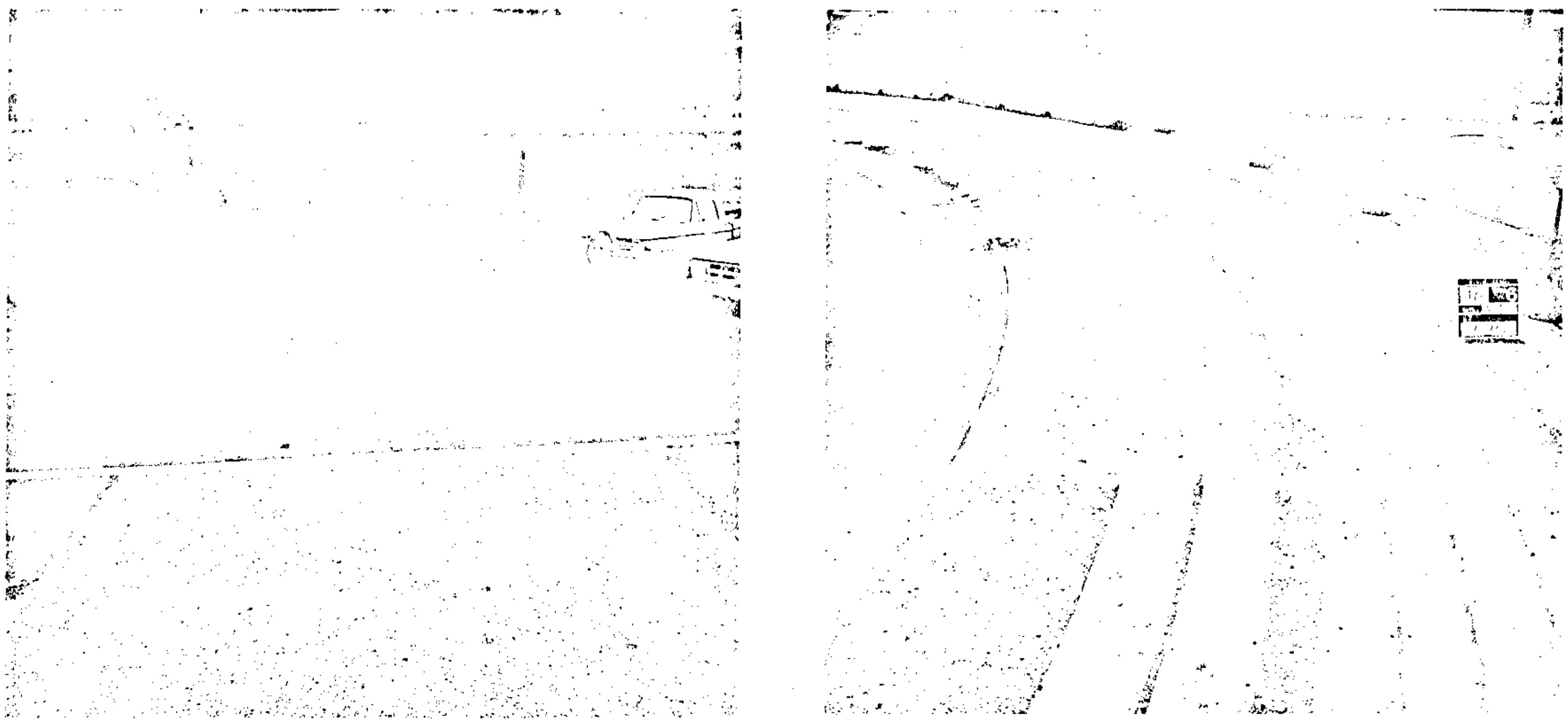
Figure 38: The overall appearance of section 080 after 250,000 and 717,102 revolutions, respectively.



(a) Zero revolutions

(b) After 717,102 revolutions

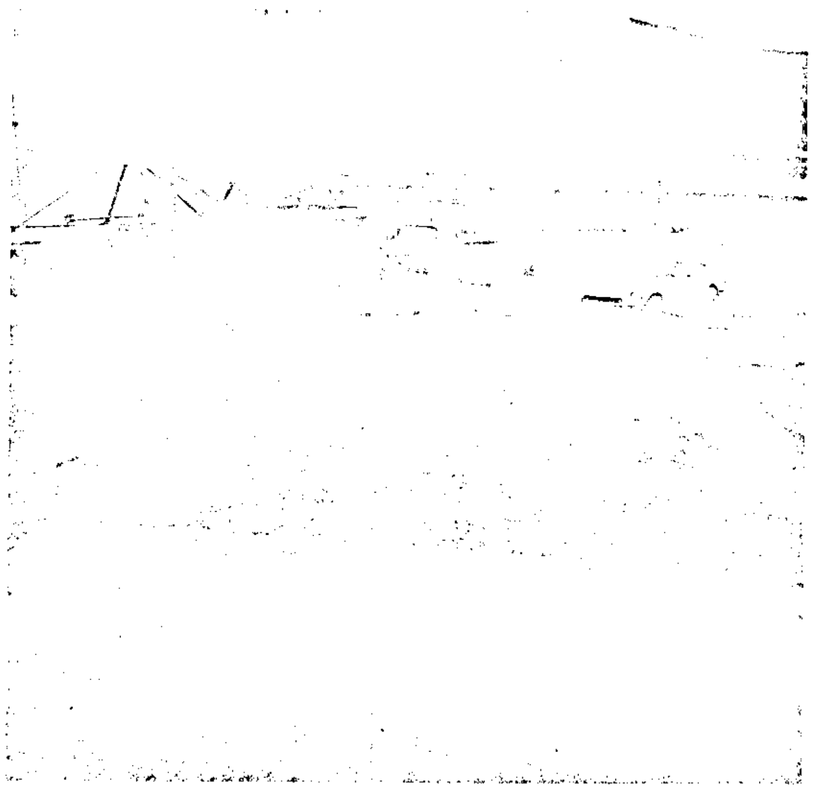
Figure 39: The overall appearance of the Class"G" A.C. overlay (090) before and after 717,102 revolutions. Note that wheel path #2 had to be filled due to the deep ruts.



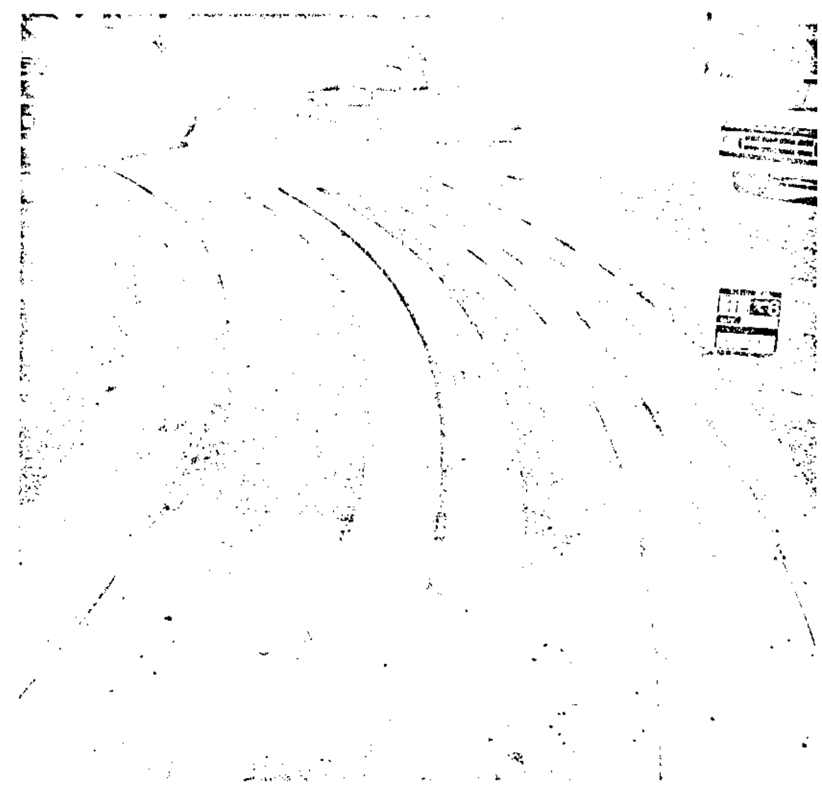
(a) Zero revolutions

(b) After 717,102 revolutions

Figure 40: The overall appearance of the Class "G" A.C. with Petroset A.T. (100) overlay before and after 717,102 revolutions. Note that all the paint stripes in the studded tire wheel paths have been removed.

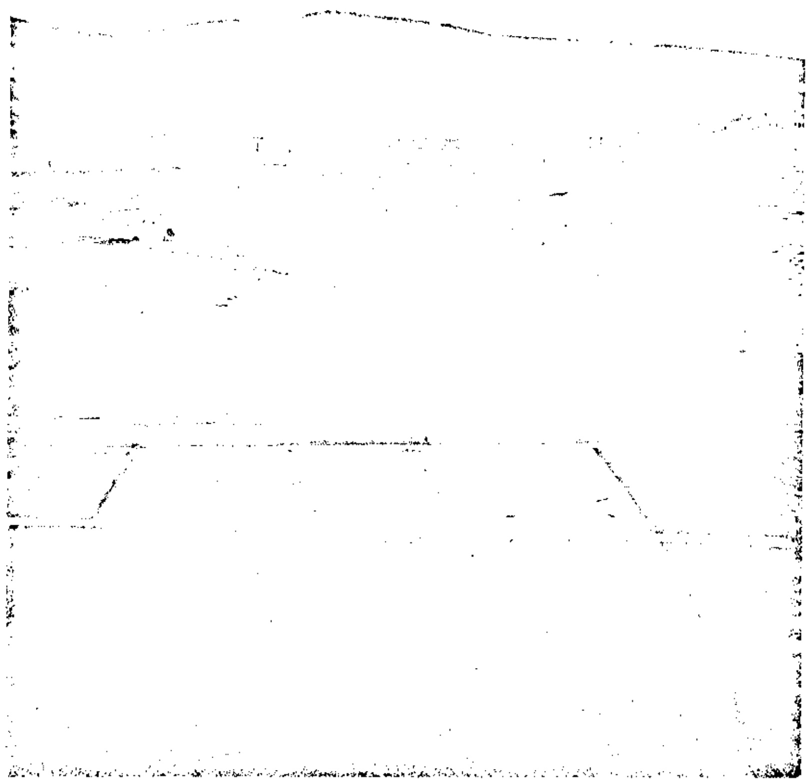


(a) Zero revolutions

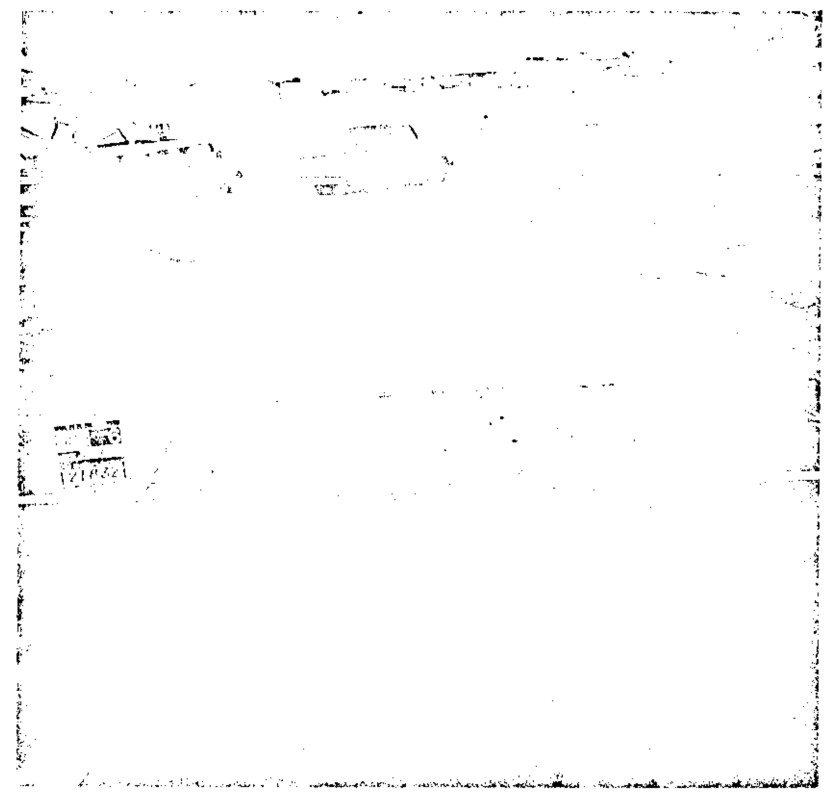


(b) After 717,102 revolutions

Figure 41: The overall appearance of Idaho Chip Seal on Class "B" A.C. overlay (110) before and after 717,102 revolutions.

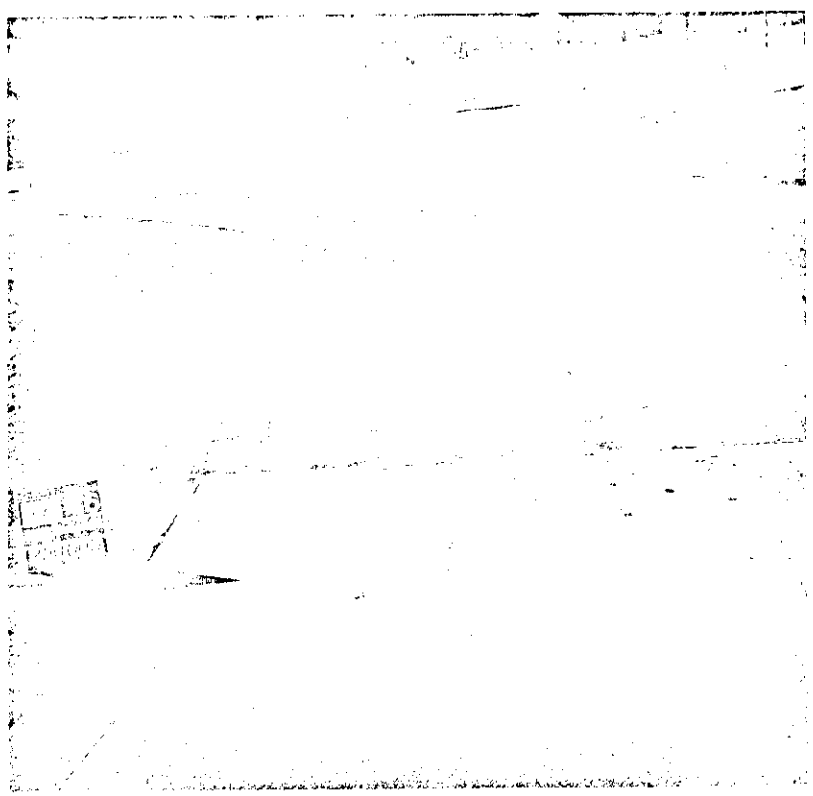


(a) Zero revolutions

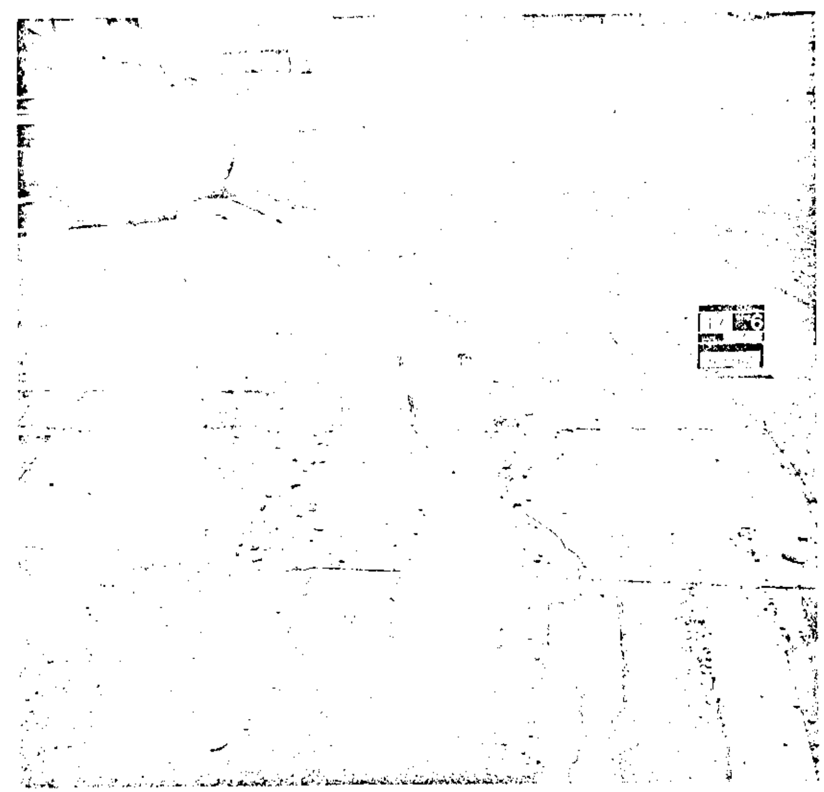


(b) After 21,832 revolutions

Figure 42: The overall appearance of the Class "B A.C. overlay (121), the mastic asphalt overlay (123) and the portland cement concrete overlay (122) at zero and after 21,832 revolutions.



(c) After 250,000 revolutions



(d) After 717,102 revolutions

Figure 42: The overall appearance of sections 121, 123 and 122 after 250,000 and 717,102 revolutions, respectively.

progressive wear in the various wheel paths for section 010. Figure 31d (p. 85) shows that some of the surfacing has stripped off. Figure 34 (p. 88) shows that the surfacing has come off in several wheel paths due to the loss of bond in section 043. Some of the asphalt concrete sections had to be patched because of deep rut depths; this is shown in Figures 36 (p. 90), 37 (p. 91) and 39 (p. 94). Figures 42a-42d (p. 97-98) show the progressive wear in sections 121, 123 and 122, respectively.

Cross-section views using a straight-edge as a horizontal reference plane are shown in Figures 43-54 (p.100-111). Each figure shows the three different tracks, and the wear caused by the different studded tires and un-studded tires can be compared. The different pavement overlays can also be compared.

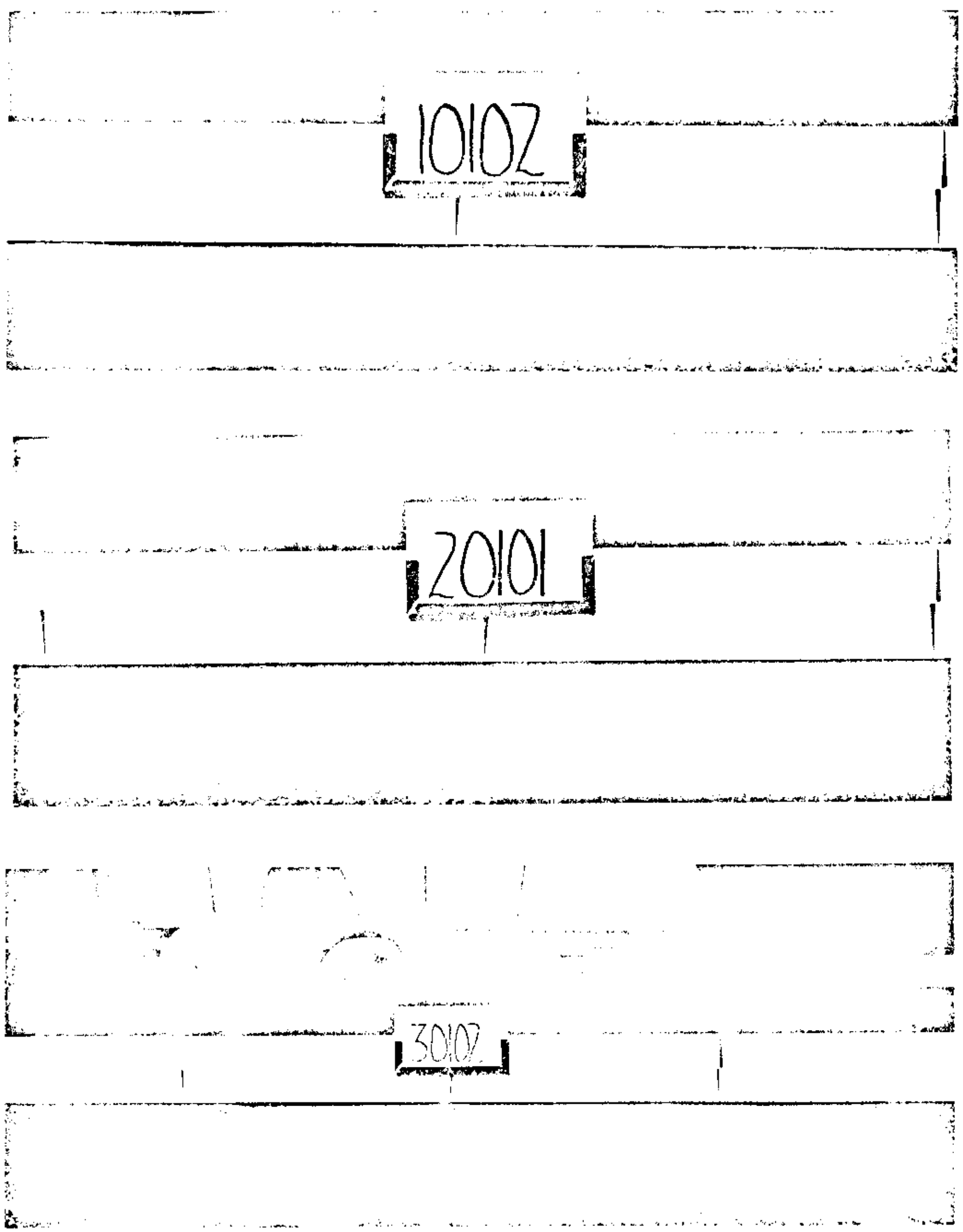
Plaster castings were taken in 16 of the 22 sections. The photographs of these castings were arranged so that the wear could be compared for the different asphalt concrete sections. The photographs are represented as Figures 55 (p.112), 56 (p.113), 57 (p.114) and 58 (p.115), respectively. These castings show the wear caused by the different types of studs and allow comparison of the different materials.

Three dimensional pictures of the sections were also taken, but due to high reproduction expenditures they are not included here. They will be available in a limited supplemental report.

COMPARISON OF RESULTS

DIFFERENT SURFACINGS GROUP

These six sections are compared in Tables 24-26 (p. 68-70) and in Table 37 (p. 116). Figure 59 (p.118) also shows this comparison. All these tables and figure show the superiority of the bauxite aggregate asphalt

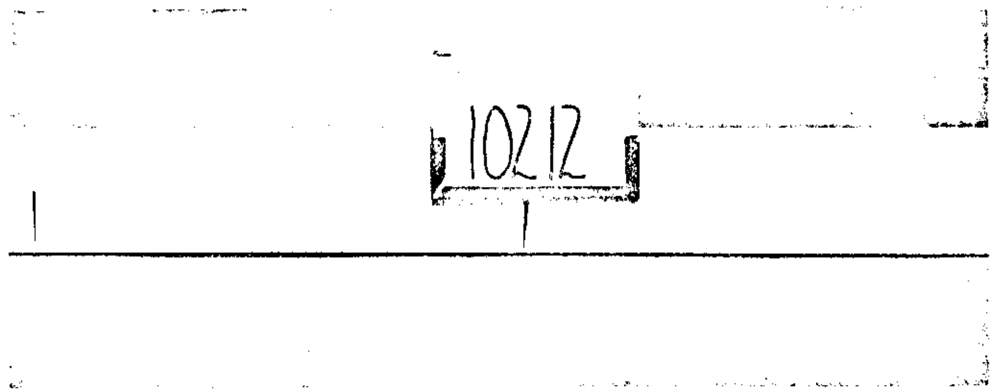


(a) Wheel path #1 and #2 after 2,151,305 wheel applications

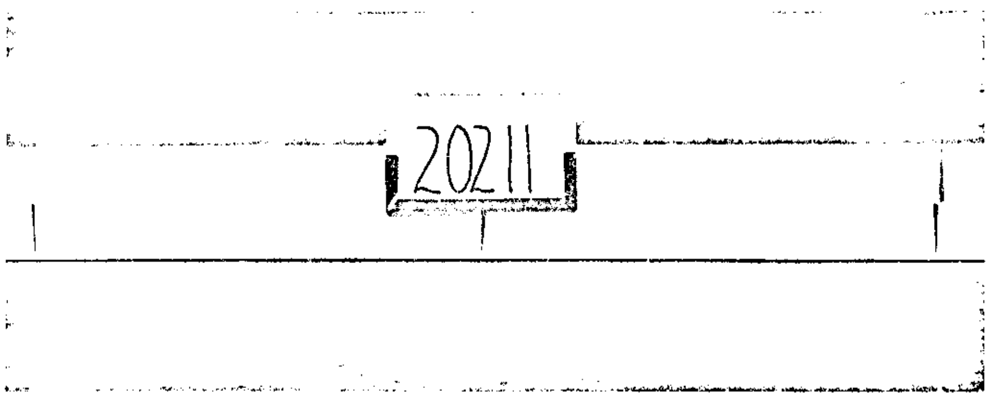
(b) Wheel paths #3 and #4 after 2,151,305 wheel applications

(c) Wheel paths #5, #6, #7 and #8 after 717,102 wheel applications

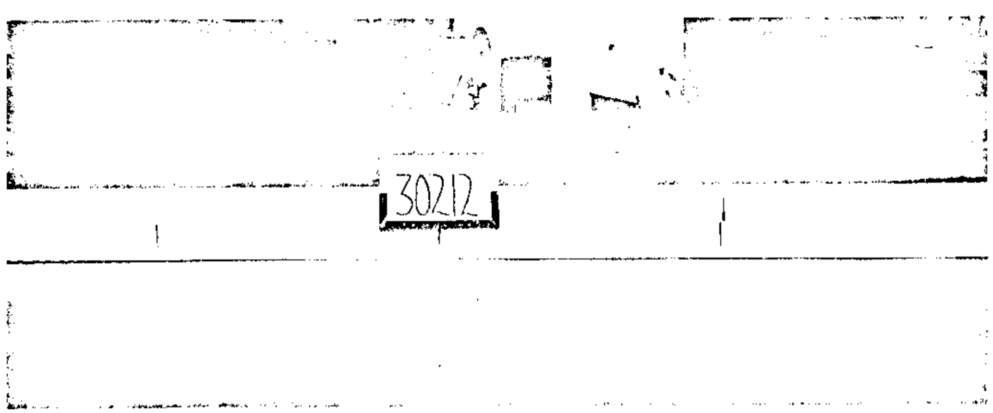
Figure 43: Cross-section views of the bauxite asphalt epoxy surfacing on high alumina cement concrete overlay (010) at the end of the test



(a) Wheel paths #1 and #2 after 2,151,306 wheel applications

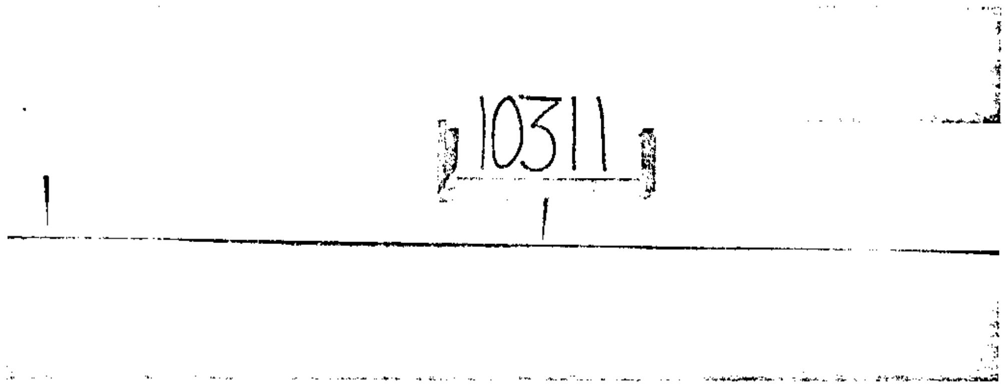


(b) Wheel paths #3 and #4 after 2,151,306 wheel applications

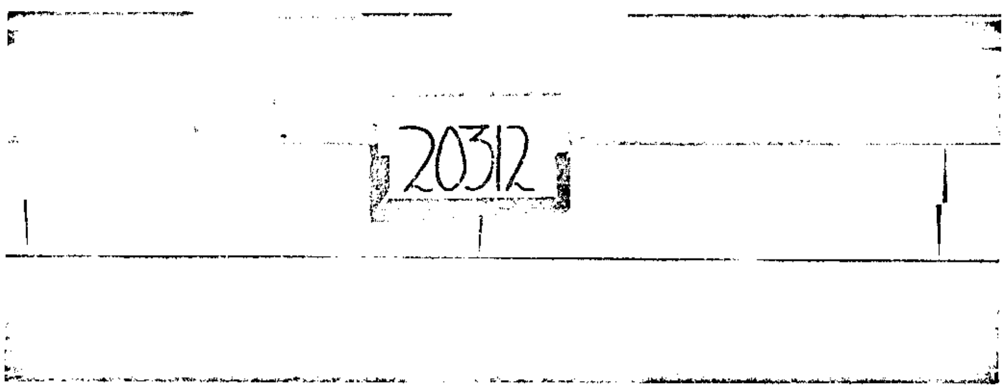


(c) Wheel paths #5, #6, #7 and #8 after 717,102 wheel applications

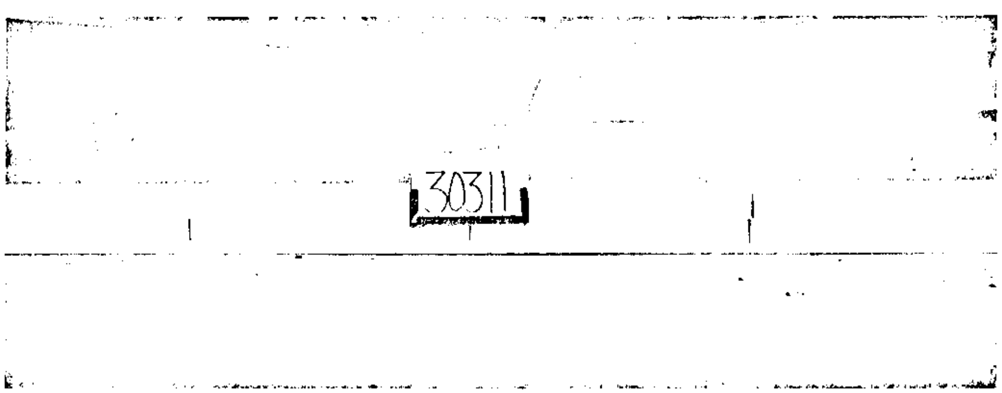
Figure 44: Cross-section views of the polymer cement concrete overlay (021) at end of test



