TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Studded Tire Pavement Wear Reduction and Repair		5. Report Date December 30, 1973 6. Performing Organization Code
7. Author(s) Milan Krukar, P.E. and John C. Cook, P.E.		8. Performing Organization Report No. H-39
9. Performing Organization Name and Address Transportation Systems Section College of Engineering Research Division Washington State University Pullman, Washington 99163		10. Work Unit No. 11. Contract or Grant No. Y-1439
12. Sponsoring Agency Name and Address Washington State Highway Commission Department of Highways Highway Administration Building Olympia, Washington 99163		13. Type of Report and Period Covered Phase I 9-3-71 to 6-30-72 14. Sponsoring Agency Code

15. Supplementary Notes

This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration, Washington Dept. of Hwys., and the Idaho Dept. of Hwys. Study title: Studded Tire Pavement Wear Reduction and Repair

16. Abstract

This report presents results obtained from testing at the G. A. Riedesel Pavement Testing Facility at Washington State University during the period from February 11 to May 4, 1972. The purpose of this project was fourfold: 1) to determine pavement wear caused by studded tires; 2) to evaluate the resistance of different pavement materials and textures used in the states of Washington and Idaho to wear caused by tire studs; 3) to test pavement materials and overlays to reduce tire stud damage; and, 4) to study the effect of studded truck tires on pavements.

Ring #5 consisted of three concentric tracks on which 16 tires travelled in eight wheel paths. Three studded types and unstudded passenger tires, three studded and unstudded truck tires, and 46 sections of various types of pavement materials surface overlays and surface textures were tested. The results are based on wear in terms of rate of wear, area removed, maximum and average rut depth using the WSU Profilometer, and the camera wire shadow apparatus, and are valid only under WSU testing conditions.

The findings indicate that some pavement materials are more resistant to the effect of studded tires than others. All types of studded tires tested caused some pavement wear and this affected the skid resistance values. The new types of studs reduced wear of various pavement materials. Studded truck tire wear was less than expected due to equipment problems.

17. Key Words	18. Distribution Statement
Pavement durability, life & performance, asphalt pavement, portland cement concretes, overlays, surface textures, studded tires, skid resistance	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

Form DOT F 1700.7 (8-69)
HWY FORM 341-004 6/72

PAVEMENT RESEARCH AT THE WASHINGTON STATE UNIVERSITY TEST TRACK

STUDDED TIRE PAVEMENT WEAR REDUCTION AND REPAIR

PHASE I

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

by

Milan Krukar and John C. Cook

Transportation Systems Section
College of Engineering Research Division
Washington State University
Pullman, Washington
December 30, 1972

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

Transportation Systems Section Publication H-39

ACKNOWLEDGEMENTS

The Transportation Systems staff wishes to thank the Washington Highway Department for their financial and technical support. There were many Highway Department personnel from Olympia who helped; particularly the following: Hollis Goff, Assistant Director Planning, Research and State Aid; Roger V. LeClerc, Materials Engineer; Ray Dinsmore, Research Coordinator; Mrs. Willa Mylroie, Special Assignments and Research Engineer; and Tom R. Marshall, Assistant Materials Engineer. The Transportation Systems staff also wishes to thank the Idaho State Highway Department for their financial and technical support, and especially "Leif" Ericson, Materials Engineer, for his interest and help.

Thanks go to Robert Bureau, Leadman with Electrical Engineering Section, who designed and built the WSU Profilometer; Dave Heinen and Jim Logan, with the Electrical Engineering Section, for developing the computer programs; and to Norm Shoup and Kal Pell, the mechanical engineers who designed and built the modifications to the G. A. Riedesel Pavement Testing Facility. Max Huffaker and Dr. Raff, of the Materials Chemistry Section, worked on the polymer concrete design and its construction.

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

Words of appreciation go to the secretary, Merrie Jane Matheson, who typed and also helped in editing this report. The list of WSU students who worked on this project was too lengthy for inclusion, but their help was necessary and was greatly appreciated. However a special thanks and credit goes to Rich Stager, civil engineering student, who did most of the figures and graphs calculations.

A word of appreciation goes to the different organizations who contributed free material for testing in this project and also for their technical help. The list of companies and advisory personnel are included at the end of the report.

The two Pullman contractors, C & S Builders and United Paving, Inc., did most of the pavement construction and did their best under adverse weather conditions. Their cooperation and advice was greatly appreciated.

TABLE OF CONTENTS

LIST OF TABLES

Table Page

LIST OF FIGURES

Figures Page

SUMMARY OF RESULTS

1. Results of tests and comparisons of materials between the three tracks should be made with care and judgment. There were enough differences in the tests, that in some cases, direct comparisons cannot be made. The center track had truck tires while the inside and outside tracks had passenger tires. Each of the tracks had different amounts of wheel passes. Wheel paths #1-4 of the outside track had 542,357 passenger tire wheel passes; wheel paths #5 and #6 had 1,627,071 truck tire wheel passes on the center track. (Wheel path #6 had 1,396,935 studded truck tire passes and 230,136 unstudded truck tire passes); while wheel paths #7 and #8 had 1,627,071 passenger tire passes. Also, the effect of speed with the inside wheels traveling at slightly lower speeds than the outside wheels could have affected the rate of wear.

2. All studded tires caused measurable wear on all surfaces of the test track. Comparative wear ratios calculated only for the outside track (Table I) show that the type #2 studs caused less wear than either the type #1 and type #3 studs in that order. Pavement surface wear caused by unstudded tires was essentially unmeasureable. It is interesting to note that even though the type #1 stud didn't reach the desired pin protrusion because of the low test speeds, pavement wear was still considerably reduced.

3. The portland cement concrete pavements showed more resistance to studded tire wear than the asphalt concrete pavements (Table I and Figure I). The skid resistance values were considerably lower for the portland cement concrete pavements than for the asphalt concrete pavements (Table II).

4. Of the asphalt concrete pavements, the Class "B" asphalt concrete sections (100% passing 5/8" sieve) showed the most initial resistance to wear by studded tires, followed by the Class "G" (100% passing 1/2" sieve) and then the Class "E" asphalt concrete (100% passing 1¼" sieve). The Class "E" asphalt concrete with respect to maximum rut depth and area removed at the end of test was slightly superior to the Class "G" asphalt concrete (Figure I).

5. Tests made on the steel fibrous concrete overlays (Wirand® Concrete) were to study different types of mix designs with respect to their wear resistance to studded tires. The Wirand® Concrete with 3/8" aggregate (Section 0-2aC) proved to be the most resistant to wear from studs and to be equal to the 1/4" polymer concrete overlay in Section 0-2bB and regular portland cement concrete.

   All the steel fibrous concrete sections showed superior skid resistance values as wear progressed. (Table II) Under WSU test conditions, the steel fibers in the studded tire wheel paths had a tendency to become dislodged and spread over the track, and protrude somewhat out of the pavement.

6. The gilsonite product (trade name, Gilsabind) rejuvenating treatment on two of the asphalt pavements showed little or no improvement over the regular asphalt concrete sections. (Table I) An initial reduction in skid resistance was observed. Final skid resistance was comparable to other asphalt types (Table II).

7. The surface materials showing the greatest resistance to studded tire

wear tested were the different types of polymer overlay--the polymer cement and polymer flyash concretes (Table I and Figure I). These materials showed good resistance to all tire studs. However, their skid resistance values decreased drastically with wear (Table II).

8. Different surface textures, formed while the portland cement concrete was plastic, showed no great advantage for wear resistance. The reason is that the textures probably consisted of sand-cement mortar deficient in coarser aggregate, and thus had relatively little strength to resist the tire studs.

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

10. Skid resistance values dropped with wear caused by the studded tires (Table II). The portland cement concrete value reduction was particularly noticeable and showed a polishing effect in the worn wheel paths.

11. The effect of studded truck tires was a high initial wear rate which slowed noticeably. This was due to the fact that as the studded driving truck tires wore a groove, the weight of the truss shifted to the free wheeling truck tires. Hence the wear rates are not indicative of those found elsewhere for truck studded tires.

12. The wear rates and some results compared favorably with those obtained at the American Oil Company tests, but seem to be low for those obtained from field highway data. This may be due to the conditions of tests.

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

14. Poor construction weather effected some results; especially the 2.0 inch thick polymer concrete, where epoxy replaced the cement in a regular portland concrete mix. Low temperatures resulted in poor bonding of the aggregate which quickly came loose with wheel passes. Therefore, the data on this material is excluded from this report.

15. The Idaho Chip Seal sections were also placed under extremely poor weather conditions with the result that the chips did not adhere to the rubberized asphalt. In areas where the chips were retained, the pavement showed good resistance to tire studs. However data is sparse and included whenever it was available (Table I).

® Registered trademark of Battelle Development Corporation.

TABLE I COMPARATIVE PAVEMENT WEAR[1]

SECTION	PAVEMENT TYPE	PERCENTAGE WEAR[2] AND WEAR RATIO[3] WITH RESPECT TO TYPE 3 STUDS							
		WP #1 No Studs		WP #2 Type #1		W.P. #3 Type #2		W.P. #4 Type #3	
		P.W.[2]	W.R.[3]	P.W.[2]	W.R.[3]	P.W.[2]	W.R.[3]	P.W.[2]	W.R.[3]
0-1bA	½" Wirand Concrete	6.1	16.4	83.6	1.2	47.8	2.1	100	1
B	½" Wirand Concrete	0.7	142.9	78.3	1.3	34.8	2.9	100	1
C	½" Wirand Concrete	2.4	41.7	117.6	0.8	41.2	2.4	100	1
D	½" Wirand Concrete	11.0	9.1	95.2	1.0	47.6	2.1	100	1
0-2aA	1" Wirand Concrete	3.0	33.3	109.0	0.9	40.9	2.4	100	1
B	1" Wirand Concrete	3.1	32.4	75.0	1.3	33.3	3.0	100	1
C	3" Wirand Concrete	1.7	60.0	122.2	0.8	77.8	1.3	100	1
0-2bA	1" Polymer Concrete[4]	0.75	133.3	183.3	0.6	80.0	1.2	100	1
B	¼" Polymer Concrete	.83	120.5	75.0	1.3	108.3	0.9	100	1
0-3a	Class "E" A.C.	10.4	9.7	82.1	1.2	50.0	2.0	100	1
b	Cl. "E" A.C. Gilsabind	2.1	47.1	71.9	1.4	46.9	2.1	100	1
0-4a	Class "B" A.C.	4.5	22.3	96.6	1.0	41.4	2.4	100	1
b	Class "B" A.C. Gilsabind	4.7	21.4	96.7	1.0	43.3	2.3	100	1
0-5a	Class "G" A.C.	6.7	15.0	73.3	1.4	46.7	2.1	100	1
b	Class "G" A.C.	2.4	40.8	76.3	1.3	39.5	2.5	100	1
0-6a	Idaho Chip Seal	--	--	--	--	--	--	100	1
b	Idaho Chip Seal	19.5	5.1	30.0	3.3	55.0	1.8	100	1

1 Passenger tires and outside track only

2 Percentage Wear (P.W.) = $\frac{\text{Stud Type Y Average Wear}}{\text{Stud Type 3 Average Wear}} \times 100\%$

4 Some of the wear was due to poor bond

3 Wear Ratio (W.R.) = $\frac{100}{\text{Percentage Wear}}$

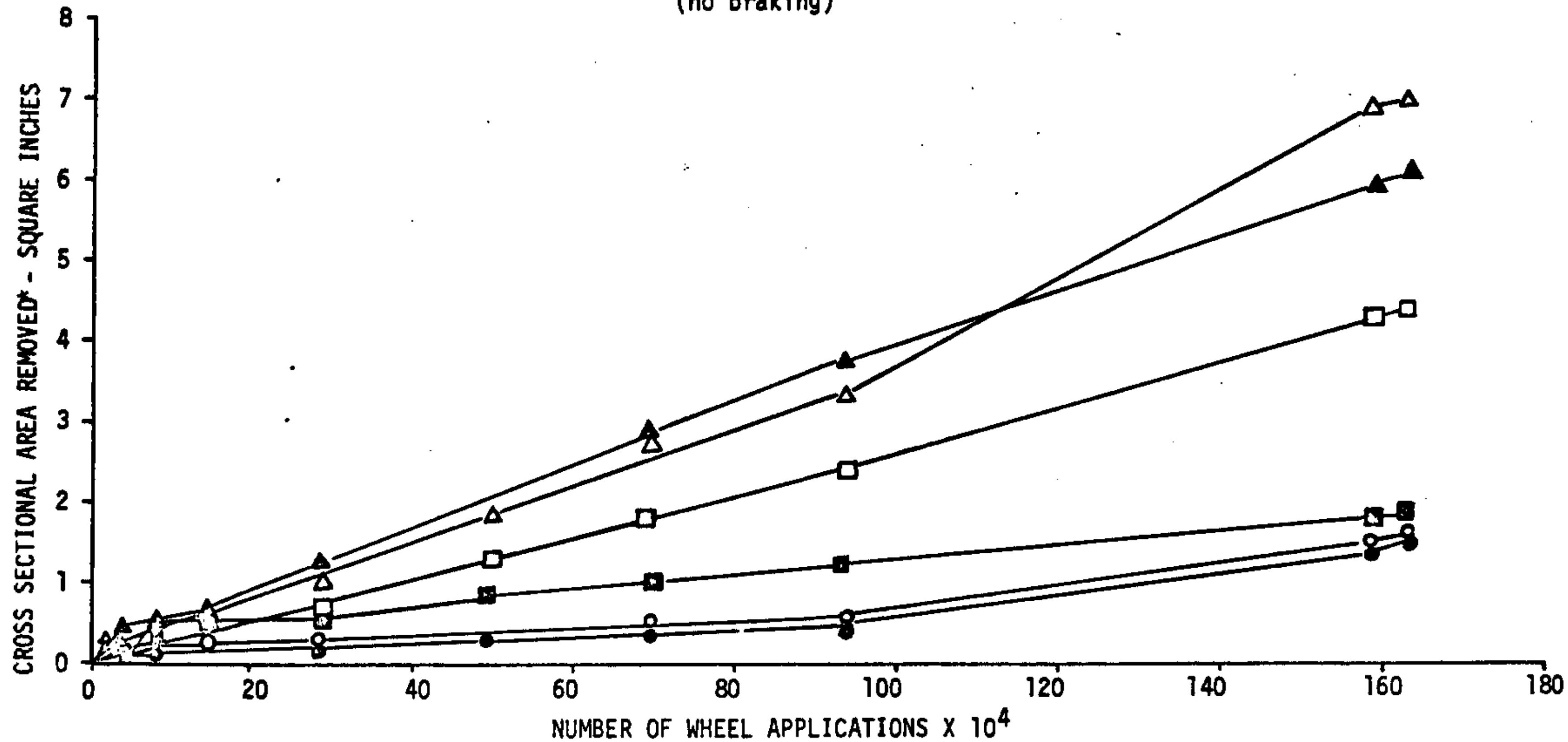
TABLE II COMPARISON OF PERCENT REDUCTION IN SKID RESISTANCE VALUES

SECTION	TYPE	NUMBER OF WHEEL PASSES - PASSENGER TIRES								
		0	540,000							
		STUD TYPES, WHEEL PATHS & PERCENT REDUCTION [1]								
		All[2]	U.S. 1/8	% Red.	#1[3] 2/7	% Red.	#2 3	% Red.	#3 4	% Red.
I-1a	PCC	47	34	28	27	43	--	--	--	--
b	PCC	47	38	19	27	43	--	--	--	--
0-1bA	0.5" Wirand Conc.	45	21	53	37	18	31	31	28	38
B	0.5" Wirand Conc.	43	17	60	38	12	27	37	30	30
C	0.5" Wirand Conc.	43	14	67	30	30	24	44	23	47
D	0.5" Wirand Conc.	45	18	60	28	38	30	33	33	27
0-2aA	1.0" Wirand Conc.	44	22	50	31	30	25	43	33	25
B	1.0" Wirand Conc.	46	23	50	34	26	30	35	30	35
C	3.0" Wirand Conc.	46	25	46	30	35	25	46	27	41
I-2aA	1/8" Poly. Cement	41	30	27	16	61	--	--	--	--
B	1/8" Poly. Flyash	25	22	12	14	44	--	--	--	--
bA	1/8" Poly. Flyash	23	29	+26	13	43	--	--	--	--
B	1/8" Poly. Cement	25	26	4	14	44	--	--	--	--
0-2bA	1.0" Poly. Concrete	40	24	40	18	55	24	40	16	60
B	0.25" Poly. Conc.	38	27	29	17	55	16	58	18	53
I-3a	Class "E" A.C.	36	31	14	25	31	--	--	--	--
b	Class "E" A.C.	43	37	14	27	37	--	--	--	--
0-3a	Class "E" A.C.	42	26	38	32	24	28	33	31	26
b	Class "E" A.C. Gils.	35	23	34	35	0	24	31	33	6
I-4a	Class "B" A.C.	39	32	18	25	36	--	--	--	--
b	Class "B" A.C.	45	31	31	25	44	--	--	--	--
0-4a	Class "B" A.C.	40	24	40	28	30	22	45	29	28
b	Class "B" A.C. Gils.	26	30	+15	39	+50	30	+15	26	0
I-5a	Class "G" A.C.	34	30	12	32	6	--	--	--	--
b	Class "G" A.C.	44	37	16	26	41	--	--	--	--
0-5a	Class "G" A.C.	40	31	23	40	0	32	20	43	+8
b	Class "G" A.C.	38	30	21	36	5	33	13	33	13

1 Minus Values except where noted.
2 Taken from the entire section.
3 Means Stud Type #1, Wheel path 2 and 7.

FIGURE I COMPARISON OF AREA REMOVED WITH TYPE OF MATERIAL

Inside Track - Type #1 Stud
(no braking)



L E G E N D

Polymer Cement Concrete
Polymer Flyash Concrete
Portland Cement Concrete
Class "B" Asphalt Concrete
Class "E" Asphalt Concrete
Class "G" Asphalt Concrete

* From WSU profilometer measurement transverse of track:

Actual wear profile, average of three inch longitudinal of track, times actual wheel path width.

STUDDED TIRE
PAVEMENT WEAR REDUCTION AND REPAIR

INTRODUCTION

This final report presents results from data obtained from testing on Ring #5 at the G. A. Riedesel Pavement Testing Facility at Washington State University, Pullman, Washington, during the period from February 11, 1972 to May 4, 1972. The purpose of this project was fourfold: 1) to determine pavement surface wear caused by studded tires; 2) to evaluate the resistance of different pavement materials 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 to reduce tire stud damage; and 4) study the effect of studded truck tires on pavements.

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

This project was divided into three phases: Phase I was to evaluate the different pavement materials and surface textures during 1971-72, while Phase II was to evaluate different pavement overlays during 1972-73 and Phase III was to compare and analyze both studies to the real world. This report is concerned only with Phase I as testing on Phase II is currently in progress.

This report presents results obtained from all the data obtained from Ring #5. 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

Studded tires were first introduced in the Scandinavian countries during the late fifties. In 1963, they were market-tested in North America, and by 1964, were on the market. The result has been a general acceptance of studs by the North American motoring public, who in general, have felt, rightly or wrongly, that studs in tires enhanced safety for winter driving. However, the increasing use of studded tires has resulted in some serious problems; namely, in accelerated wear of highway pavements.

Much time and effort has gone into investigating the mechanism of the studded tires (1,2,3,4,32). The performance of studded tires concerning stopping distance, skid resistance, and maneuverability on ice and snow has likewise been extensively investigated (4,5,6,7,8,9,10). The safety aspects of studded tires has resulted in some controversy whether or not studded tires prevent accidents. Normand (11) found little reduction in car accidents by studded tire users, while Perchonok (12), in a statistical study, found safety definitely enhanced by the use of studded tires for winter driving. Overend (13) has tried to cover the pros and cons of the studded tires for winter driving; there are side-effects which may negate these advantages and may outweigh any safety considerations (5,7,8,14,26,31,32,35). However, this report is not on studed tire safety except where skid resistance is involved.

The Europeans were first to notice the problem of pavement wear and this was reported on by Jensen and Korfhage (15) and Hode Keyser (16). In the United States, this problem was recognized early and was reported on by

Jensen and Korfhage of Minnesota (17), Burnett and Kearney of New York State (18), Burke and McKenzie of Illinois (5), Bellis and Dempster, Jr. of New Jersey (7), White and Jenkins of Oregon (19), and Lee, Page, and DeCarrera of Maryland (20). The latter report also included some studies on studded truck tires. The results of these reports were extensively studied by Cornell Aeronautical Laboratory for the NCHRP (4). Other reports which summarized studies performed in Europe and North America were by Hogbin of Great Britain (21) and Rosengren of Sweden (22). Studies on both passenger and truck studded tires were performed by the French (23); while studies using a test track were made by the National Swedish Road Research Institute (24). The Ontario Highway Department of Canada was perhaps the first to raise serious questions on the economic consequences of studded tires in a series of reports by Smith and Schonfeld (25,26). One of the results was that the state of Minnesota with other contributing states sponsored research with the American Oil Company on studded tire effects. The results were presented in a series of reports (27,28,29,30). The wear problem and the safety arguments have been summarized by Smith and Schonfield (31). The overall problem of winter damage as experienced in Europe and North America has been studied by the Organization for Economic Co-operation and Development (32). These studies all showed that studded tires caused various amounts of wear tc different pavements which would have serious economic costs and cause some safety problems. All these studies, except for the supplement study done by Speer and Gorman (30), used the old type stud or the conventional type stud, Type #3 stud in this report.