(a) Wheel paths #1 and #2 after 2,151,300 wheel applications

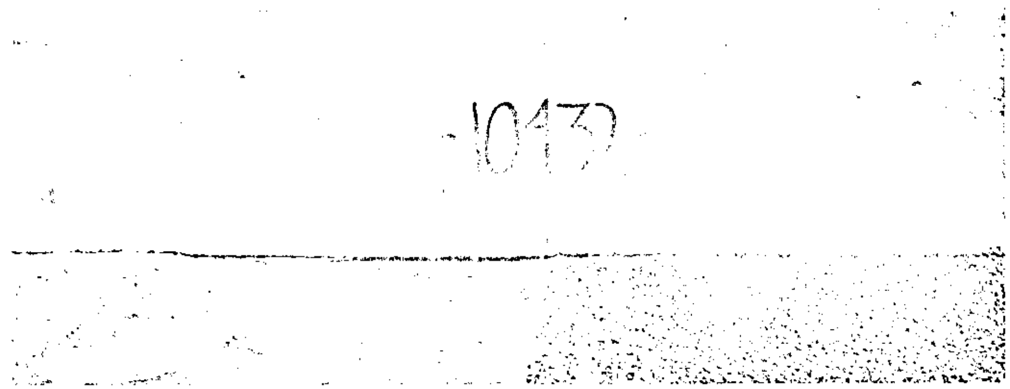


(b) Wheel paths #3 and #4 after 2,151,306 wheel applications



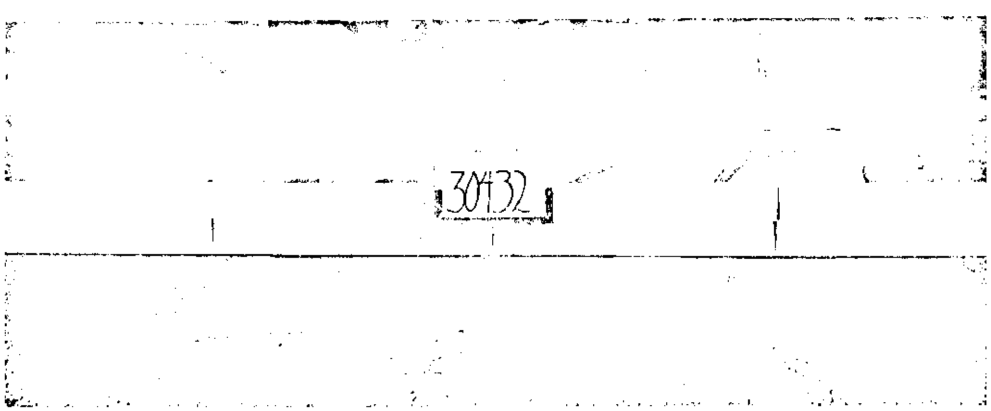
(c) Wheel paths #5, #6, #7 and #8 after 717,102 wheel applications

Figure 45: Cross-section views of the polymer concrete overlay (031) at the end of the test



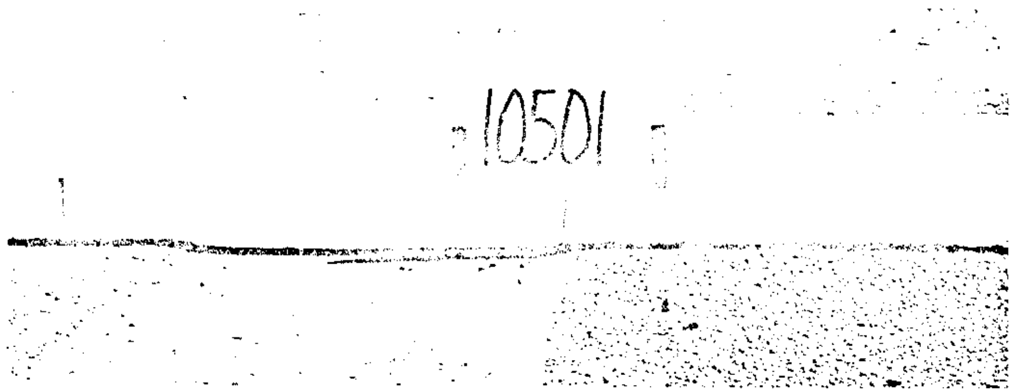
(a) Wheel paths #1 and #2 after 2,151,306 wheel applications

(b) Wheel paths #3 and #4 after 2,151,305 wheel applications

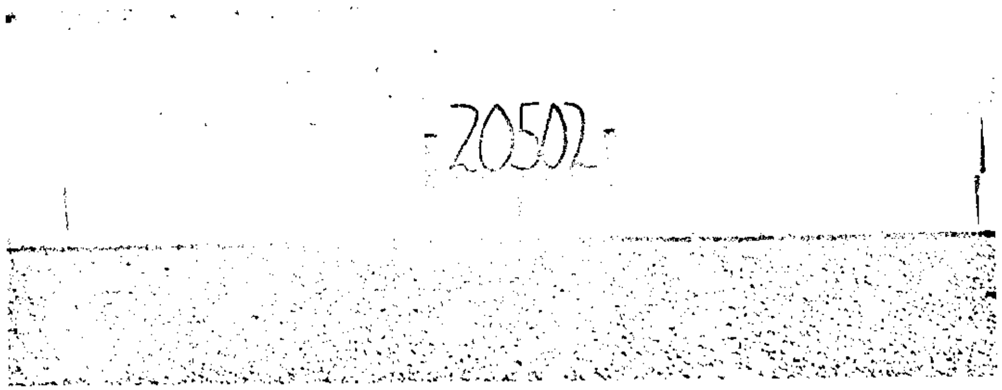


(c) Wheel paths #5, #6, #7 and #8 after 717,102 wheel applications

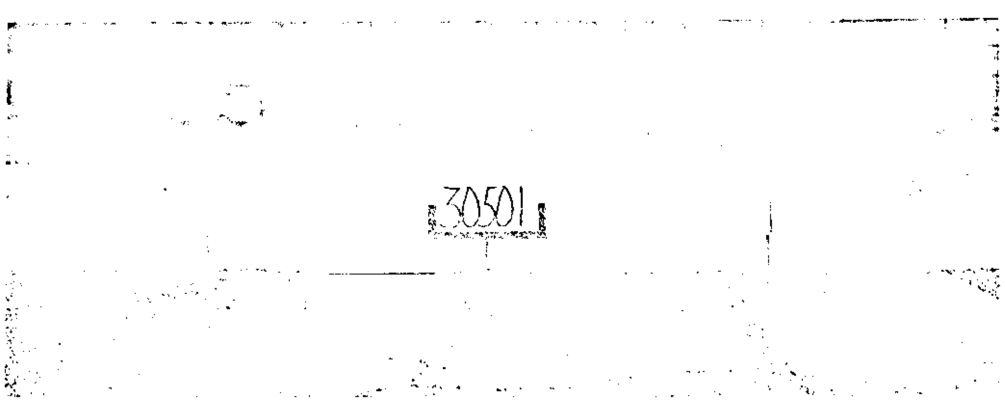
Figure 46: Cross-section views of the bauxite asphalt epoxy surfacing on the portland cement sand mix overlay (043) at the end of the test



(a) Wheel paths #1 and #2 after 2,151,306 wheel applications

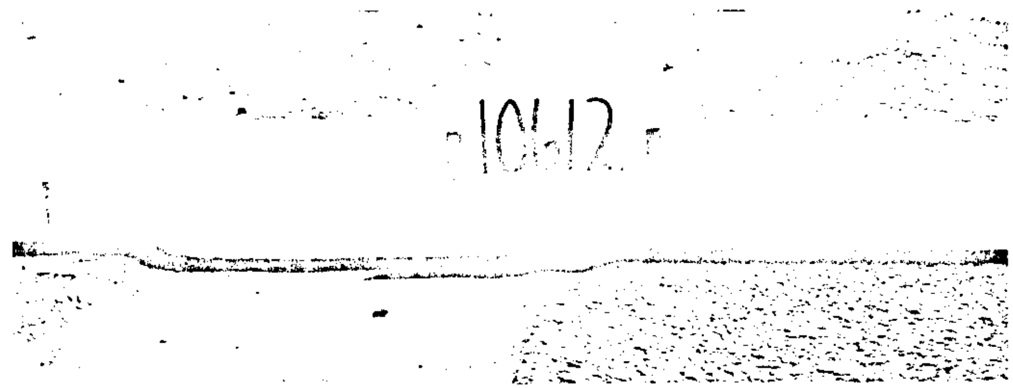


(b) Wheel paths #3 and #4 after 2,151,306 wheel applications



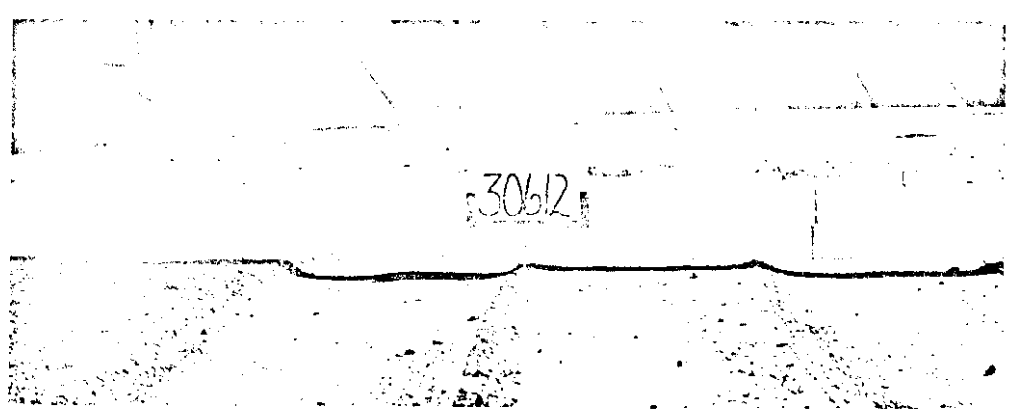
(c) Wheel paths #5, #6, #7 and #8 after 717,102 wheel applications

Figure 47: Cross-section views of the bauxite asphalt epoxy surfacing on Class "B" A.C. overlay (050) at the end of the test



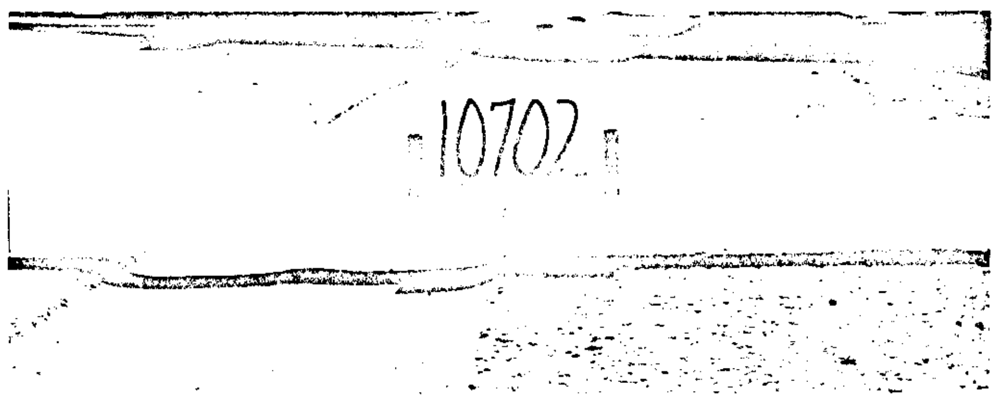
(a) Wheel paths #1 and #2 after 2,151,306 wheel applications

(b) Wheel paths #3 and #4 after 2,151,306 wheel applications

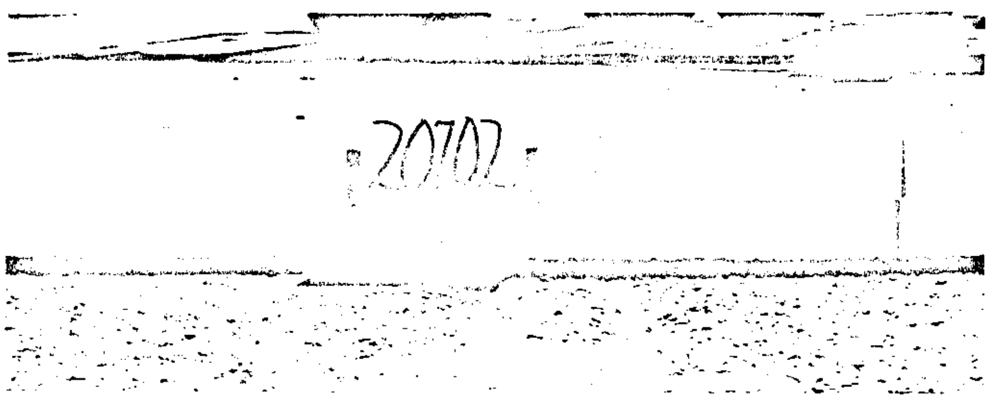


(c) Wheel paths #5, #6, #7 and #8 after 717,702 wheel applications

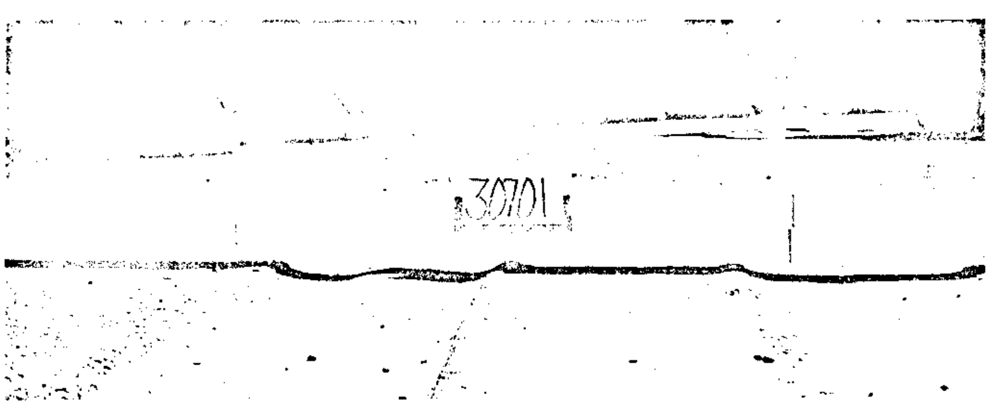
Figure 48: Cross-section views of the Class "D" A.C. overlay (060) at the end of the test



(a) Wheel paths #1 and #2 after 2,151,306 wheel applications

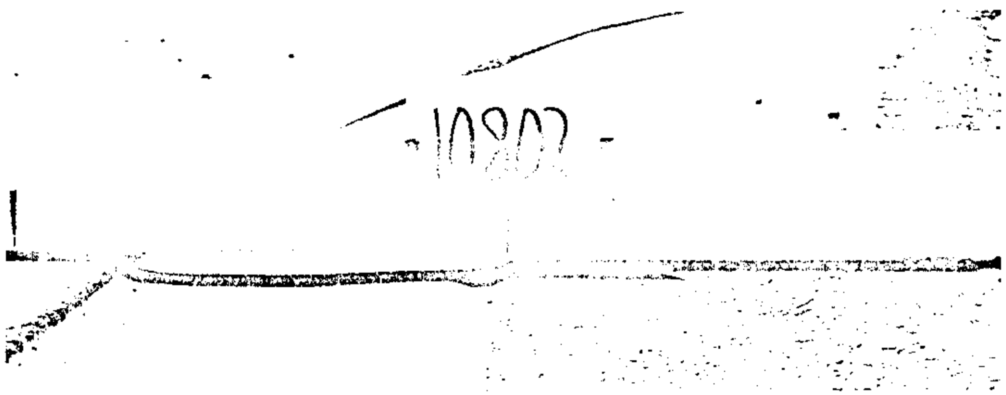


(b) Wheel paths #3 and #4 after 2,151,306 wheel applications

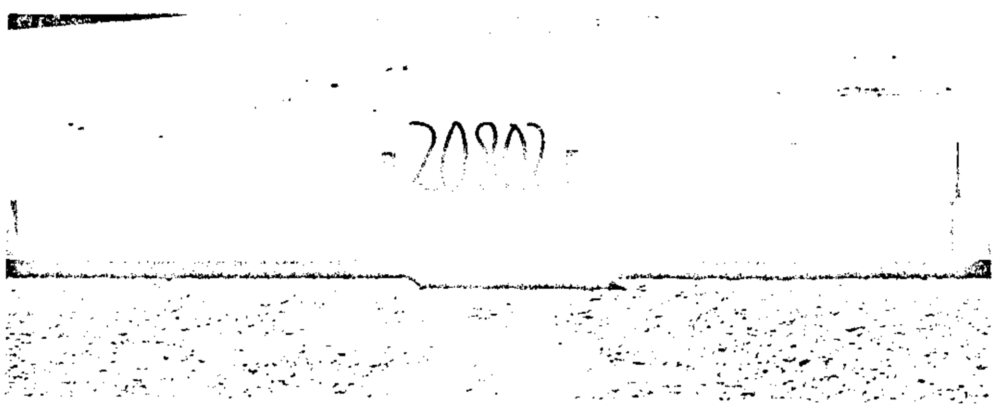


(c) Wheel paths #5, #6, #7 and #8 after 717,102 wheel applications

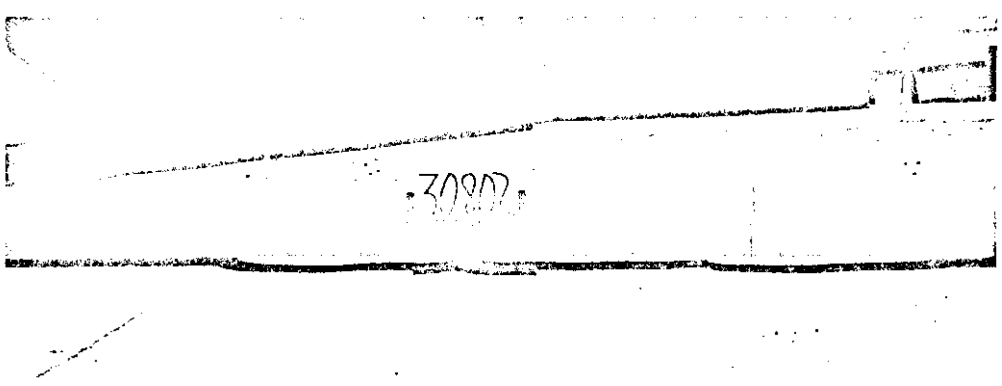
Figure 49: Cross-section views of the Class "G" A.C. with Pliopave (070) at the end of the test



(a) Wheel paths #1 and #2 after 2,151,306 wheel applications

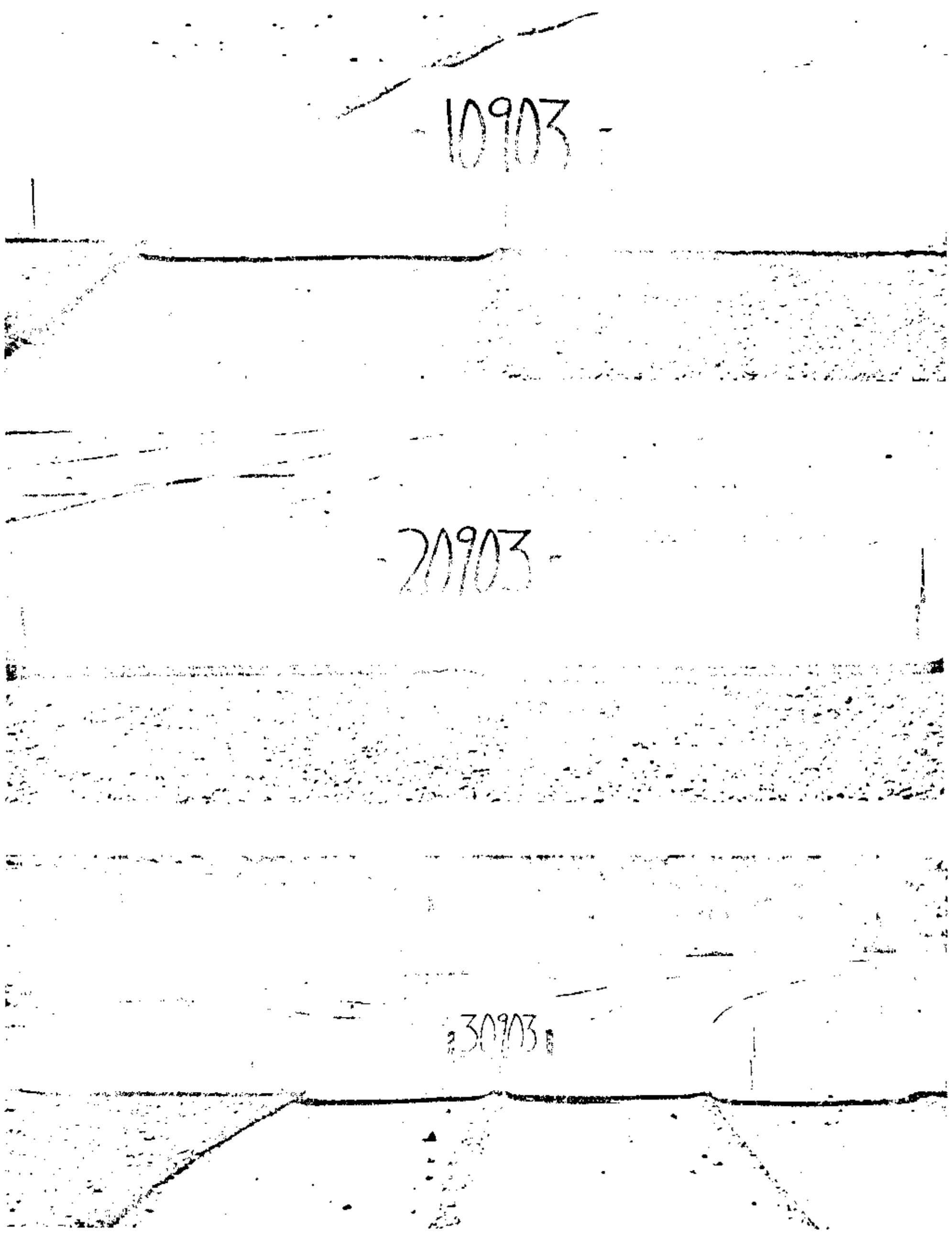


(b) Wheel paths #3 and #4 after 2,151,306 wheel applications



(c) Wheel paths #5, #6, #7 and #8 after 717,102 wheel applications

Figure 50: Cross-section views of the Class "G" asphalt extended epoxy concrete overlay (080) at the end of the test

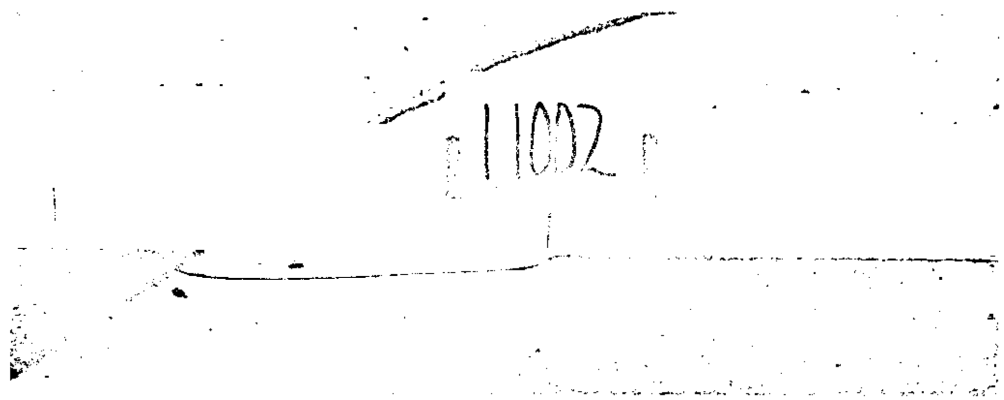


(a) Wheel paths #1 and #2 after 2,151,306 wheel applications

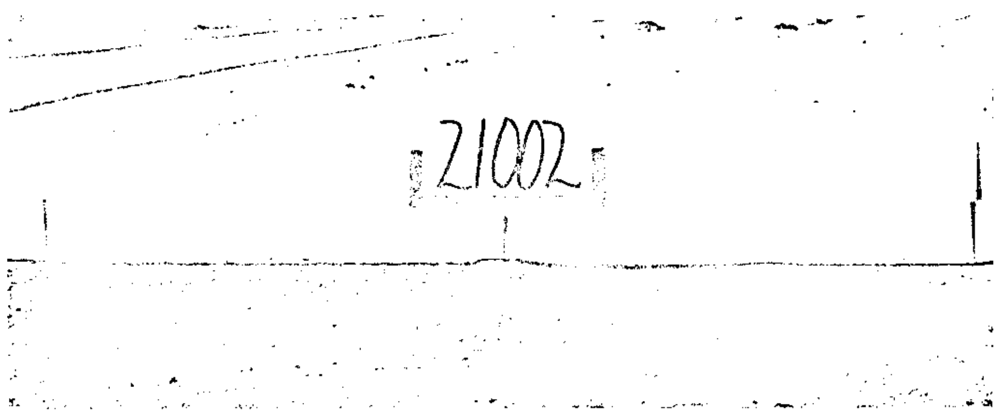
(b) Wheel paths #3 and #4 after 2,151,306 wheel applications

(c) Whcel paths #5, #6, #7 and #8 after after 717,102 wheel applications

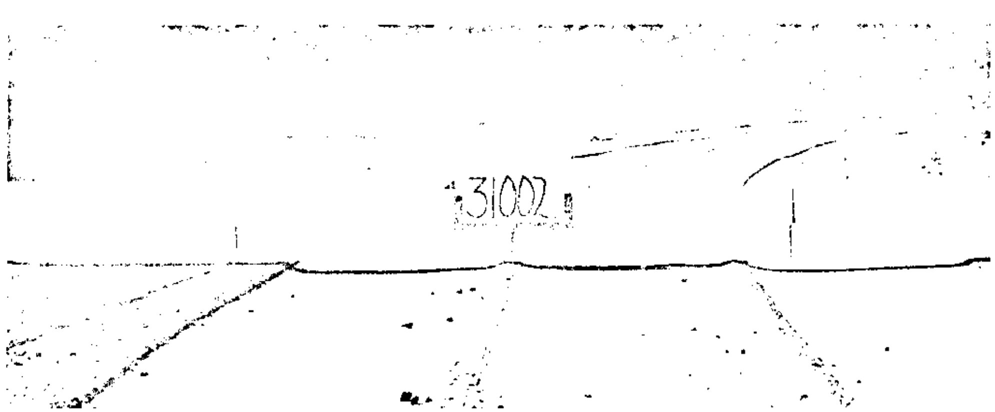
Figure 51: Cross-section views of the Class "G" A.C. overlay (090) at the end of the test