Research has also been focused on developing and finding a pavement or pavement surfaces which are resistant to studded tire wear. The Canadians have been quite active in this area. Hode Keyser (33,34), Smith and Schonfeld (26), Fromm and Corkill (35) have reported on efforts to use different pavement materials and establish design criteria from stud tire resistant pavement. The Europeans have also been active and this is mentioned in several reports (22,24,32). The Minnesota Study (29) mentions some attempts to study different pavement mixes. Industry has also been active in developing types of pavement resistant to studded tires (36). These studies have tried to develop new types of resistant pavements by varying the asphalt content, the aggregate gradation and size, chipseal coats, using harder chip rock, and epoxy-mixture and polymeric materials. Although the results have been encouraging, the costs have been usually too high. The result has been that studded tires have had limitations on their use placed on them (32) or have been banned as in the Canadian province of Ontario and in several United States states (37).

The state of Washington Legislature approved the use of studded tires only in 1969. Washington state can be divided into winter north-south zones, east and west of the Cascade Mountains. The latter area has generally mild winters, mainly rain with little frost while the former area has been known to have very severe winters with much snow and low temperatures. It is in eastern Washington where studded tire use is most prevalent and most needed. The effects of studded tires in Washington were first noticed on the highways going through the mountain passes, on bridges, and then other highways (38,39). 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 in use, and (d) to obtain data on new types of studs that are presently being developed and introduced. This report is only concerned with the items (a), (b), and (d) as item (c) is part of Phase II 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 are not considered, except for skid resistance measurements. An interim report on some findings from Phase I has been published (40); the complete findings are presented in this final report.

DESCRIPTION OF TEST

G. A. RIEDESEL PAVEMENT TESTING FACILITY

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

The apparatus was extensively modified so that more tires could be used for these test series. These modifications allowed the placing of two sets of passenger tires on the existing frame, on the inside of the truck dual tires, so that these tires could run on the inside track. The truck dual tires ran on the center track; the studded truck tire was the driving tire while the other was free wheeling. Two extension frames were bolted on arms #1 and #2 so that two passenger tires were placed in such a way so as to travel in four separate wheel paths on the outside track. A total of 16 tires were mounted on the apparatus. An overall view of the facility, with the apparatus, the modifications and the track is shown in Figure 1. Figure 2 shows the arrangement of the tires and the modifications done to the apparatus; Figure 3 is a close-up view of the frame extension with tires, the modifications, and the center and outside tracks. The passenger car tires each carried 1,000 pound loads, applied via load cells (see Figures 2 and 3), and the truck dual tires carried 6,600 pounds on two of the arms; the load on the truck dual tires on arm #3 was 8,600 pounds. These modifications were made by the Applied Mechanics and Heat Transfer Section of the College of Engineering Research Division and took four months.

A hydraulic braking system was installed on arms #1 and #2 on the two inside passenger tires. Brakes were automatically applied at intervals of 62 seconds on and 4 minutes off on the alternate inside sections; these were the inside "b" sections.

Three different types of studs were tested on the test track pavement for pavement wear reduction. Two of them were supplied by the Kennametal Inc. of Latrobe,Pennsylvania. These were the conventional type stud, hereby designated type #3 stud and the controlled protrusion stud, hereby designated type #1 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, maintain nearly uniform protrusion through out their life time. To maintain this critical protrusion length and pin movement, certain dynamic impact limits have to be attained to obtain this pin movement (41). These studs are 18 per cent in weight lighter and have a 5 per cent smaller flange.

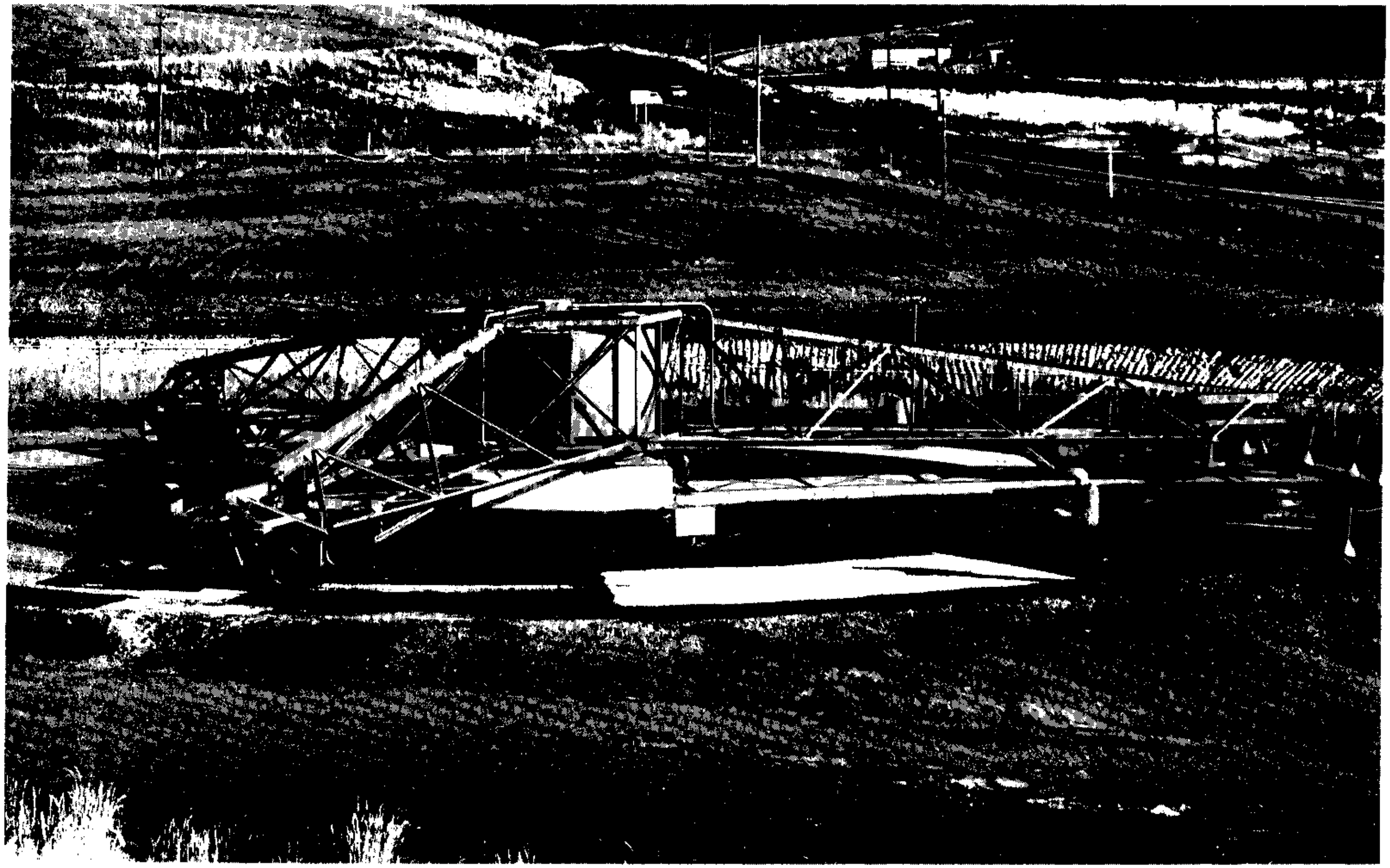


Figure 1: An overall view of the G. A. Riedesel Pavement Testing Facility with modifications and the track. The track shown here is Ring No. 6.

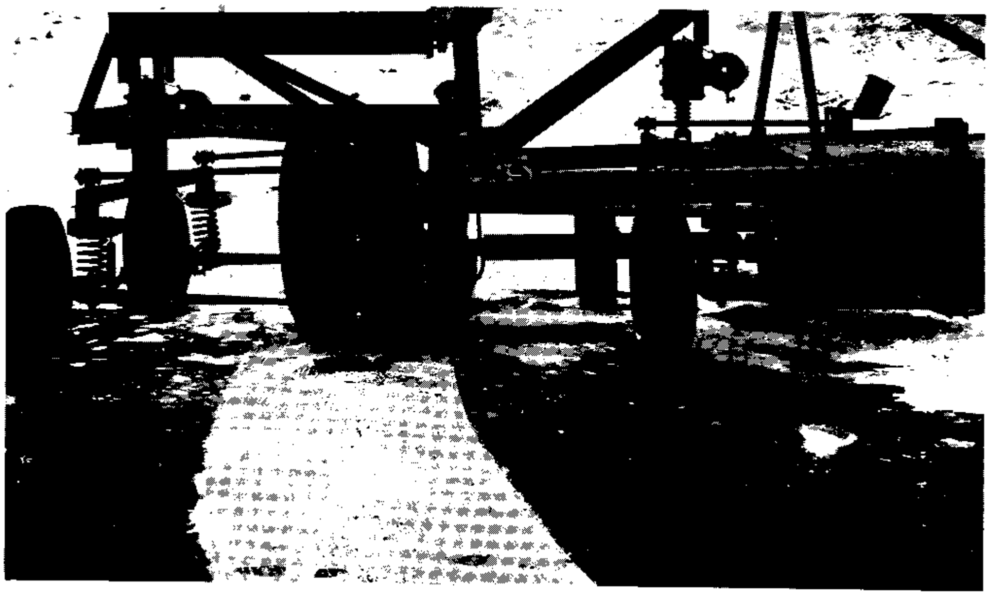


Figure 2: A view of the Modifications and the Placing of the tires on the three tracks.

Figure 3: A close-up of the frame extension and the truck and passenger tires on the center and outside tracks.

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 than the tire tread; hence the stud protrusion will increase. These are the types of studs that were on the market before the winter of 1973.

The other type of stud tested was the Perma-T-Gripper manufactured by Permanence Corporation of Detroit, Michigan. Hereafter it will be designated as Type #2 stud. The tungsten carbide pin here has been replaced with a composite material consisting of relatively small tungsten carbide chips in a soft bonding matrix and is enclosed in a copper jacket. This composite core wears within 10 per cent of the tire and maintains a minimal particulate protrusion of approximately 0-020 inches or less according to the manufacturer (42). It is supposed to wear as it is used, thus always exposing a consistent, fresh, rough, short, stable surface.

TIRES AND STUD TYPES

A total of 16 tires were on the apparatus during the testing period; 6 truck tires, 3 of which were studded and 3 unstudded; and 10 passenger winter snow tires, 4 unstudded and 6 with different types of studs. The six truck tires used on the center track were size 11 x 22.5, inflated to 80 psi air pressure; the three inside tires which were the driving tire had 240 type #3 studs; the three outside tires were free-wheeling and unstudded. The latter travelled in wheel path #5 while the former travelled in wheel path #6. Since 3 tires travelled in the same path, this represented three passes per revolution.

The 10 passenger tires were all G78 x 14 with winter snow tread design made with oil-extended synthetic rubber; four were unstudded, four with 112 type #1 studs, one with 112 type #3 studs and one was with 112 type

#2 studs. Each tire was inflated to 28 psi and carried a 1,000 pound load.

The inside track had three unstudded and the three type #1 studded tires. The studded tires travelled in wheel path #7 and the unstudded tires travelled in wheel path #8. The inside track had three passenger car tires revolutions in each wheel path.

On the outside track, four passenger car tires were used on four different wheel paths. The unstudded, the type #1, the type #2, and the type #3 studded tires were in wheel paths #1, #2, #3, and #4, respectively. Each wheel path in the outside track had one pass per revolution. Figure 4 shows the eight different wheel paths. Figure 5 shows the studded and plain passenger tires used, their tread design and stud arrangement.

TEST PAVEMENT CONCENTRIC TRACKS

Ring #5 consisted of three concentric tracks; the inside and outside track were 3-5 feet wide and center track was 3.0 feet wide. The tracks were divided into six sections of 43 feet lengths, which were further subdivided.

The pavement structure consists of 6.0 inches of asphalt treated base and 6.0 inches of surfacing of different types. The center ring was constructed of reinforced portland cement concrete with 12 different surface textures. The inside and outside tracks were constructed of asphalt concrete consisting of the types used by the Washington State Department of Highways and portland cement concrete with different types of overlays. A total of 46 sections were tested; 20, 12 and 14 sections in the outside, center, and inside rings, respectively. Figure 4 shows the arrangement of sections of the test track, and Table 1 shows the types of materials, their surface textures, lengths

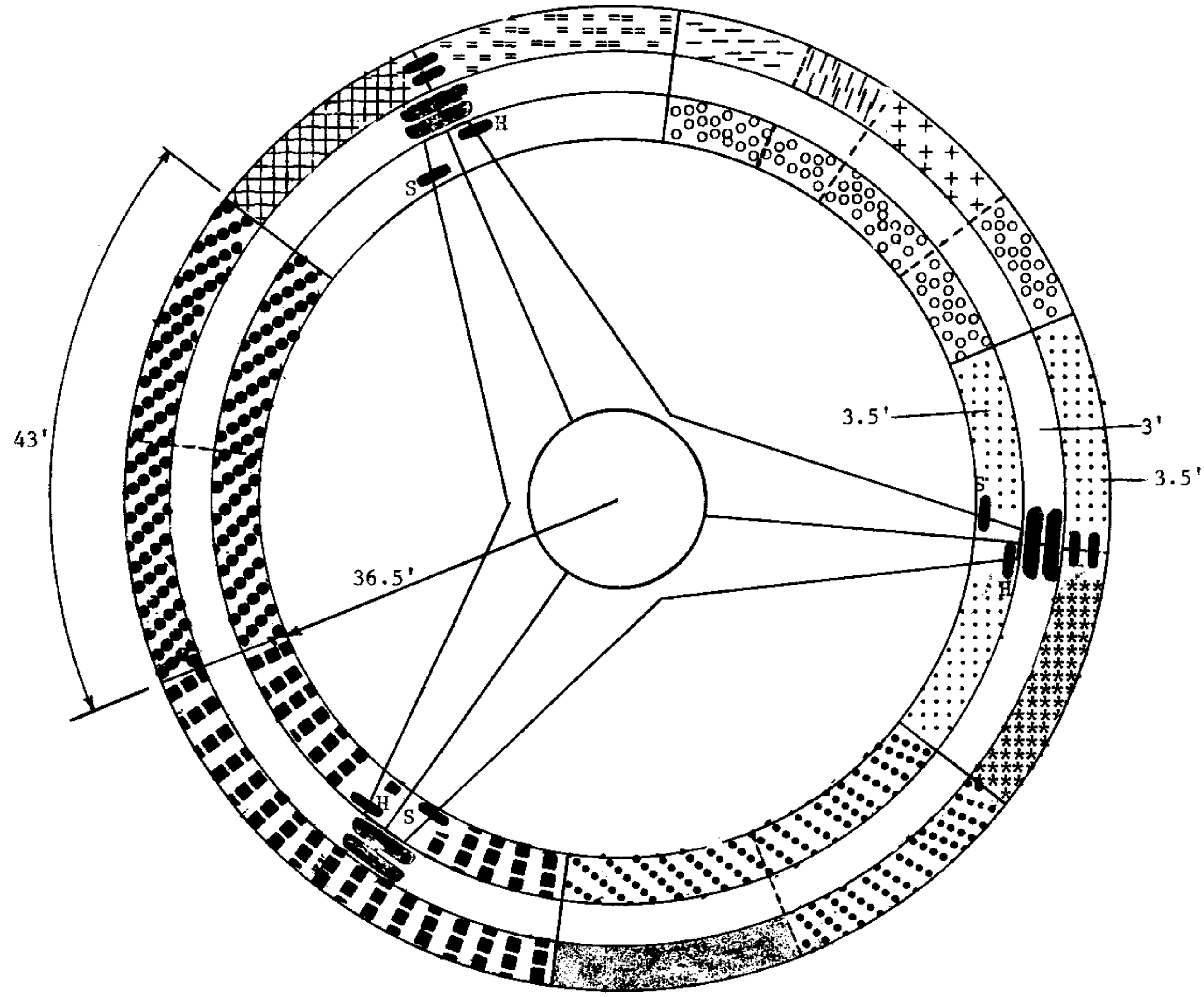
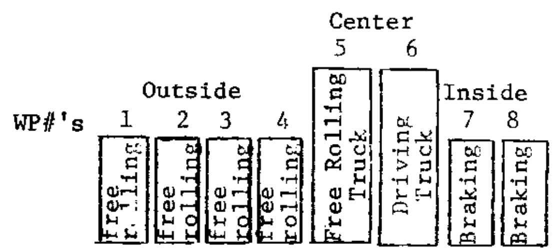


FIGURE 4 Not Drawn to Scale
PLAN VIEW OF
TESTING APPARATUS AND PAVEMENT SECTIONS FOR STUDDED TIRE STUDY

Class "B" AC
Class "E" AC
Class "G" AC
Class "B" Gilsabind
Class "E" Gilsabind
Class "B" Idaho Chip

6.0" PCC RC
1/2" Wirand
1" Wirand
3" Wirand
2" Polymer Concrete
1" Polymer Concrete
1/8" Polymer



1 Unstudded
2 Stud Type #1
3 Stud Type #2
4 Stud-Old Type #3

5 Unstudded
6 Studded-Type #3 240 studs/tire
7 Stud Type #1
8 Unstudded

S = Studded H = Highway

Figure 5: This shows the G78 x 14 studded and unstudded passenger tires used, their tread design and stud placement arrangement.

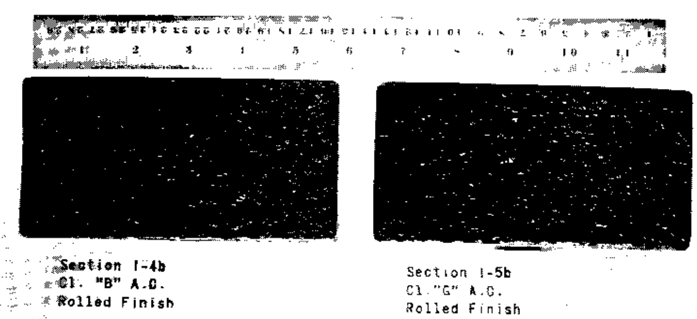


Figure 6: This shows the appearance of the asphalt concrete rolled finish surface made from plaster castings.

TABLE 1

RING #5 - TYPES OF SECTIONS AS BUILT

Types of Pavement Materials & Textures - Outside Track

Section	Type	Texture	Dimensions - Ft.	
			Length	Width
0-1aA	Polymer Concrete-2"-Mix A	Hand Trowelled Finish	3.0	3.5
B	Polymer Concrete 2"-Mix A	Hand Trowelled Finish	10.0	3.5
C	Polymer Concrete 2"-Mix B	Hand Trowelled Finish	9.0	3.5
0-1bA	1/2" Wirand Concrete - Mix 1	Light Transverse Brooming	7.5	3.5
B	1/2" Wirand Concrete - Mix 2a	Light Transverse Brooming	5.0	3.5
C	1/2" Wirand Concrete - Mix 2b	Light Transverse Brooming	3.5	3.5
D	1/2" Wirand Concrete - Mix 3	Light Transverse Brooming	6.5	3.5
0-2aA	1" Wirand Concrete - Mix 4	Light Transverse Brooming	7.5	3.5
B	1" Wirand Concrete - Mix 5	Light Transverse Brooming	7.5	3.5
C	3" Wirand Concrete - Mix 6	Plastic Grooving	7.5	3.5
0-2bA	1" Polymer Concrete - Mix C	Hand Trowelled Finish	11.0	3.5
B	1/4" Polymer Concrete - Mix C	Hand Trowelled Finish	11.0	3.5
0-3a	Class "E" A.C.	Rolled Finish	22.0	3.5
b	Class "E" A.C. Gilsabind	Rolled Finish	22.0	3.5
0-4a	Class "B" A.C.	Rolled Finish	22.0	3.5
b	Class "B" A.C. Gilsabind	Rolled Finish	22.0	3.5
0-5a	Class "G" A.C.	Rolled Finish	22.0	3.5
b	Class "G" A.C.	Rolled Finish	22.0	3.5
0-6a	Idaho Chip Seal - Cl "B" A.C.	Rolled Finish	22.0	3.5
b	Idaho Chip Seal - Cl "B" A.C.	Rolled Finish	22.0	3.5

20 DIFFERENT SECTIONS

TABLE 1

RING #5 - TYPES OF SECTIONS AS BUILT

Types of Pavement Materials & Textures - Center Track

Section	Type	Texture	Dimensions - Ft. Length	Width
C-1a	Portland Cement Concrete--Reinforced	Heavy Longitudinal Brooming	21	3.0
b	" " "	Light Transverse Brooming	21	3.0
C-2a	Portland Cement Concrete--Reinforced	Heavy Transverse Brooming	21	3.0
b	" " "	Burlap	21	3.0
C-3a	Portland Cement Concrete--Reinforced	Longitudinal Grooving	21	3.0
b	" " "	Light Longitudinal Brooming	21	3.0
C-4a	Portland Cement Concrete--Reinforced	Transverse Grooving	21	3.0
b	" " "	Light Transverse Brooming	21	3.0
C-5a	Portland Cement Concrete--Reinforced	Light Plastic Grooving	21	3.0
b	" " "	Light Plastic Grooving	21	3.0
C-6a	Portland Cement Concrete--Reinforced	Medium Longitudinal Brooming	21	3.0
b	" " "	Light Longitudinal Brooming	21	3.0

12 DIFFERENT SECTIONS

TABLE 1

RING #5 - TYPES OF SECTIONS AS BUILT

Types of Pavement Materials & Textures - Inside Track

Section	Type	Texture	Dimensions-Ft.	
			Length	Width
I-1a	Portland Cement Concrete	Heavy Longitudinal Grooving	20	3.5
b	Portland Cement Concrete	Heavy Longitudinal Grooving	20	3.5
I-2aA	1/8" Poly. Cement Conc.-Mix C	Hand Trowelled	10	3.5
aB	1/8" Poly. Flyash Conc.-Mix D	Hand Trowelled	10	3.5
bA	1/8" Poly. Flyash Conc.-Mix D	Hand Trowelled	10	3.5
bB	1/8" Poly. Cement Conc.-Mix C	Hand Trowelled	10	3.5
I-3a	Class "E" A.C.	Rolled Finish	20	3.5
b	Class "E" A.C.	Rolled Finish	20	3.5
I-4a	Class "B" A.C.	Rolled Finish	20	3.5
b	Class "B" A.C.	Rolled Finish	20	3.5
I-5a	Class "G" A.C.	Rolled Finish	20	3.5
b	Class "G" A.C.	Rolled Finish	20	3.5
I-6a	Idaho Chip Seal-Cl "B" A.C.	Rolled Finish	20	3.5
b	Idaho Chip Seal-Cl "B" A.C.	Rolled Finish	20	3.5

14 DIFFERENT SECTIONS

46 DIFFERENT SECTIONS

and widths. Figures 6,7,8 and 9 show the different textures obtained by plaster castings; Table 2 gives the depths of these various textures.

The three tracks were constructed during the months of October and November, 1971 under less than ideal construction weather. Some of the polymer concrete overlays were laid down in December, January and February. The result was that some of the sections suffered premature failure and wear due to construction difficulties rather than to the materials themselves. The design mixes and construction conditions and time tables are given in Appendix A.

MEASUREMENT

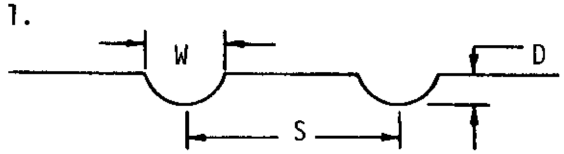
Reference pins were installed in all the sections so that transverse profile measurements could be taken. Profiles were made by the camera box/wire technique developed by the Ontario Highway Department (25). A shadow of the wire is superimposed on the pavement and the difference in wear between successive readings can be detected. Due to the difficulty and length of time needed to read and analyze the results from this technique, the readings were used as back-up measurements and as a check on other techniques. Figures 10 and 11 shows pictures of this apparatus in actual use.

Another apparatus used to measure transverse profiles was the WSU profilometer which is shown in Figure 12. This apparatus consisted of ten fingers which travel across each wheel path. Each finger was connected to a capacitor. Figure 13 shows these fingers. A direct current linear electric motor drove the apparatus and the results were recorded on a brush recorder. The driving mechanism is shown in Figure 14. The results are plotted on a chart as a transverse profile of the section; any point on the chart represents the average of ten different readings over a 3-inch wide span. The depth

TABLE 2: DEPTH, WIDTH AND SPACING OF THE VARIOUS PLASTIC GROOVES

	SECTION C-5a			SECTION C-5b			SECTION C-3a			SECTION I-1a			SECTION C-4a		
	Light Longitudinal Plastic Grooving			Light Longitudinal Plastic Grooving			Longitudinal Plastic Grooving			Heavy Longitudinal Plastic Grooving			Transverse Plastic Grooving		
SAMPLE	W[1]	S[1]	D[1]	W[1]	S[1]	D[1]	W[1]	S[1]	D[1]	W[1]	S[1]	D[1]	W[1]	S[1]	D[1]
1	7[2]		2½	9		2½	7		4½	10		5	8	4½	4½
2	8		3	8		2½	7		5	8		5	9	6	5
3	9		3	8		2	8		4½	10		5	6		5
4	7		3	6		2	8		4½	9		5	7	4½	4½
5	7		3	7		1½	8		4½	10		4½	7	6	4½
6	9		2½	8		2	9		4½	10		5	8	3¾	4
7	7		2½	6		2	9		4½	10		5	8	5	4½
8	6		3	6		2	8		5	10		5	7		4½
9	8		3	6		1½	8		4½	10		5	7		4
10	7		3	8		1½	7		5	11		5	8		4½
AVERAGE	0.234	0.719	0.089	0.225	0.719	0.061	0.247	0.750	0.145	0.306	0.792	0.155	0.234	0.750	0.141

1.



2. 1/32" x y = depth in inches

e.g. $\frac{1}{32}$ x 8 = 0.25"

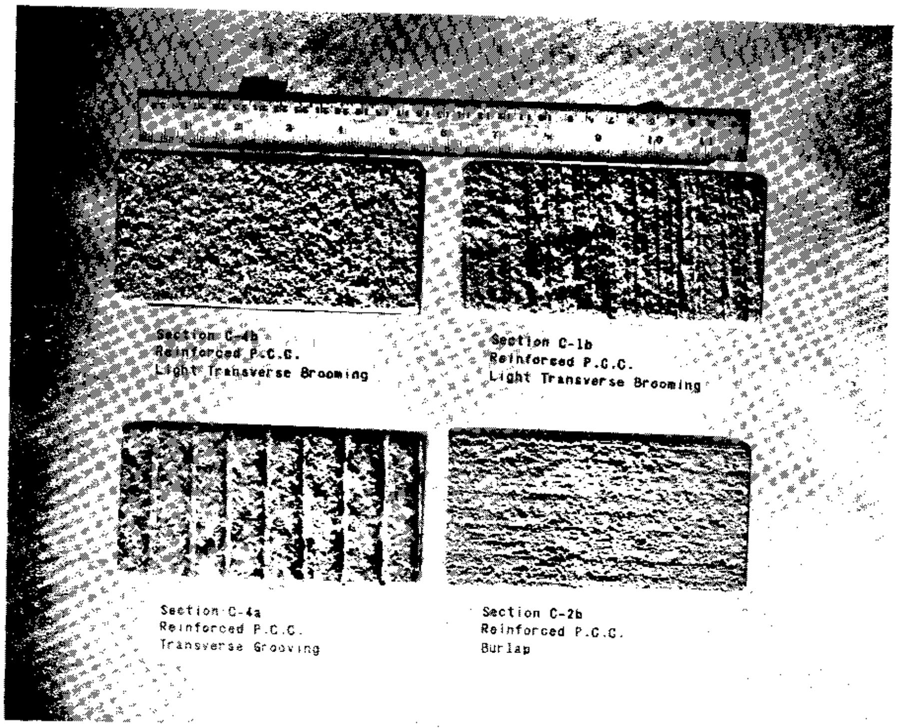


Figure 7: Plaster castings of P.C.C. surface textures showing transverse brooming and grooving and burlap surfacing.

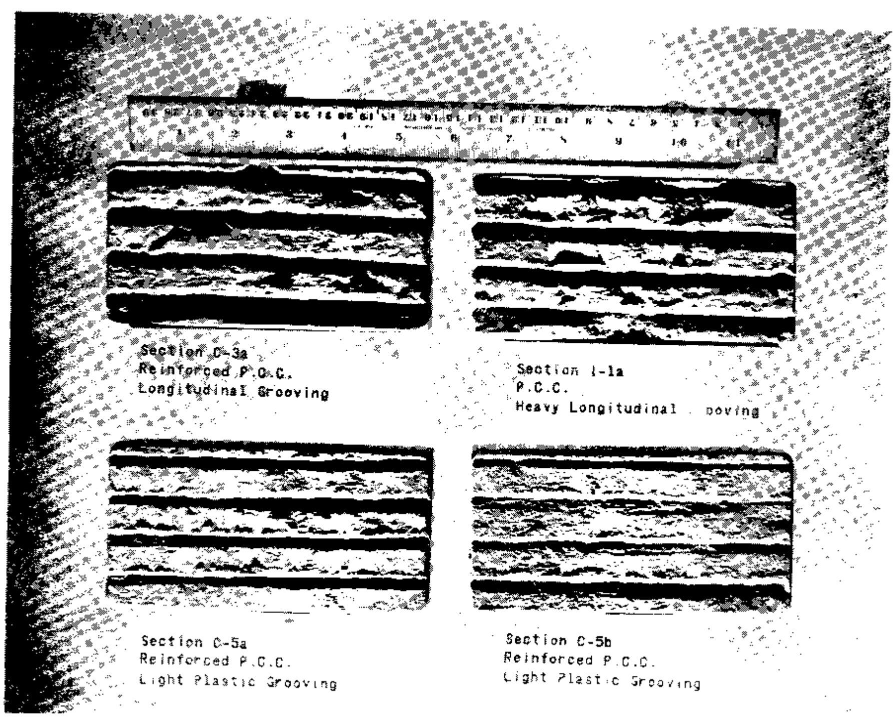


Figure 8: Plaster castings of P.C.C. surface textures showing the different types of longitudinal grooving.

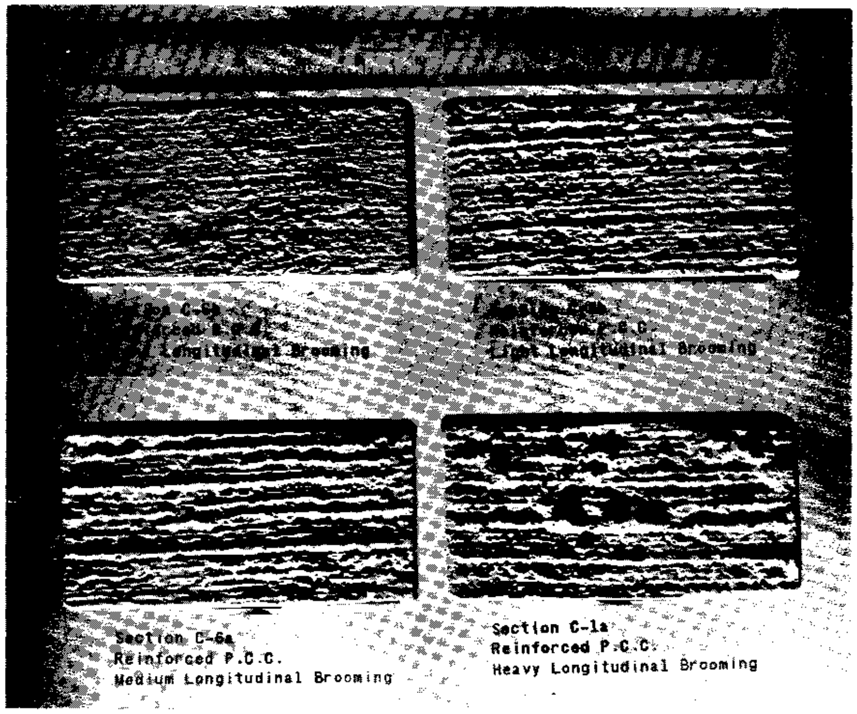


Figure 9: Plaster casting P.C.C. surface textures showing the different types of longitudinal brooming.

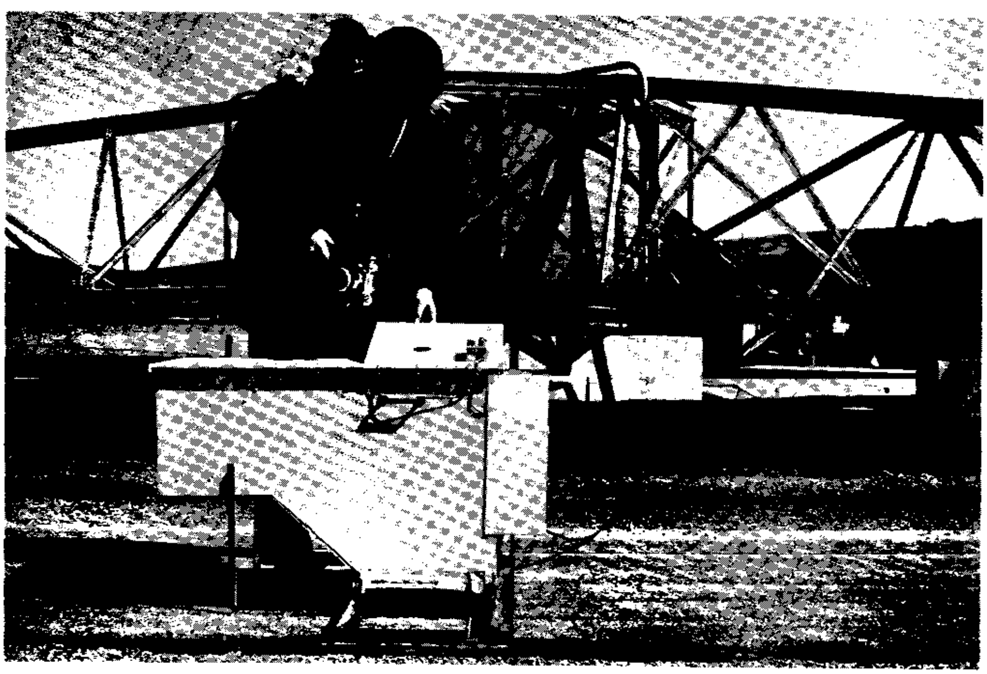


Figure 10: The camera is being put into the camera-wire box. Note that the Box is on a steel frame.

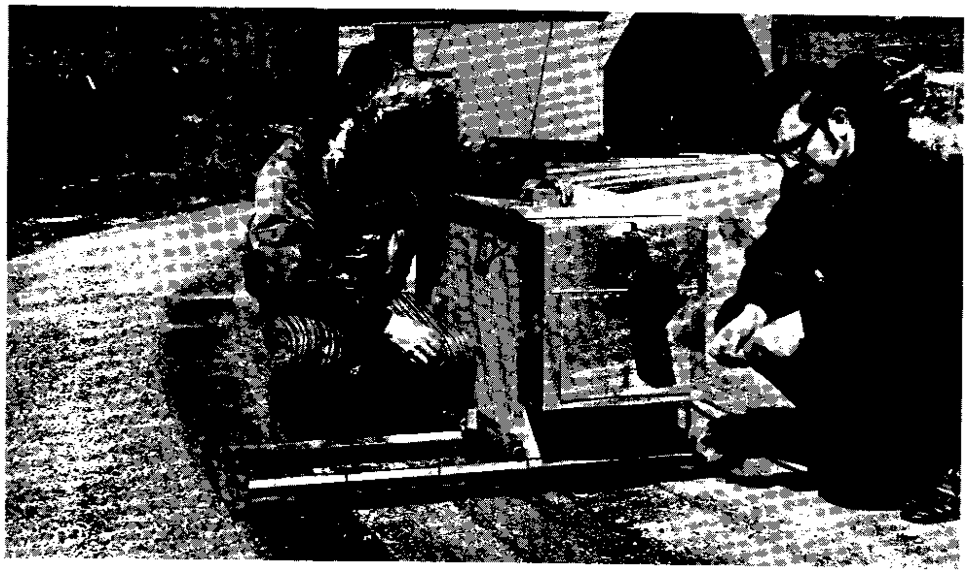


Figure 11: The camera-wire box is being used on the Idaho Chip Seal Section.

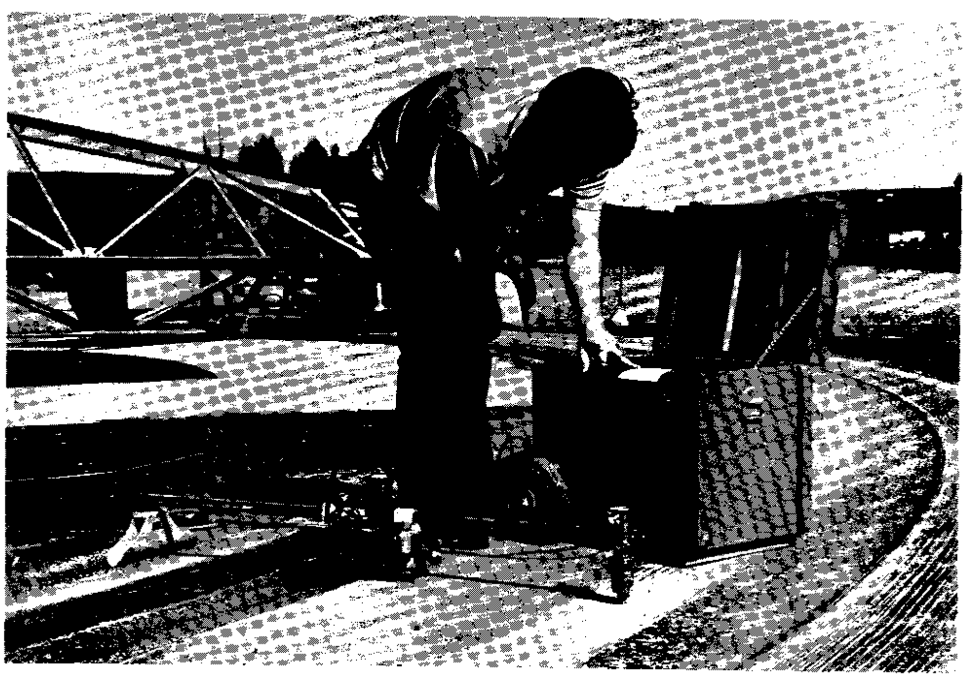


Figure 12: The WSU Profilometer with control and read-out box.

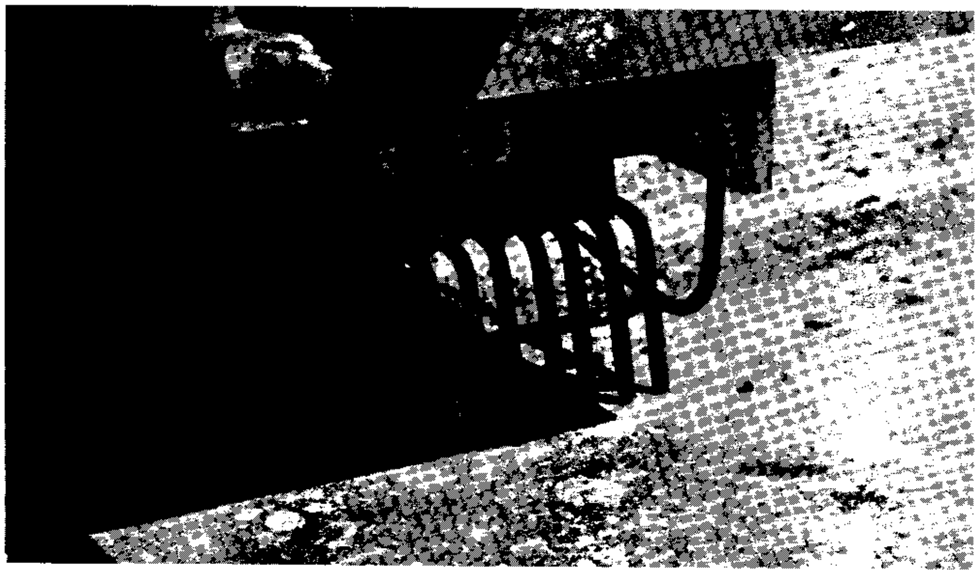


Figure 13: A view of the 10-fingers averaging measuring device of the WSU Profilometer.