(a) Wheel paths #1 and #2 after 2,151,306 wheel applications

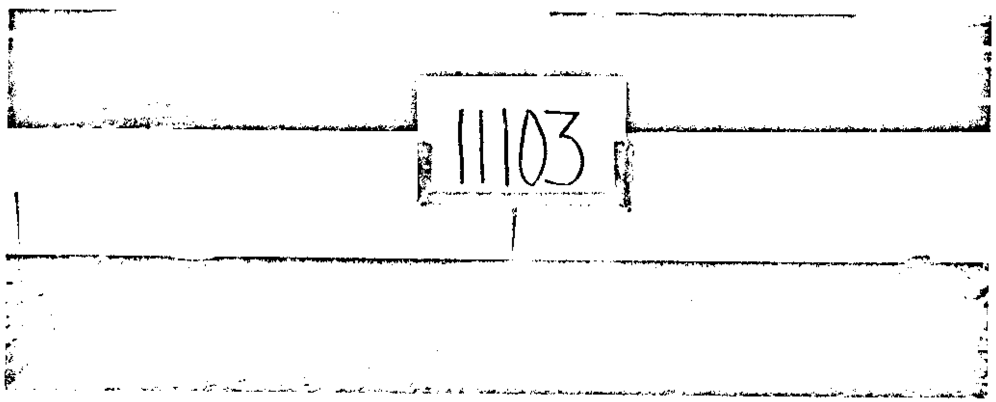


(b) Wheel paths #3 and #4 after 2,151,306 wheel applications

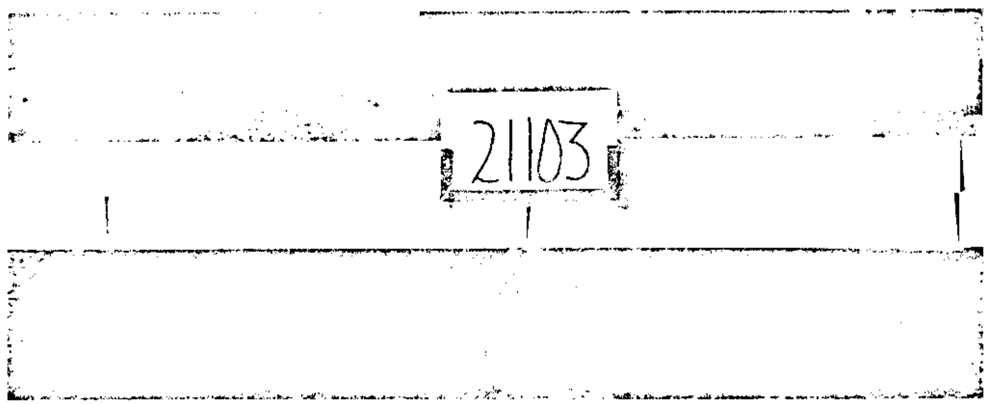


(c) Wheel paths #5, #6, #7 and #8 after 717,102 wheel applications

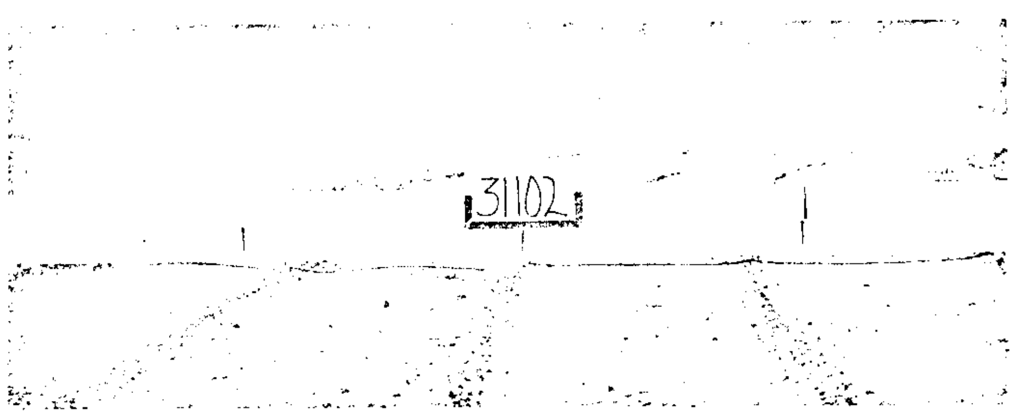
Figure 52: Cross-section views of the Class "G" A.C. with Petroset A.T. overlay (100) at the end of the test



(a) Wheel paths #1 and #2 after 2,151,306 wheel applications

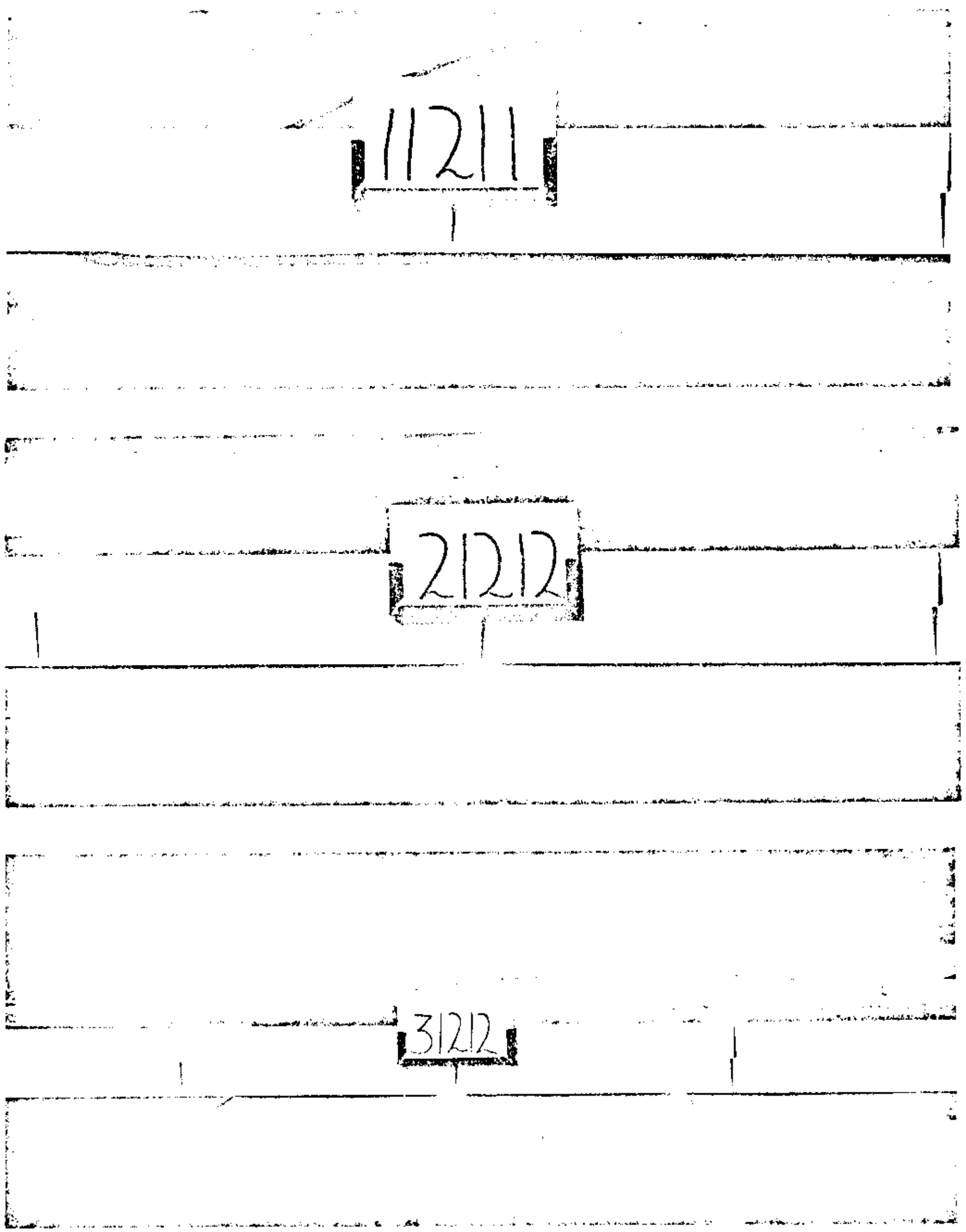


(b) Wheel paths #3 and #4 after 2,151,306 wheel applications



(c) Wheel paths #5, #6, #7 and #8 after 717,102 wheel applications

Figure 53: Cross-section views of the Idaho Chip Seal on Class "B" A.C. overlay (110) at the end of the test

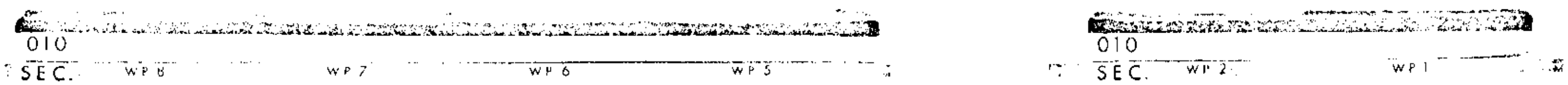


(a) Wheel paths #1 and #2 after 2,151,306 wheel applications

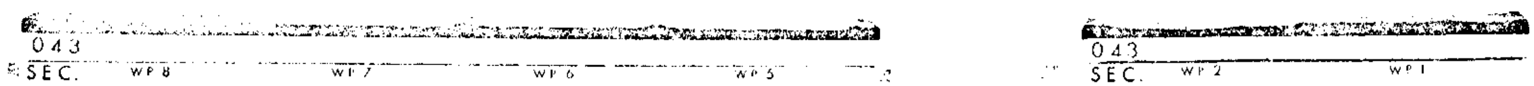
(b) Wheel paths #3 and #4 after 2,151,306 wheel applications

(c) Wheel paths #5, #6, #7 and #8 after 717,102 wheel applications

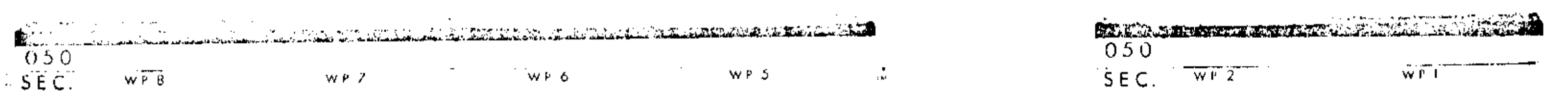
Figure 54: Cross-section views of the Class "B" A.C. overlay (121) at the end of the test



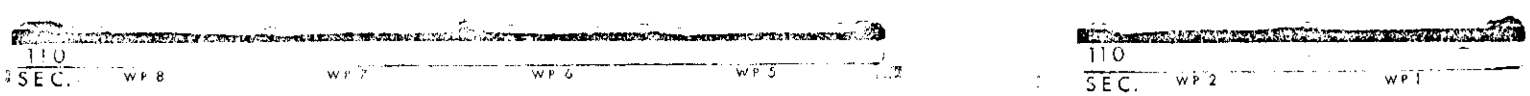
Bauxite asphalt epoxy surfacing on high alumina cement concrete overlay (010)



Bauxite asphalt epoxy surfacing on portland cement sand mix overlay (043)

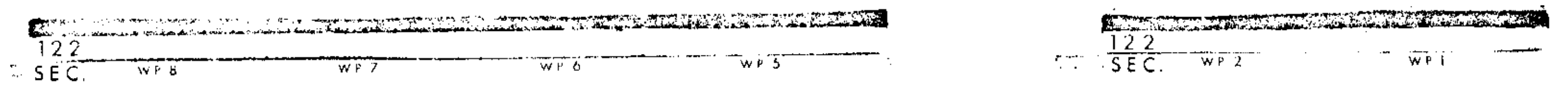


Bauxite asphalt epoxy surfacing on Class "G" A.C. overlay (050)

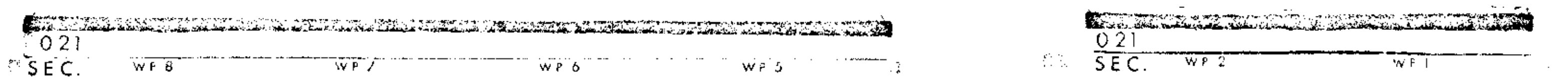


Idaho Chip Seal on Class "B" A.C. overlay (110)

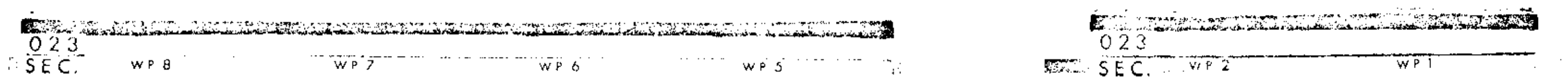
Figure 55: Plaster castings of the various surfacings from top to bottom, - Sections 010, 043, 050 and 110, respectively



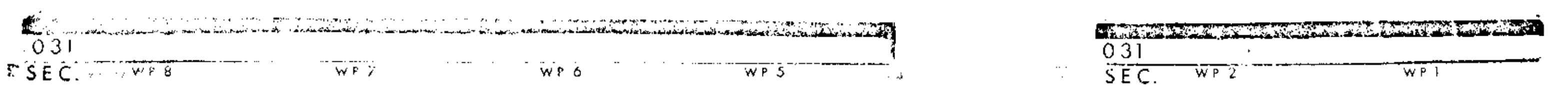
Portland cement concrete overlay (122)



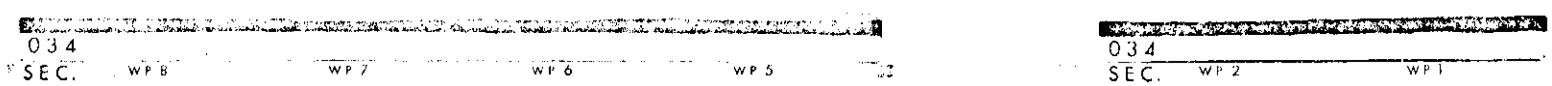
Polymer cement concrete overlay (021)



Garnet surfacing on polymer cement concrete (023)

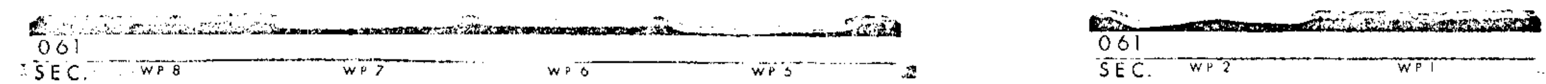


Polymer concrete (031)

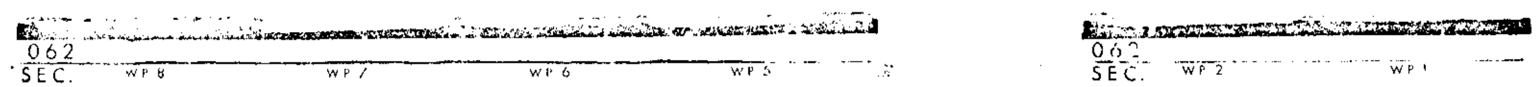


Rubber-sand on polymer concrete (034)

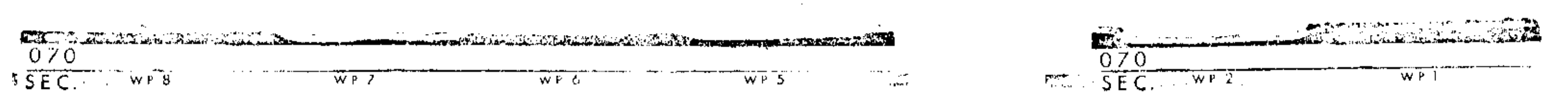
Figure 56: Plaster castings on the different portland cement and polymer concrete overlays. From top to bottom - Sections 122, 021, 023, 031 and 034, respectively.



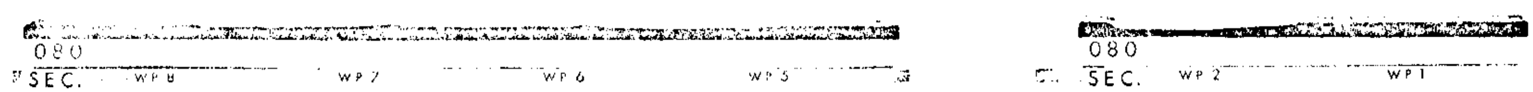
Class "D" A.C. overlay (061)



Class "D" A.C. with Petroset AT overlay (062)

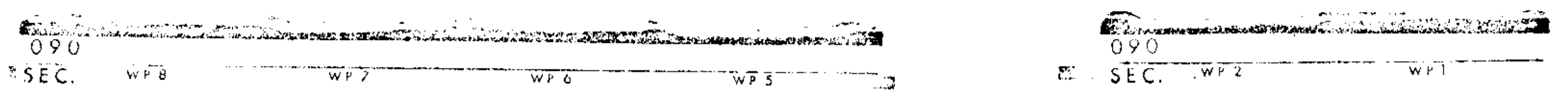


Class "G" A.C. with Pliopave overlay (070)

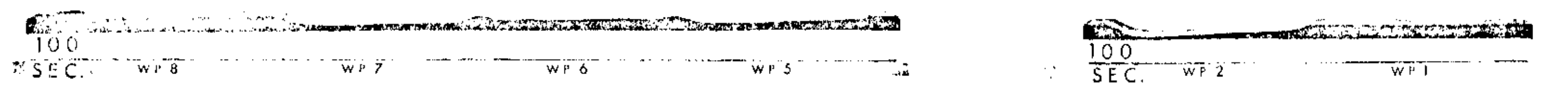


Class "G" asphalt extended epoxy concrete overlay (080)

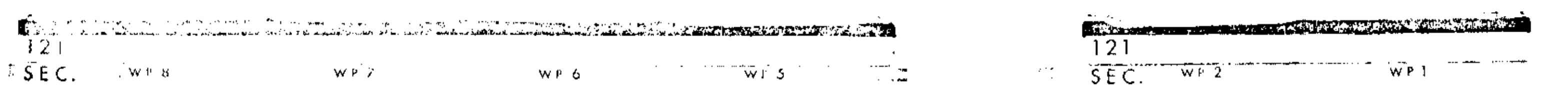
Figure 57: Plaster castings of the different asphalt concrete overlays. From top to bottom - Sections 061, 062, 070 and 080, respectively.



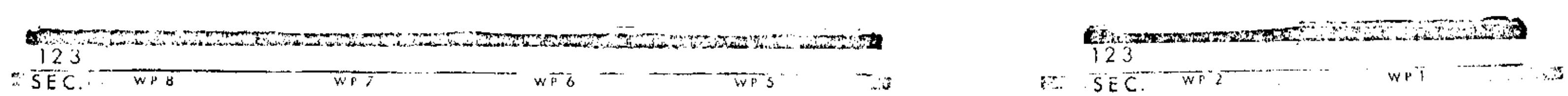
Class "G" A.C. overlay (090)



Class "G" A.C. with Petroset A.T. overlay (100)



Class "B" A.C. overlay (121)



Mastic asphalt (Gussasphalt) overlay (123)

Figure 58: Plaster castings of the different asphalt concrete overlays. From top to bottom - Sections 090, 100, 121 and 123, respectively.

TABLE 37

COMPARISON OF AVERAGE RUT DEPTHS OF 717,102 WHEEL APPLICATIONS

SECTION	TYPE OF OVERLAY	AVERAGE RUT DEPTHS - INCHES					
		NO STUDS		STUD TYPE			
		U.S.[1]	GST	#1	#2	#3	#4
010	Bauxite Asphalt Epoxy/High Alumina C.C.	.010	.020	.047	.063	.095	.111
041	Mineral Slag Asphalt Epoxy Surfacing/ P.C. Sand Mix	.009	.022	.109	.085	.105	.140
042	Garnet Asphalt Epoxy Surfacing/ P.C. Sand Mix	.011	.003	.039	.064	.046	.076
043	Bauxite Asphalt Epoxy Surfacing/ P.C. Sand Mix	.015	.030	.090	.110	.127	.138
050	Bauxite Asphalt Epoxy Surfacing/ Class "B" Asphalt Concrete	.015	.046	.078	.096	.105	.131
110	Idaho Chip Seal on Class "G" A.C.	.036	.029	.092	.095	.239	.148
122	Portland Cement Concrete	.005	.013	.065	.031	.051	.048
021	Polymer Cement Concrete	.008	.002	.021	.027	.025	.014
022	Polymer Steel Fibrous Concrete	.003	.006	.028	.033	.036	.016
023	Garnet Surfacing on Polymer Cement Concrete	.005	.016	.021	.030	.014	.025
031	Polymer Concrete	.004	.004	.009	.009	.005	.009
032	Garnet Surfacing on Polymer Concrete	.006	.004	.009	.040	.027	.024
033	Mineral Slag-Sand on Polymer Concrete	.002	.001	.008	.012	.011	.007
034	Rubber-Sand on Polymer concrete	.001	.007	.042	.054	.040	.104

[1] These average rut depths were interpolated from the data obtained with the WSU Profilometer on the inside track.

TABLE 37 (Continued)

COMPARISON OF AVERAGE RUT DEPTHS OF 717,102 WHEEL APPLICATIONS

SECTION	TYPE OF OVERLAY	AVERAGE RUT DEPTHS - INCHES					
		NO STUDS		STUD TYPE			
		U.S.[1]	GST	#1	#2	#3	#4
061	Class "D" Asphalt Concrete	.013	.062	.301	.183	.461	.293
062	Class "D" Asphalt Concrete with Petroset AT	.010	.049	.408	.060	.407[2]	.748
070	Class "G" Asphalt Concrete with Pliopave	.010	.024	.159	.125	.259	.236
080	Class "G" Asphalt Extended Epoxy Concrete	.002	.002	.236	.085	.121	.159
090	Class "G" Asphalt Concrete	.007	.031	.295	.123	.267	.360
100	Class "G" Asphalt Concrete with Petroset AT	.006	.035	.240	.146	.281	.350
121	Class "B" Asphalt Concrete	.007	.020	.141	.099	.115	.117
123	Mastic Asphalt Concrete (Gussasphalt)	.010	.021	.089	.057	.080	.091

[1] These average rut depths were interpolated from the data obtained with the WSU Profilometer on the inside track.

[2] Calculated from the rate of wear since these ruts were filled after 500,000 wheel applications.

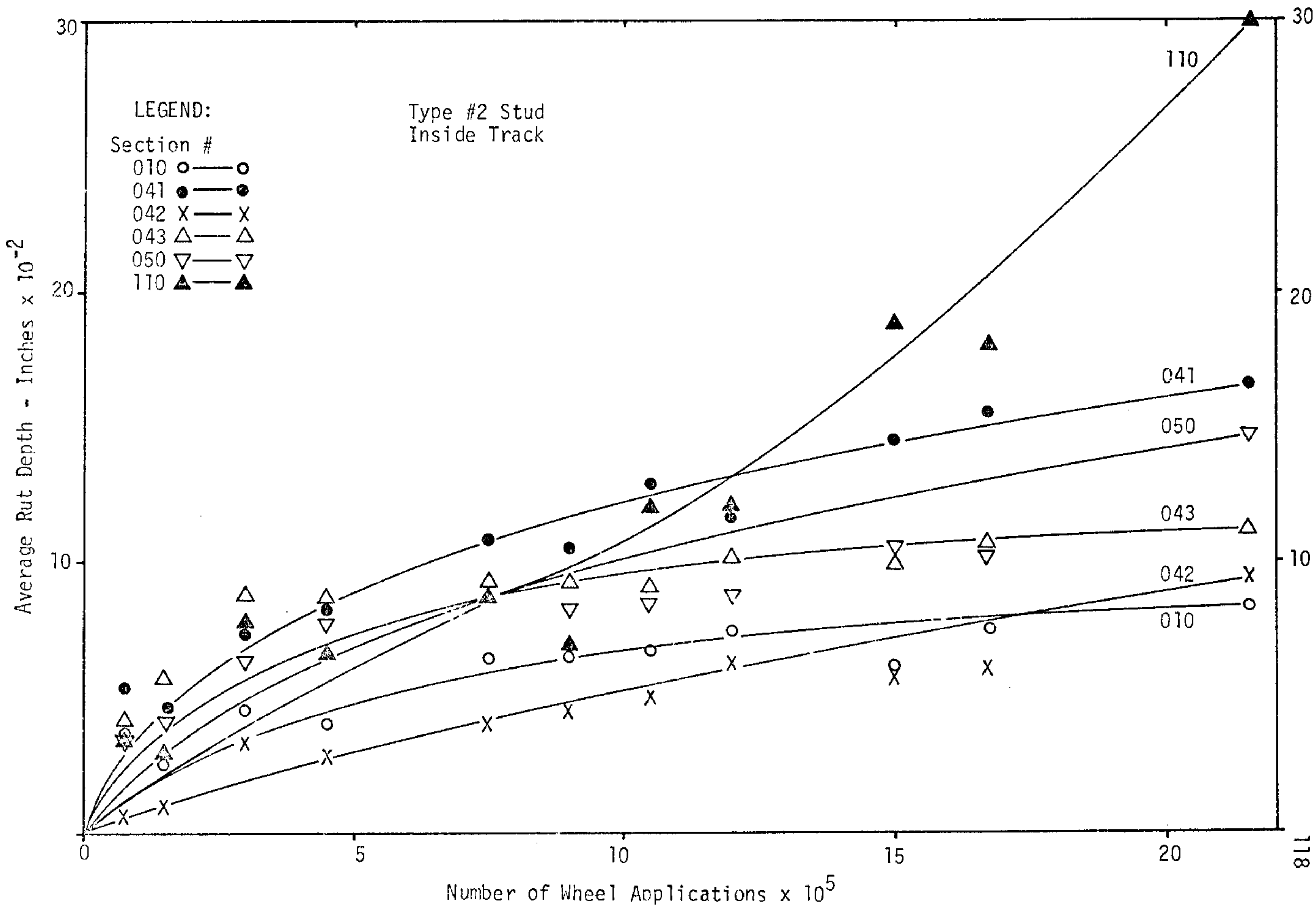


Figure 59: Average Rut Depth with Wheel Applications for the Various Surfacings

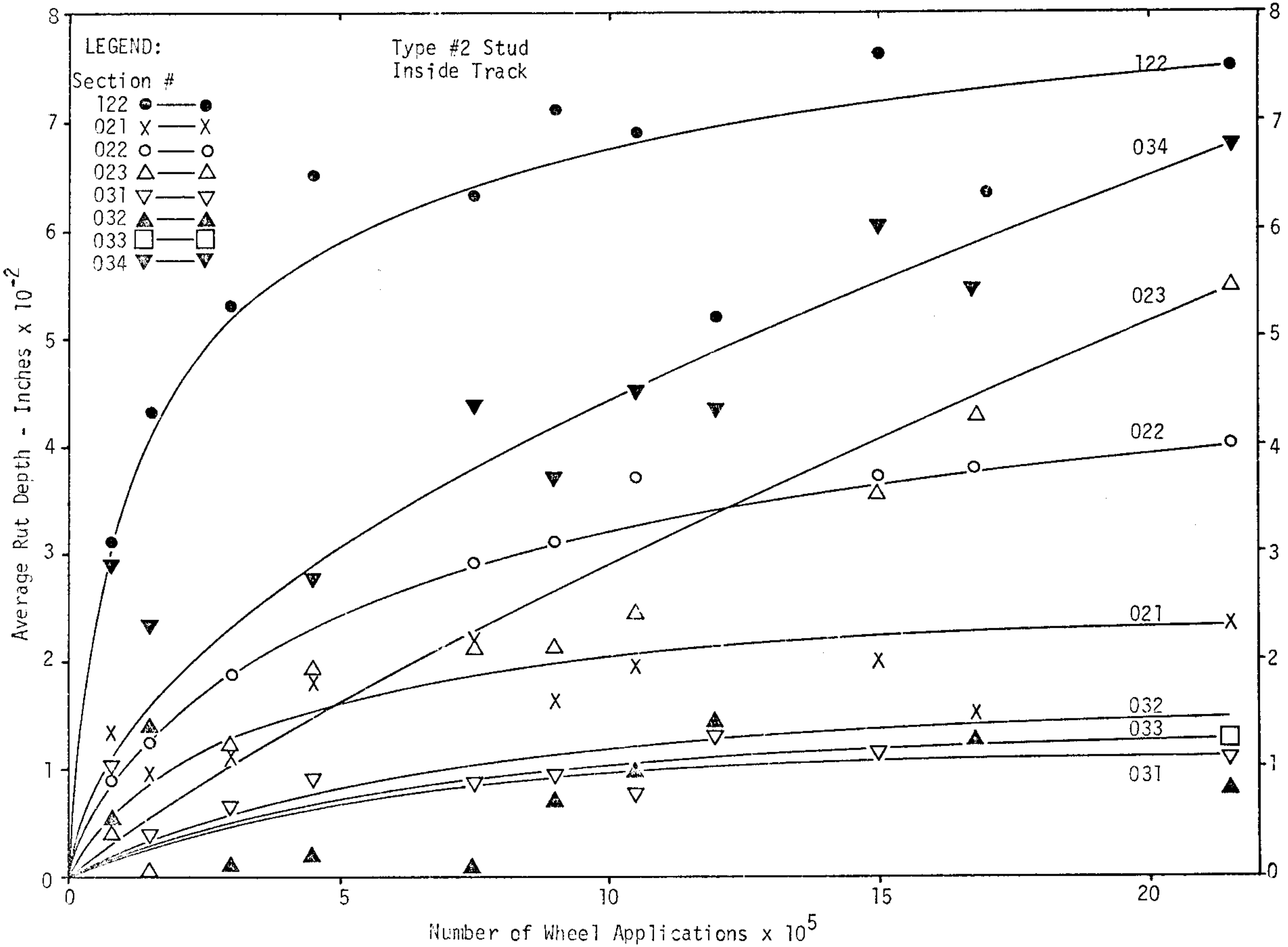


Figure 60: Average Rut Depth with Wheel Applications for the PCC and Polymer Concrete Group

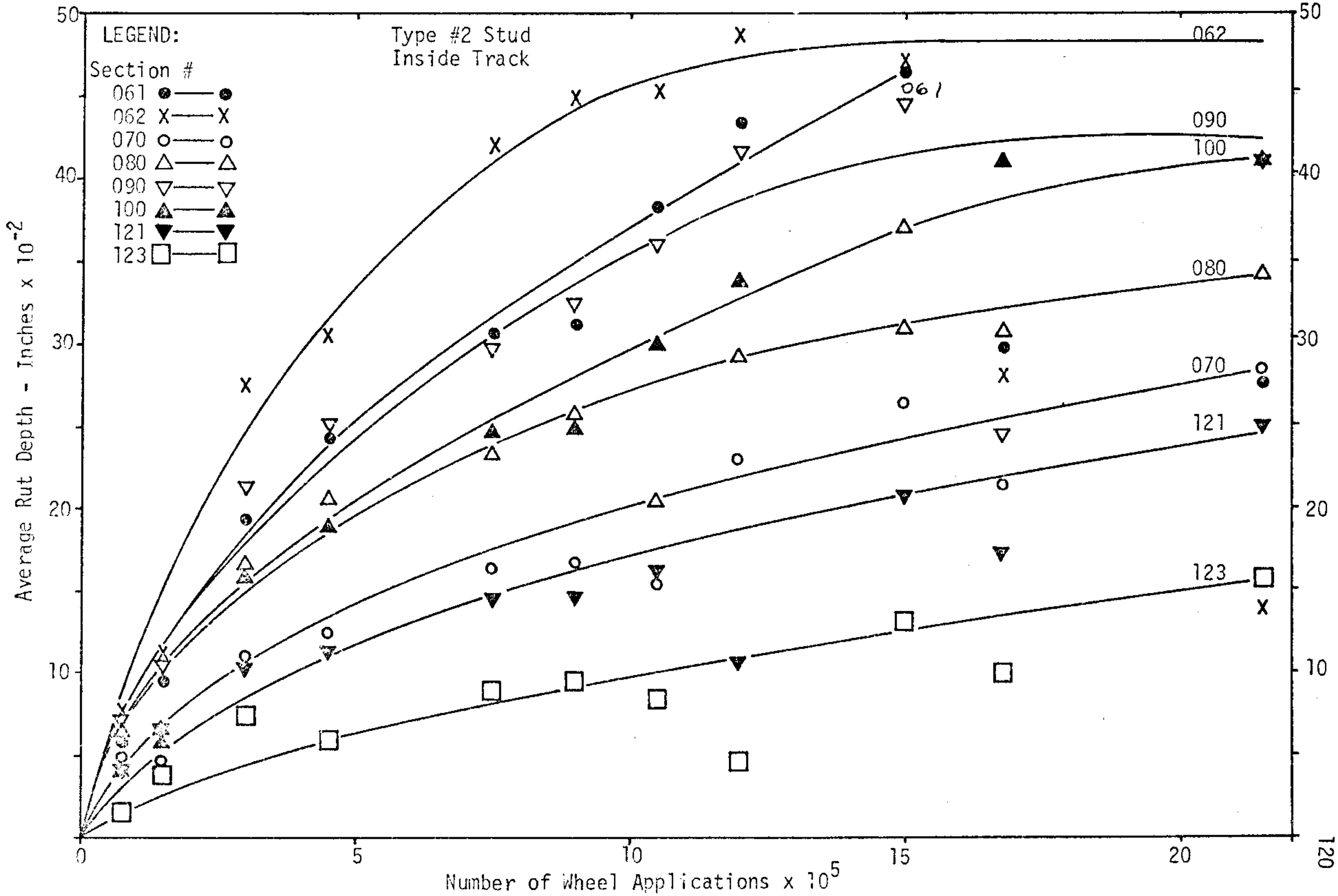


Figure 61: Average Rut Depths with Wheel Applications for the Different Asphalt Concrete Group

extended epoxy surfacing on the high alumina cement concrete overlay (010) over the other five sections in resisting wear effects of tires and studs. Similar surfacing on the class "G" asphalt (050) concrete overlay was fourth out of the six sections in wear resistance. The type of overlay may have contributed to differences in wear in these two sections (010 and 050) since the same company put down the bauxite aggregate and the asphalt epoxy surfacing under similar conditions.