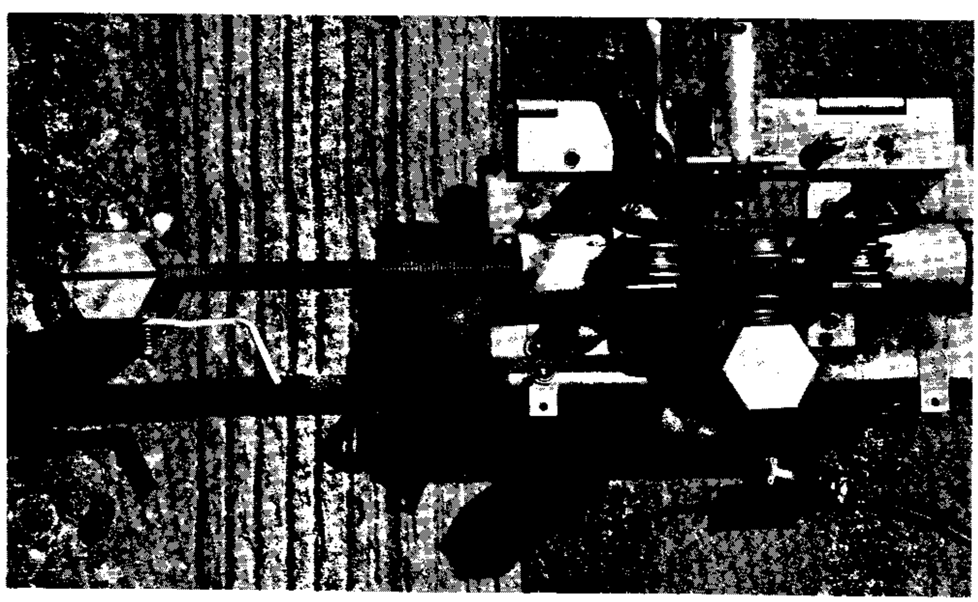


Figure 14: Top view of the driving mechanism of the WSU Profilometer

of the apparatus was ± 0.50 inches with an error of ± 0.02 inches. Typical curves are shown in Figures 15, 16 and 17. Most of the data presented in this report were obtained from the WSU profilometer. The principle and design of this apparatus is in Appendix B. A computer program was developed so that the data could be analyzed on the basis of rate of wear, average area removed, average and maximum net depths. The complexities of this program is in Appendix C.

Depth measurements with a straight edge were also taken.

Temperature measurements using iron-constantan thermocouples were used for measuring surface and air temperatures on a 48 multi-point Honeywell recorder. A Belfort Thermograph was also used to monitor ambient temperatures.

Tire tread depth measurements and stud protrusion lengths were also taken at regular intervals.

The California Skid Tester, loaned by Washington Highway Department, was used to measure the skid resistance of the various sections and wheel paths. Figures 18 and 19 show the California Skid Tester.

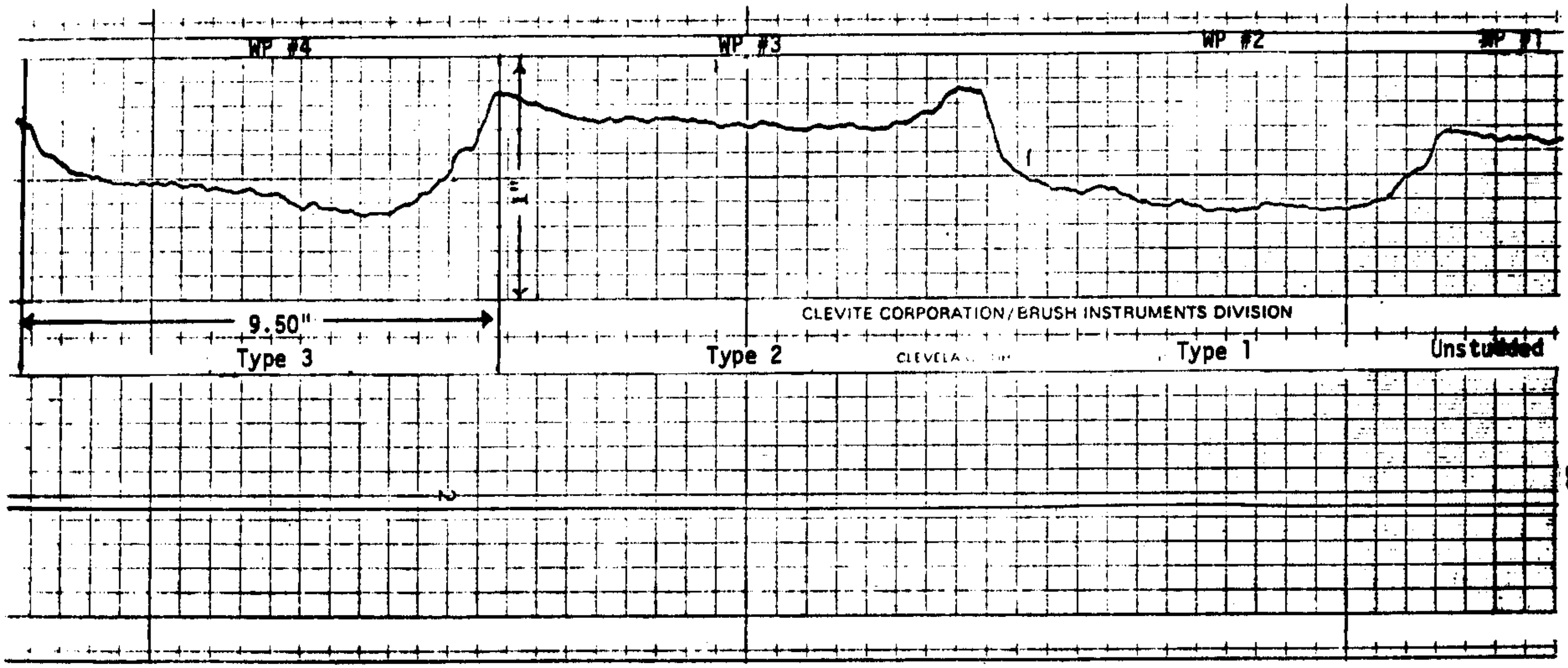


Figure 15 A Typical Chart Obtained from WSU Profilometer
Section 0-4a: Class "B" Asphalt Concrete
528,000 Wheel Passes - Outside Track

Horizontal scale compressed
Vertical scale expanded

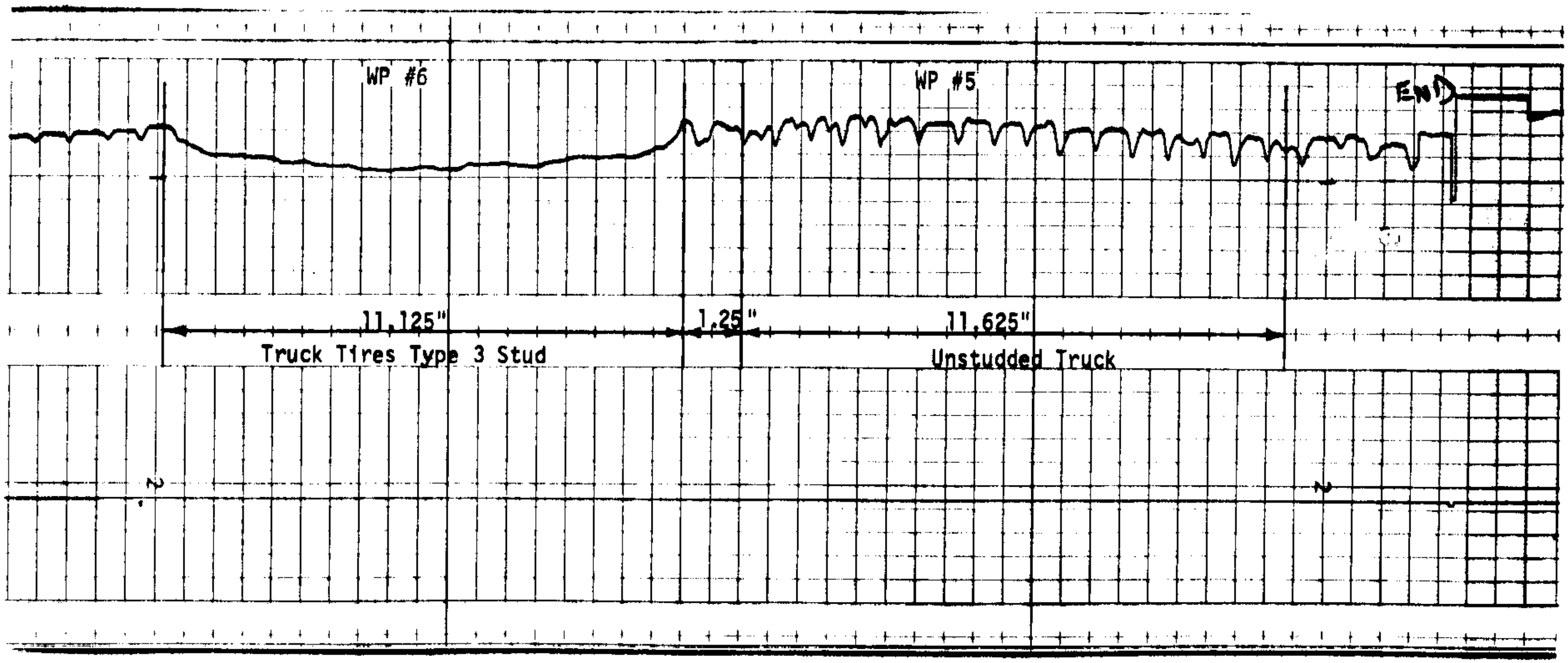
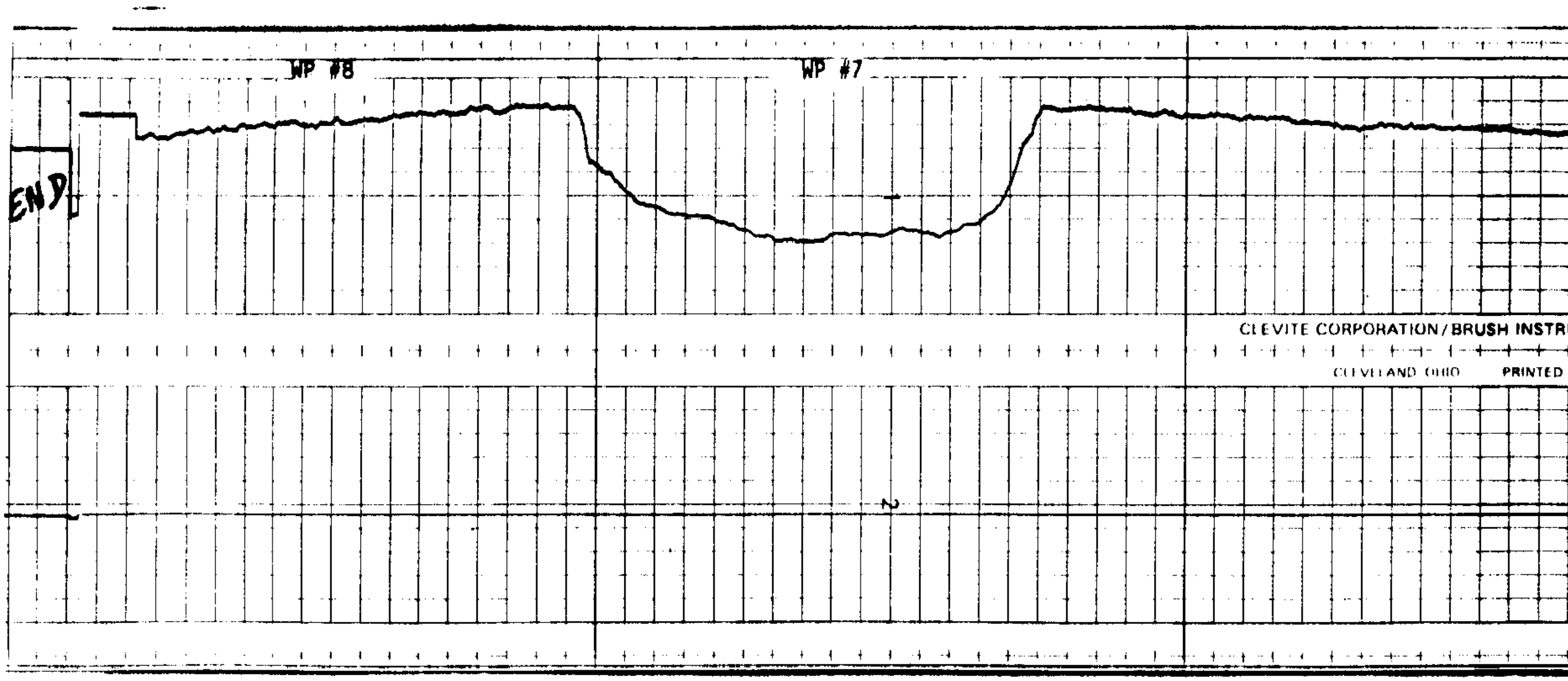


Figure 16 A Typical Chart Obtained from WSU Profilometer
Section: C-3a: Portland Cement Concrete with Plastic Longitudinal Grooving Texture

Horizontal Scale Compressed
Vertical Scale Expanded

1,368,421 Wheel Passes - WP #6
1,568,421 Wheel Passes - WP #5 Center Track

Unstudded Type 1 Stud



Horizontal scale compressed
Vertical scale expanded

Figure 17 A Typical Chart Obtained from WSU Profilometer
Section I-4a: Class "B" Asphalt Concrete
1,584,300 wheel passes - Inside Track

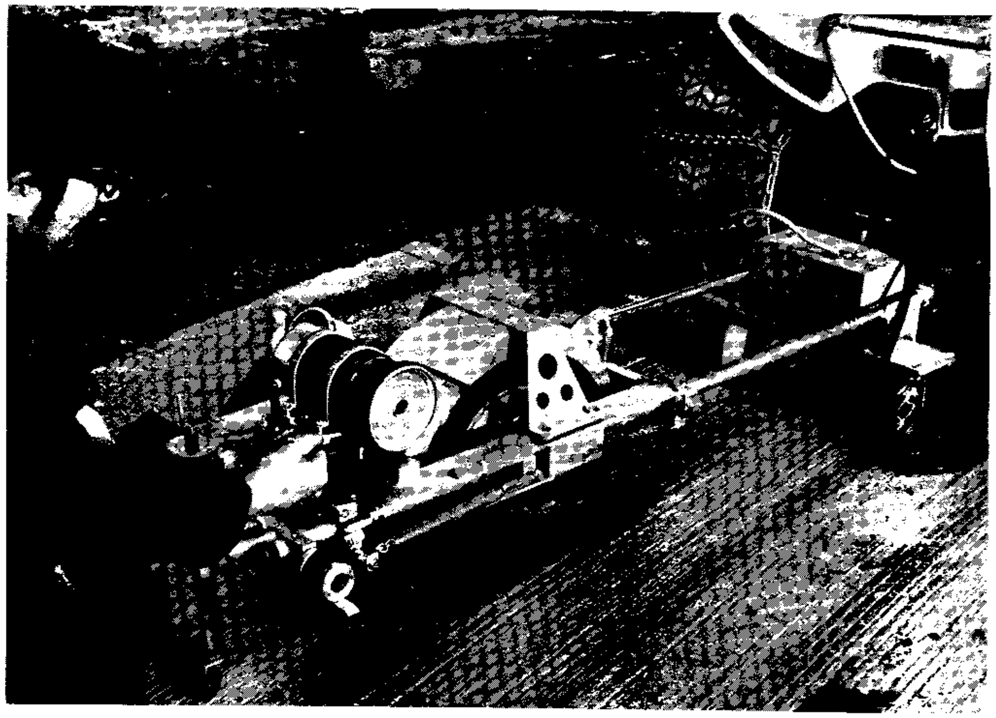


Figure 18: A view of the California Skid Tester being used on a grooved section of P.C.C. Note the tractor as the source of power and braking device.

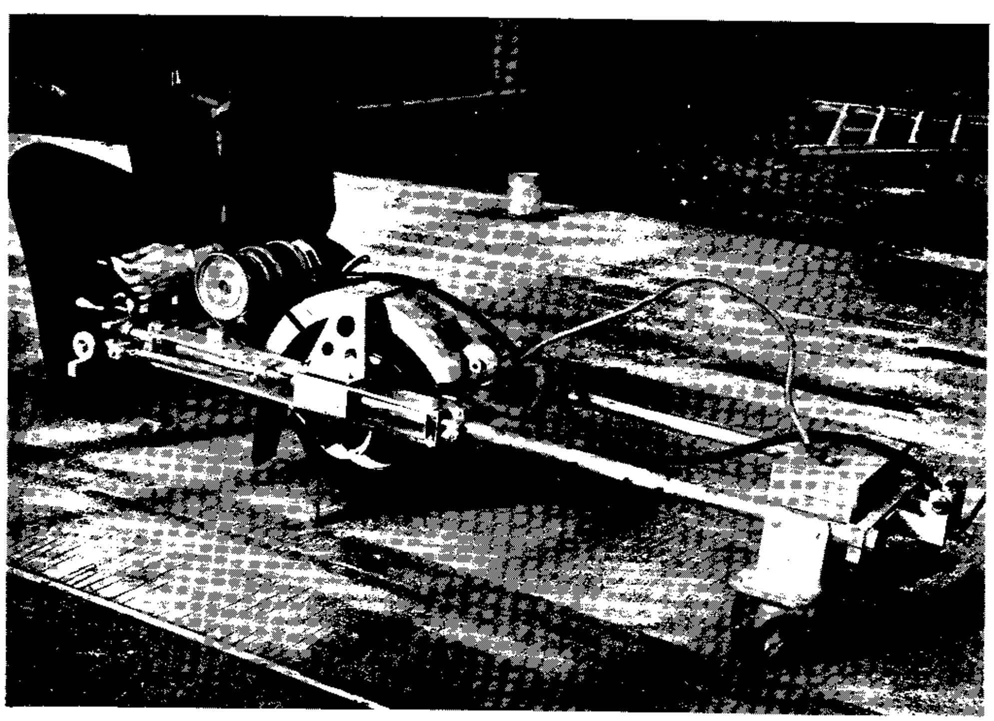


Figure 19: The California Skid Tester.

CONDITIONS AND LIMITATIONS OF TEST

TIME PERIOD

Testing started on February 11, 1972 and was terminated on May 4, 1972. A total of 542,357 revolutions had been applied. This meant that 542,357; 1,627,071 and 1,627,071 wheel passes had been applied on the outside, center and inside tracks. The late start was due to modifications made to the apparatus.

A total of 12,601 brake applications were applied on the "b" sections of the inside track. Problems with the braking system did not allow more applications.

The apparatus was in operation for a total of 1304 hours and 12 minutes; the rest of the time was spent in taking measurements, maintenance and repairs. Figure 20 shows the time the apparatus was in operation with down times. An abbreviated log of operations is shown in Appendix D.

SPEED

The speed of the apparatus was kept between 20-25 mph as shown in Figure 21 and in Appendix D. The difference in wear occurring on the various pavement 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 to control protrusion length was not achieved. Although this low speed is probably the speed that is common on many city streets during winter, this speed is much less than what can be expected on highways periodically, even in the winter.

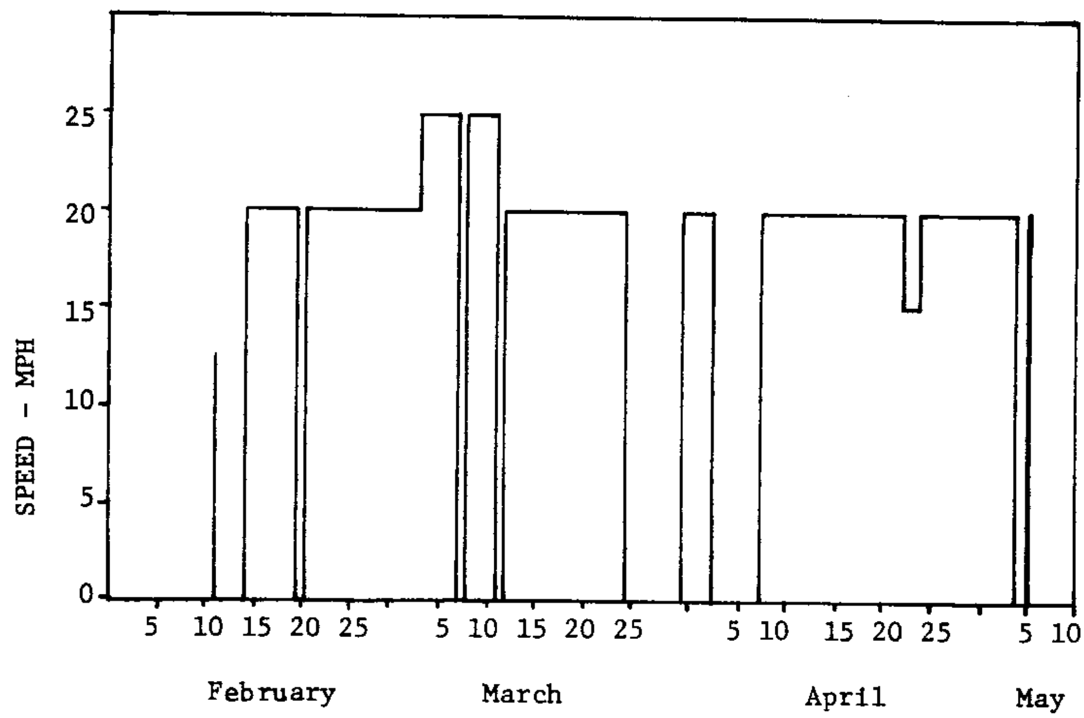


FIGURE 21 SPEED OF APPARATUS DURING THE TEST

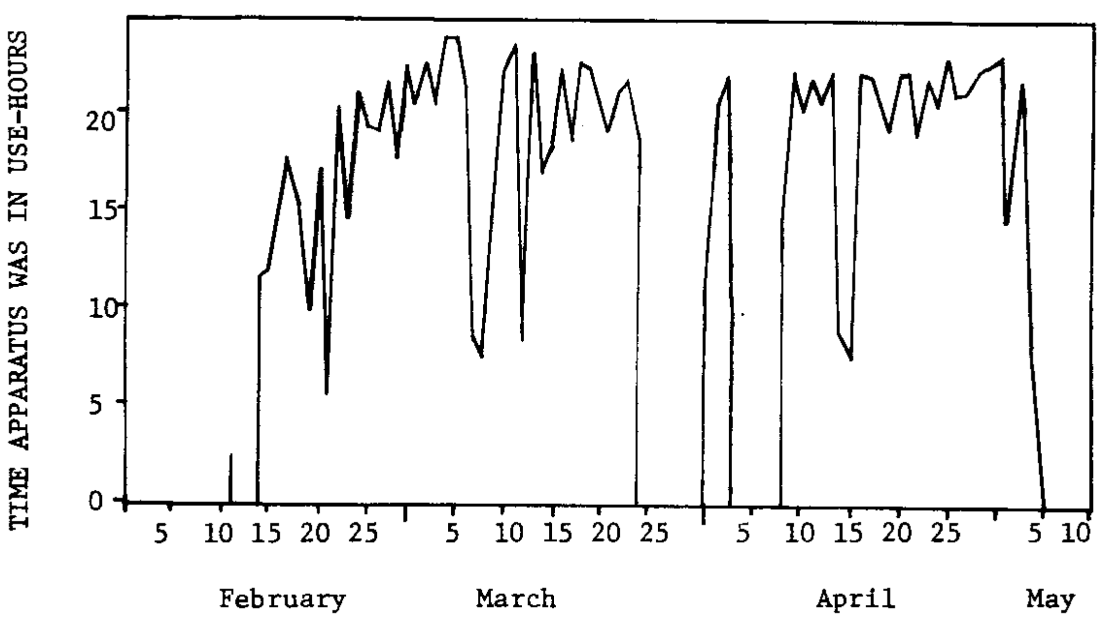


FIGURE 20 THE TIME THE APPARATUS WAS IN OPERATION DURING THE TEST

ECCENTRICITY

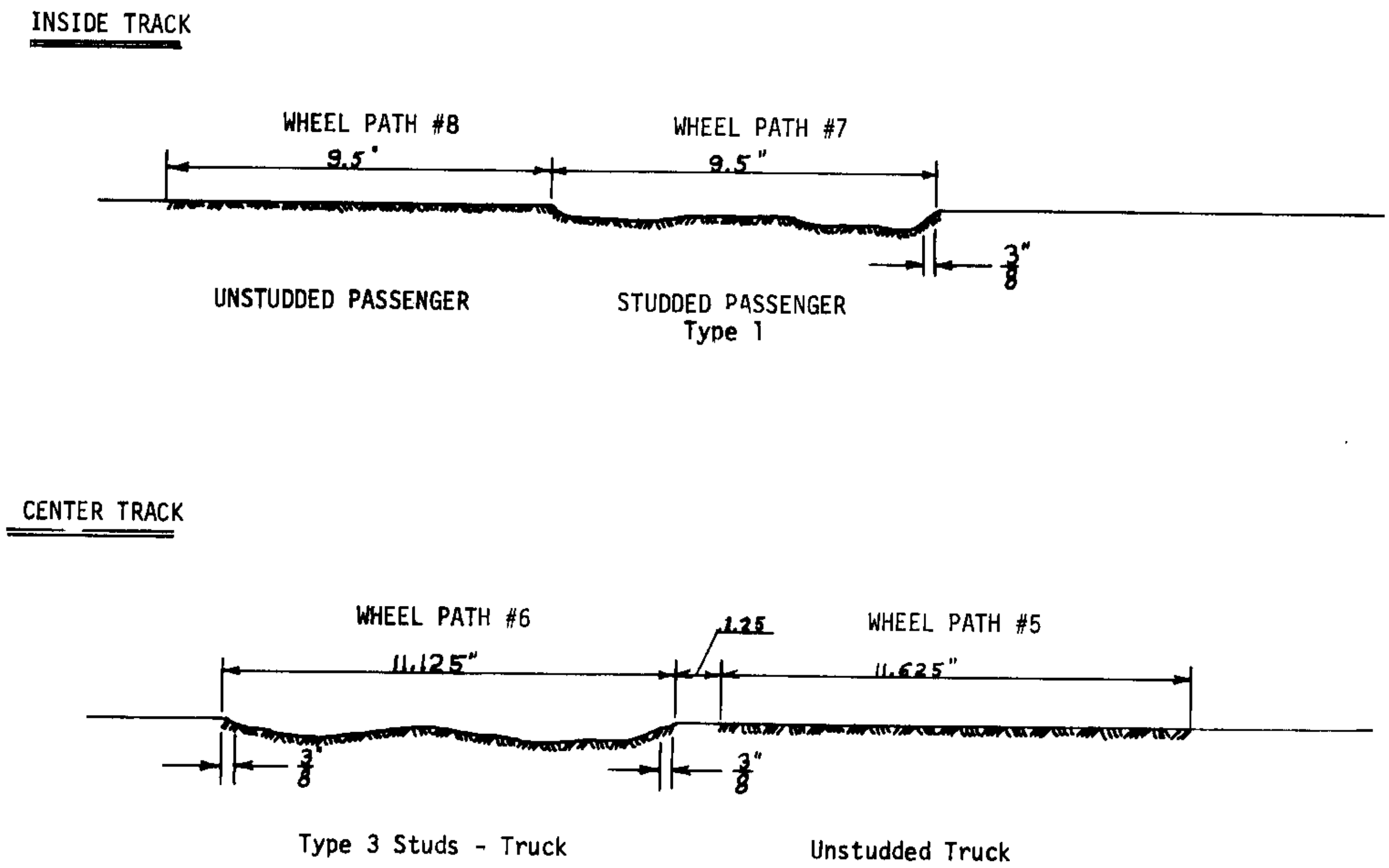
Initially, the eccentricity was kept at zero inches. This was changed to 0.50 inches total at 13,535 revolutions and then to 3.50 inches total at 62,357 revolutions. The eccentricity was increased so that tire grooves in wheel paths could be eliminated. The closeness of the tires did not allow a larger eccentricity. The wheel paths for the individual tires are shown in Figures 22 and 23.

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. Snow was not allowed to accumulate on the pavements. This was done to make sure that 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 wear comparison 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 this part of Washington during this time period. Figure 24 shows the maximum and minimum daily air temperatures and the amount of daily precipitation that fell in the Pullman area. Table 3 shows the high, low, and average ambient temperatures for the testing months.

Thermocouples measured the pavement surface and air temperatures around the track. Data was taken around the clock at every hour and has proved too voluminous to be included in this report. Therefore the temperature data

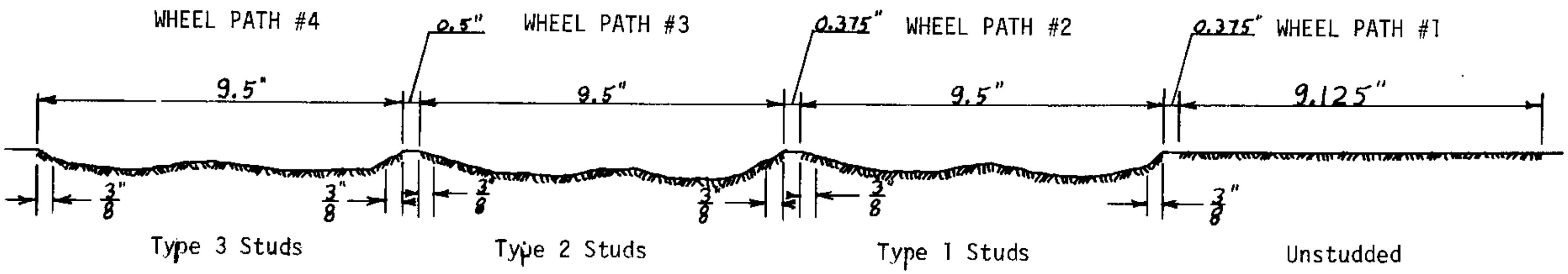


SCALE

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

Figure 22 Actual Widths of Wheel Paths at WSU Test Track
Eccentricity = 1.75 inches
Ring #5

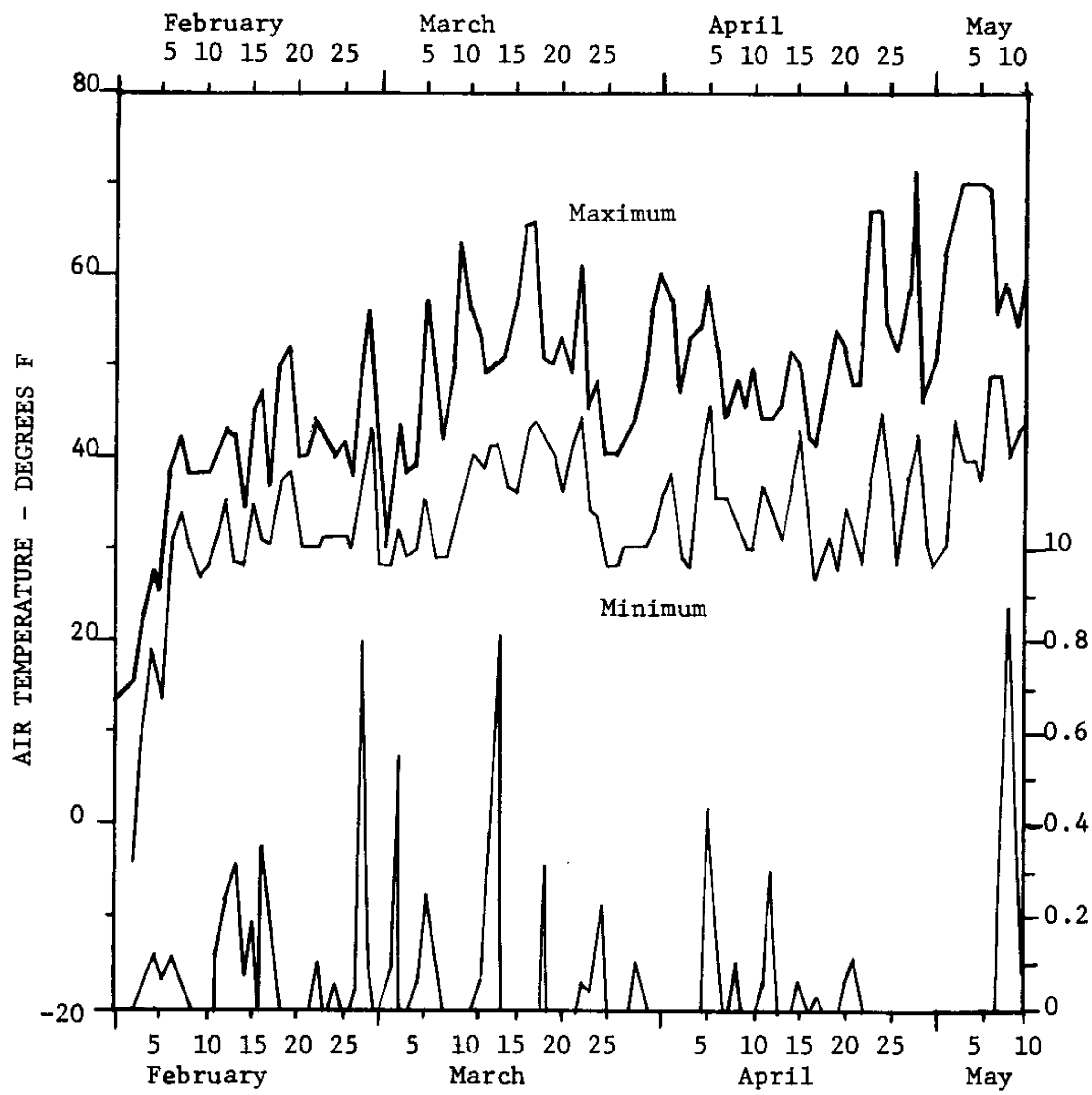
OUTSIDE TRACK



SCALE

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

Figure 23 Actual Widths of Wheel Paths at WSU Test Track
Eccentricity = 1.75"
Ring #5 - 112,000 revolutions



(Palouse Conservation Field Station)

FIGURE 24 DAILY MAXIMUM AND MINIMUM AIR TEMPERATURES AND DAILY PRECIPITATION - Pullman NW

TABLE 3

HIGH, LOW AND AVERAGE AMBIENT TEMPERATURES*

Month '72	Ambient[1] Temperature °F		Average[2] Ambient Temperature °F	
	Maximum	Minimum	Maximum	Minimum
February	56	-4	38.8	27.6
March	66	28	49.6	35.0
April	70	27	51.2	34.0

*Palouse Conservation Field Station

[1] Total Month

[2] Monthly Average of Daily Maximum and Minimums

is summarized in Table 4 and in Appendix E as maximum and minimum temperature ranges for the portland cement concrete and asphalt concrete pavements.

RESULTS AND ANALYSIS

STUD PROTRUSION AND TREAD DEPTH

Frequent measurements of stud protrusion showed variations with the different types of studs and over the length of test. Tread depth measurements also showed variations. The results of the measurements are summarized in Table 5 and in Figures 25, 26, and 27.

The tires were removed after 25,756 miles. Even after these many miles, there was quite a bit of tire tread remaining, although the stud protrusion lengths had increased. In normal road use, a winter tire will usually last about 10,000 miles before it has to be discarded.[1] This is one of the limitations of the test track in that normal use could not be duplicated; fast starts and sudden stops at various speeds could not be duplicated thus increasing the tire life. The tires on the test track were free-rolling except for the driving truck tire in wheel path #6.

These limitations, along with the slow speed, increased life of the tire considerably. This low speed also caused the type #1 studs to have higher than normal protrusion. Impact force needed to promote controlled protrusions was probably not great enough because the tire has to be driven 25 per cent or more at high speeds of 60-70 mph. This same problem was noticed with the American Oil Company Test Track Tests by Speer and Gorman (30).

---

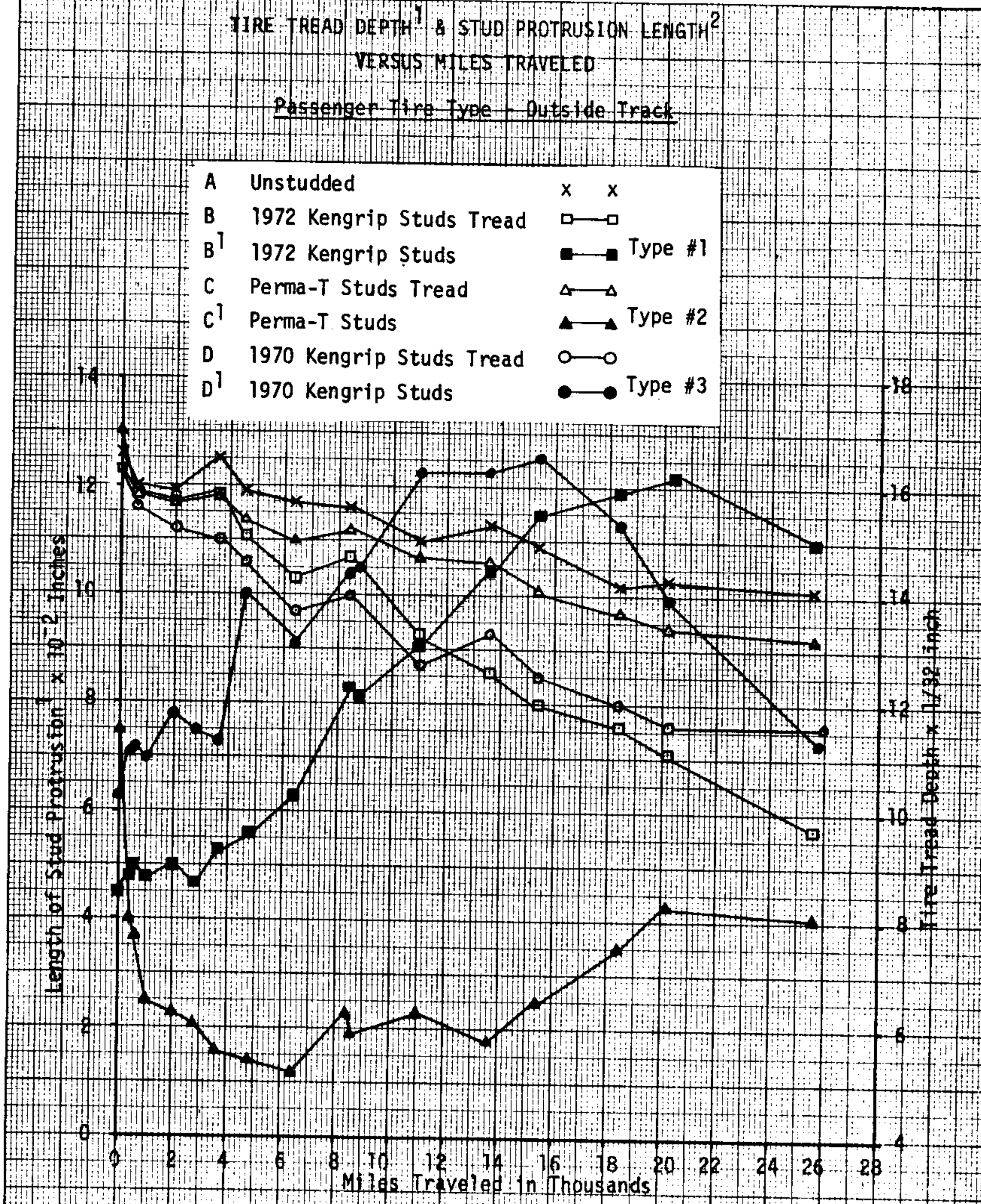
[1]Measurements made on winter studded tires used on Washington State University motor pool cars indicate that the average miles travelled were 7329 and 6107 for glass belted and nylon tires was 8.6 and 6.5 (x 1/32 inches), respectively. The final average stud protrusion, with type #3 studs, was 0.074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

TABLE 4

HIGH, LOW AND AVERAGE SURFACE PAVEMENT TEMPERATURES

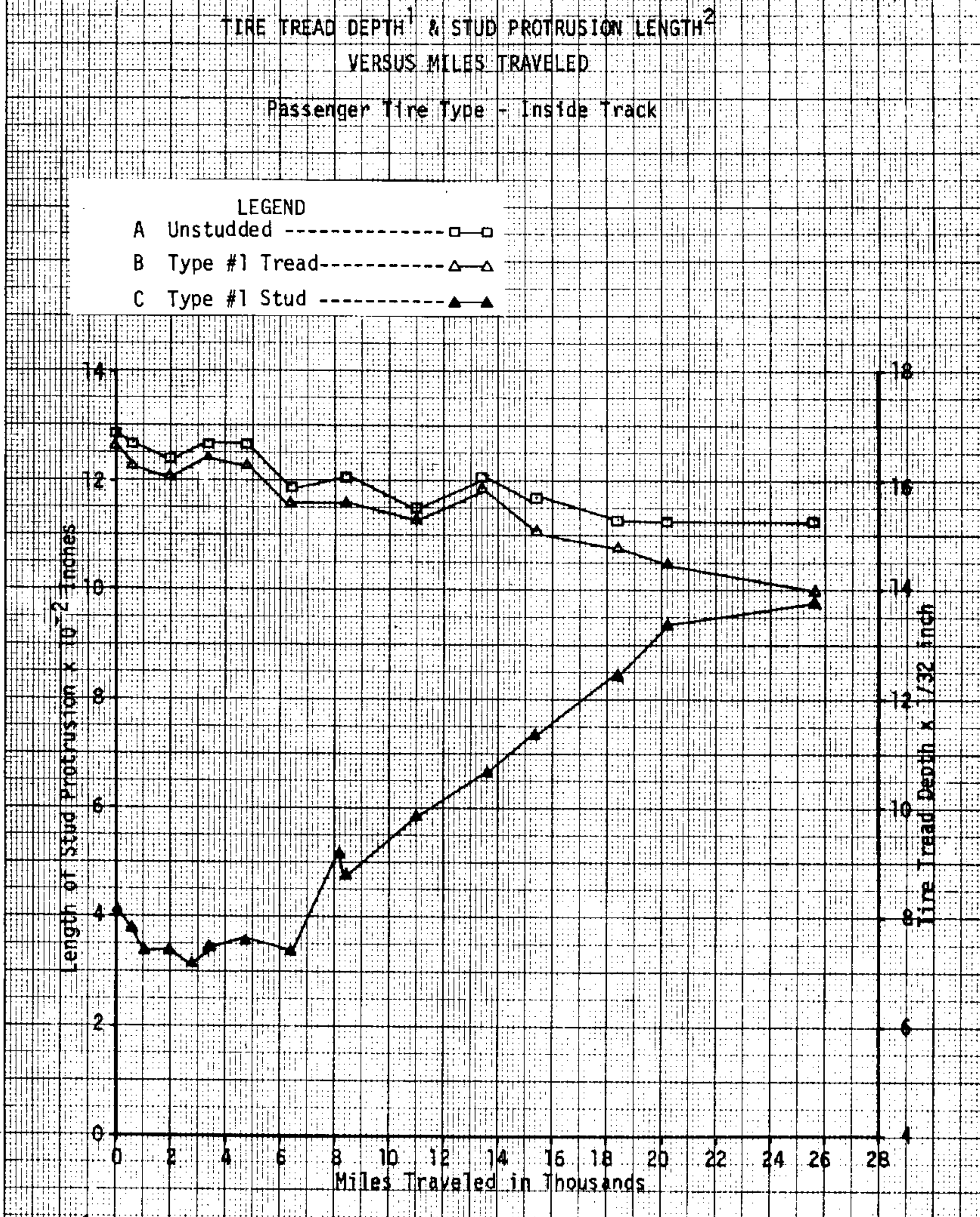
Pavement Type	Surface Temperature °F For the Month & the Average		February	March	April	The Testing Period[1]
Portland Cement Concrete	Average	MAXIMUM[2]	70.5	82	95.5	106
		MINIMUM[2]	27.5	26.5	25.5	25.5
		MAXIMUM[3]	50.3	60.9	69.8	64.4
		MINIMUM[3]	33.4	35.8	33.6	34.8
Asphalt Concrete	Average	MAXIMUM[2]	74	91.5	105	124
		MINIMUM[2]	27.5	25	24.5	24.5
		MAXIMUM[3]	54.6	66.5	78.2	71.2
		MINIMUM[3]	33.9	35.7	32.8	34.3

1 This includes the 5 days the test track was in operation during May.
2 Total Month.
3 Monthly Average of Daily Maximums and Minimums.