The other bauxite section (043) done by a different company showed more wear but some of this was no doubt to premature stripping of the surfacing due to loss of bond. The other two asphalt extended epoxy sections with the mineral slag aggregate (041) and the garnet aggregate (043) did not resist wear as well. The Idaho Chip Seal surfacing on class "B" asphalt concrete base (110) showed the poorest resistance to wear in the group.

When the retention of skid resistance values as shown in Table 15 (p. 52) is examined, the Idaho Chip Seal surfacing (110) was the best. The bauxite aggregate asphalt extended epoxy surfacing on class "G" asphalt concrete (050) was second best. The worst was the section with the garnet (042) and the next was the section with the mineral slag (041). This was probably due to the size of aggregates used in these sections. The aggregates were worn, exposing the polished asphalt epoxy surfacing. The garnet and mineral slag aggregates sizes were passing #40 sieve; the size of the bauxite aggregate was passing #4 sieve and retained on #16 sieve; the Idaho Chip aggregate was 3/8 of an inch in size. It appears that the larger the size of aggregate used for surfacing, the better the resistance value and the longer this value will be retained. This wear-polishing of the surface was due to the action of studded tires. Table 15 (p. 52) shows that the S.R.N. was not reduced to the minimum value of 25 in the unstudded and garnet retread passenger tires.

The unstudded truck tires action did lower the S.R.N. in some cases to 25 or lower as shown in Table 12 (p. 43). Some of this may have been due to oil leaks which developed in the driving mechanism.

PORTLAND CEMENT CONCRETE AND POLYMER CONCRETE GROUP

Comparison of these eight sections are shown in Tables 27-29 (p. 71-73),Table 37 (p.116) and in Figure 60 (p.119). These tables and figure show that the polymer concrete section (031) was superior in this group in resisting wear from tires and studs. The section with the least resistance to wear was the portland cement concrete (122), with the second least resistant section being the rubber-sand polymer concrete (034). The polymer steel fibrous concrete section (122) was third with the portland cement concrete section (122) fourth.

All of these sections showed very good comparative resistance to wearing effects of unstudded and studded tires. However, their skid resistance values left much to be desired. More research is needed to develop better skid resistance characteristics of these polymer concrete sections so that their extremely good wear resistance characteristics can be utilized.

ASPHALT CONCRETE GROUP

These eight sections are compared in Tables 30-32 (p. 74-76), Table 37 (p.116) and Figure 61 (p.120). The mastic asphalt concrete (Gussasphalt) section (123) had the best wear resistance characteristics of this group. The class "B" asphalt concrete section (121) had the second best wear resistance characteristics. The two worst sections with respect to wear resistance were the class "D" asphalt concrete section (061) and the class "D" asphalt concrete with Petroset AT section (062).

Table 15 (p. 52) shows the opposite with respect to retaining skid resistance values. The two class "D" asphalt concrete sections without and with Petroset AT (061 and 062) were one and two, respectively. The worst was the mastic asphalt concrete (Gussasphalt) section (123). The apparent reason for the poor showing of the mastic asphalt concrete was that the aggregate chips did not adhere to mastic asphalt concrete because of construction problems.

The use of additives to the class "G" asphalt concrete did two things - 1) generally improved the wear resistance characteristics and 2) lowered the retention of skid resistance characteristics of these pavements. In this sub-group, the class "G" asphalt extended epoxy concrete section (080) had the best wear resistance characteristics compared to the regular class "G" asphalt concrete. Conversely, it showed the poorest skid resistance retention. The other two additives, Petroset AT and Pliopave, did improve wear resistance characteristics; the latter more than the former.

It is interesting to note that the asphalt concrete sections which had the best wear resistance characteristics conversely had the worse retention of skid resistance characteristics.

ALL THE SECTIONS

The portland cement concrete and polymer concrete sections had the least wear with the asphalt concrete sections having the most wear. The different surfacings had much less wear than the asphalt concrete sections but more than the polymer concrete sections. The portland cement concrete section had less wear than the asphalt concrete sections and most of the different surfacings, but more wear than the different polymer cement concrete and polymer concrete sections. All this is shown in Table 37 (p.116) and in Figures 59-61 (p.118-120).

WEAR RATES

Although the initial, middle and final wear rates were not calculated, the results show that all the pavements had high initial wear rates, and then progressively lower middle and final wear rates. Tables 24-32 (p. 68-76) give the overall wear rates in inches per 10^6 wheel applications.

THE DIFFERENT TYPES OF STUDS, TIRES AND WEAR

All the studded tires caused measureable wear on all surfaces of the test track. Table 38 (p. 125) shows the comparative pavement wear for the different pavements at 717,102 wheel applications. The standard was the type #3 stud which has been predominantly sold on the market during the past five years.

Table 38 shows that the type #2 stud almost consistently caused less pavement wear than the other three types of studs. The type #1 stud was second best compared to the type #3 stud and the type #4 stud was generally last. The type #4 stud generally caused more pavement wear than the other three studs. The unstudded passenger tires and the garnet dust retread tires caused the least amount of wear. Generally, the unstudded passenger tire caused less wear than the garnet dust retread tire.

Tables 25 (p. 68), 28 (p. 72) and 31 (p. 75) show that the unstudded truck tires on the center track caused more wear than the unstudded passenger tires on the inside track on the same pavement types. The driving truck tire generally caused more pavement wear than the free-wheeling truck tire. In some cases, this wear was 10 to 40 percent of the wear caused by the type #1 stud at similar wheel applications.

Table 15 (p. 52) shows that the type #2 stud lowered the S.R.N. more quickly than the other three studs. The type #4 stud affected the skid

TABLE 38

COMPARATIVE PAVEMENT WEAR[1]

SECTION	TYPE OF OVERLAY	WEAR RATIO[2] WITH RESPECT TO TYPE #3 STUD					
		NO STUDS		STUD TYPE			
		U.S.[1]	GST	#1	#2	#3	#4
010	Bauxite Asphalt Epoxy/High Alumina C.C.	9.50	4.75	2.02	1.51	1.00	.86
041	Mineral Slag Asphalt Epoxy Surfacing/ P.C. Sand Mix	11.67	4.77	.96	1.24	1.00	.75
042	Garnet Asphalt Epoxy Surfacing/P.C. Sand Mix	4.18	15.3	1.18	.72	1.00	.61
043	Bauxite Asphalt Epoxy Surfacing/P.C. Sand Mix	8.47	4.23	1.41	1.15	1.00	.92
050	Bauxite Asphalt Epoxy Surfacing/Class "G" A.C.	6.8	2.28	1.31	1.09	1.00	.80
110	Idaho Chip Seal on Class "B" A.C.	6.64	8.24	2.60	2.52	1.00	1.62
122	Portland Cement Concrete	10.20	3.92	.79	1.65	1.00	1.06
021	Polymer Cement Concrete	3.13	12.5	1.19	.93	1.00	1.79
022	Polymer Steel Fibrous Concrete	12.0	6.0	1.29	1.09	1.00	2.25
023	Garnet Surfacing on Polymer Cement Concrete	2.8	.88	.67	.47	1.00	.56
031	Polymer Concrete	1.25	1.25	.56	.56	1.00	.56
032	Garnet Surfacing on Polymer Concrete	4.5	6.75	3.0	.68	1.00	1.13
033	Mineral Slag-Sand on Polymer Concrete	5.5	11.0	1.38	.92	1.00	1.57
034	Rubber-Sand on Polymer Concrete	40.0	5.7	.95	.74	1.00	.38

1 Passenger tires, inside and outside tracks only, and at 717,102 Wheel Applications.

2 Wear Ratio (W.R.) = $\frac{\text{Stud Type \#3 Average Rut Depth}}{\text{Stud Type \#Y Average Rut Depth}}$

TABLE 38 (Continued)

COMPARATIVE PAVEMENT WEAR[1]

SECTION	TYPE OF OVERLAY	WEAR RATIO[2] WITH RESPECT TO TYPE #3 STUD					
		NO STUDS		STUD TYPE			
		U.S.[1]	GST	#1	#2	#3	#4
061	Class "D" Asphalt Concrete	35.46	7.44	1.53	2.52	1.00	1.57
062	Class "D" Asphalt Concrete with Petroset AT	40.90	8.31	1.00	6.78	1.00	.54
070	Class "G" Asphalt Concrete with Pliopave	25.90	10.79	1.63	2.07	1.00	1.10
080	Class "G" Asphalt Extended Epoxy Concrete	60.5	60.5	.51	1.42	1.00	.76
090	Class "G" Asphalt Concrete	38.14	8.61	.91	2.17	1.00	.74
100	Class "G" Asphalt Concrete with Petroset AT	46.83	8.03	1.17	1.92	1.00	.80
121	Class "B" Asphalt Concrete	16.43	5.75	.82	1.16	1.00	.98
123	Mastic Asphalt Concrete (Gussasphalt)	8.0	3.81	.90	1.40	1.00	.88

1 Passenger tires, inside and outside tracks only, and at 717,102 Wheel Applications.

2 $\text{Wear Ratio (W.R.)} = \frac{\text{Stud Type \#3 Average Rut Depth}}{\text{Stud Type \#Y Average Rut Depth}}$

resistance characteristics of the different surfacings and the portland cement concrete and polymer concrete groups the least. The type #1 stud affected the skid resistance characteristics of the asphalt concrete group the least.

It appears that stud protrusion lengths may not be as important in causing pavement as the hardness of the stud, the contact angle, and the pin shape.

COMPARISON WITH OTHER STUDIES

This report has been concerned with the findings of Phase II of this project. Comparison of results from Phases I and II and with other studies are included in Phase III of this project. Some initial comparison of results from Phase I and II was made and is included in reference 19.

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LIST OF CONTRIBUTORS

Kennametal - passenger car tires, with and without studs.

Permanence - passenger car tires, studded

Norfin, Inc. - passenger car tires, studded

Marketing Industries - passenger car tires, garnet dust retread

Chevron Asphalt Company - Trinidad Epure and 40-50 penetration asphalt cement

Phillips Petroleum Company - Petroset AT

Charles R. Watts Company - Pliopave

United Paving Company, Inc. - Ground rubber

Battelle Pacific Northwest Laboratories - steel fibers

Idaho Garnet Abrasive Company - garnet aggregates

Robert A. Barnes, Inc. - mineral slag aggregates

Prismo Universal Corporation - equipment, bauxite aggregates for asphalt extended epoxy surfacings for sections 010 and 050. British Portable Skid Tester.

Lehigh Portland Cement Company - limestone flyash

ADDITIONAL ADVISORY PERSONNEL

Kennametal Inc., Kengrip Division, P.O. Box 95, Slippery Rock, PA 16057
Edwin W. Hines, Technical Director

Permanence Corporation, 944 Harper Avenue, Detroit, MI 48211
Charles S. Baum, President

Norfin, Inc., 526 First Avenue South, Seattle, WA 98104
Mr. Snellman, President

Marketing Industries, P.O. Box 247, Coeur D'Alene, ID 83814
James I. Scheller

Chevron Asphalt Company, 555 Market Street, P.O. Box 3069, San Francisco, CA 94120
W.J. Kari; Manager, Technical

Phillips Petroleum Company, 66 Bovet Road, San Mateo, CA 94402
Don D. Schultz, Manager, Western Region, Paving Systems

Charles R. Watts Company, 6th N.W. and Leary Way N.W., Seattle, WA

United Paving Company, Inc., Pullman, WA 99163
Dave Shardlow, Superintendent

Battelle Pacific Northwest Laboratories, Battelle Boulevard, Richland, WA 99352
C.H. Henager, Structures and Mechanics

Idaho Garnet Abrasive Company, P.O. Box 1080, Kellogg, ID 83837

Robert A. Burns, Inc., 5611 First Avenue South, Seattle, WA 98108
Cal Lowe

Prismo Universal Corporation, Huntingdon, PA 16652
Gerald L. Rieker, Regional Manager
Alan White, Manager; Prismo Universal Ltd, Great Britain

Lehigh Portland Cement Company, Metalline Falls, WA 99153

APPENDIX A

CONSTRUCTION SCHEDULE - RING #6

August 8, 1972

The portland cement concrete sections, the Wirand® Concrete sections (1b) and the portland cement concrete center section (C-5a) of Ring #5 were sand blasted. The wheel ruts in section 5a were patched with polymer concrete. The temperature was in the high eighties. The work was done by members of the Applied Materials Chemistry and the Transportation Systems Section.

August 14, 1972

The two-inch polymer concrete section (0-1a) was removed by means of the jack hammer and air compressor. The three-inch Wirand® Concrete section (0-2aC) was also removed. The work was done by the Transportation Systems Section crew.

August 15, 1972

The portland cement concrete sections (1a, 5b, 6a and 6b) were sand blasted. Forms were put in section 1a for the 3/4 inch overlay of concrete.

August 16, 1972

The wheel ruts in the portland cement concrete sections (1a, 5b and 6a) were first covered with a concrete epoxy bond liquid and then patched with high alumina cement sand mix.

August 17, 1972

The high alumina cement concrete was mixed in a 1/4 cubic yard portable electric mixer and poured in section 010 (formerly 1a) to a depth of 3/4 inches. The surface was hand trowelled. Wet burlap bags were put on the surface, and a sprinkler system was installed to keep the concrete wet during the curing period.

August 21, 1972

Forms were cut and put in sections 020 (formerly 1b) and 040 (formerly 2b). The forms were set to meet an overlay depth of 3/4 inches.

August 22, 1972

The portland cement concrete sections (2b, 3a and 3b, and 4a) were sand blasted. The wheel ruts were then tacked with a concrete epoxy bonding liquid and filled with a portland cement sand mix.

August 23, 1972

Section 040 (formerly 3b) was first tacked with a concrete epoxy bonding liquid and then a portland cement sand mix overlay was poured on top. This was mixed in a 1/4 cubic yard electric portable concrete mixer and then poured into wheelbarrows. The surface was hand trowelled and covered with wet burlap sacks. These were kept constantly wet with a sprinkler system. The work was done by the Transportation Systems Section staff.

August 25, 1972

The combined staff of the Applied Materials Chemistry and Transportation Systems Section mixed and laid polymer cement concrete in sections 021, 022 and 023. The latter had a 1/4 inch surfacing of garnet with epoxy. Chuck Henager of Battelle Pacific Northwest Laboratories was also present to help out with the mixing of the polymer steel fibers concrete for section 022. Some problems occurred with this mix as the steel fibers made the mixture difficult to work with, and the steel fibers caused the epoxy to set very rapidly. The temperature varied between 65-70^{0} F in the morning to 85-90^{0} F in the afternoon. This caused the amount of water required in the mix to change. The epoxy mix had a tendency to come up to the surface in section 021 thus causing an uneven surface of varying skid resistance values.

August 29, 1972

The two-man crew from the Adhesive Engineering Company of California arrived and started to put the surfacing on section 040. The section was subdivided into three foot widths for applying the asphalt extended epoxy. The rest of the section was covered with paper to protect the surface and other sec-sections. The epoxy was hand mixed in buckets and applied on the surface with a squeeze wiper. Then the mineral aggregate was hand poured on top of the mix. In section 041, mineral slag aggregate was applied instead of bauxite, and in section 042, garnet aggregate was used; in the remaining section 043, bauxite aggregate was applied on top of the asphalt extended epoxy. There was twenty minutes working time once the asphalt extended epoxy was mixed. A total of seven three-foot sections were done. The temperature was 80-90^{0} F and the weather was sunny and hot. It took most of the day to do the 21-foot section.

August 31, 1972

Adhesive Engineering leased the United Paving, Inc., asphalt mixing equipment and started to lay the Class "G" asphalt extended epoxy concrete in section 080 (formerly 4b). The amount of asphalt cement normally used for this asphalt concrete mix was replaced by the asphalt extended epoxy, and the same procedure normally used for mixing Class "G" A.C. was followed. The only difference was that once the mix was ready and put into a truck, the Class "G" asphalt extended epoxy concrete mix had to sit in the truck for at least 20 minutes before it could be laid. Then the mix had to be rolled within 30 minutes. A tack coat was applied to the surface of the existing pavements and the mix was laid with the Blow-Knox paving machine. Then it was rolled and compacted. After compaction, the color of this pavement was a dark brown. The temperature was in the high seventies.

September 1, 1972

A longitudinal reflection crack was noticed in the Class "G" asphalt extended epoxy concrete section (040), between the outside edge of the old portland cement concrete and the old asphalt concrete, and may have been due to temperature differentials between the two different pavement materials and the overnight temperatures. The Adhesive Engineering staff claimed that this crack would heal as the temperature rose. This never occurred and eventually this crack was filled with asphalt cement.

United Paving, Inc., put the Class "G" asphalt concrete section in 050 (formerly 3a), after tacking the existing surface.

September 5, 1972

The portland cement concrete sections (1b and 4b) were sand blasted. Forms were put in sections 1b and 6b.

September 6, 1972

United Paving, Inc., tacked the existing surfaces of sections 5a and b and laid Class "G" asphalt concrete in sections 090 (formerly 5a) and 100 (formerly 5b). The temperature was in the seventies.

September 7, 1972

United Paving, Inc., tacked the existing surfaces of sections 6b and 7a. The Class "G" asphalt concrete with 2 % Pliopave was laid in section 070 (formerly 7a) and compacted. Then United Paving, Inc., put in the Class "D" asphalt concrete mix in section 060 (formerly 6b) and compacted. This mix was difficult to compact as there were almost no fines present. A coarse open-graded texture was the result.

September 9, 1972

The Applied Materials Chemistry section applied polymer cement concrete patches on section 4a in the wheel rut of the portland cement concrete.

September 11, 1972

The Applied Materials Chemistry staff and the Transportation Systems Section staff put in the polymer concrete in sections 031, 032, 033 and 034. Skid resistant toppings of 1/4" depth were placed at the end of the section. Garnet aggregate, mineral slag-sand, and rubber-sand toppings were placed in sections 032, 033 and 034, respectively.

September 21, 1972

The Prismo Corporation brought in its equipment and staff. The sections and shoulders beside sections 010 and 050 were covered with plastic sheets so that the asphalt extended epoxy mix would not be put on these sections by accident. The Prismo Corporation apparatus, in which the asphalt extended epoxy was mixed, applied the mix uniformly on the surface of sections 050 and 010. The automatic aggregate spreader was not used but instead the bauxite aggregate was spread by shovelling it up in the air onto the surfacing, and then the excess was swept away. A four-man crew was used.

September 25, 1972

Forms were put in section 120 (formerly 6b).

September 26, 1973

Petroset AT was applied on the Class "G" AC section 110 and five feet of the Class "D" A.C. section 060 (now 061 which has no Petroset and 062 which has Petroset AT). The Petroset AT was hand mixed and applied at a rate of 0.13 gallons per square yard to obtain penetration of twenty minutes or more. Two gallons of concentrated Petroset AT made six gallons of diluted mix.

<u>September 27, 1972</u>

A three-foot width of portland cement concrete type II was laid in section 120 nearest to 010. This was numbered section 122. The surface was broom finished.

<u>September 29, 1972</u>

United Paving, Inc., put in the Idaho Chip aggregate on top of rubberized asphalt in section 110 (formerly 6a). The temperature was in the seventies. Uneven amounts of asphalt surfacing was put on the end nearest to section 100. This was corrected as the crew moved towards section 120.

<u>October 2, 1972</u>

United Paving, Inc., laid on the inside and outside Class "G" asphalt concrete shoulders.

<u>October 19, 1972</u>

The staff of the Transportation Systems Section started to drill holes for the reference pins.

<u>October 31, 1972</u>

The temperature was between 35-40^{0} F with a cold wind blowing. United Paving, Inc., with the staff of the Transportation Systems Section looking on, laid the mastic asphalt concrete (gussasphalt) in section 121. The Trinidad Epure and the 40-50 penetration asphalt cements were heated in a tar pot to a temperature of 475^{0} F and then poured into five gallon cans which were poured into the batch plant pug mill. The aggregate was also weighed individually and hand carried into the mill. Insulation was put on the outside of the mixing bins and conveyor belt. The weather was so cold that the mastic asphalt balled up and would not pour into the truck. A small amount was obtained and by means of applying heat by torches, both on the pavement surface and to the mix, it was placed in a three-foot wide section. This mix was practically hand placed and leveled. The coarse aggregate for the surface was heated and placed on top to act as a skid resistance surface. Unfortunately, it was impossible to mix the aggregates with the asphalt cement so that it had an asphalt coat and it failed to adhere to the mastic asphalt concrete. This section became 123.

The remaining part of the section was overlaid with a Class "B" asphalt concrete and was number 121. The shoulders in this section were finished.

November 1, 1972

The staff of the Transportation Systems Section started to set in the reference pins.

November 2, 1972

The staff of the Transportation Systems Section finished setting in all of the reference pins.

November 6, 1972

Yellow paint stripes were painted to divide and identify the different overlays.

November 8, 1972

All the yellow paint stripes were finished.

November 13, 1972

All thermocouples were connected and automatic recorder switched on.

November 14, 1972

The four different start stripes were put on sections 021 and 100.

November 20, 1972

The testing started.

TABLE A-1 MIX DESIGN FOR HIGH ALUMINA CEMENT AND PORTLAND CEMENT-SAND MIX FOR 1 CUBIC YARD

HIGH ALUMINA CEMENT (Section 010)	PORTLAND CEMENT-SAND MIX (Section 040)
7 sacks of Fondre Cement	7 sacks of portland cement
3/8 inch pea-gravel	coarse sand
4 - 4 1/2 US gallons of water per sack	5 US gallons of water per sack
No slump	No slump

TABLE A-2 PORTLAND CEMENT CONCRETE MIX DESIGN[1]

Ingredients[2]	
Cement Type II, lbs.	611
Sand, lbs.	1,462
3/4" - Aggregate, lbs.	1,787
Water, lbs.	208
Darex AEA, oz.	7.5
Properties:	
Air-Entrainment	3.5
Slump	3"

[1] This mix design conforms with the Standard Specifications of the State of Washington for a class AX, 6½ sack type II Portland Cement Concrete Mix.

[2] Expressed as quantities per cubic yard.

TABLE A-3 ASPHALT CONCRETE MIX DESIGNS[1]

GRADING AND ASPHALT REQUIREMENTS

Percentages by Weight Passing Sieves			
	Class B	Class D	Class G[2]
1 1/4" sieve (square opening)	---	---	---
1" sieve (square opening)	---	---	---
3/4" sieve (square opening)	---	---	---
5/8" sieve (square opening)	100	---	---
1/2" sieve (square opening)	90-100	100	100
3/8" sieve (square opening)	75-90	90-100	97-100
1/4" sieve (square opening)	55-75	54-72	55-82
U.S. No. 10 sieve	32-48	12-28	32-48
U.S. No. 40 sieve	11-24	0-10	11-24
U.S. No. 80 sieve	6-15	---	6-15
U.S. No. 200 sieve	3-7	0-3	3-7
Mineral Filler	0-2	---	0-2
Asphalt % of total mixture	4.0-7.5	4-6	4-7.5

[1] These mix designs were taken from the Standard Specifications for Road and Bridge Construction 1972 of the State of Washington.

[2] For section 070, 2% Pliopave was added with the asphalt cement during the mixing. For section 080, the 4-7.5% asphalt was replaced by asphalt extended epoxy.

TABLE A-4 MASTIC ASPHALT CONCRETE MIX DESIGN

GRADING AND ASPHALT REQUIREMENTS

Percentages by Weight Passing Sieves		
	Specification[1]	WSU Minimum
1/2" sieve (square opening)	100	100%
3/8" sieve (square opening)	85-100	98%
1/4" sieve (square opening)	---	86%
U.S. No. 4 sieve	60-80	78%
U.S. No. 8 sieve	50-70	58%
U.S. No. 10 sieve	---	54%
U.S. No. 16 sieve	---	--
U.S. No. 30 sieve	32-50	38%
U.S. No. 40 sieve	---	33%
U.S. No. 50 sieve	---	--
U.S. No. 80 sieve	---	27%
U.S. No. 100 sieve	24-34	26%
U.S. No. 200 sieve	18-28	23%
Bitumen Total (% by weight)	6.5-9.5	9.5
Petroleum Asphalt Cement	5.7-8.2	7.6
Trinidad Epure	1.6-2.5	1.9

Cover Chips: Passing 3/16" sieve #4 / Retained 1/8" sieve #8 — coated with 0.5-1.0% A.C.

[1] Pennsylvania Highway Department specifications

TABLE A-5(a) DESCRIPTION OF POLYMER CEMENT AND POLYMER CONCRETE MIX DESIGN (RING #6)

August 2, 1972	Polymer Concrete Patch for Section 5a (Ring #5) 6 lb. 3 oz. Epon 828 495 g. Crecyl Glycedal Ether CGE 331 g. Furfuryl Alcohol 8 lb. of Above Mix 0.9 lb. DETA diethylenetriamine 6.25 lb. Epoxy 37.5 lb. sand (screened) Used remaining Epoxy for priming.
September 9, 1972	Polymer Cement Concrete (Patch for Section 4b (Ring #5) Mixed Epoxy as per Section 5a 3.5 lb H_2O 7 lb. Portland cement Mixed 35 lb. sand mixed Added 7 lbs. Epoxy Used remaining Epoxy for priming

COMMENTS: Set much slower than straight Epoxy.
Both patches applied over sandblasted surface.