[1]Based on five positions on the tire and 15 readings, and then averaged.
[2]Based on five positions on the tire and 30 readings, and then averaged.

FIGURE 25

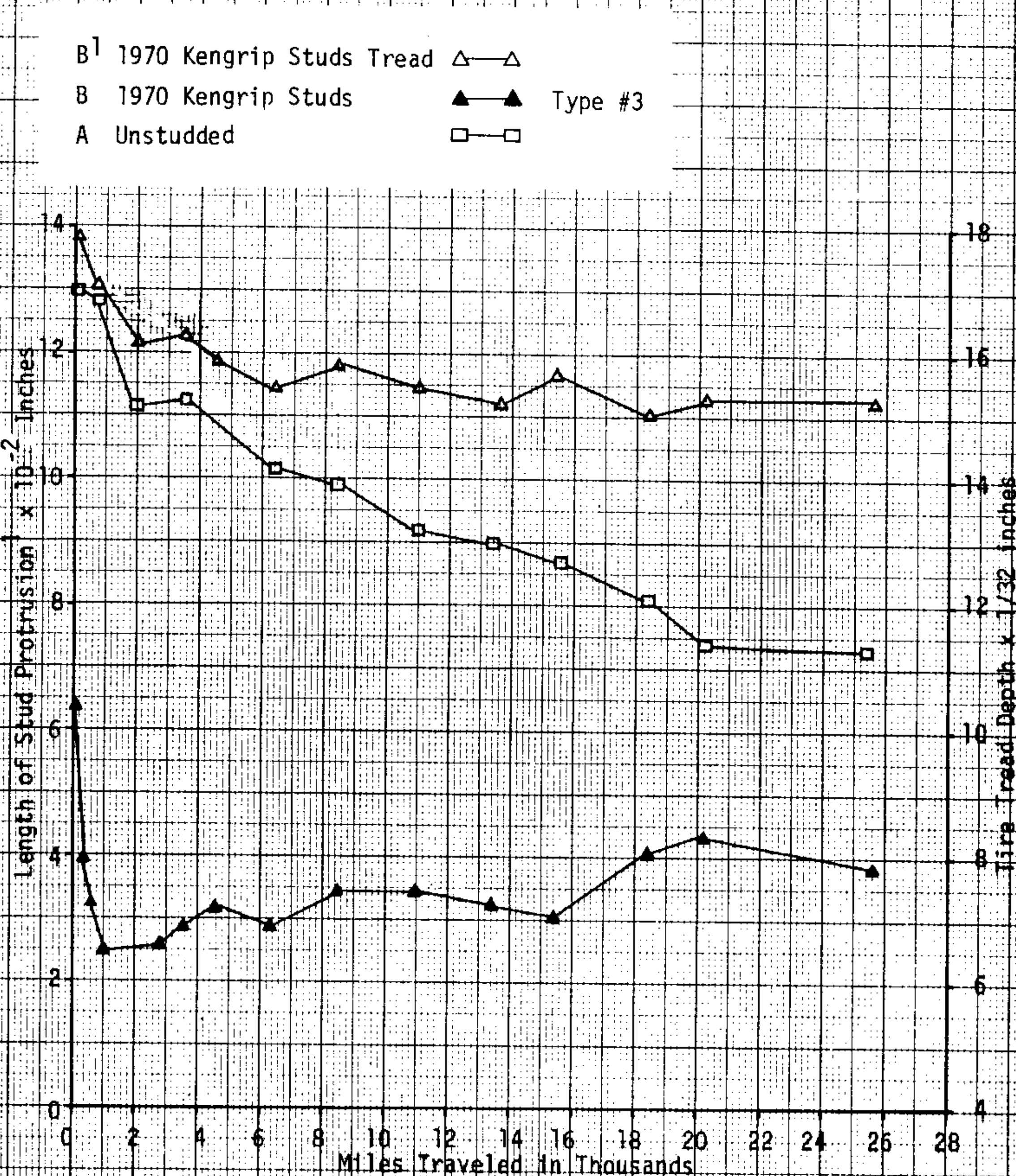


[1]Based on five positions on the tire and 15 readings, and then averaged.
[2]Based on five positions on the tire and 30 readings, and then averaged.

FIGURE 26

TIRE TREAD DEPTH[1] & STUD PROTRUSION LENGTH[2]
VERSUS MILES TRAVELED

Truck Tire Type - Center Track



[1]Based on five positions on the tire and 15 readings, and then averaged.
[2]Based on five positions on the tire and 30 readings, and then averaged.

FIGURE 27

Figure 27 and Table 5 show the type #3 studs used in the truck tires had consistently lower protrusions than for similar studs on the passenger tires. This may be due to the weight on the truck tires which may have worn the stud tips rapidly thus resulting in a fairly consistent protrusion.

Figure 28 shows the appearance of the six passenger tires after 25,756 miles. Note the amount of tire tread left and the appearance of the three tires used on the inside track; these are Tires #4, 5, 6 with the type #1 studs. The left edges were worn down due to nibbling of the tire sides and edges with the outside pavement rut sides; this also removed some of the studs in this row. Tires #2 and 3, with stud types 3 and 2, respectively, also show this same effect but not to the extent of the inside tire. Figures 29, 30 and 31 show the comparison of the different studs when they were new and after they had been used for 25,756 miles.

From the above mentioned table and figures, it can be seen that the type #2 stud had the least amount of protrusion, followed by the type #1 stud and then the type #3 stud. This is shown in Table #6.

SKID RESISTANCE VALUES

Skid resistance measurements were taken in each of the wheel paths. The length of time needed to take these readings along with need for dry pavements surfaces for measurement precluded their frequency. However, the few that were taken are summarized in Tables 7, 8, 9 for the outside, center, and inside tracks, respectively. Table 10 shows the comparison of percent reduction in skid resistance values between the section and different stud types.

The results show that the skid resistance values were reduced considerably in the studded tire wheel paths. A comparison made from the Tables 7, 9 and 10 between the polymer concrete, the Wirand® concretes and portland

TABLE 5

STUD PROTRUSIONS FOR DIFFERENT STUDS AND CORRESPONDING TREAD DEPTH

TRACK	WHEEL PATH	STUD TYPE	STUD PROTRUSION - INCH[1]						TREAD DEPTH - 1/32 INCH[2]					
			Miles Travelled						Miles Travelled					
			0	5,000	10,000	15,000	20,000	Final[3]	0	5,000	10,000	15,000	20,000	Final[3]
OUTSIDE	1	Unstudded	--	--	--	--	--	--	16.6	15.8	15.2	15.0	14.3	14.1
	2	1	0.045	0.056	0.086	0.112	0.121	0.110	16.3	14.8	13.8	12.0	11.1	9.7
	3	2	0.075	0.014	0.021	0.024	0.042	0.041	17.0	15.3	14.9	14.2	13.4	13.2
	4	3	0.063	0.097	0.114	0.125	0.101	0.073	16.2	14.4	13.2	12.7	11.6	11.6
CENTER	5[4]	Unstudded	--	--	--	--	--	--	17.0	14.7	13.4	12.7	11.5	11.3
	6[5]	3	0.064	0.031	0.034	0.031	0.043	0.038	17.8	15.7	15.6	15.5	15.2	15.3
INSIDE	7[5]	1	0.041	0.036	0.054	0.073	0.092	0.097	16.6	16.2	15.4	15.2	14.5	14.0
	8[4]	Unstudded	--	--	--	--	--	--	16.9	16.6	15.7	15.7	15.3	15.3

[1] Based on Five Positions on the Tire and 30 Readings, and then Averaged.

[2] Based on Five Positions on the Tire and 15 Readings, and then Averaged.

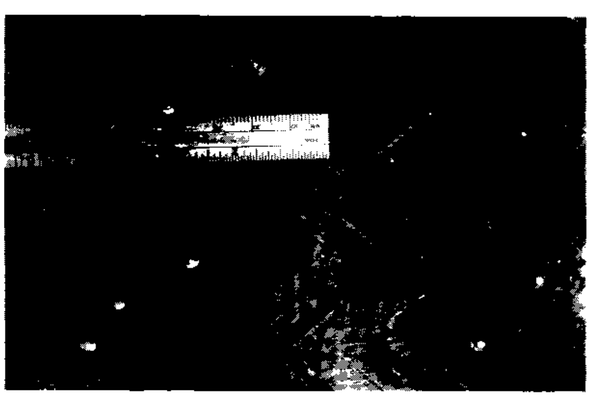
[3] Final Readings were taken at 25,756 Miles.

[4] Data Taken as in [2] from three tires, and then Averaged.

5 Data Taken as in [1] and [2] from three tires, and then Averaged.

Figure 28: Appearance of Passenger Tires after 25,756 Miles

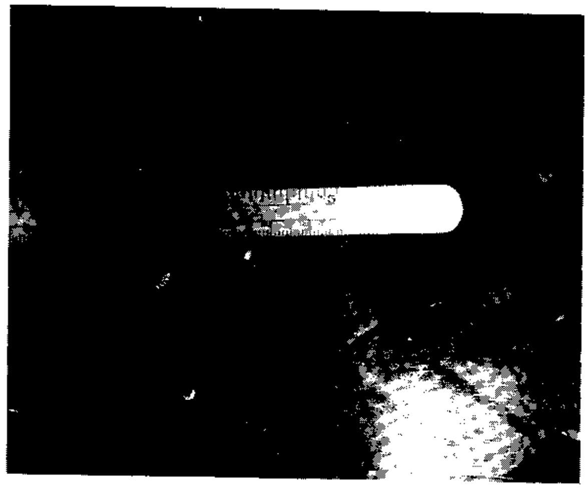
Left to right: Tire #1 with type #2 studs in wp #3; Tire #2 with type #3 studs in wp #4; Tire #3 with type #1 studs in wp #2 and Tires #5, 6, and 7 with type #1 studs in wp #7.



NEW OLD

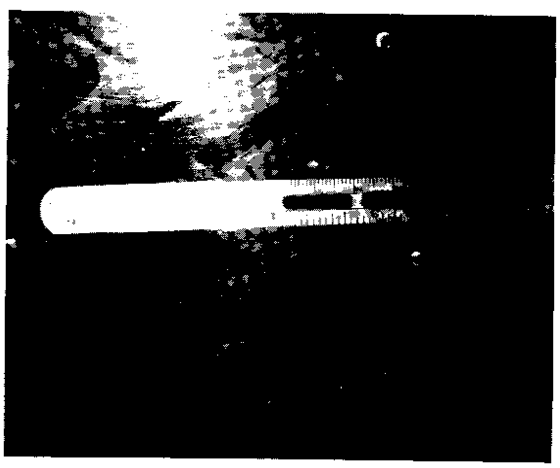
Figure 29: Appearance of Type #1 Studs New and After 25,756 Miles

New

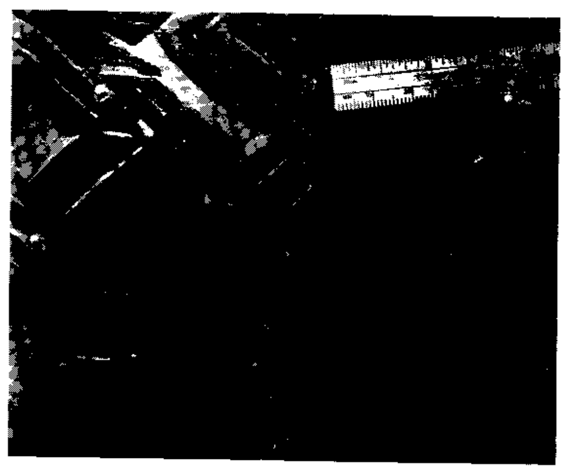


Old

Figure 30: Appearance of Type #2 Studs New and After 25,756 Miles



Old



New

Figure 31: Appearance of Type #3 studs New and After 25,756 Miles

Table 6: AVERAGE STUD PROTRUSIONS FOR DIFFERENT STUDS

TRACK	WHEEL PATH	STUD TYPE	AVERAGE STUD PROTRUSIONS - INCHES					
			MILES TRAVELLED					
			0 - 5,000	5 - 10,000	10 - 15,000	15 - 20,000	20 - FINAL[1]	0 - FINAL[1]
Outside	2	1	0.051	0.071	0.099	0.117	0.116	0.088
Outside	3	2	0.045	0.018	0.023	0.033	0.042	0.036
Outside	4	3	0.080	0.106	0.120	0.113	0.087	0.096
Center	6[2]	3	0.048	0.033	0.033	0.037	0.041	0.040
Inside	7[2]	1	0.039	0.045	0.064	0.083	0.095	0.066

[1] Final Readings were taken at 25,756 miles.

[2] Data taken from three tires, and then averaged.

TABLE 7 SKID RESISTANCE VALUES[1] ON OUTSIDE TRACK

SECTION	TYPE	NUMBER OF WHEEL PASSES - PASSENGER TIRES																
		0	30,000				130,000				350,000				542,357			
		STUD TYPES AND WHEEL PATHS																
		ALL[2]	U.S. #1	#1 #2	#2 #3	#3 #4	U.S. #1	#1 #2	#2 #3	#3 #4	U.S. #1	#1 #2	#2 #3	#3 #4	U.S. #1	#1 #2	#2 #3	#3 #4
0-1a A	2.0" Poly. Conc.	45		48														
B	2.0" Poly. Conc.	45		43														
C	2.0" Poly. Conc.	44		40														
0-1bA	0.5" Wirand Conc.	45	35	44	34	35	35[3]	32[3]	34[3]	35[3]					21	37	31	28
B	0.5" Wirand Conc.	43	32	42	26	31	32[3]	29[3]	26[3]	31[3]					17	38	27	30
C	0.5" Wirand Conc.	43	30	30	27	29									14	30	24	23
D	0.5" Wirand Conc.	45	36	31	32	36									18	28	30	33
0-2aA	1.0" Wirand Conc.	44	38	39	35	31									22	31	25	33
B	1.0" Wirand Conc.	46	39	36	33	34									23	34	30	30
C	3.0" Wirand Conc.	46	43	30	29	32									25	30	25	27
0-2bA	1.0" Poly. Conc.	40	35	25	25	30	31	19	18	22	22	15	17	19	24	18	24	16
B	0.25" Poly Conc.	38	31	24	26	30	29	13	13	13	23	15	14	17	27	17	16	18
0-3a	Cl "E" A.C.	42	39	40	35	38	28	31	17	26	16	12	16	27	26	32	28	31
b	Cl "E" Gilsabind	35	33	32	34	33	31	25	32	36	25	21	20	25	23	35	24	33
0-4a	Cl "B" A.C.	40	35	38	37	33	21	29	26	26	19	16	17	15	24	28	22	29
b	Cl "B" Gilsabind	26	24	22	24	26	19	21	24	31	26	30	27	33	30	39	30	36
0-5a	Cl "G" A.C.	40	36	38	37	34	31	27	22	29	31	30	25	31	31	40	32	43
b	Cl "G" A.C.	38	37	37	36	33	29	36	34	26	30	37	35	28	30	36	33	33
0-6a	Idaho Chip Seal	39	41	37	35	38		21	22									
b	Idaho Chip Seal	34	38	36	35	25		21	23									

[1] These are average values. [2] For the entire section [3] Taken at 73,000 wheel passes.

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

TABLE 8 SKID RESISTANCE VALUES[1] ON CENTER TRACK

SECTION	TYPE	SURFACE TEXTURES	NUMBER OF WHEEL PASSES - TRUCK TIRES												
			0	80,000		170,000		220,000		540,000		1,000,000		1,627,071	
			STUD TYPE AND WHEEL PATHS												
			ALL[2]	U.S. #5	#3 #6	U.S. #5	#3 #6	U.S. #5	#3 #6	U.S. #5	#3 #6	U.S. #5	#3[3] #6[3]	U.S. #5	#3[4] #6[4]
C-1a	PCC	Heavy Long, Brooming	52	49	34	42	27	39	18	37	22	37	14	34	13
b	PCC	Light Transverse Brooming	45	40	36	38	26	34	18	39	23	21	13	35	13
C-2a	PCC	Heavy Transverse Brooming	58	44	37	38	28	35	20	34	17	30	16	35	14
b	PCC	Burlap	50	35	35	30	24	29	18	26	15	24	14	26	14
C-3a	PCC	Longitudinal Grooving	38	42	32	34	28	30	21	28	14	27	14	27	13
b	PCC	Light Long. Brooming	53	48	36	40	24	33	18	27	15	28	14	32	14
C-4a	PCC	Transverse Grooving	48	41	37	37	25	34	19	33	16	35	15	37	14
b	PCC	Light Transverse Brooming	46	42	38	38	23	35	20	34	15	36	15	40	13
C-5a	PCC	Light Plastic Grooving	38	35	29	33	24	29	21	26	14	31	14	34	13
b	PCC	Light Plastic Grooving	33	33	26	35	22	30	19	26	13	30	13	37	13
C-6a	PCC	Med. Long. Brooming	43	48	27	44	23	43	21	35	15	35	15	38	14
b	PCC	Light Long. Brooming	45	45	26	42	21	39	19	31	17	30	16	29	14

1 These are average values.
2 For the entire section.
3 The correct number of truck wheel passes are: 978,887 with studs and 21,113 with no studs. The reason for is that on Arm #3 the studded truck tire was replaced with an unstudded one.
4 The correct number of truck wheel passes are: 1,396,935 with studs and 230,036 with no studs.

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

TABLE 9 SKID RESISTANCE VALUES [1] ON INSIDE TRACK

SECTION	TYPES	NUMBER OF WHEEL PASSES - PASSENGER TIRES												
		0	80,000		170,000		220,000		540,000		1,000,000		1,627,071	
		STUD TYPE AND WHEEL PATHS												
		All[2]	#1 #7	U.S. #8	#1 #7	U.S. #8	#1 #7	U.S. #8	#1 #7	U.S. #8	#1 #7	U.S. #8	#1 #7	U.S. #8
I-1a	PCC Heavy Long. Grooving	47	37	40	31	38	25	33	27	34	26	28	17	24
b	PCC Heavy Long. Grooving	37	34	42	28	38	23	38	27	38	16	31	20	27
I-2aA	1/8" Poly. Cement	41	32	38	20	31	17	30	16	30	18	29	19	34
aB	1/8" Poly. Flyash	25	26	25	18	24	16	24	14	22	15	21	16	22
bA	1/8" Poly. Flyash	23	24	26	18	25	16	26	13	29	14	29	17	30
bB	1/8" Poly Cement	25	27	26	15	26	151	25	14	26	23	22	15	22
I-3a	Class "E" A.C.	36	32	34	27	32	26	32	25	31	21	26	19	27
b	Class "E" A.C.	43	38	38	26	27	27	31	27	37	24	27	21	26
I-4a	Class "B" A.C.	39	36	37	29	33	27	34	25	32	24	28	25	27
b	Class "B" A.C.	45	40	42	30	38	28	36		31	18	26	22	25
I-5a	Class "G" A.C.	34	36	33	33	31	31	32	32	30	29	30	29	27
b	Class "G" A.C.	44	38	43	36	42	34	40		37	26	31	32	27
I-6a	Idaho Chip Seal	37	29	36	21	33	--	--	27	34	--	--	--	--
b	Idaho Chip Seal	37	30	38	21	36	--	--	27	38	--	--	16	23

[1] These are average values

[2] For the entire section

NOTE: The Washington State Highway Department considers pavement with skid resistance value of less than 25 to be dangerous.

TABLE 10: COMPARISON OF PERCENT REDUCTION IN SKID RESISTANCE VALUES

SECTION	TYPE	NUMBER OF WHEEL PASSES - PASSENGER TIRES								
		0	540,000							
		STUD TYPES, WHEEL PATHS & PERCENT REDUCTION [1]								
		All[2]	U.S. 1/8	% Red.	#1[3] 2/7	% Red.	#2 3	% Red.	#3 4	% Red.
I-1a	PCC	47	34	28	27	43	--	--	--	--
b	PCC	47	38	19	27	43	--	--	--	--
0-1bA	0.5" Wirand Conc.	45	21	53	37	18	31	31	28	38
B	0.5" Wirand Conc.	43	17	60	38	12	27	37	30	30
C	0.5" Wirand Conc.	43	14	67	30	30	24	44	23	47
D	0.5" Wirand Conc.	45	18	60	28	38	30	33	33	27
0-2aA	1.0" Wirand Conc.	44	22	50	31	30	25	43	33	25
B	1.0" Wirand Conc.	46	23	50	34	26	30	35	30	35
C	3.0" Wirand Conc.	46	25	46	30	35	25	46	27	41
I-2aA	1/8" Poly. Cement	41	30	27	16	61	--	--	--	--
B	1/8" Poly. Flyash	25	22	12	14	44	--	--	--	--
bA	1/8" Poly. Flyash	23	29	+26	13	43	--	--	--	--
B	1/8" Poly. Cement	25	26	4	14	44	--	--	--	--
0-2bA	1.0" Poly. Concrete	40	24	40	18	55	24	40	16	60
B	0.25" Poly. Conc.	38	27	29	17	55	16	58	18	53
I-3a	Class "E" A.C.	36	31	14	25	31	--	--	--	--
b	Class "E" A.C.	43	37	14	27	37	--	--	--	--
0-3a	Class "E" A.C.	42	26	38	32	24	28	33	31	26
b	Class "E" A.C. Gils.	35	23	34	35	0	24	31	33	6
I-4a	Class "B" A.C.	39	32	18	25	36	--	--	--	--
b	Class "B" A.C.	45	31	31	25	44	--	--	--	--
0-4a	Class "B" A.C.	40	24	40	28	30	22	45	29	28
b	Class "B" A.C. Gils.	26	30	+15	39	+50	30	+15	26	0
I-5a	Class "G" A.C.	34	30	12	32	6	--	--	--	--
b	Class "G" A.C.	44	37	16	26	41	--	--	--	--
0-5a	Class "G" A.C.	40	31	23	40	0	32	20	43	+8
b	Class "G" A.C.	38	30	21	36	5	33	13	33	13

1 Minus Values except where noted.
2 Taken from the entire section.
3 Means Stud Type #1, Wheel Path 2 and 7.

cement concrete sections shows that the polymer concrete sections had the lowest skid resistance values, with portland cement concrete next and the Wirand® concrete sections last. A comparison between the asphalt concrete sections show that the Class "G" A.C. had the highest skid resistance values followed by the Class "B" and the Class "E" asphalt concretes in that order. The asphalt concrete pavements had,on the average, higher skid resistance values at end of testing than the portland cement concrete and the different polymer concrete sections, with the exception of the Wirand® concrete sections. The portland cement concrete sections in the center track as shown in Table 8 suffered drastic reductions in skid resistance values.

Examination of the different types of studs on skid resistance show that the type #3 stud lowered skid resistance values in the wheel path on comparable sections more than did the type #1 or # 2 studs. The unstudded tires caused skid resistance values to drop; their values were lower than in the studded tire wheel paths in almost all the outside track sections. This can be seen in Table 7 and 10. The studded truck tires really reduced the portland cement concrete skid resistance value drastically. Since the Washington State Highway Department considers pavement surfaces with skid resistance values of less than 25 to be dangerous, the three tables show that many sections in the different wheel paths at the end of the test had values less than 25.

MEASUREMEMENTS OF WHEEL PATHS

a) Profilometer Measurements

Each profilometer chart and section profile was transferred onto computer cards. A computer program was developed to obtain certain data. The results were obtained from the computer in a typical format as shown in Appendix F. Three typical formats are included for the various sections. The computer also plotted typical cross-sections for each of the tracks, the wheel path and wheel passes.

The final results are summarized in a series of tables. Tables 11 and 12 summarize the profilometer for the concrete type and asphalt type section on the outside track respectively. The different Wirand® concrete sections can be compared with the two polymer concrete sections in Table 11. Several of the Wirand® concrete sections, especially O-2aC, did as well or better than the polymer concrete sections in all the wheel paths. According to Table 12, the Class "E" asphalt concrete seems to be superior than the Class "G" or Class "B" asphalt concrete pavements in all the wheel passes.

The final results for the inside track are summarized in Table 13 for the concrete types and Table 14 for the asphalt types. The polymer concrete sections seemed to wear better than the portland cement concrete pavements as shown in Table 13. The Class "B" asphalt concrete seemed to be superior to the Class "E" and the Class "G" asphalt concrete pavements, respectively. This was reverse of the findings on the outside track for the type #1 stud wheel path. The brakes were applied to the inside "b" sections; unfortunately too few applications were made so that it is difficult to assess the effect of braking.

Table 15 shows the data summarized from the center track and the truck tires. From the results, it is difficult to evaluate the effect of the different portland cement concrete surfaces. It should be noted that the wear was less than for portland cement concrete sections on inside track. This was due to apparatus, and it is felt that once the driving inside studded

TABLE 11 PROFILOMETER DATA SUMMARY FOR OUTSIDE TRACK CONCRETE SECTIONS

STUD TYPE	PARAMETERS	UNITS	WIRAND® CONCRETE SECTIONS							POLYMER CONCRETE SEC.	
			0-1aA[1]	0-1bB[1]	0-1bC[1]	0-1bD[1]	0-2aA[1]	0-2aB[1]	0-2aC[2]	0-2bA	0-2bB
#1	Area Removed	sq. inches	1.84	1.68	1.92	1.90	2.31	1.74	1.05	2.07	0.91
	Rate of Wear	in./10^6 w.a.[4]	0.358	0.330	0.371	0.365	0.446	0.337	0.197	0.398	0.174
	Maximum Depth	inches	0.30	0.26	0.30	0.28	0.35	0.24	0.16	0.30	0.20
	Average Depth	inches	0.19	0.18	0.20	0.20	0.24	0.18	0.11	0.22	0.09
#2	Area Removed	sq. inches	1.05	0.74	0.62	0.94	0.92	0.78	0.72	0.91	1.31
	Rate of Wear	in./10^6 w.a.[4]	0.201	0.144	0.122	0.181	0.171	0.146	0.133	0.177	.247
	Maximum Depth	inches	0.19	0.16	0.12	00.15	0.16	0.16	0.14	0.15	0.21
	Average Depth	inches	0.11	0.08	0.07	0.10	0.09	0.08	0.07	0.096	0.13
#3	Area Removed	sq. inches	2.27	2.29	1.62	2.00	2.12	2.30	0.83	1.08	1.07
	Rate of Wear	in./10^6 w.a.[4]	0.428	0.430	0.319	0.378	0.404	0.444	0.162	0.212	0.212
	Maximum Depth	inches	0.37	0.36	0.30	0.33	0.36	0.34	0.15	0.20	0.20
	Average Depth	inches	0.23	0.23	0.17	0.21	0.22	0.24	0.09	.12	.12
U.S.	Area Removed[3]	sq. inches	--	--	--	--	--	--	--	--	--
	Rate of Wear	in./10^6 w.a.[4]	.0255	.0028	0.0082	0.0431	.0122	0.0127	0.0028	.0066	--
	Maximum Depth	inches	0.02	0.036	0.028	0.053	.05	0.035	0.034	.026	.047
	Average Depth	inches	0.014	0.0015	.004	.023	.0066	.0074	.0015	.0009	--

® Registered trade mark of Battelle Development Corporation
1 These sections had light transverse brooming surfaces.
2 This section had longitudinal grooving surface.
3 Insignificant value.
4 w.a. means wheel applications.

TABLE 12 PROFILOMETER DATA SUMMARY FOR OUTSIDE TRACK ASPHALT SECTIONS

STUD	PARAMETERS	UNITS	DIFFERENT ASPHALT CONCRETE SECTIONS							
			0-3a	0-3b	0-4a	0-4b	0-5a	0-5b	0-6a[1]	0-6b[2]
#1	Area Removed	sq. inches	2.22	2.25	2.66	2.74	2.15	2.82	--	1.10
	Rate of Wear	in./10^6 w.a.[3]	0.422	0.423	.511	.535	.405	.539	--	0.214
	Maximum Depth	inches	.31	0.32	.38	.38	.30	.38	--	.26
	Average Depth	inches	.23	0.23	.28	.29	.22	.29	--	.12
#2	Area Removed	sq. inches	1.39	1.42	1.20	1.21	1.28	1.41	--	2.15
	Rate of Wear	in./10^6 w.a.[3]	0.268	0.273	.228	.239	.250	.269	--	0.411
	Maximum Depth	inches	.213	.23	.196	.23	.20	.20	--	.37
	Average Depth	inches	.14	.15	.12	.13	.14	.15	--	.22
#3	Area Removed	sq. inches	2.69	3.11	2.83	2.90	2.94	3.65	--	3.77
	Rate of Wear	in./10^6 w.a.[3]	.520	.595	.542	.551	.562	.699	--	0.742
	Maximum Depth	inches	.39	.43	.42	.44	.42	.52	--	.53
	Average Depth	inches	.28	.32	.29	.30	.30	.38	--	.40
U.S.	Area Removed	sq. inches	--	--	--	--	--	--	--	--
	Rate of Wear	in./10^6 w.a.[3]	0.053	0.0125	0.0244	0.0264	.0360	.0171	--	0.144
	Maximum Depth	inches	0.044	0.042	0.038	.084	.045	.024	--	0.11
	Average Depth	inches	0.029	0.0068	0.013	.014	.020	.0093	--	.078

1 Readings Unavailable.
2 From Photo-Wire Data
3 w.a. means wheel applications

TABLE 13 PROFILOMETER DATA SUMMARY FOR INSIDE TRACK CONCRETE SECTIONS

STUD TYPE	PARAMETERS	UNITS	Portland Cement Concrete		Polymer Concrete			
			I-1a	I-1b	I-2aA	I-2aB	I-2bA	I-2bB
U.S.	Area Removed	square inch						
	Rate of Wear	$in^2/10^6$ w.a.[1]						
	Maximum Depth	inches		.054				
	Average Depth	inches						
#1	Area Removed	square inch	1.89	1.41	1.52	1.56	.929	1.25
	Rate of Wear	$in^2/10^6$ w.a.[1]	.112	.0859	.0945	.0979	.0592	.0801
	Maximum Depth	inches	.32	.26	.25	.24	.15	.22
	Average Depth	inches	.20	.14	.16	.16	0.10	.13

1 w.a. stands for wheel applications

TABLE 14 PROFILOMETER DATA SUMMARY FOR INSIDE TRACK ASPHALT SECTIONS

STUD TYPE	PARAMETERS	UNITS	ASPHALT CONCRETE SECTIONS							
			I-3A	I-3b	I-4a	I-4b	I-5a	I-5b	I-6a	I-6b
U.S.	Area Removed	square inches								
	Rate of Wear	in./10^6 w.a.[1]			.0025			.0024		
	Maximum Depth	inches			0.05			.048		.091
	Average Depth	inches			0.004			.004		
#1	Area Removed	square inches	5.79	6.12	5.34	5.37	6.84	6.09	--	4.44[2]
	Rate of Wear	in./10^6 w.a.[1]	.367	.389	.338	.338	.423	.387	--	.286
	Maximum Depth	inches	.78	.81	.72	.75	.90	.81	--	.65
	Average Depth	inches	.60	.63	.55	.55	.69	.63	--	.47

1 w.a. means wheel applications

2 From Photo-wire data

TABLE 15 SUMMARY OF PROFILOMETER DATA - CENTER TRACK

STUD TYPE	PARAMETERS	UNITS	PORTLAND CEMENT CONCRETE					
			C-1a	C-1b	C-2a	C-2b	C-3a	C-3b
U.S.[1]	Area Removed	sq. inches	0.18			.11		.20
	Rate of Wear	in./10^6 w.a.[3]	.0096		.0140	.0034		.0022
	Maximum Depth	inches	0.064	.025	0.048	.044	.053	.060
	Average Depth	inches	0.016		0.023	0.006		.004
#3[2]	Area Removed	sq. inches	1.53	1.75	1.24	1.23	1.52	1.42
	Rate of Wear	in./10^6 w.a.[3]	.0887	.1114	.0811	.0811	.0936	.0901
	Maximum Depth	inches	0.22	0.25	0.21	0.18	0.25	.20
	Average Depth	inches	.12	.16	.11	.11	.13	.13
STUD TYPE	PARAMETERS	UNITS	C-4a	C-4b	C-5a	C-5b	C-6a	C-6b
U.S.[1]	Area Removed	sq. inches	.055	.156	.150	.311	.198	
	Rate of Wear	in./10^6 w.a.[3]	.0022	.0058	.0059	.0110	.0105	
	Maximum Depth	inches	.055	.042	.069	.063	.055	.037
	Average Depth	inches	.004	.009	.010	.018	.017	
#3[2]	Area Removed	sq. inches	1.41	1.51	1.26	2.08	1.58	1.38
	Rate of Wear	in./10^6 w.a.[3]	.0904	.0950	.0796	.0674	.101	.0809
	Maximum Depth	inches	.20	.21	0.19	.18	.23	0.21
	Average Depth	inches	.13	.13	.11	.094	.14	.13

1 1,627,071 unstudded truck wheel passes.
2 1,396,955 truck studded wheel passes + 230,136 unstudded truck wheel passes.
3 w.a. means wheel applications

tires wore down a groove,the weight of truss shifted to the outside unstudded truck tires. This was shown by the extreme slowing of rate of wear and by the rapid wear to outside truck tires. This was due to the design of the apparatus and could have been avoided if the studded tires had been installed on the outside wheel path.

Tables 16, 17 and 18 show the maximum rut depth values obtained using four 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.

The profilometer had some limitations. Since no reference pins were used, this caused the same problem of lining up the starting positions and caused much unnecessary work for the analyst. Maximum depth that the profilometer could measure was 1.00 inch but this was frequently limited to about 0.75 inches, and hence some deep rut values may be less than obtained using different methods. However, the profilometer readings proved to be quickest to take and hence most of the results are based on this method.

b) Photo-wire Picture Measurements

This method was used mainly as back-up measurements for the profilometer readings, and thus all the rolls of film were not analyzed. A typical strip of film for one of the sections is shown in Figure 32. The data was handled similarly to the profilometer readings and was analyzed by computer. Some of this data, concerning maximum rut depth, is shown in Tables 16, 17 and 18. The results indicate measuring method variability.

Reference pins were used for placing the camera box frame. It was found that the frame was too short to take all the pictures frames on the outside track. The frame was built before the plans to have four wheel paths

TABLE 16 COMPARISON OF FINAL MAXIMUM RUT DEPTHS USING DIFFERENT METHODS
- OUTSIDE TRACK - INCHES -

SECTION	Unstudded - WP #1				Stud Type #1 - WP #2				Stud Type #2 - WP #3				Stud Type #3 - WP #4			
	MEASURING METHODS[1]															
	#1	#2	#3	#4	#1	#2	#3	#4	#1	#2	#3	#4	#1	#2	#3	#4
0-1bA	0.02	0.01	0.05	--	0.22	0.30	0.27	0.30	0.12	0.19	0.15	0.13	0.32	0.37	0.40	0.38
B	0.02	0.04	0.03	--	0.30	0.26	0.28	0.27	0.14	0.16	0.17	0.15	0.38	0.36	--	0.38
C	0.02	0.02	0.02	--	0.28	0.30	0.25	0.23	0.14	0.12	0.12	0.13	0.29	0.30	0.36	0.33
D	0.04	0.05	--	--	0.27	0.28	--	0.25	0.13	0.15	--	0.15	0.32	0.33	--	0.29
0-2aA	0.04	0.05	0.07	--	0.33	0.35	0.31	0.31	0.14	0.16	0.23	0.29	0.36	0.36	0.35	0.35
B	0.05	0.04	0.08	--	0.29	0.24	0.30	0.29	0.15	0.16	0.17	0.13	0.40	0.34	0.25	0.35
C	0.02	0.09	0.17	--	0.15	0.16	0.22	0.21	0.19	0.14	0.21	0.19	0.16	0.15	0.30	0.21
0-2bA	0.03	0.03	0.08	--	0.27	0.30	0.32	0.30	0.15	0.15	0.18	0.19	0.24	--	--	0.42
B	0.05	0.05	0.05	--	0.14	0.20	0.17	0.23	0.18	0.21	0.20	0.19	0.20	0.20	0.29	0.21
0-3a	0.02	0.06	--	--	0.31	0.31	--	0.36	0.20	0.18	--	0.26	0.40	0.39	--	0.46
b	0.02	0.04	0.03	--	0.29	0.32	0.30	0.36	0.21	0.23	0.23	0.26	0.44	0.43	--	0.46
0-4a	0.02	0.04	--	--	0.35	0.38	0.43	0.45	0.19	0.24	--	0.25	0.44	0.44	--	0.44
b	0.02	0.08	--	--	0.31	0.38	--	0.39	0.19	0.24	--	0.25	0.44	0.44	--	0.44
0-5a	0.02	0.04	0.03	--	0.31	0.30	0.33	0.39	0.20	0.20	0.26	0.24	0.39	0.42	0.47	0.49
b	0.02	0.02	0.06	--	0.36	0.38	0.40	0.43	0.16	0.22	0.22	0.29	0.56	0.52	0.65	0.58
0-6a	--	--	0.11	--	--	--	0.26	0.33	--	--	0.37	0.29	--	--	0.53	0.66
b	--	--	--	.26	--	--	--	0.36	--	--		--	0.25	--	--	0.50

Method #1: Measured from Profilometer Charts
#2: Computed by Computer from Profilometer Charts
#3: Computed by Computer from Photo-wire Pictures

Method #4: Measured by Straight-Edge; Average of 5 readings.