TABLE A-5(b) POLYMER CEMENT CONCRETE MIX DESIGN

Sections 021, 022 and 023

Ring #6

August 25, 1972	Formulation:	8.0 lb.	H_2O	1 part
		16.0 lb.	Cement	2 parts
		16.0 lb.	Epoxy	2 parts
		96.0 lb.	Sand	12 parts
	Epoxy Formulation Resin Mix:			
		Epon 828		85 pt.
		Crecyl Glycedol Ether		15 pt.
		Furfuryl Alcohol		10 pt.
	100 parts resin mix 10 parts diethylenetriamine			

COMMENTS: Water in the sand reduced the amount of water added. This had to be changed as the day progressed as air temperature varied between 65-70°F in the morning to 85-90°F in the afternoon.

The last strip (023), about 3 feet, was covered with 1/4" of Garnet mix using 5 parts garnet, 40 mesh, to 1 part of the above epoxy over 1/2" of the above mix.

The next to the last strip (022) contained Wirand[R] steel fibers furnished by Battelle. The steel fibers caused the epoxy to set very rapidly. It was very hard to mix.

TABLE A-5(c) POLYMER CONCRETE MIX DESIGN

Sections 031, 032, 033 and 034

Ring #6

September 11, 1972	Epoxy Formulation:	85 parts 828	
		15 parts Crecyl Glycedol Ether	
		10 parts Furfuryl Alcohol	
	10 parts Epoxy 1 part Diethylenetriamine	Catalyzed Epoxy	
	1 part Cayalyzed Epoxy 6 parts Sand		

COMMENTS: Three sections of skid resistant toppings were placed at the end of the section at approximately 1/4" depth. The first section (032) contained 1 part epoxy and 6 parts garnet (same size as used in 023). The center section (033) contained 1 part epoxy, 2.25 parts sand and 2.25 parts of Black Diamond (a mine slag). The last section (034) contained 1 part epoxy, 4 parts sand, and 1/2 part rubber as received from United Paving.

The above remarks were made by Max Huftaker of Materials Chemistry Section, Washington State University.

TABLE A-6 FLEXURAL TESTS[1] ON EPOXY WIRAND® CONCRETE[2]

Section 022

Identification	Size and Amount of Wires	Curing Time	Proportional Limit psi	Ultimate Flexural Strength psi
0367	.006"x1/2"-200#/yd	28 days in air at 72°F	356	1699
0368	" "	"	638	1521
0369	" "	"	675	1438
AVERAGE	.006"x1/2"-200#/yd	28 days in air at 72°F	556	1553

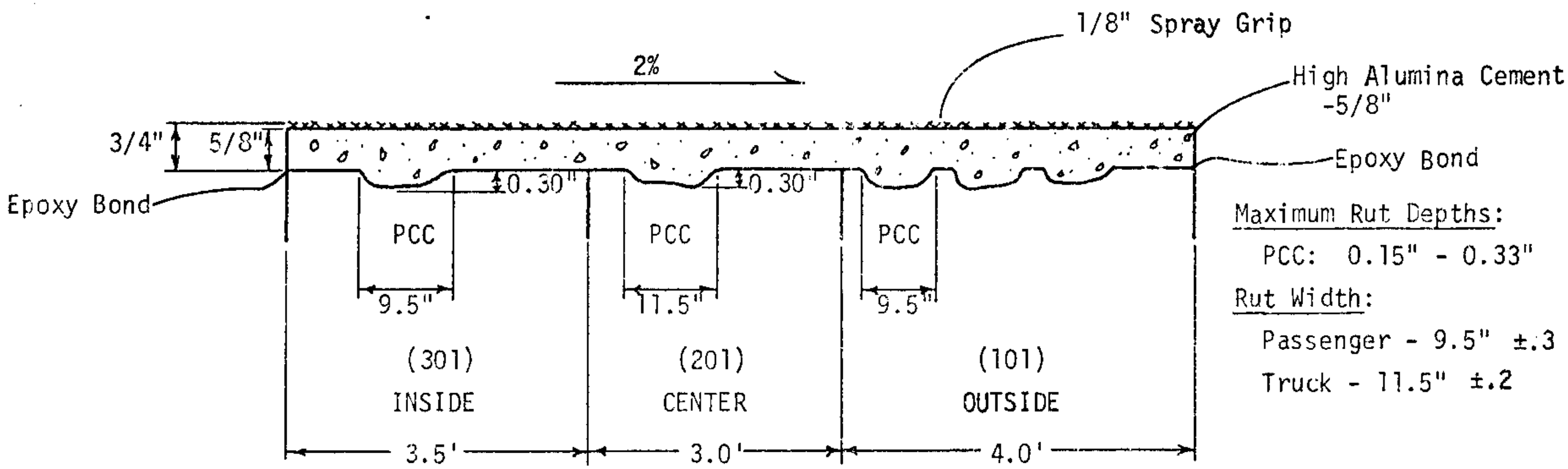
[1] Flexural test done on three beams, each 4" x 4" x 14" by Battelle Pacific Northwest Laboratories.

[R] Registered trademark of Battelle Development Corporation

[2] This is called Polymer Steel Fibers Concrete in the report.

RING #6

Section 1a/010

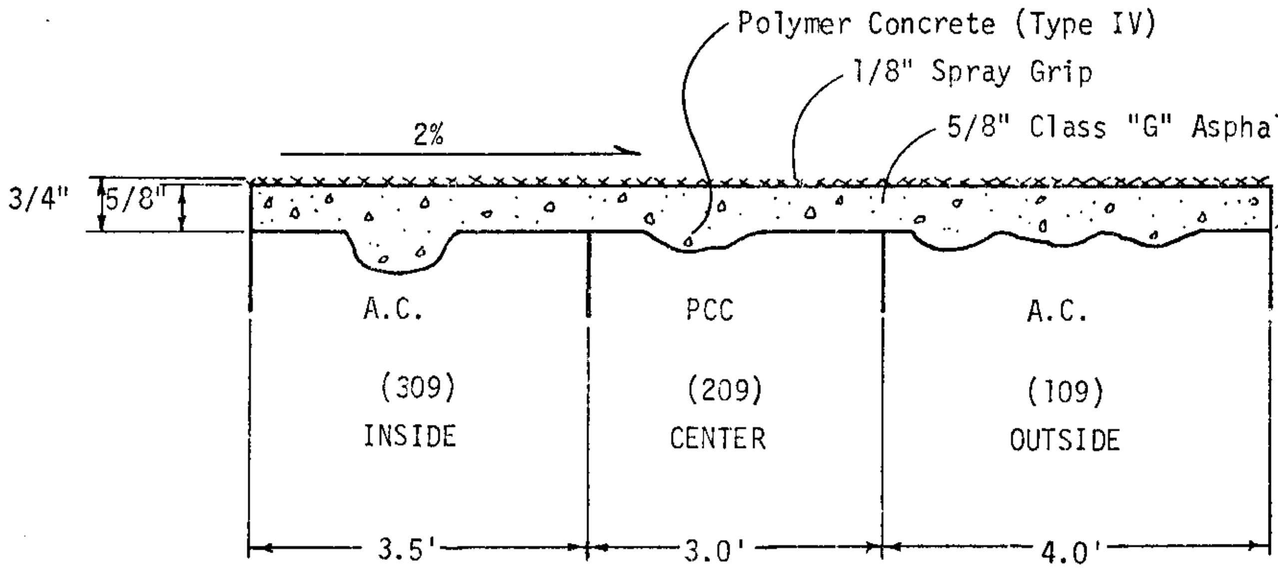


Area: 10.5' x 21.0' = 220.5 sq. ft.

Figure A-1: Typical Cross-section of Overlay

RING #6

Section 3A/050



Maximum Rut Depths:

PCC = 0.25"

A.C. = 0.35" - 1.00"

Rut Width:

Passenger - 9.5" ±.3

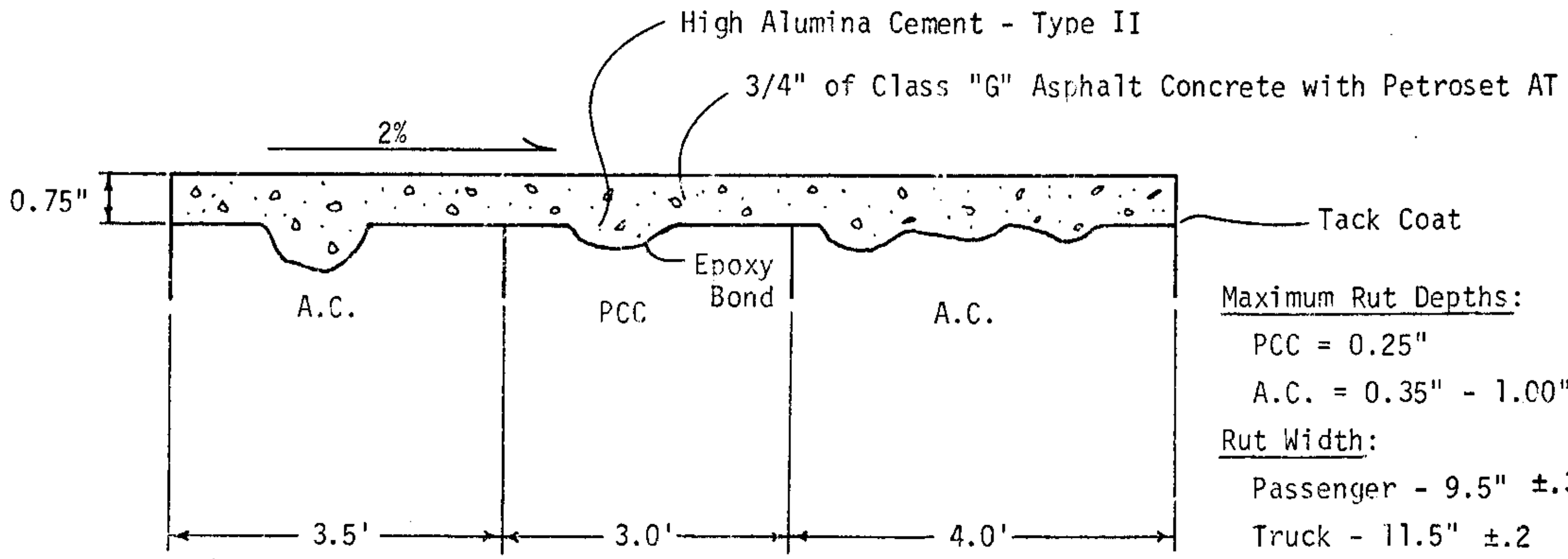
Truck - 11.5" ±.2

Area: 10.5' x 21.0' = 220.5 sq. ft.

Figure A-2: Typical Cross-section of Overlay

RING #6

Section 5b/100



Maximum Rut Depths:

PCC = 0.25"

A.C. = 0.35" - 1.00"

Rut Width:

Passenger - 9.5" ±.3

Truck - 11.5" ±.2

Area: 10.5' x 21.0' = 220.5 sq. ft.

Figure A-3: Typical Cross-section of Overlay

APPENDIX B

PROFILOMETER

PURPOSE

Initially, it was thought that it would be advantageous to have an instrument capable of simultaneously averaging a number of adjacent profiles.

This average reading would increase the accuracy beyond that obtainable from single line shadowgraphs subject to parallax and individual aggregate distortions and single line profile devices also subject to individual aggregate error.

METHOD

A practical compromise was selected between the ideal number of adjacent points and the structural limitations of the equipment. It was decided that the initial model should sample and average ten lines spanning three inches.

Each sampling pin was attached to a capacitor plate which would pivot at a radius of 10 inches and vary in capacitance linearly with pin position. As the pins are drawn across the surface, each pin moves individually varying 10% of the total capacitance change that would be obtained if all pins moved the same distance. Thus, when all pins are moved through their entire range, 100% of the capacitance change is obtained within the gauged capacitance.

This motion summation capacitor is then read by a capacitor bridge circuit with a dc voltage output proportional to capacitance. This output voltage is then recorded on a chart recorder calibrated to give full scale deflection for one-inch average change in profile.

The chart and pin carriage speed were selectively matched to give a calibrated display for a given distance of measured profiles.

PROBLEMS

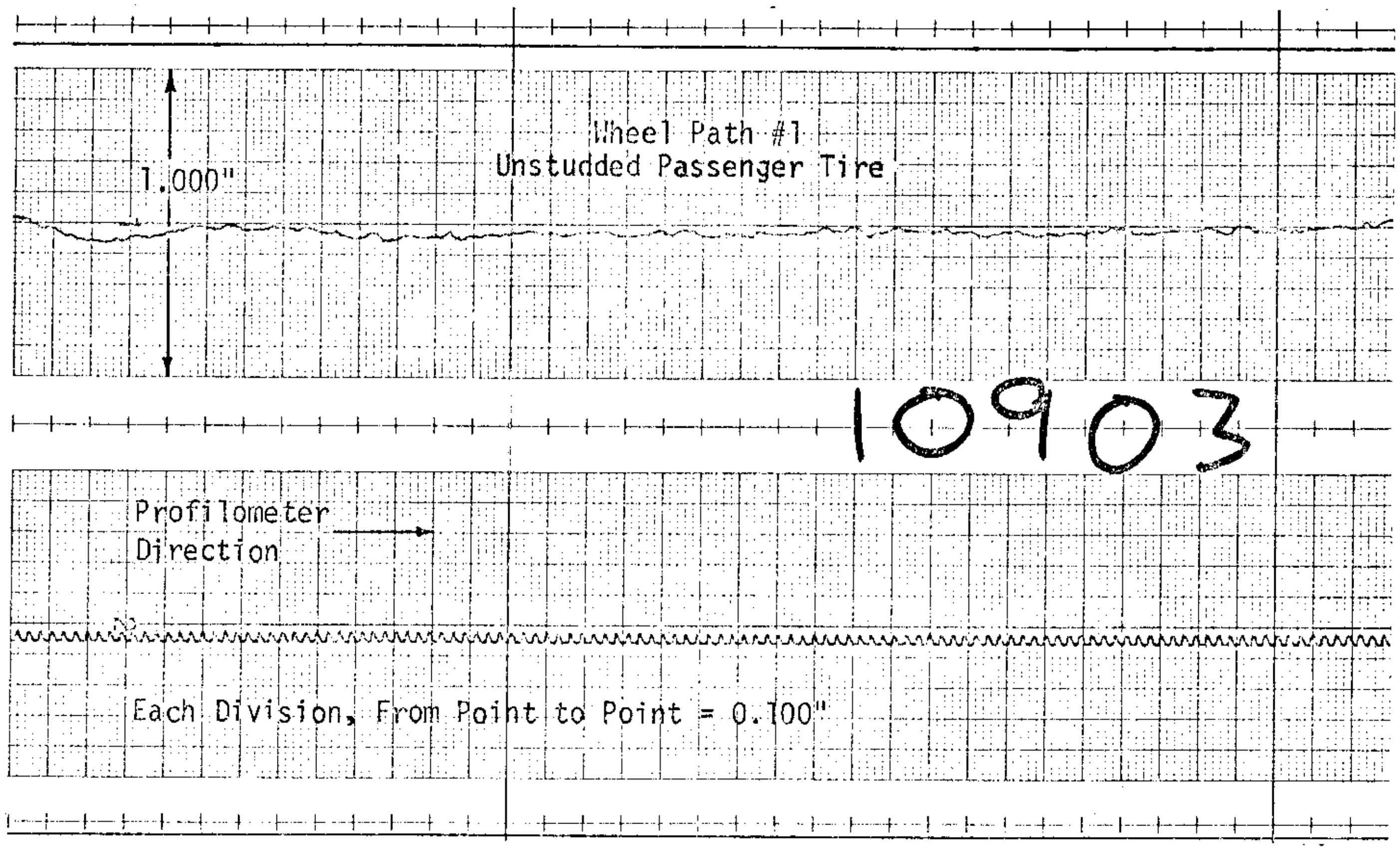
The following corrections were incorporated into the modified model to eliminate minor problems. These were as follows:

1. Structural changes in support beam to eliminate errors due to beam sag, which were removed from data by computer techniques for Ring #5.
2. The addition of a distance traveled indicator and marker to allow corrections and verifications in carriage drive.
3. The addition of a digital recorder output to facilitate the direct input of the data to computers.

LIMITATIONS

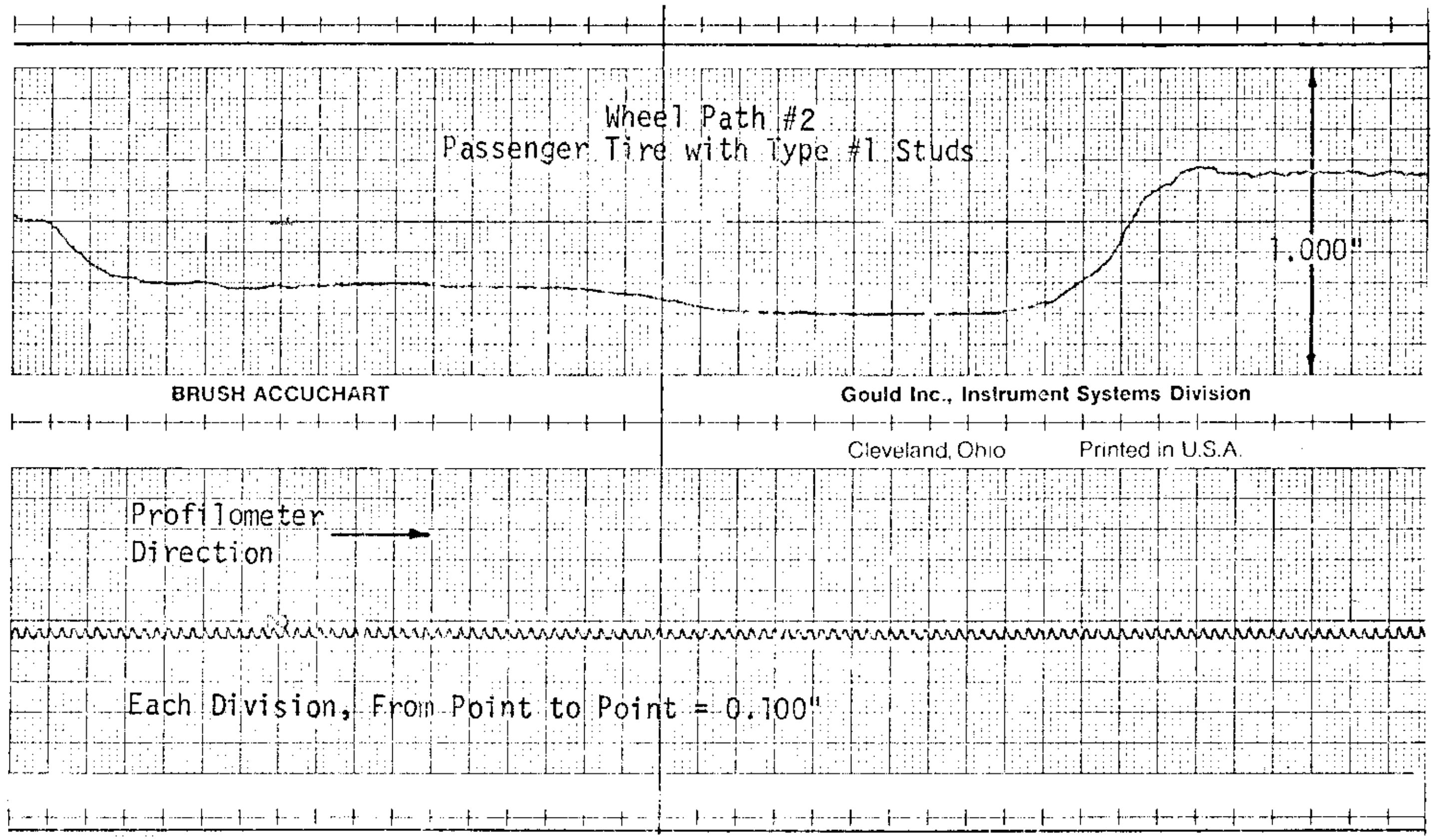
Since it is impossible to obtain a perfect point source, the cross sectional area of the groove is reduced by the cross sectional area of the rod measuring the groove.

APPENDIX B (Continued)



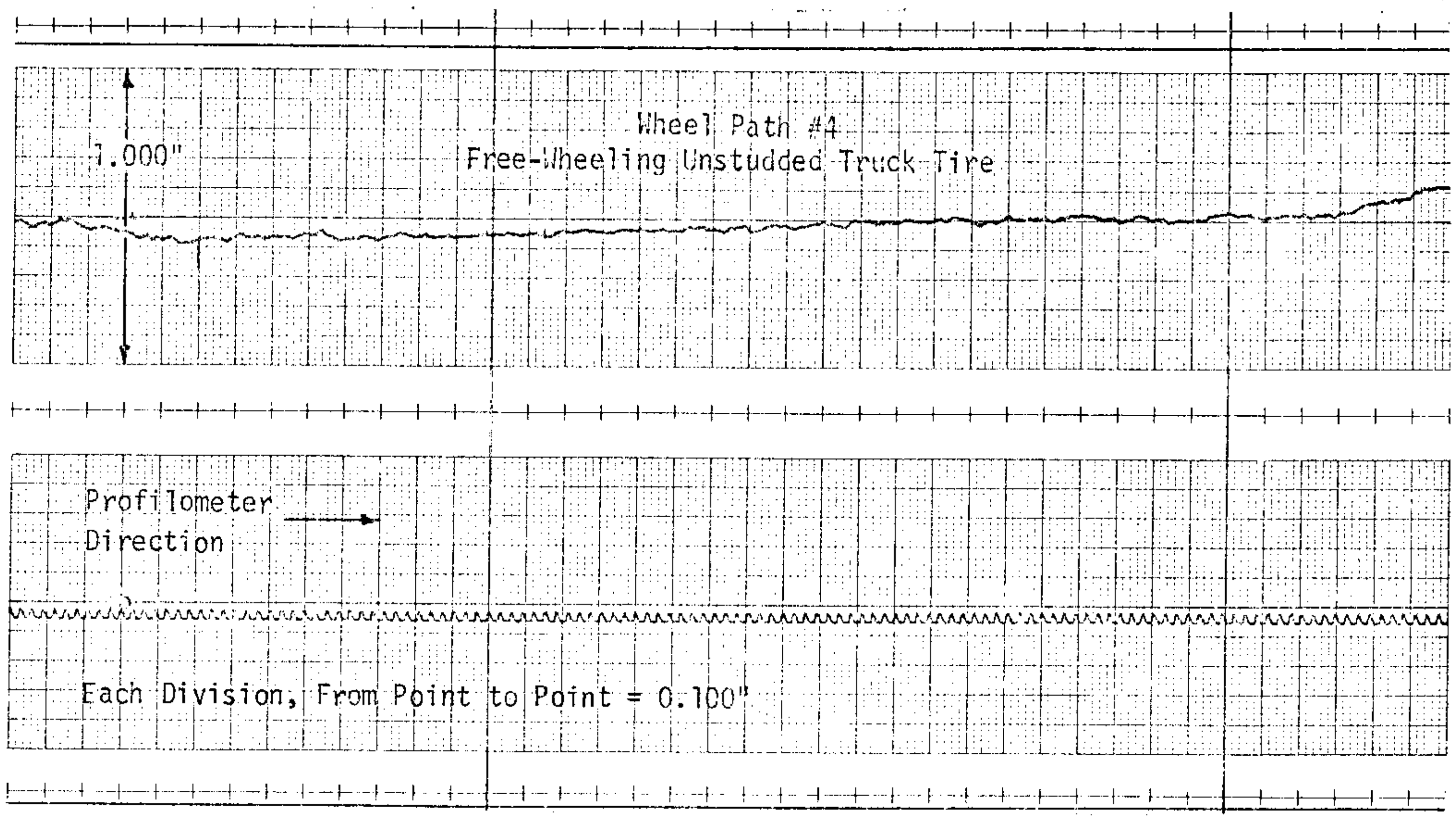
-Horizontal Scale Compressed-
-Vertical Scale Expanded-

Figure B-1A: A Typical Strip Chart obtained from the WSU Profilometer.
Section 090: Class "G" Asphalt Concrete, Inside Track,
Reference Pin Series #3
Wheel Applications: 2,151,306



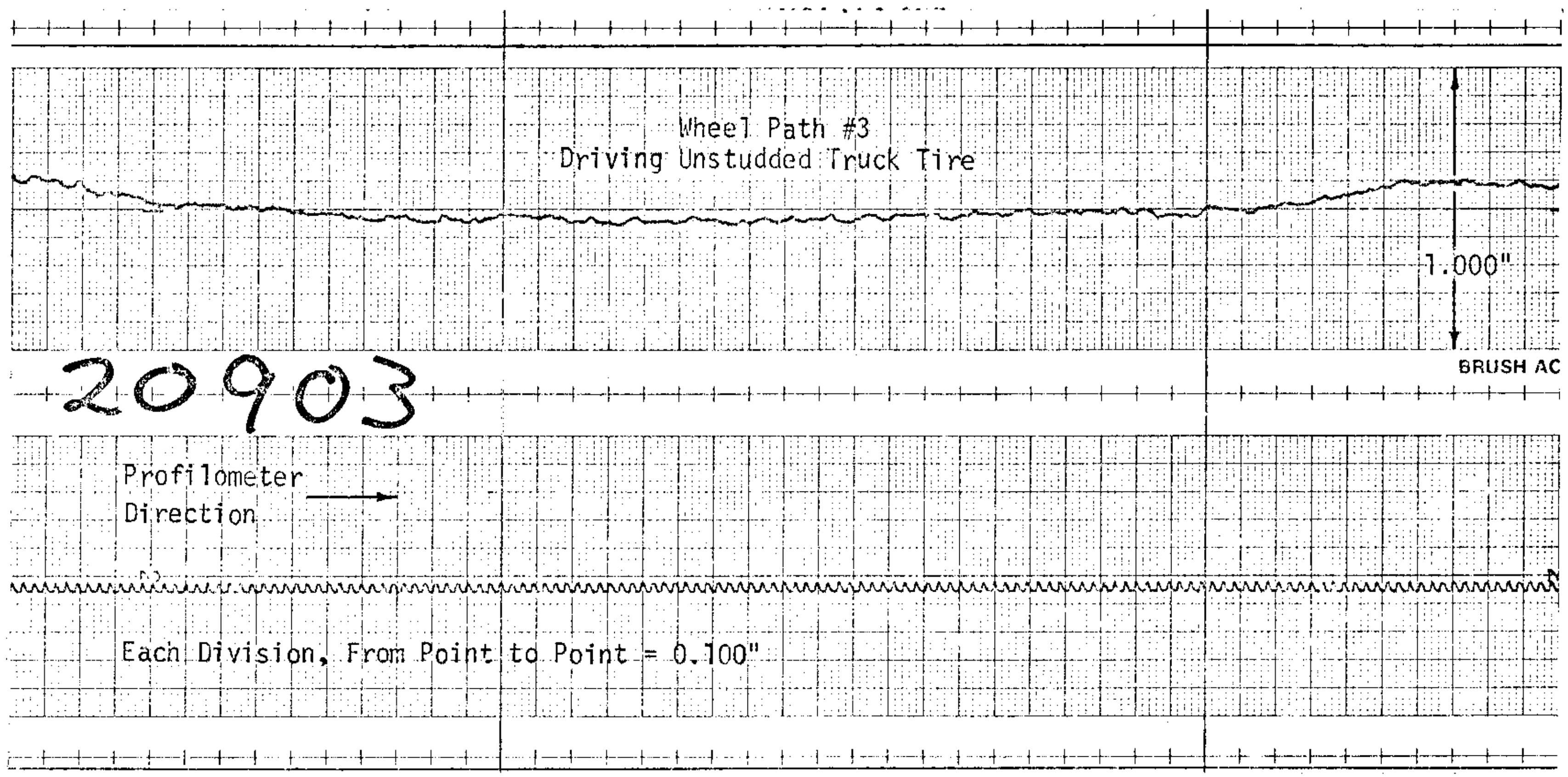
-Horizontal Scale Compressed-
-Vertical Scale Expanded-

Figure B-1B: A Typical Strip Chart obtained from the WSU Profilometer.
Section 090: Class "G" Asphalt Concrete, Inside Track,
Reference Pin Series #3
Wheel Applications: 2,151,306



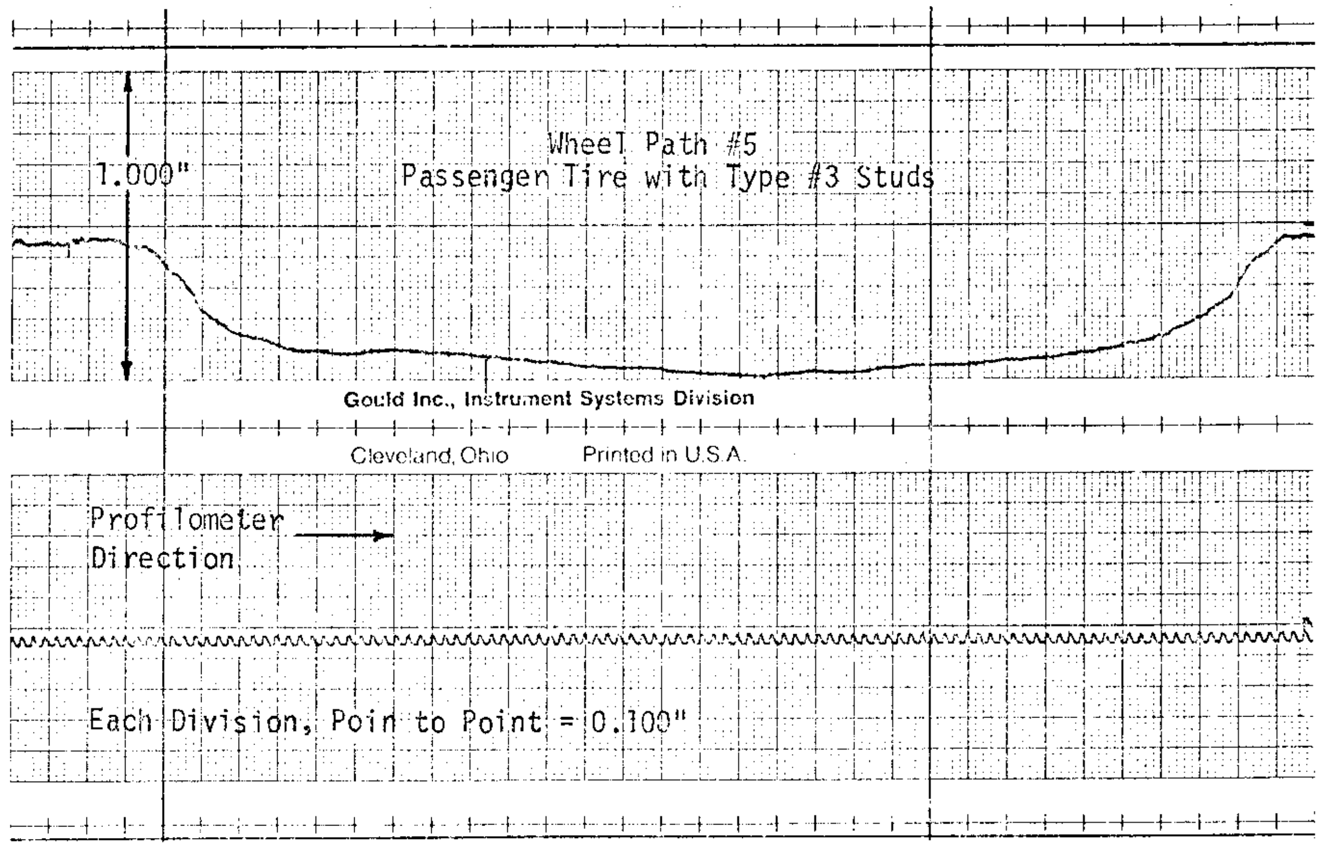
-Horizontal Scale Compressed-
-Vertical Scale Expanded-

Figure B-2A: A Typical Strip Chart obtained from the WSU Profilometer
Section 090: Class "G" Asphalt Concrete; Center Track,
Reference Pin Series #3
Wheel Applications: 2,151,306



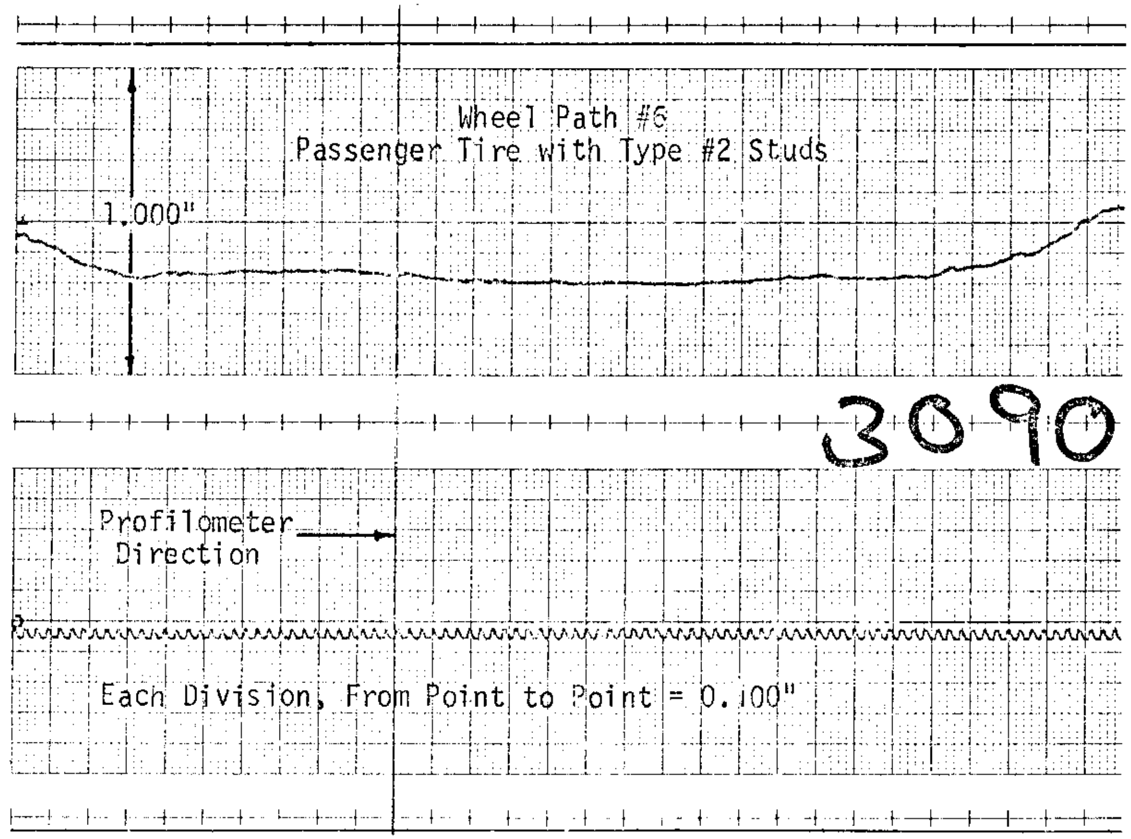
-Horizontal Scale Compressed-
-Vertical Scale Expanded-

Figure B-2B: A Typical Strip Chart obtained from the WSU Profilometer.
Section 090: Class "G" Asphalt Concrete, Center Track,
Reference Pin Series #3
Wheel Applications: 2,151,306



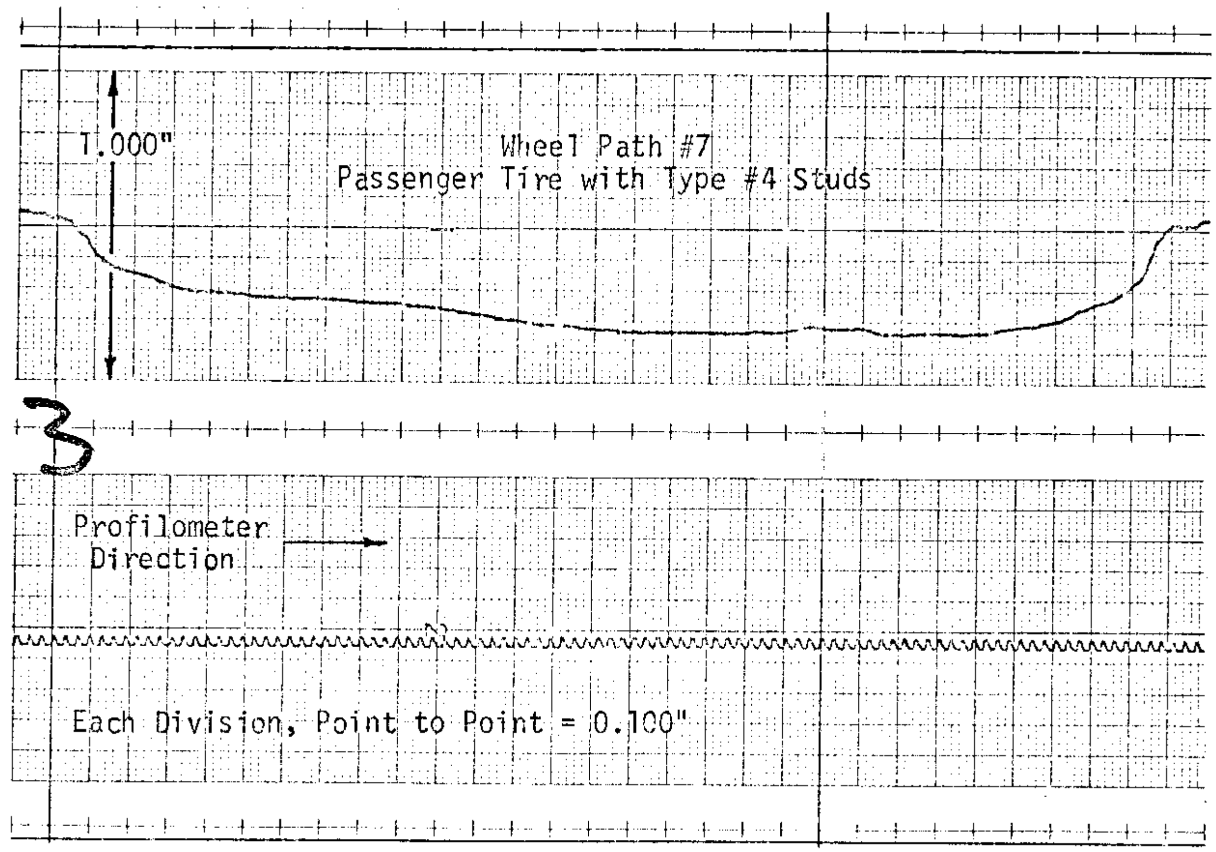
-Horizontal Scale Compressed-
-Vertical Scale Expanded-

Figure B-3A: A Typical Strip Chart obtained from the WSU Profilometer.
Section 090: Class "G" Asphalt Concrete; Outside Track,
Reference Pin Series #3
Wheel Applications: 717,102



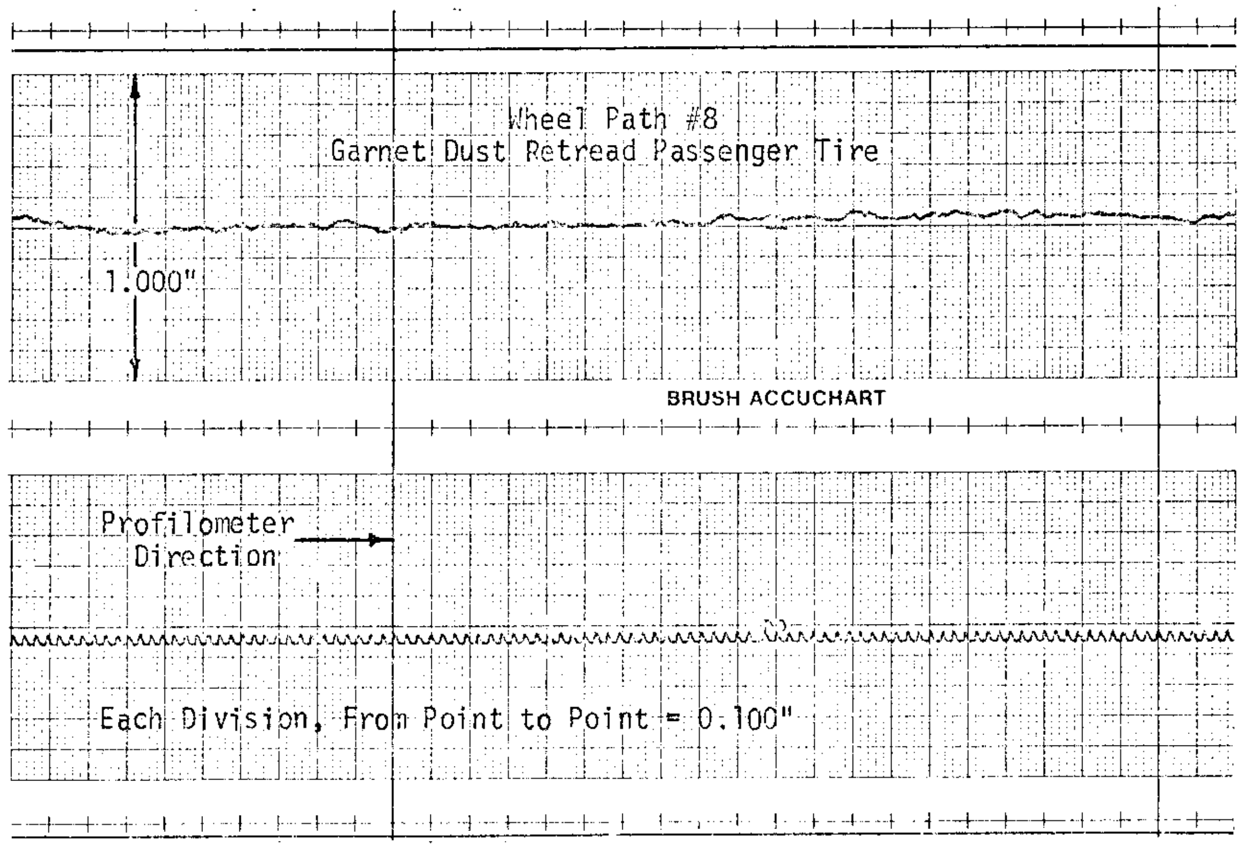
-Horizontal Scale Compressed-
-Vertical Scale Expanded-

Figure B-3B: A Typical Strip Chart obtained from the WSU Profilometer.
Section 090: Class "G" Asphalt Concrete; Outside Track, Reference Pin Series #3
Wheel Applications: 717,102



-Horizontal Scale Compressed-
-Vertical Scale Expanded-

Figure B-3C: A Typical Strip Chart obtained from the WSU Profilometer.
Section 090: Class "G" Asphalt Concrete; Outside Track, Reference Pin Series #3
Wheel Applications: 717,102



-Horizontal Scale Compressed-
-Vertical Scale Expanded-

Figure B-3D: A Typical Strip Chart obtained from the WSU Profilometer.
Section 090: Class "G" Asphalt Concrete; Outside Track, Reference Pin Series #3
Wheel Applications: 717,102

APPENDIX C

DATA PROCESSING PROCEDURES

INTRODUCTION

The large quantities of data involved in this project and the accuracy of that data make the handling and analysis of great interest. Great care has been taken to obtain any and all data that might be of significance to this project. Types of data recorded include: pavement channeling and deformation, tire wear, stud wear, pavement temperature, rainfall, snowfall, and skid tests. The collection of the data at the degree of accuracy desired was made possible through the use of equipment designed and built by the resident engineers of the Washington State University, College of Engineering Research Division.

When possible, data was taken by more than one method. This provided a double check on the significance of our findings.

REDUCTION AND COMPUTATION

After collection, all pavement wear data is automatically reduced on paper tape, which is then transferred to IBM punch cards. This is an excellent high accuracy method for converting graphic or plotted data to computer compatible form and eliminates human error. All other data is placed on punch cards by hand and verified.

The data cards are then fed to an IBM 360/67 computer. Additional equipment includes a Calcomp Pen Plotter that is used to produce all graphs and lots for the project. The computer program that makes the raw data understandable was developed specifically for Project 1168 and is constantly being added to and modified to further meet necessary requirements.

HIGHWAY COMPUTER PROGRAM

This program was written in Fortran IV programming language and is designed to be able to be enlarged easily to continue to fit the ever growing needs of the project. It includes the Calcomp Plotter within its control region, making it possible to obtain graphs of all data, raw or calculated, against all other data. Calculated data includes average and maximum pavement wear and multiple sit average pavement wear for each of the thirteen types of pavement. All data is available to the program as further calculations and outputs are anticipated.

APPENDIX D

CAMERA WIRE-BOX TECHNIQUE

Procedure for Recording Pavement Wear on Test Track

Ring #6

1. A. Camera track mechanism placed on two reference pins and levels with camera box in position closest to pin-end.
   (Hands Off) Levels are marked with arrow towards center to index appropriate level to use.

   B. Each set of pins was checked for clearance, and when necessary, adjusted - by raising pin or changing nut thickness to maintain proper contact. Each pin set when moved was re-leveled with respect to each other.

2. The pictures were then taken in sequence along the rail starting from the pin end to the opposite side. EXCEPTION: center ring in 050 to 080 region, the fourth picture of the sequence deleted because camera track off edge of pavement.

3. Reference height (calibration) ruler system was placed at the pavement edges where possible while the center track placement was at 42" on the track ruler, a position outside the drive wheel track.

   INSIDE: generally at 8" or 9" on track ruler except 050 and 080
   CENTER: 42" on track ruler
   OUTSIDE: track edge averaging just inside 47" on track ruler

4. Inside pin sets used only for inside ring
   Outside pin sets used for both center and outside

5. Started at 010 inside ring clockwise completing stations 1, 2, 3
   then 010 center clockwise through 1, 2, 3
   then 010 outer ring clockwise through 1, 2, 3

NOTATIONS: Pins in center of 090 especially loose. Many pins were loose in mounting holes. Some had been depressed by the roller in 010.

Sun can enter picture area under skid system which is not long enough. Operator must stand to mask sun from picture area when necessary. Level does shift as camera box moves down track about one line on level. Occasionally, level would shift drastically, possibly due to pin settling under weight of system.

APPENDIX E

PHOTOGRAPHIC TECHNIQUE FOR SHOWING PAVEMENT WEAR

OBJECTIVE: To show pavement wear and distortion in reference to straight edge.

EQUIPMENT

35mm Topcon camera - (motor drive used)
waist level finder
58mm f1:3.5 macro lens

Cambo Tripod ball head

Metal base with screw legs

Gossen meter

1/4" x 3" x 48" steel straight edge, painted white with center marks

C-clamp to hold edge verticle

Card holder for straight edge

Set of 3" x 5" ID cards with ring section, subsection, and row pre-marked

Chalk line

Ruler (tape measure)

1. Identify locations to be photographed by instrument reference pin location.
2. Locate and mark center between instrument pins.
3. Using center mark between pins apply chalk lines radially on track across full width of instrument rows. These lines identify position of straight edge in photographs. Center mark on straight edge is positioned at the center of track group being photographed. (Example: Straight edge center for tracks 5, 6, 7, 8 would be between tracks 6 and 7.)
4. Measure and mark the following positions. (These marks identify the camera position.)
   a) All of ring 1 between tracks 1 and 2 at 3 1/2 ft. counter-clockwise from the line.
   b) All of ring 2 between tracks 3 and 4 at 4 1/2 ft. counter-clockwise from the line.
   c) All of ring 3 between tracks 6 and 7 at 7 ft. counter-clockwise from the line.
5. Position camera on metal base using Cambo ball head. (Camera lens facing single screw leg end.)

5. (Continued) Focus on straight edge and adjust exposure.- With appropriate ID card in holder in center of straight edge expose one frame, advance to the next station doing each complete ring without a focus change for that ring.

APPENDIX F

TABLE F-1

LOG OF OPERATIONS FOR RING NO. 6 - 1972-73

Month	Day	Total Operating Time		Speed MPH	Revolutions	
		Hours	Minutes		Daily	Accumulated
November	20	1	00	3.5	170	170
	21	7	00	24	3578	3748
	22	2	10	25	2224	5074
	27	10	48	25	4926	10000
	29	6	00	25	2715	12715
	30	11	20	25	4619	17334
December	1	18	39	25	7666	25000
	4	9	25	25	4521	29521
	5	17	50	20-25	8361	37882
	6	16	50	20-22	8386	46268
	7	10	05	22	3878	50146
	13	4	32	22-15	928	52174
	14	12	20	20	3981	56155
	15	11	55	20	6530	62685
	16	14	02	20	4838	67423
	17	20	02	20	7367	74890
	18	5	45	20	2671	77561
	19	16	55	20	7076	84637
	20	15	13	20	4340	88977
	21	20	15	20	8573	96550
	22	8	43	20	3450	100000
January	5	9	52	20	2570	102570
	6	22	18	20	7954	110524
	7	14	39	20	5265	115789
	8	14	00	20	4665	120454

TABLE F-1 (Continued)

LOG OF OPERATIONS FOR RING NO. 6 - 1972-73

Month	Day	Total Operating Time		Speed MPH	Revolutions	
		Hours	Minutes		Daily	Accumulated
January	9	20	10	20	8060	128514
	10	22	20	20	7952	136466
	11	18	47	20	7818	143284
	12	16	54	20	6717	150001
	14	4	01	20	1669	151670
	15	15	25	20	5621	157297
	16	8	53	20	2749	160030
	17	8	57	20	2136	162146
	18	21	29	20	8499	170645
	19	18	03	20	7767	178412
	20	14	54	20	5422	183834
	21	22	58	20	8325	192159
	22	12	10	20	5464	197623
	23	3	35	21	1387	200010
	29	8	06	20	3648	203658
	30	19	08	21	7585	211243
	31	21	01	20	7916	219159
February	2	8	05	20	2368	227527
	3	14	23	20	5050	232577
	4	20	58	20	8434	241011
	5	20	56	20	8515	249019
	6	2	30	20	498	250024
	7	7	05	20	2527	252551
	8	16	51	20	7660	260221
	9	22	08	20	8048	268269
	10	11	10	20	5401	273670
	11	4	41	20	1613	275283
	12	7	15	20	2640	277923
	13	21	39	20	8011	285934

TABLE F-1 (Continued)

LOG OF OPERATIONS FOR RING NO. 6 - 1972-72

Month	Day	Total Operating Time Hours	Total Operating Time Minutes	Speed MPH	Revolutions Daily	Revolutions Accumulated
February	14	21	10	20	7557	293491
	15	16	23	20	5568	299059
	16	2	21	20	941	300000
	26	6	54	20	2796	302796
	27	9	50	20	2893	305689
	28	5	41	20	2232	308921
March	1	20	58	20	7939	316860
	2	19	51	20	6771	323731
	3	23	25	20	8565	332296
	4	17	07	20	6560	338856
	5	8	51	20	3293	342149
	6	21	00	20	7960	350109
	9	4	33	20	1551	351660
	10	20	58	20	7507	359167
	11	23	27	20	8270	367437
	12	21	36	20	7757	375194
	13	22	45	20	7596	382790
	14	18	24	20	7859	390649
	15	21	20	20	6937	397586
	16	12	8	20	4259	401845
	17	16	26	20	5937	407782
	18	1	55	20	560	408495
	19	00	10	20	53	408495
	20	12	03	20	4298	412793
	21	19	59	20	7796	420589
	22	22	13	20	7836	428425
	23	22	20	20	7485	435910
	24	21	35	20	7733	443643

TABLE F-1 (Continued)

LOG OF OPERATIONS FOR RING NO. 6 - 1972-73

Month	Day	Total Operating Time		Speed MPH	Revolutions	
		Hours	Minutes		Daily	Accumulated
March	25	15	07	20	5392	449035
	26	14	45	20	5216	454251
	27	14	33	20	5185	459436
	28	21	32	20	7749	467185
	29	20	15	20	7344	474529
	30	22	28	20	7733	482262
	31	20	38	20	8025	490287
April	1	16	11	20	5767	496054
	2	16	10	20	5820	501874
	3	15	27	20	6409	508283
	4	20	56	20	6957	515240
	5	22	39	20	8024	523264
	6	22	34	20	8167	531431
	7	23	06	20	8276	539707
	8	24	00	20	8767	548474
	9	15	06	20	5541	554015
	10	15	51	20	5690	559705
	11	13	49	20	5733	565438
	12	22	7	20	8321	573759
	13	23	10	20	8318	582077
	14	22	33	20	8056	590133
	15	22	17	20	7955	598088
	16	20	40	20	7639	605727
	17	20	22	20	7362	613089
	18	20	50	20	7795	620884
	19	22	30	20	7911	628795
	20	20	48	20	7768	636563
	21	23	53	20	8241	644804
	22	21	10	20	7713	652517

TABLE F-1 (Continued)

LOG OF OPERATIONS FOR RING NO. 6 - 1972-73

Month	Day	Total Operating Time		Speed MPH	Revolutions	
		Hours	Minutes		Daily	Accumulated
April	23	22	02	20	7631	660148
	24	21	05	20	7350	667498
	25	18	51	20	6601	674099
	26	19	20	20	7226	681325
	27	23	27	20	8541	689866
	28	22	04	20	8041	697907
	29	21	27	20	8695	706603
	30	17	18	20	7758	714102
May	1	6	09	20	2741	717102
TOTAL	79 days	1896	43			

APPENDIX G

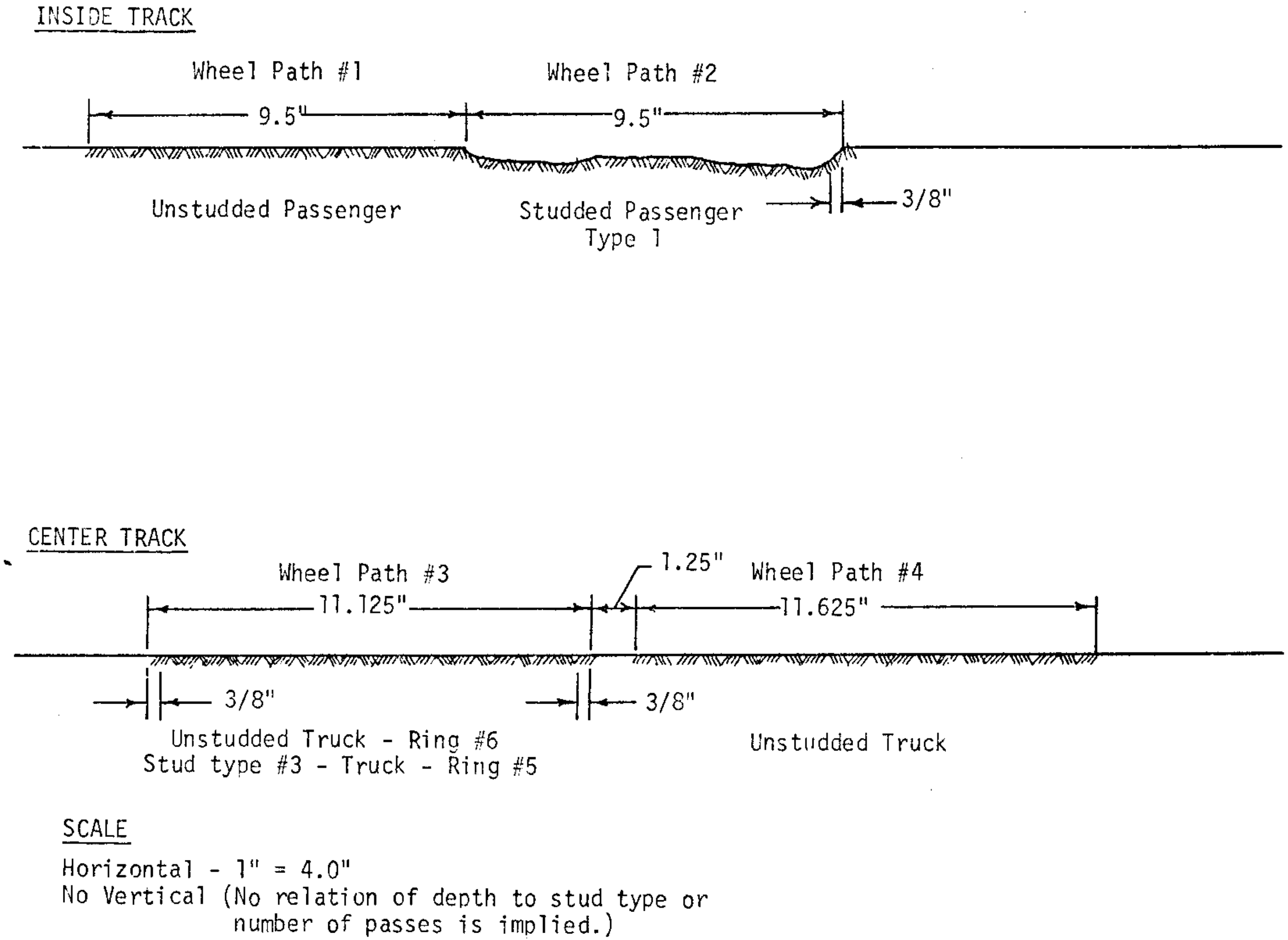
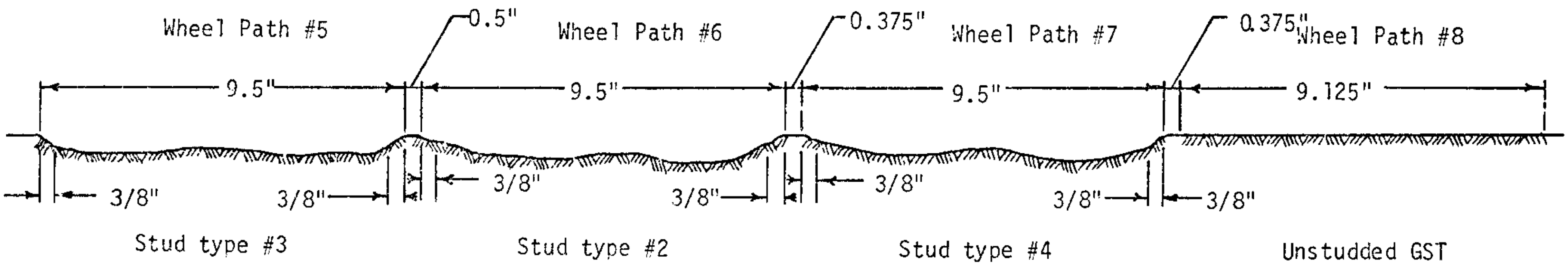


Figure G-1: Actual Widths of Wheel Paths at WSU Test Track
Eccentricity = 1.75 inches
Rings #5 and #6

OUTSIDE TRACK



SCALE

Horizontal - 1" = 4.0"
No Vertical (No relation to depth to stud type or number of passes is implied.)

Figure G-2: Actual Widths of Wheel Paths at WSU Test Track
Eccentricity = 1.75 inches
Rings #5 and #6

APPENDIX H

TABLE H-1

DAILY AIR AND PAVEMENT TEMPERATURES AND PRECIPITATION

Month and Year	Day	Test Track[1] Service °F		Palouse[2] Conservation Service °F		Daily[2] Precipitation (inches)	Pavement[1,3] Temperature °F	
		High	Low	High	Low		High	Low
November, 1972	17	41	37	56	38	.04	40	36
	18	42	32	42	36	T	36	31
	19	46	32	43	34	.14	44	29
	20	40	27	46	34	T	38	27
	21	42	23	40	30	-	43	30
	22	40	20	40	26	-	39	25
	23	34	31	44	30	.02S	30	26
	24	39	31	36	32	-	36	28
	25	42	28	40	32	.35	32	27
	26	42	30	43	34	-	37	27
	27	37	29	39	27	-	35	25
	28	39	24	36	28	-	38	25
	29	34	28	36	26	-	30	24
	30	38	28	36	31	-	29	24
December, 1972	1	52	31	48	32	.03	38	26
	2	33	17	51	31	.04S	37	24
	3	22	13	35	20	-	23	21
	4	12	0	24	7	-	23	21

TABLE H-1 (Continued)

DAILY AIR AND PAVEMENT TEMPERATURES AND PRECIPITATION

Month and Year	Day	Test Track[1] Service °F		Palouse[2] Conservation Service °F		Daily[2] Precipitation (Inches)	Pavement[1,3] Temperature °F	
		High	Low	High	Low		High	Low
December, 1972	5	15	-1	15	0	-	19	8
	6	14	9	14	6	-	16	10
	7	12	0	14	3	TS	18	8
	8	0	-10	13	-9	-	14	-1
	9	6	-14	4	-10	-	16	-5
	10	10	-4	6	-8	-	17	-4
	11	12	5	10	-8	-	12	5
	12	12	-9	14	10	.05S	12	8
	13	18	-9	13	-4	TS	14	8
	14	24	10	20	7	TS	18	14
	15	27	15	24	12	-	18	14
	16	36	25	32	19	.29	24	18
	17	36	35	37	32	.29	25	14
	18	44	33	39	35	.17	33	25
	19	45	40	46	34	.04	30	26
	20	49	35	47	37	.37	34	26
	21	52	42	50	41	.78	36	32
	22	43	36	54	37	.87	33	30
	23	43	36	43	38	.66	32	28

TABLE H-1 (Continued)

DAILY AIR AND PAVEMENT TEMPERATURES AND PRECIPITATION

Month and Year	Day	Test Track[1] Service °F		Palouse[2] Conservation Service °F		Daily[2] Precipitation (Inches)	Pavement[1,3] Temperature °F	
		High	Low	High	Low		High	Low
December, 1972	24	40	32	44	36	.08	32	28
	25	45	34	39	34	-	33	26
	26	45	34	45	35	-	38	30
	27	46	33	47	40	-	35	28
	28	33	24	50	30	.06S	32	24
	29	30	18	34	19	-	25	20
	30	31	25	31	22	.03S	23	22
	31	32	16	32	24	-	28	20
January, 1973	1	35	16	34	19	.12	22	19
	2	24	10	39	24	-	22	17
	3	18	7	32	19	-	20	14
	4	20	16	27	8	TS	21	16
	5	17	12	20	12	.01S	22	21
	6	12	-8	22	-6	.03S	20	18
	7	14	-10	14	-8	-	19	16
	8	16	-9	15	-6	-	18	15
	9	16	1	13	-5	-	16	14
	10	27	2	15	2	-	18	14
	11	34	24	27	11	.11	14	18

TABLE H-1 (Continued)

DAILY AIR AND PAVEMENT TEMPERATURES AND PRECIPITATION

Month and Year	Day	Test Track[1] Service °F		Palouse[2] Conservation Service °F		Daily[2] Precipitation (Inches)	Pavement[1,3] Temperature °F	
		High	Low	High	Low		High	Low
January, 1973	12	40	33	39	22	.43S	25	24
	13	49	34	42	13	.60	28	24
	14	50	38	49	40	T	31	25
	15	51	40	52	41	.04	31	23
	16	42	31	52	40	.41	32	24
	17	44	32	45	33	-	32	24
	18	43	34	43	32	.04	31	26
	19	34	27	42	30	-	28	24
	20	34	25	34	26	-	24	23
	21	38	25	34	28	-	27	23
	22	40	25	37	25	-	25	22
	23	41	32	35	27	-	30	25
	24	35	25	42	34	T	32	23
	25	31	21	43	32	-	28	17
	26	33	21	36	20	-	26	19
	27	39	27	31	20	-	28	22
	28	38	26	33	23	-	27	23
	29	38	32	40	30	TS	26	24
	30	42	32	38	31	-	33	24

TABLE H-1 (Continued)

DAILY AIR AND PAVEMENT TEMPERATURES AND PRECIPITATION

Month and Year	Day	Test Track[1] Service °F		Palouse[2] Conservation Service °F		Daily[2] Precipitation (Inches)	Pavement[1,3] Temperature °F	
		High	Low	High	Low		High	Low
January, 1973	31	40	25	42	30	.08S	30	25
February, 1973	1	40	24	38	25	-	33	23
	2	41	33	38	28	-	33	25
	3	41	34	40	33	-	33	26
	4	37	22	40	28	.01	38	24
	5	36	21	38	22	-	33	22
	6	38	18	35	20	-	32	21
	7	43	16	36	16	-	34	19
	8	37	14	41	18	-	31	18
	9	41	20	36	21	-	29	21
	10	35	26	41	30	.45S	25	24
	11	39	21	34	26	-	27	24
	12	39	17	38	22	-	31	23
	13	38	20	35	20	-	31	22
	14	45	19	38	19	-	34	23
	15	43	31	39	29	.03	35	24
	16	47	31	39	30	-	40	24
	17	39	34	43	33	.03	31	23

TABLE H-1 (Continued)

DAILY AIR AND PAVEMENT TEMPERATURES AND PRECIPITATION

Month and Year	Day	Test Track[1] Service °F		Palouse[2] Conservation Service °F		Daily[2] Precipitation (Inches)	Pavement[1,3] Temperature °F	
		High	Low	High	Low		High	Low
February, 1973	18	44	29	36	30	-	39	24
	19	44	26	41	28	-	38	24
	20	50	28	36	26	-	45	22
	21	53	28	44	29	-	45	24
	22	51	29	48	30	-	42	23
	23	54	32	49	32	-	45	26
	24	47	36	51	36	-	37	28
	25	54	38	46	38	.05	41	31
	26	56	38	52	38	-	44	29
	27	55	34	44	36	-	50	31
	28	51	38	53	38	.19	43	34
March, 1973	1	47	36	40	35	.13	37	30
	2	47	34	47	33	-	46	27
	3	49	33	46	33	-	43	28
	4	45	30	47	38	T	38	30
	5	48	30	43	32	-	45	29
	6	56	35	47	33	-	54	29
	7	55	37	53	36	-	51	37
	8	55	31	53	30	-	58	31

TABLE H-1 (Continued)

DAILY AIR AND PAVEMENT TEMPERATURES AND PRECIPITATION

Month and Year	Day	Test Track[1] Service °F		Palouse[2] Conservation Service °F		Daily[2] Precipitation (Inches)	Pavement[1,3] Temperature °F	
		High	Low	High	Low		High	Low
March, 1973	9	48	35	53	36	T	46	35
	10	45	35	46	38	.35	36	31
	11	47	2[illegible]	44	28	-	46	31
	12	42	28	46	30	.08	36	26
	13	44	33	40	30	.32	40	27
	14	45	27	43	25	-	41	26
	15	54	29	42	29	-	51	26
	16	58	36	52	37	.03	46	33
	17	42	32	55	30	-	37	28
	18	49	28	32	27	-	46	25
	19	59	--[4]	46	31	--	--[4]	--[4]
	20	--[4]	--	57	39	.13	--	--
	21	--	--	44	36	-	--	--
	22	--	--	45	32	-	46	37
	23	--	--	50	30	-	52	36
	24	--	--	54	31	-	--	--
	25	--	--	58	36	T	--	--
	26	47	44	57	33	-	45	37

TABLE H-1 (Continued)

DAILY AIR AND PAVEMENT TEMPERATURES AND PRECIPITATION

Month and Year	Day	Test Track[1] Service °F		Palouse[2] Conservation Service °F		Daily[2] Precipitation (Inches)	Pavement[1,3] Temperature °F	
		High	Low	High	Low		High	Low
March, 1973	27	48	36	45	32	-	55	32
	28	50	28	46	26	-	54	29
	29	53	24	48	25	-	56	26
	30	53	32	51	31	-	56	34
	31	50	33	52	33	.21	48	30
April, 1973	1	49	27	45	29	-	48	26
	2	53	25	48	30	-	50	25
	3	59	27	51	29	-	59	26
	4	62	33	56	34	-	55	31
	5	60	40	61	42	-	54	38
	6	49	33	59	33	-	48	34
	7	50	23	48	25	-	52	26
	8	59	24	48	26	-	58	26
	9	62	36	59	36	-	67	34
	10	67	38	60	39	-	71	38
	11	69	34	66	39	-	62	37
	12	65	39	66	42	-	65	40
	13	64	42	63	46	-	67	45

TABLE H-1 (Continued)

DAILY AIR AND PAVEMENT TEMPERATURES AND PRECIPITATION

Month and Year	Day	Test Track[1] Service °F		Palouse[2] Conservation Service °F		Daily[2] Precipitation (Inches)	Pavement[1,3] Temperature °F	
		High	Low	High	Low		High	Low
April, 1973	14	54	27	63	28	-	65	34
	15	52	29	54	31	-	50	33
	16	51	34	51	36	.18	43	35
	17	49	34	52	37	.01S	44	33
	18	48	30	47	32	T	50	28
	19	47	30	48	34	T	54	32
	20	55	29	48	31	-	62	30
	21	59	36	56	35	-	68	33
	22	60	45	60	46	-	58	42
	23	54	35	59	37	-	61	36
	24	60	32	53	31	-	73	37
	25	66	31	58	30	-	75	37
	26	72	36	64	34	-	78	41
	27	56	41	70	45	-	63	46
	28	52	32	56	32	-	68	36
	29	58	26	53	28	-	66	33
	30	60	28	57	26	-	65	35
May, 1973	1	64	24	62	27	-	76	32

TABLE H-1 (Continued)

DAILY AIR AND PAVEMENT TEMPERATURES AND PRECIPITATION

Month and Year	Day	Test Track[1] Service ^oF		Palouse[2] Conservation Service ^oF		Daily[2] Precipitation (Inches)	Pavement[1,3] Temperature ^oF	
		High	Low	High	Low		High	Low
May, 1973	2	68	31	66	34	-	75	38
	3	60	48	60	47	.15	61	48
	4	62	42	60	41	.10	65	43
	5	66	32	66	35	-	76	37

1 Measured at the Test Track with the Belfort Thermograph

2 Measured at the Palouse Conservation Service - Pullman 2NW

3 Pavement Temperatures measured in Class "G" A.C. at an average depth of 0.40 inches

4 Thermograph was not operating properly

APPENDIX I

TABLE I-1 ACTUAL MILES TRAVELLED WITH REVOLUTIONS

	INSIDE TRACK #1		CENTER TRACK #2		OUTSIDE TRACK #3			
	WP 1	WP 2	WP 3	WP 4	WP 5	WP 6	WP 7	WP 8
Radius to Center of WP (feet)	36.67	37.50	40.75	41.83	43.33	44.17	45.00	45.83
Circumference of WP (miles)	.0436332	.0446249	.0484923	.0497815	.0515665	.0525582	.0535498	.0545415
Circumference of WP (feet)	230.38	235.62	256.04	262.85	272.27	277.51	282.74	287.98
Number of Revolutions per mile	22.92	22.41	20.63	20.09	19.39	19.03	18.67	18.33
MILES TRAVELLED (per Tire) AT:								
5,000 Revolutions	218.2	223.1	242.5	248.9	257.8	262.8	267.7	272.7
10,000 Revolutions	436.3	446.2	484.9	497.8	515.7	525.6	535.5	545.4
25,000 Revolutions	1090.8	1115.6	1212.3	1244.6	1289.2	1314.0	1338.7	1363.5
50,146 Revolutions	2188.0	2237.8	2431.7	2496.4	2585.8	2635.6	2685.3	2735.0
100,000 Revolutions	4363.3	4462.5	4849.2	4978.2	5156.6	5255.9	5354.9	5454.2
150,000 Revolutions	6544.9	6693.8	7273.9	7467.3	7734.9	7883.8	8032.4	8181.2
200,000 Revolutions	8726.5	8925.0	9698.5	9956.4	10313.3	10511.7	10709.8	10908.3
250,000 Revolutions	10908.3	11156.2	12123.1	12445.4	12891.6	13139.6	13387.5	13635.4
300,000 Revolutions	13090.0	13387.5	14547.7	14934.5	15470.0	15767.5	16064.9	16362.5
350,000 Revolutions	15271.6	15618.7	16972.3	17423.5	18048.2	18395.4	18742.4	19089.5
400,000 Revolutions	17453.3	17850.0	19396.9	19912.6	20626.6	21023.3	21419.9	21816.6
450,000 Revolutions	19634.9	20081.2	21821.5	22401.7	23204.9	23651.2	24097.4	24543.7
500,000 Revolutions	21816.6	22312.5	24246.2	24890.8	25783.2	26279.1	26774.9	27270.8
550,000 Revolutions	23998.3	24543.7	26670.8	27379.8	28361.6	28907.0	29452.4	29997.8
600,000 Revolutions	26179.9	26774.9	29095.4	29868.9	30939.9	31534.9	32129.9	32724.9
650,000 Revolutions	28361.6	29006.2	31520.0	32358.0	33518.2	34162.8	34807.4	35452.0
700,000 Revolutions	30543.2	31237.4	33944.6	34847.0	36096.6	36790.7	37484.9	38179.0
717,102 Revolutions	31287.2	31999.2	34760.2	35694.5	36983.1	37682.7	38409.3	39121.8

APPENDIX J

TABLE J-1 SKID RESISTANCE VALUES[1] FOR INSIDE AND OUTSIDE TRACKS

NUMBER OF WHEEL APPLICATIONS	SECTION 010						SECTION 021						SECTION 022					
	US	#1	#3	#2	#4	GST	US	#1	#3	#2	#4	GST	US	#1	#3	#2	#4	GST
0	50	50	50	50	50	50	29	29	29	29	29	29	37.5	37.5	37.5	37.5	37.5	37.5
10,000			50	50	50	50			30.5	32	29.5	37.5			26	30	33	44
25,000			44	47.5	49	49			25	26	23	28.5			26	30	29	33
30,000	50	48.5					34.5	21					31	19				
50,000																		
75,000	46.5	43					34	21.5					27	22				
100,000			30	35	28	46			18	18	16	31			19	22	22	29
150,000	47	24	36.5	30	38	50			23	36	26	32			20.5	18.5	23.5	29.5
200,000			25	23	26	39			17	16	17	22			15	17	16	26
250,000			20	26	25	39			17	17	16	19			17	18	19	22
300,000	47	21	20.5	26	22	35.5	36	16	16	16.5	16.5	17.5	34	24	16.5	16.5	16.5	20
350,000			19	24	23.5	40			14	14	14	22			16	15	16	29.5
400,000			18.5	17	19	38			15	14	14.5	15.5			16	16.5	14	20
450,000	48	42.5					24	20					28	15.5				
500,000			23.5	25	25	43			16	15	18.5	15			17	15	17	20
600,000	41	18					35	17					30	.9				
717,102			21	21	22	47			16	14.5	15.5	16			16	15	16	15
750,000	48	18					33	18					32	17				
900,000	47	21					26	17					24	16.5				
1,050,000	43	16					25	15					26	18				
1,200,000	43	14					22	14					22.5	13.5				
1,500,000	46	16					23	14					29	14				
2,151,306	40.5	14.5					20.5	13					18.5	14.5				

[1] California Skid Tester

TABLE J-1 SKID RESISTANCE VALUES[1] FOR INSIDE AND OUTSIDE TRACKS

NUMBER OF WHEEL APPLICATIONS	SECTION 023						SECTION 031						SECTION 032					
	US	#1	#3	#2	#4	GST	US	#1	#3	#2	#4	GST	US	#1	#3	#2	#4	GST
0	37	37	37	37	37	37	24	24	24	24	24	24	33.5	33.5	33.5	33.5	33.5	33.5
10,000			17	28	34	38			18	20.5	15	21.5			28	32	30	33
25,000			24	27	33	27			17.5	18	16.5	21.5			28	29	27	35
30,000	28	20					30.5	21.5					26	27				
50,000																		
75,000	40	17					24.5	18					36	19				
100,000			16	18	20	31			15	19	15	22			17	19	28	31
150,000			19	21	18.5	38.5			15.5	16.5	13.5	22.5			18.5	18.5	20.5	36
200,000			15	18	19	24			16	17	18	24			18	23	20	28
250,000			17	17	19	20			17	18	17	17			18	18	19	25
300,000	48	15	17.5	17	18.5	26.5	23	16	14.5	15	16.5	15.5	39	17	16	16.5	16	28.5
350,000			14	14.5	14.5	19			14	14	14	15			13	14.5	14	22
400,000			15	16	22	33			13.5	13	14	13.5			13.5	14.5	14	20.5
450,000	43	20					25	15					36	15.5				
500,000			17.5	15	20	27			13.5	14	14	16.5			15	17	15.5	28
600,000	35	17					22	17					26	17				
717,102			20	19	20	21			13.5	14	15	15			17	18	15.5	20
750,000	34	17					25	18					41	18				
900,000	34	17.5					19.5	15.5					35	17.5				
1,050,000	39	15					22.5	13					29	13				
1,200,000	27.5	16					22	12.5					34.5	14.5				
1,500,000	33	15					19	14.5					38	19				
2,151,306	27	13.5					15.5	14					25.5	12.5				

[1] California Skid Tester

TABLE J-1 SKID RESISTANCE VALUES[1] FOR INSIDE AND OUTSIDE TRACKS

NUMBER OF WHEEL APPLICATIONS	SECTION 033						SECTION 034						SECTION 041					
	US	#1	#3	#2	#4	GST	US	#1	#3	#2	#4	GST	US	#1	#3	#2	#4	GST
0	35	35	35	35	35	35	32.5	32.5	32.5	32.5	32.5	32.5	45	45	45	45	45	45
10,000			32	36	25	24			31	30	30	31			41	40	39	45
25,000			23	22	17	21			31	32	35	37			35	33	38	49
30,000	39	36					32	31					39	41				
50,000																		
75,000	24	19					30	27					41	26				
100,000			17	18	15.	24			30	30	27	34			24	21	23	48
150,000			16.5	15	13.5	26			24.5	25	27.5	30.5			25	21	26.5	40
200,000			18	19	18	19			25	26	25	29			21	24	25	37
250,000			18	17	18	21			24	23	24	27			20	19	19	40
300,000	30	16	15.5	16	16.5	20	21	23	22	24	20	29	50	20	19.5	18	22	38
350,000			14	13	13.5	14			19.5	17.5	19	24			18.5	15	19	36
400,000			13	13	13	14			19	16	20	18.5			--	14	--	36
450,000	33	17					27.5	21.5					40.5	19.5				
500,000			15	12.5	16	15			19	15	22.5	24			--	14	--	36
600,000	30	18					35	22					43	20				
717,102			17.5	16.5	15	15			25	19	24.5	23.5			--	--	--	34
750,000	31	17					29	24					42	22				
900,000	32	17					27	17.5					46.5	17				
1,050,000	27.5	14					24	15					37	14				
1,200,000	24.5	13.5					23.5	15					38	--				
1,500,000	27.5	15					29	19					36	--				
2,151,306	16.5	14					22	15					38	--				

[1] California Skid Tester

TABLE J-1 SKID RESISTANCE VALUES[1] FOR INSIDE AND OUTSIDE TRACKS

NUMBER OF WHEEL APPLICATIONS	SECTION 042						SECTION 043						SECTION 050					
	US	#1	#3	#2	#4	GST	US	#1	#3	#2	#4	GST	US	#1	#3	#2	#4	GST
0	46	46	46	46	46	46	47.7	47.7	47.7	47.7	47.7	47.7	46.2	46.2	46.2	46.2	46.2	46.2
10,000			39	39	33	37			43.5	45	43	46			42.5	45	45.5	46
25,000			28	31	29	44			48	46	45.5	49			45.5	49	49.5	50
30,000	43	40					50	49.5					49.5	47.5				
50,000																		
75,000	38	23					46.5	38.5					46	43.5				
100,000			17	16	20	33			28	28	25	50			28	32	33	50
150,000			17	17	24	44.5			26.5	30	32	47.5			37	39	34.5	47
200,000			17	17	19	31			25	24	23	50			23	28	24	44
250,000			18	18	22	37			22	25	21	45			19	32	25	50
300,000	47	16	17.5	17.5	17.5	36	50	22	18	19.5	18	43	50	25	24	31.5	19.5	48
350,000			14	14	14.5	28			18.5	15	22	38			18	17	21.5	42
400,000			13.5	14	15	34			16	15	17	46			16.5	16.5	21	50
450,000	39	16.5					45	19					52	21				
500,000			15	15	--	36			18	15	17	40			20	23	20	48
600,000	39	17					39	17					45	23				
717,102			31	27	16	21			27.5	20	19	40			27	17.5	16	38
750,000	46	18					50	22					50	20				
900,000	36.5	17					50	20					47.5	17.5				
1,050,000	38.5	13					42	14.5					40	15				
1,200,000	38.5	13.5					42	14					43	13.5				
1,500,000	38.5	21					41	15					41.5	23				
2,151,306	35	--					38.5	14.5					36	14				

[1] California Skid Tester

TABLE J-1 SKID RESISTANCE VALUES[1] FOR INSIDE AND OUTSIDE TRACKS

NUMBER OF WHEEL APPLICATIONS	SECTION 061						SECTION 062						SECTION 070					
	US	#1	#3	#2	#4	GST	US	#1	#3	#2	#4	GST	US	#1	#3	#2	#4	GST
0	37.7	37.7	37.7	37.7	37.7	37.7	37	37	37	37	37	37	43.7	43.7	43.7	43.7	43.7	43.7
10,000			39	37.5	38.5	44.5			45	42	42	42			37.5	38.5	40.5	39.5
25,000			41	41.5	40	39.5			48	42	37	32			36.5	35	37	35
30,000	36.5	39					35	42					41	39.5				
50,000																		
75,000	41	40					36	39					38	39.5				
100,000			45	35	40	40			37	40	50	46			39	28	39	37
150,000			46	40.5	48.5	35.5			38	40.5	42	45.5			38.5	33.5	39.5	42.5
200,000			32	32	41	35			37	28	31	33			29	24	28	36
250,000			34	25	29	36			43	25	33	34			25	21	26	39
300,000	42	44	29.5	27	32	35	34	33	31.5	27	30.5	28	44	37	23	17	23	29
350,000			38	27	39	33			42	24	41	33			33	21	29.5	33
400,000			22.5	28	24	30.5			33	24	30	29			23	18	21.5	29
450,000	40	42					43	31.5					40	37				
500,000			24	24	28	30			23	27	30	31			19	15	20	27
600,000	30	24					32	20					37	18				
717,102			20	17	25	27			16	14.5	17.5	28.5			15.5	14.5	17.5	28.5
750,000	33	27					38	20					44	24				
900,000	34	24					32.5	18					40	22				
1,050,000	28.5	30					29	29					33	20				
1,200,000	27	22.5					30	17.5					35.5	15				
1,500,000	30	23.5					31	16					31.5	20				
2,151,306	25	14					25	15					25	14				

[1] California Skid Tester

TABLE J-1 SKID RESISTANCE VALUES[1] FOR INSIDE AND OUTSIDE TRACKS

NUMBER OF WHEEL APPLICATIONS	SECTION 080						SECTION 090						SECTION 100					
	US	#1	#3	#2	#4	GST	US	#1	#3	#2	#4	GST	US	#1	#3	#2	#4	GST
0	34.3	34.3	34.3	34.3	34.3	34.3	39.7	39.7	39.7	39.7	39.7	39.7	39	39	39	39	39	39
10,000			35.5	32.5	34	29.5			42.5	39.5	42.5	37.5			40.5	36	35	36
25,000			33.5	37	30.5	32			40.5	40	42.5	39.5			31	31.5	37.5	34.5
30,000	30	37					36.5	37.5					35	33.5				
50,000																		
75,000	32	37.5					34.5	38					34	35				
100,000			28	27	36	35			31	37	43	40			47	34	46	37
150,000			37.5	31.5	40	37			26.5	28	44.5	45			28.5	28.5	48	46.5
200,000			19	18	23	31			27	25	35	30			28	23	27	31
250,000			18	20	20	26			26	21	32	31			25	23	29	33
300,000	41	34	18	18	14.5	31	38	42	27	25.5	27	32.5	37	32	23	18	23	32
350,000			23	16	22	23.5			29.5	17.5	30	31			23.5	15.5	36	30
400,000			15	15	16.5	27			22	18.5	21	27			24	16	21.5	27
450,000	39	34					45	43					38	35	23	17	20	26
500,000			23	251	16	28			30	26	24	29			--	--	--	--
600,000	26	19					33	20					32	17				
717,102			17	15	20	28.5			15	16	15	21			--	--	21	30
750,000	30	18					32	19					34	17				
900,000	35	19					29.5	18					33.5	19				
1,050,000	38	17					37	21					23	17				
1,200,000	33.5	15					32	19					29	14.5				
1,500,000	37	14					23	21					28	18				
2,151,306	24	17					22	13.5					26	13.5				

[1] California Skid Tester

TABLE J-1 SKID RESISTANCE VALUES[1] FOR INSIDE AND OUTSIDE TRACKS

NUMBER OF WHEEL APPLICATIONS	SECTION 110						SECTION 121						SECTION 123					
	US	#1	#3	#2	#4	GST	US	#1	#3	#2	#4	GST	US	#1	#3	#2	#4	GST
0	37	37	37	37	37	37	36	36	36	36	36	36	47.5	47.5	47.5	47.5	47.5	47.5
10,000			39	39	41.5	37			40	43	37.5	41.5			34	36	37	39
25,000			35.5	34.5	34.5	36.5			28	32.5	28	32			29	31	31	39
30,000	39.5	34					37.5	32.5					46	36				
50,000																		
75,000	35	32.5					27	27.5					39	32				
100,000			46	36	37	36			23	23	28	35			19	20	30	43
150,000			34	29.5	39.5	40.5			41.5	32	42.5	40.5			35.5	29.5	39.5	38
200,000			24	21	26	36			24	21	18	28			18	19	22	32
250,000			26	29	32	28			18	17	16	21			19	18	18	20
300,000	39	17	25.5	22.5	23	25	27	26	15.5	16.5	16	31	41	17	17	15	17.5	30
350,000			31	25	33.5	29			18	15	16	27.5			15	15.5	15.5	32
400,000			16	15	20	29			13	13.5	14	26			13.5	14	16.5	28
450,000	39	24					40	22					47	23.5				
500,000			18	14	17	22			21	17	16	34			23	18	17	28
600,000	31	21					24	18					31	21				
717,102			14.5	14	14	21.5			16	14	14	29.5			15.5	14.5	17	24.5
750,000	34	21					25	17					38	24				
900,000	32	20					23	15.5					36.5	16				
1,050,000	27.5	16.5					28	15.5					34	16				
1,200,000	25	13					25.5	13.5					32	14				
1,500,000	27.5	17					30	18					37	16				
2,151,306	27	13.5					26	17					26	15				

[1] California Skid Tester

TABLE J-1 SKID RESISTANCE VALUES[1] FOR INSIDE AND OUTSIDE TRACKS

NUMBER OF WHEEL APPLICATIONS	SECTION 122					
	US	#1	#3	#2	#4	GST
0	47.5	47.5	47.5	47.5	47.5	47.5
10,000			37	40	36	44
25,000			29	31	33	41
30,000	48	32				
50,000						
75,000	32	28				
100,000			17	17	21	39
150,000			27	22.5	30	42
200,000			17	18	21	28
250,000			18	22	17	29
300,000	35	18	16.5	17	17	31.5
350,000			15	13	16	27
400,000			14	14.5	14.5	30
450,000	47	16				
500,000			15.5	15	18	27.5
600,000	31	19				
717,102			--	--	14	28
750,000	35	17				
900,000	34.5	16				
1,050,000	32	14				
1,200,000	35	13.5				
1,500,000	41	16				
2,151,306	31	14				

[1] California Skid Tester

APPENDIX K

TABLE K-1 COMPUTER READOUT FOR SECTION 090, CLASS "G" ASPHALT CONCRETE, INSIDE TRACK

WHEEL PATH NUMBER 2

PASS NUMBER	AREA REMOVED SQ INCH	RATE OF WEAR SQ INCH/PASS	MAX DEPTH INCH	AVE DEPTH INCH	AREA/WD INCH	AVE DEPTH/PASS INCH/10**6 PASSES
387.	0.0	0.0	0.0	0.0	0.0	0.0
75000.	0.701561E 00	0.940266E-05	0.12211	0.07312	0.07385	0.974905E 00
150000.	0.114650E 01	0.593248E-05	0.17969	0.11924	0.12068	0.794952E 00
300000.	0.211784E 01	0.647561E-05	0.31760	0.22115	0.22293	0.737175E 00
450000.	0.240264E 01	0.189866E-05	0.34191	0.25138	0.25291	0.558614E 00
750000.	0.291393E 01	0.170432E-05	0.41745	0.30431	0.30673	0.405741E 00
900000.	0.325906E 01	0.230085E-05	0.47374	0.34104	0.34306	0.378934E 00
1050000.	0.364706E 01	0.258662E-05	0.52106	0.38135	0.38390	0.363192E 00
1200000.	0.411884E 01	0.314522E-05	0.59106	0.43073	0.43356	0.358939E 00
1500000.	0.441155E 01	0.975694E-06	0.62750	0.46202	0.46437	0.308015E 00
1670514.	0.0	0.0	0.38486	0.30431	0.00000	0.182167E 00
2151304.	0.503418E 01	0.104706E-04	0.70544	0.52812	0.52991	0.245490E 00

WHEEL PATH NUMBER 1

PASS NUMBER	AREA REMOVED SQ INCH	RATE OF WEAR SQ INCH/PASS	MAX DEPTH INCH	AVE DEPTH INCH	AREA/WD INCH	AVE DEPTH/PASS INCH/10**6 PASSES
387.	0.0	0.0	0.0	0.0	0.0	0.0
75000.	0.130170E 00	0.174460E-05	0.03976	0.01343	0.01370	0.179131E 00
150000.	0.695317E-01	-0.808512E-06	0.04564	0.00708	0.00732	0.471972E-01
300000.	0.104413E 00	0.232542E-06	0.05252	0.01072	0.01099	0.357292E-01
450000.	0.118530E 00	0.941153E-07	0.05262	0.01214	0.01248	0.269701E-01
750000.	0.171175E 00	0.175482E-06	0.04758	0.01764	0.01802	0.235261E-01
900000.	0.834379E-01	-0.584913E-06	0.04324	0.00855	0.00878	0.949619E-02
1050000.	0.142538E 00	0.394332E-06	0.05624	0.01471	0.01501	0.140124E-01
1200000.	0.716074E-01	-0.473202E-06	0.04391	0.00729	0.00754	0.607371E-02
1500000.	0.497900E-01	-0.727244E-07	0.04466	0.00499	0.00524	0.332918E-02
1670514.	0.972659E-01	0.278428E-06	0.06082	0.00994	0.01024	0.595103E-02
2151304.	0.915219E-01	-0.119472E-07	0.06272	0.01194	0.00963	0.554953E-02

TABLE K-2 COMPUTER READOUT FOR SECTION 090, CLASS "G" ASPHALT CONCRETE, CENTER TRACK

WHEEL PATH NUMBER 4

PASS NUMBER	AREA REMOVED SQ INCH	RATE OF WEAR SQ INCH/PASS	MAX DEPTH INCH	AVE DEPTH INCH	AREA/WD INCH	AVE DEPTH/PASS INCH/10**6 PASSES
387.	0.0	0.0	0.0	0.0	0.0	0.0
2151306.	0.138585E 01	0.644307E-06	0.18098	0.11857	0.11921	0.551148E-01

WHEEL PATH NUMBER 3

PASS NUMBER	AREA REMOVED SQ INCH	RATE OF WEAR SQ INCH/PASS	MAX DEPTH INCH	AVE DEPTH INCH	AREA/WD INCH	AVE DEPTH/PASS INCH/10**6 PASSES
387.	0.0	0.0	0.0	0.0	0.0	0.0
2151306.	0.105582E 01	0.490870E-06	0.13202	0.08981	0.09082	0.417481E-01

TABLE K-3 COMPUTER READOUT FOR SECTION 090, CLASS "G" ASPHALT CONCRETE, OUTSIDE TRACK

WHEEL PATH NUMBER 6

PASS NUMBER	AREA REMOVED SQ INCH	RATE OF WEAR SQ INCH/PASS	MAX DEPTH INCH	AVE DEPTH INCH	AREA/WD INCH	AVE DEPTH/PASS INCH/10**6 PASSES
129.	0.0	0.0	0.0	0.0	0.0	0.0
50000.	0.555412E 00	0.111370E-04	0.10181	0.05788	0.05846	0.115752E 01
100000.	0.595526E 00	0.802262E-06	0.13213	0.06188	0.06269	0.618842E 00
150000.	0.657231E 00	0.123411E-05	0.11575	0.06848	0.06918	0.456518E 00
250000.	0.693279E 00	0.360480E-06	0.14269	0.07232	0.07298	0.289274E 00
300000.	0.630314E 00	-0.129929E-05	0.14877	0.06566	0.06635	0.218878E 00
350000.	0.779428E 00	0.298227E-05	0.15590	0.08122	0.08205	0.232065E 00
400000.	0.845063E 00	0.131270E-05	0.14504	0.08811	0.08895	0.220284E 00
500000.	0.821227E 00	-0.228358E-06	0.15403	0.08551	0.08644	0.171014E 00
556838.	0.817800E 00	-0.602988E-07	0.15456	0.08550	0.08608	0.153540E 00
717102.	0.131320E 01	0.309113E-05	0.22009	0.13653	0.13823	0.190386E 00

WHEEL PATH NUMBER 5

PASS NUMBER	AREA REMOVED SQ INCH	RATE OF WEAR SQ INCH/PASS	MAX DEPTH INCH	AVE DEPTH INCH	AREA/WD INCH	AVE DEPTH/PASS INCH/10**6 PASSES
129.	0.0	0.0	0.0	0.0	0.0	0.0
50000.	0.506741E 00	0.101610E-04	0.09768	0.05318	0.05334	0.106362E 01
100000.	0.520754E 00	0.280248E-06	0.10901	0.05461	0.05482	0.546053E 00
150000.	0.612614E 00	0.183720E-05	0.11674	0.06396	0.06449	0.426424E 00
250000.	0.577643E 00	-0.349660E-06	0.10591	0.06055	0.06081	0.242198E 00
300000.	0.545340E 00	-0.646158E-06	0.10467	0.05702	0.05740	0.190082E 00
350000.	0.947719E 00	0.804758E-05	0.15011	0.09915	0.09976	0.283278E 00
400000.	0.118280E 01	0.470153E-05	0.21294	0.12333	0.12450	0.308234E 00
500000.	0.162740E 01	0.444609E-05	0.27036	0.16981	0.17131	0.339626E 00
556838.	0.173924E 01	0.196770E-05	0.28098	0.18144	0.18308	0.325846E 00
717102.	0.234067E 01	0.375269E-05	0.36989	0.24413	0.24639	0.340434E 00

(Continued)

TABLE K-3 COMPUTER READOUT FOR SECTION 090, CLASS "G" ASPHALT CONCRETE, OUTSIDE TRACK

WHEEL PATH NUMBER 8

PASS NUMBER	AREA REMOVED SQ INCH	RATE OF WEAR SQ INCH/PASS	MAX DEPTH INCH	AVE DEPTH INCH	AREA/WD INCH	AVE DEPTH/PASS INCH/10**6 PASSES
129.	0.0	0.0	0.0	0.0	0.0	0.0
50000.	0.237683E 00	0.476595E-05	0.05584	0.02481	0.02502	0.496266E 00
100000.	0.288947E 00	0.102530E-05	0.08150	0.03036	0.03042	0.303645E 00
150000.	0.225150E 00	-0.127594E-05	0.07711	0.02342	0.02370	0.156129E 00
250000.	0.188303E 00	-0.368479E-06	0.08564	0.01962	0.01982	0.784997E-01
300000.	0.185639E 00	-0.532651E-07	0.07477	0.01940	0.01954	0.646579E-01
350000.	0.281181E 00	0.191084E-05	0.08578	0.02925	0.02960	0.835666E-01
400000.	0.385660E 00	0.208957E-05	0.09263	0.04029	0.04060	0.100729E 00
500000.	0.352219E 00	-0.334406E-06	0.08595	0.03687	0.03708	0.737334E-01
556828.	0.282240E 00	-0.123121E-05	0.09589	0.02948	0.02971	0.529485E-01
717102.	0.581625E 00	0.186807E-05	0.11486	0.06114	0.06122	0.852667E-01

WHEEL PATH NUMBER 7

PASS NUMBER	AREA REMOVED SQ INCH	RATE OF WEAR SQ INCH/PASS	MAX DEPTH INCH	AVE DEPTH INCH	AREA/WD INCH	AVE DEPTH/PASS INCH/10**6 PASSES
129.	0.0	0.0	0.0	0.0	0.0	0.0
50000.	0.118972E 01	0.238560E-04	0.20478	0.12433	0.12523	0.248661E 01
100000.	0.164711E 01	0.914776E-05	0.25909	0.17203	0.17338	0.172025E 01
150000.	0.176811E 01	0.241997E-05	0.27210	0.18459	0.18612	0.123059E 01
250000.	0.210262E 01	0.334508E-05	0.30332	0.21962	0.22133	0.878479E 00
300000.	0.223227E 01	0.259200E-05	0.32400	0.23305	0.23498	0.776840E 00
350000.	0.241174E 01	0.358894E-04	0.45652	0.35611	0.35913	0.101746E 01
400000.	0.467345E 01	0.252343E-04	0.62439	0.48766	0.49194	0.121915E 01
500000.	0.504769E 01	0.374240E-05	0.63384	0.52685	0.53134	0.105370E 01
556838.	0.479092E 01	-0.451756E-05	0.61825	0.50021	0.50431	0.898311E 00
717102.	0.534212E 01	0.343933E-05	0.64111	0.55799	0.56233	0.778111E 00

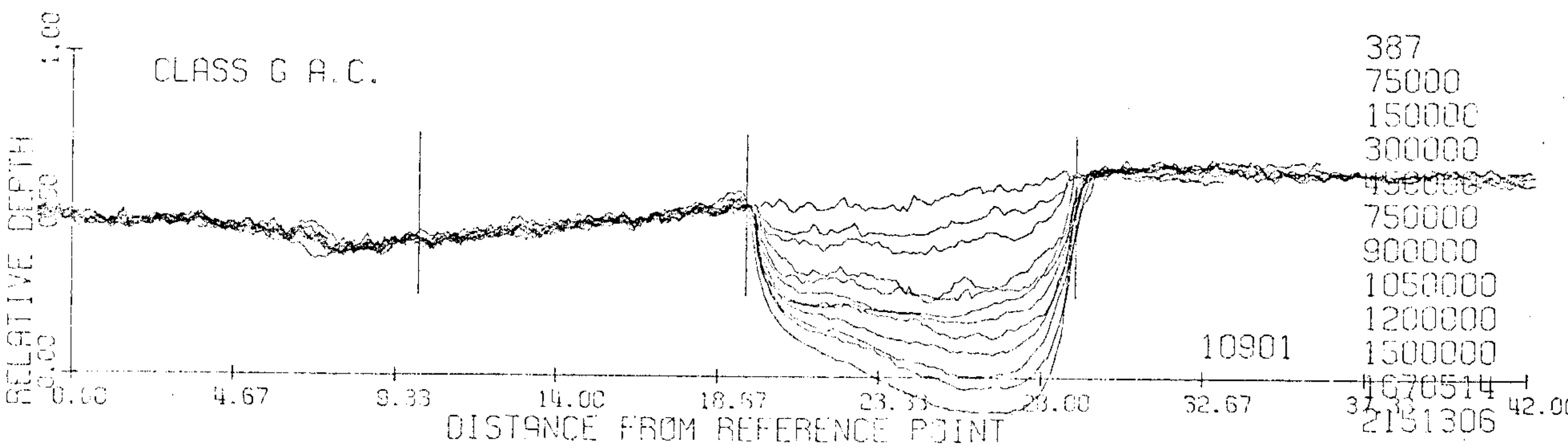


FIGURE K-1: Computer Plotted Transverse Cross-section of 090 - Inside Track

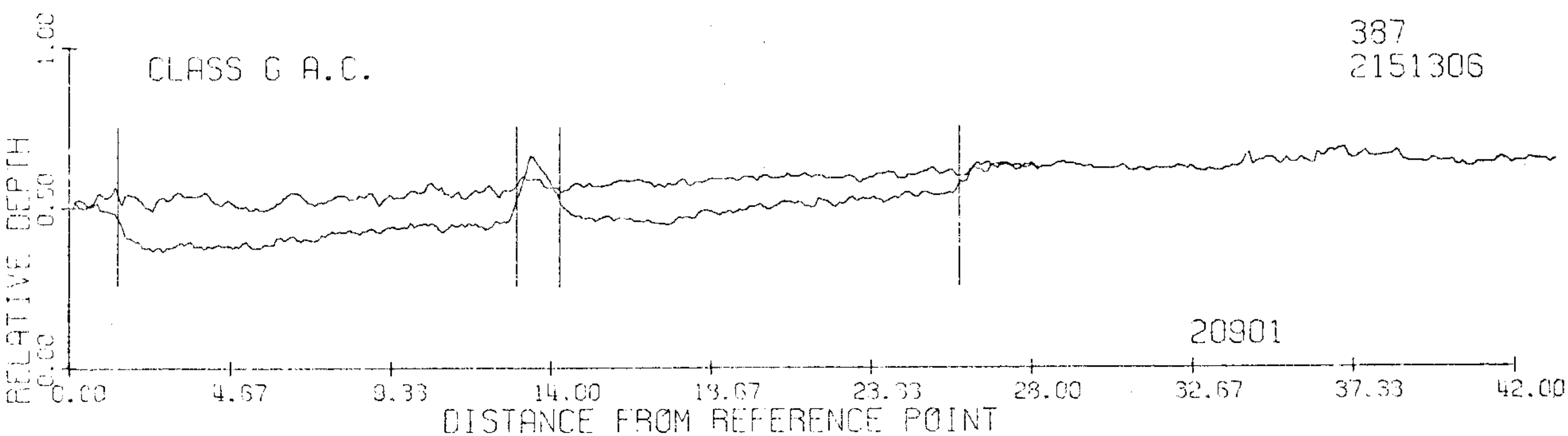


FIGURE K-2: Computer Plotted Transverse Cross-section of 090 - Center Track

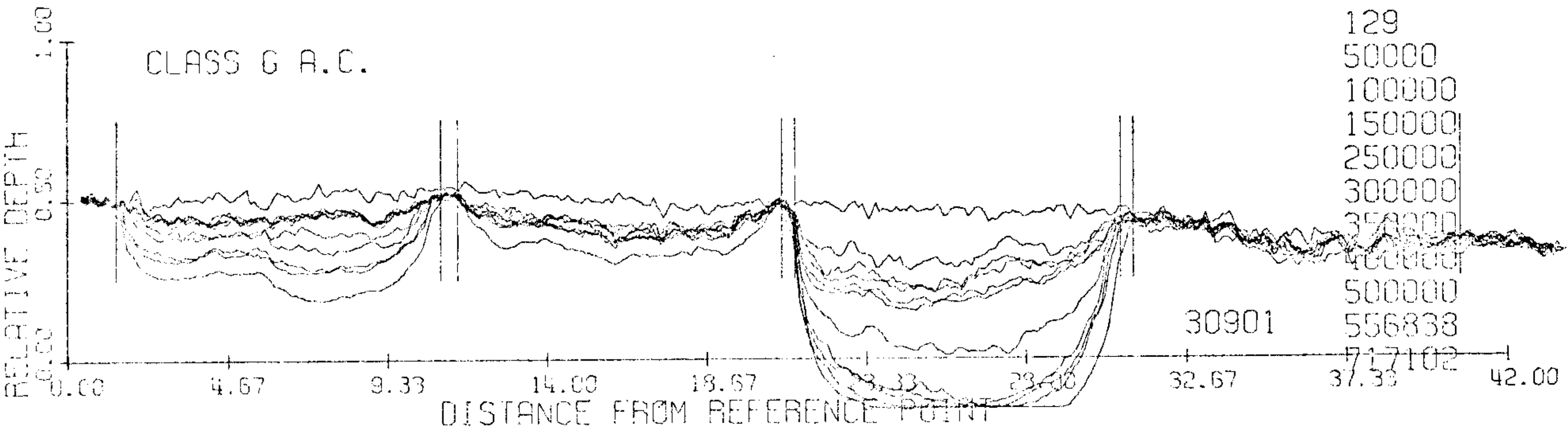


FIGURE K-3: Computer Plotted Transverse Cross-section of 090 - Outside Track

APPENDIX L

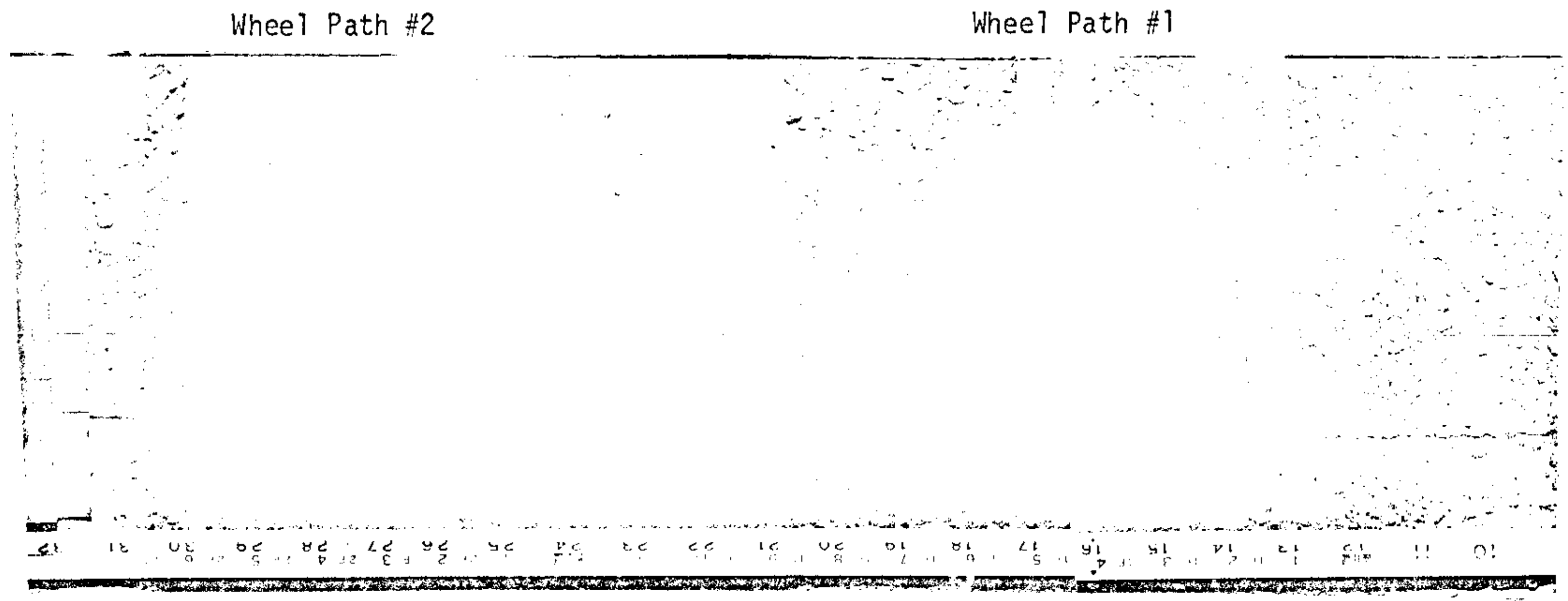


FIGURE L-1: A Typical Sample of Picture Obtained from the Photo-Wire Profile Apparatus. - Section 090, Class "G" Asphalt Concrete; Inside Track, Reference Pin Series #3; 2,151,306 Wheel Applications.

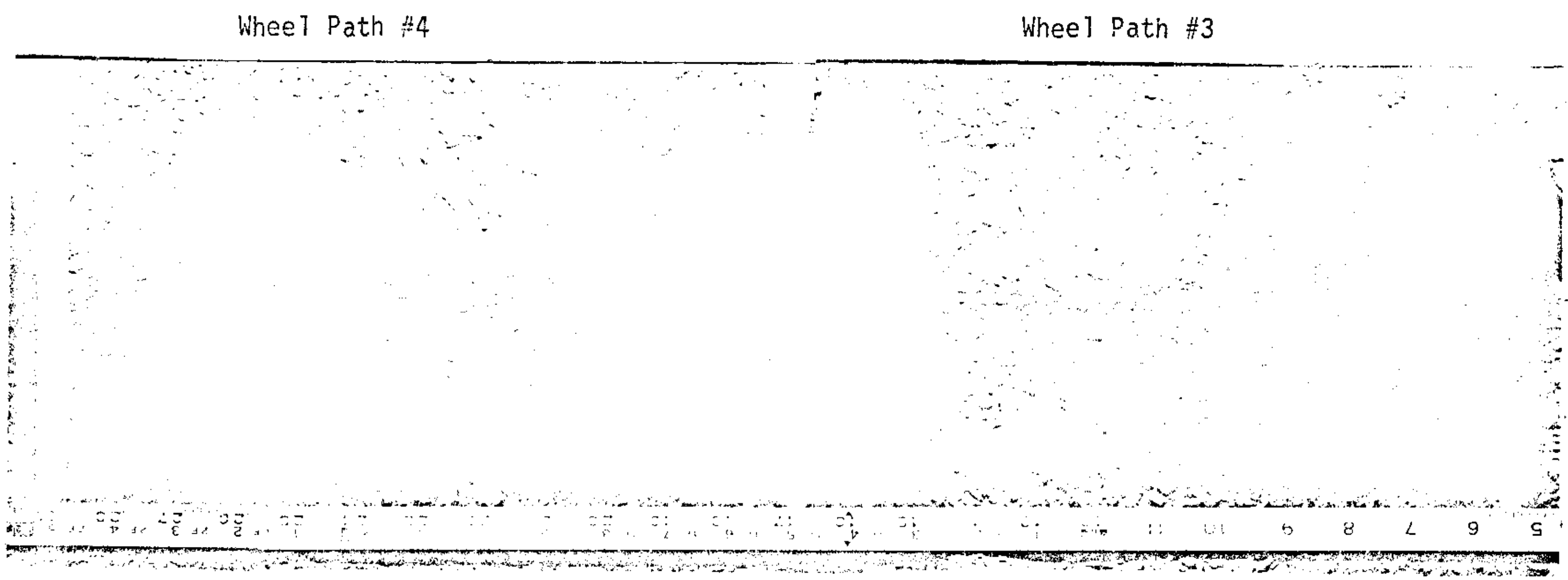


FIGURE L-2: A Typical Sample of Pictures Obtained from the Photo-Wire Profile Apparatus. - Section 090, Class "G" Asphalt Concrete; Center Track, Reference Pin Series #3; 2,151,306 Wheel Applications.

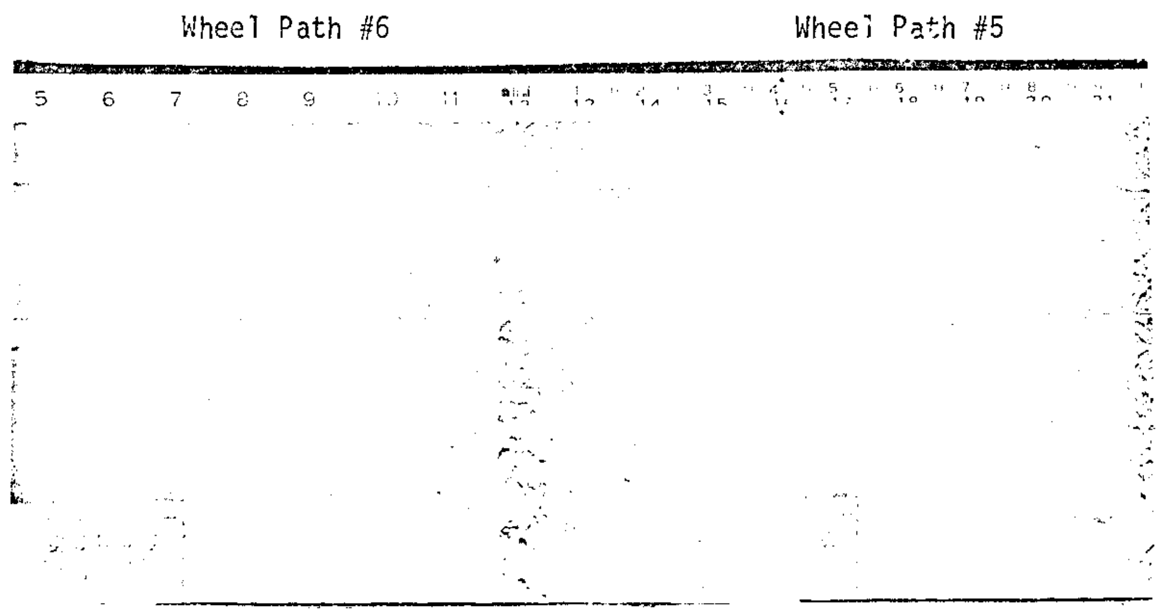


FIGURE L-3a: A Typical Sample of Pictures Obtained from the Photo-Wire Apparatus. - Section 090, Class "G" Asphalt Concrete; Outside Track, Reference Pin Series #3; 717,102 Wheel Applications.

Wheel Path #8 Wheel Path #7

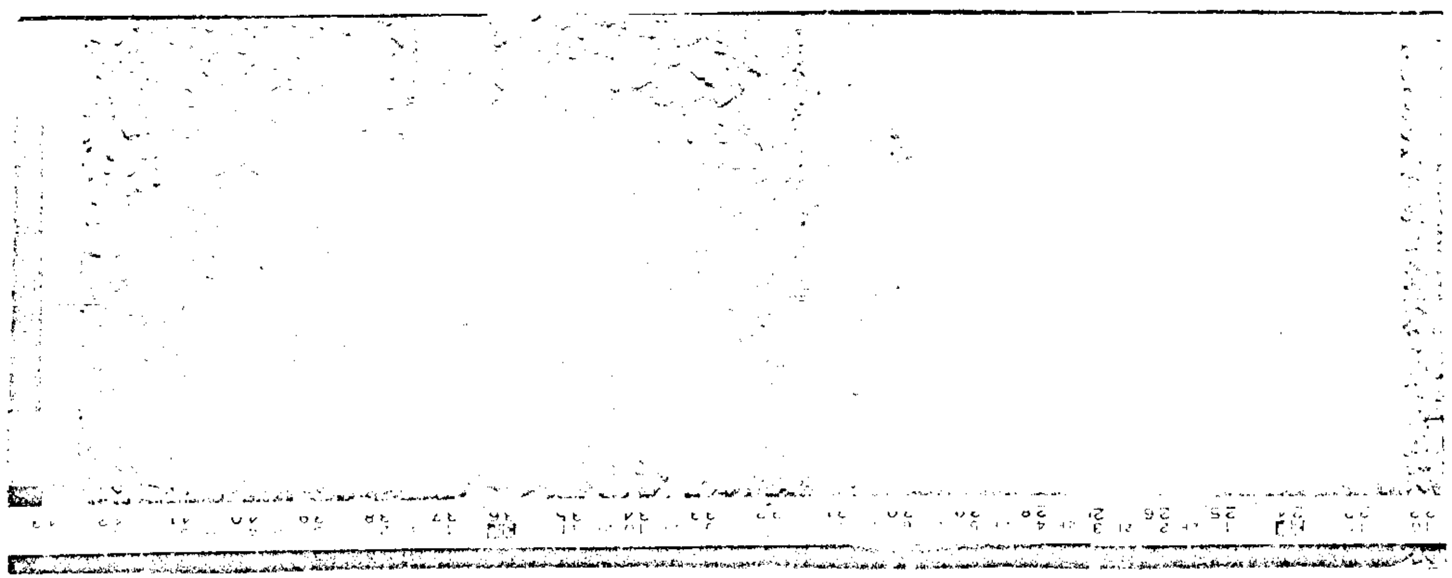


FIGURE L-3b: A Typical Sample of Pictures Obtained from the Photo-Wire Profile Apparatus. - Section 090, Class "G" Asphalt Concrete, Outside Track, Reference Pin Series #3; 717,102 Wheel Applications.