TABLE 17 COMPARISON OF FINAL MAXIMUM RUT DEPTHS USING DIFFERENT METHODS

- Center Track - Inches -

SECTION	TYPE OF MATERIAL AND SURFACE TEXTURES	TRUCK TIRE UNSTUDDED - WP#5				TRUCK TIRE STUD TYPE #3 - WP#6			
		MEASURING METHODS[1]							
		#1	#2	#3	#4	#1	#2	#3	#4
C-1a	PCC Heavy Long. Grooving	0.02	0.06	0.07	--	0.24	0.22	0.25	0.26
b	PCC Light Transverse Brooming	0.05	0.02	0.05	--	0.24	0.25	0.25	0.25
C-2a	PCC Heavy Transverse Brooming	0.05	0.03	0.05	--	0.20	0.19	0.19	0.25
b	PCC Burlap	0.03	0.05	0.03	--	0.20	0.20	--	0.20
C-3a	PCC Longitudinal Grooving	0.02	0.09	0.13	--	0.23	0.26	0.21	0.30
b	PCC Light Long. Brooming	0.04	0.05	0.06	--	0.19	0.21	0.34	0.20
C-4a	PCC Transverse Grooving	0.02	0.02	0.12	--	0.23	0.21	0.26	0.26
b	PCC Light Transverse Grooving	0.02	0.03	0.05	--	0.22	0.21	0.24	0.23
C-5a	PCC Light Plastic Grooving	0.02	0.07	0.09	--	0.22	0.21	0.22	0.24
b	PCC Light Plastic Grooving	0.04	0.06	0.14	--	0.22	0.18	0.28	0.26
C-6a	PCC Med. Long. Brooming	0.02	0.05	0.06	--	0.21	0.23	0.25	0.23
b	PCC Light Long. Brooming	0.02	0.04	0.04	--	0.18	0.21	0.21	0.23

[1] Method #1: Measured from Profilometer Charts
#2: Computed by Computer from Profilometer Charts
#3: Computed from Photo-Wire Pictures
#4: Measured by Straight Edge - average of 5 readings

TABLE 18 COMPARISON OF FINAL MAXIMUM RUT DEPTHS USING DIFFERENT METHODS

- Inside Track - Inches -

SECTION	TYPE OF MATERIAL AND SURFACE TEXTURES	STUD TYPE #1 - WP#7				UNSTUDDED - WP#8			
		MEASURING METHODS[1]							
		#1	#2	#3	#4	#1	#2	#3	#4
I-1a	PCC Heavy Longitudinal Grooving	0.28	0.32	0.44	0.30	0.02	--	--	--
b	PCC Heavy Longitudinal Grooving	0.32	0.26	0.48	0.39	0.02	0.05	--	--
I-2aA	1/8" Poly. Cement	0.24	0.25	0.33	0.27	0.03	--	--	--
B	1/8" Poly. Flyash	0.23	0.24	0.23	0.25	0.03	--	--	--
2bA	1/8" Poly. Flyash	0.17	0.16	0.17	0.17	0.03	--	--	--
B	1/8" Poly. Cement	0.22	0.22	0.22	0.25	0.02	--	--	--
I-3a	Class "E" A.C.	0.77	0.78	0.81	0.80	0.04	--	--	--
b	Class "E" A.C.	0.78	0.81	0.83	0.83	0.03	--	--	--
I-4a	Class "B" A.C.	0.69	0.72	0.66	0.84	0.03	0.05	--	--
b	Class "B" A.C.	0.75	0.75	0.75	0.81	0.03	--	--	--
I-5a	Class "G" A.C.	0.88	0.91	0.88	0.98	0.02	0.03	--	--
b	Class "G" A.C.	0.82	0.81	0.82	0.98	0.02	0.05	--	--
I-6a	Idaho Chip Seal	--	--	--	0.83	--	--	--	0.21
b	Idaho Chip Seal	--	--	0.65	0.93	--	--	0.09	0.21

[1] Method #1: Measured from Profilometer Charts
#2: Computed by Computer from Profilometer Charts
#3: Computed from Photo-Wire Pictures
#4: Measured by Straight Edge - average of 5 readings

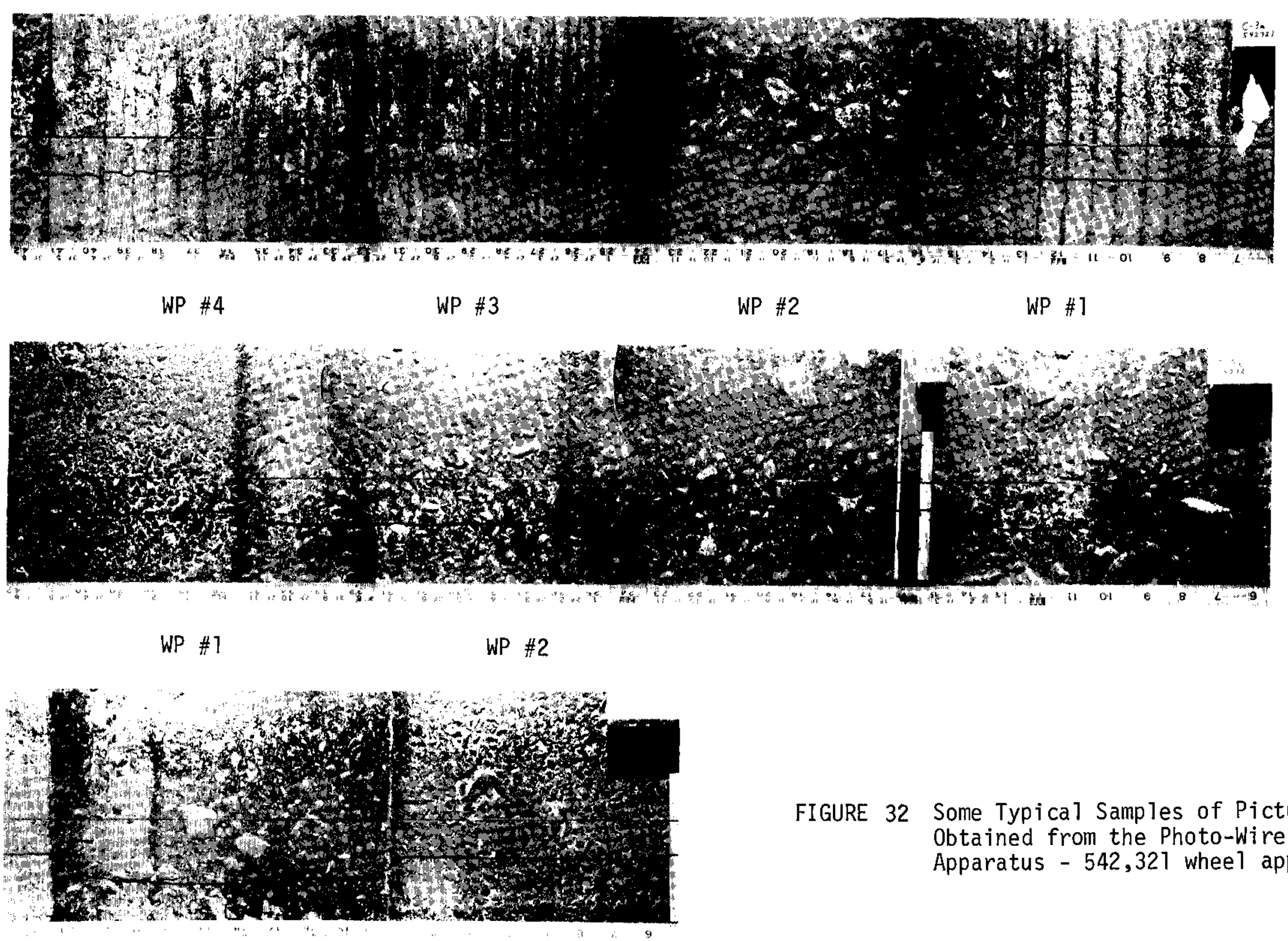


FIGURE 32 Some Typical Samples of Pictures Obtained from the Photo-Wire Profile Apparatus - 542,321 wheel applications

was finalized. The punch card operator found that the picture seemed to be more difficult to put on computer cards and more time was needed than for the profilometer charts. In the field, it took more time and manpower to operate and take picture frames of the sections. For these reasons this apparatus was used as a back-up equipment.

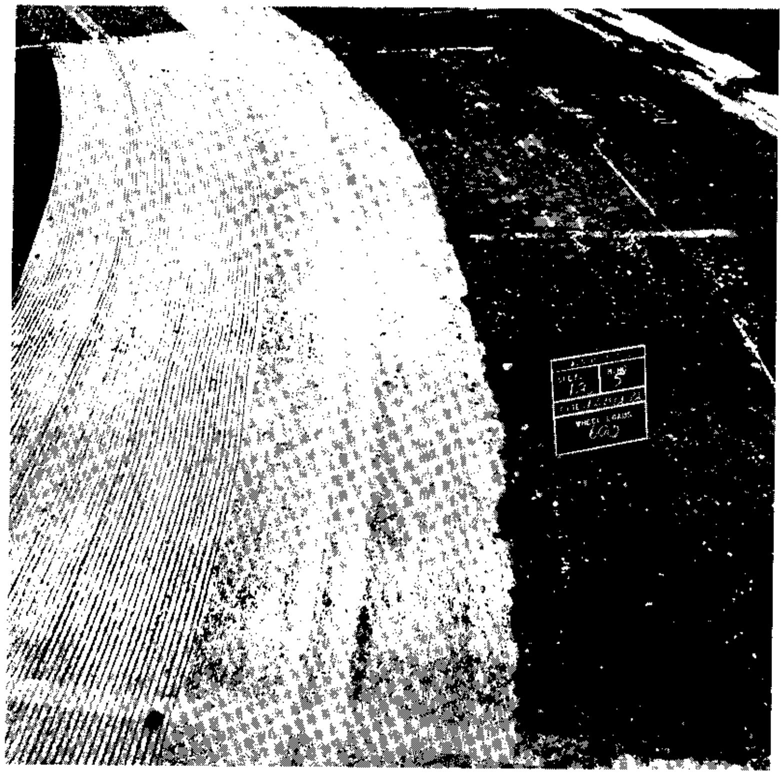
c) Straight-edge Measurements

These measurements were taken only at the end of the test, mainly to check the measurements obtained with other means. Each reading represents an average of five measurements in different locations of each section. The data is represented in Tables 16, 17 and 18. The values were within reason except for the unstudded tires. This method could not be used for measuring unstudded tire wear.

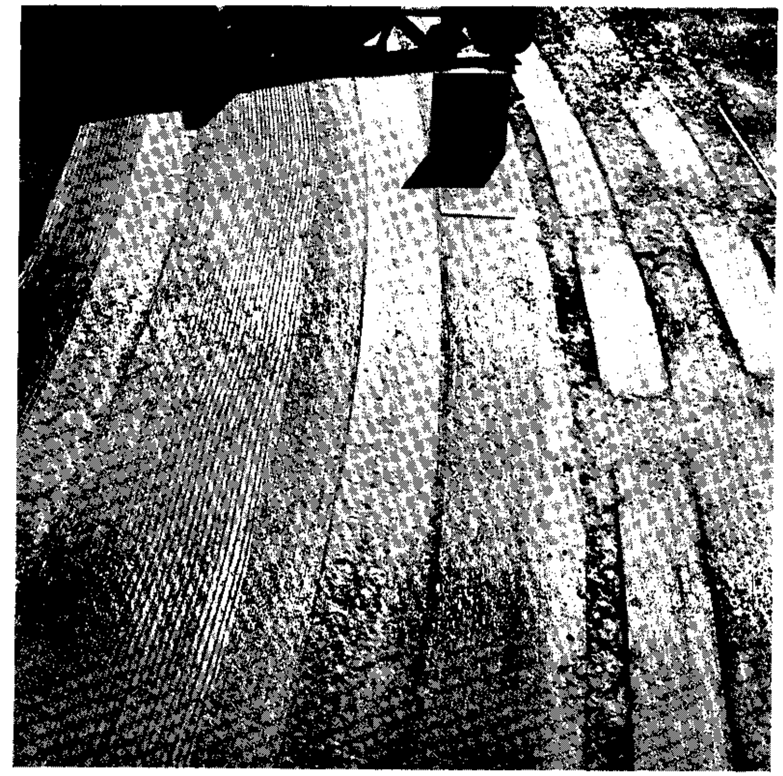
The problem of using a straight-edge are that a smooth transverse surface is assumed which may not be correct, and the limit of measurement was to the nearest 1/16 of an inch. For these reasons, the use of a straight-edge was minimized and was used for comparison purposes.

PHOTOGRAPH SERIES

The use of photographs can show up many unusual features which data cannot bring to light. Hence a series of photographs are included for comparison purposes. Before and after photographs of the different sections are shown in Figures 33-44. Figures 33 and 43 are interesting in that they depict the miniature failures of the polymer concrete and Idaho chip seal sections, respectively. Figures 33 (a) and 37 (a) at 600 w.a. show the initial wear due to studs which looks worse than it is. The wear at 600 w.a. was unmeasureable. Figure 37 (b) shows that the eccentricity had to be increased

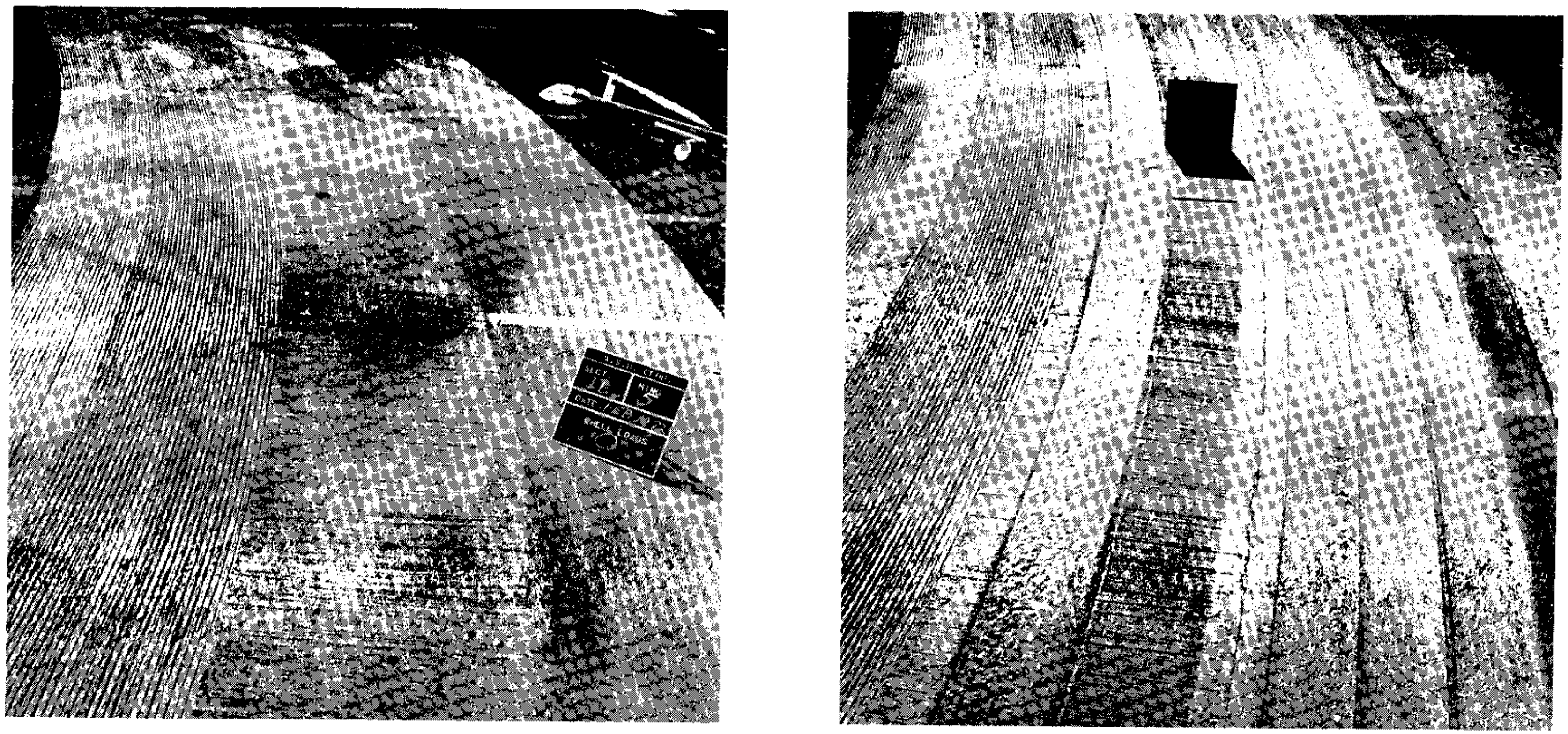


(a) After 600 w.a.



(b) After 542,321 w.a.

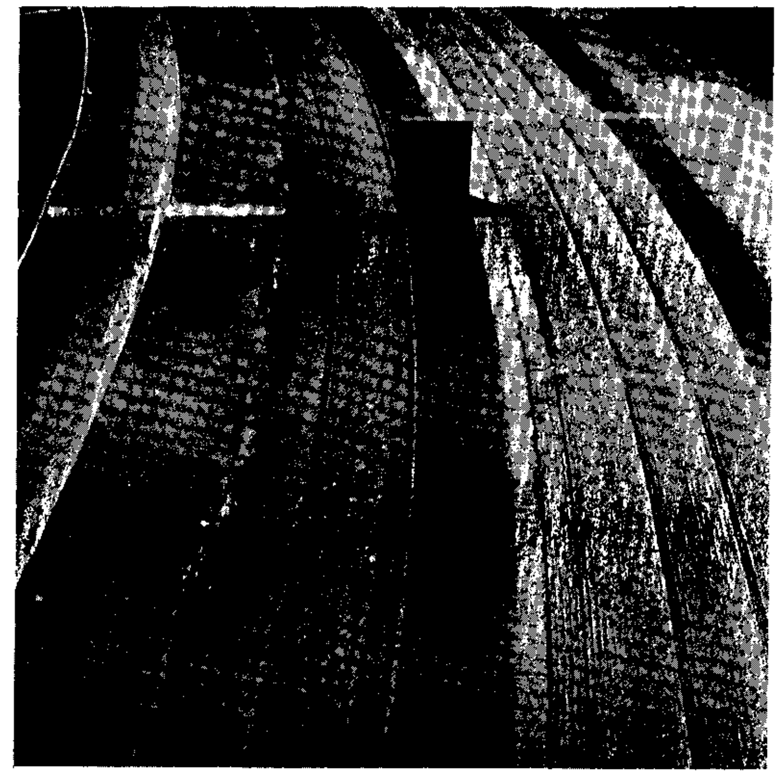
Figure 33: The appearance of Section 1a after the test. Note that at 600 wheel applications, the stud tires had scratched the surface of the pavement. Also note that the polymer concrete sections on the outside track had deteriorated due to poor construction.



(a) zero w.a. (b) After 542,321 w.a.

Figure 34: The appearance of section 1b after end of test. Note the wear in the different wheel paths.

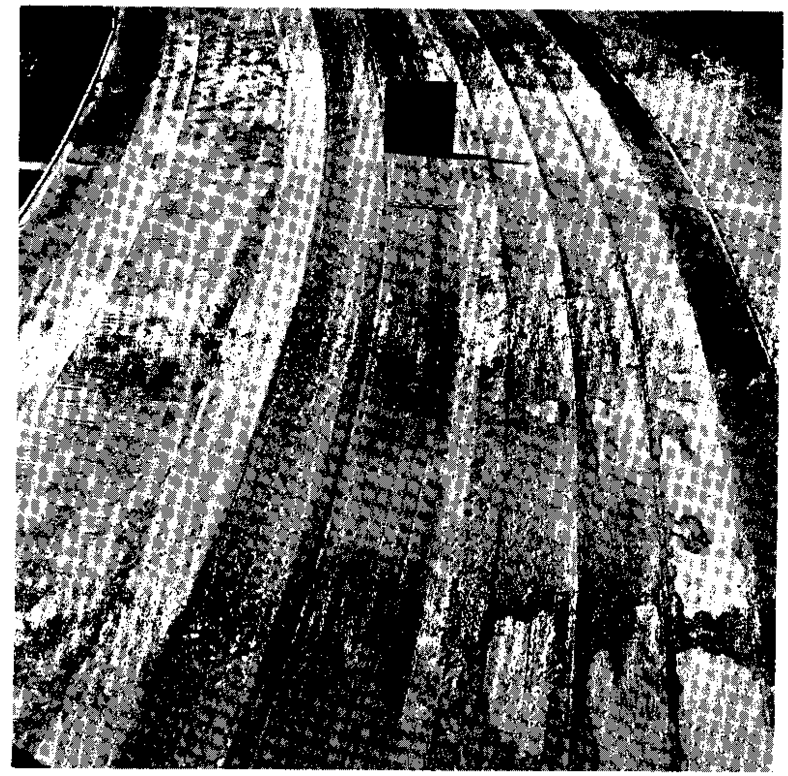
(a) zero w.a.



(b) 542,321 w.a.

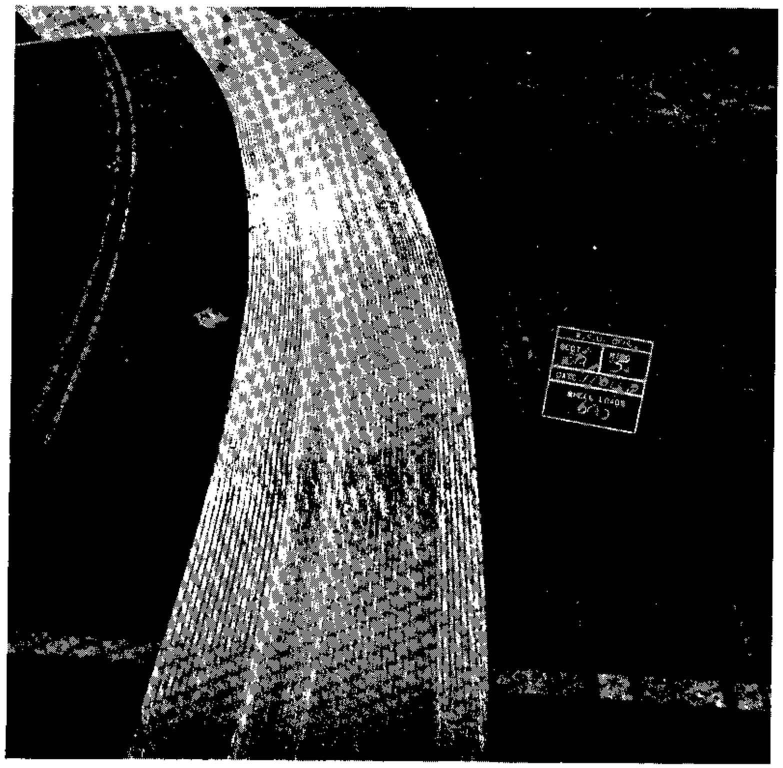
Figure 35: The appearance of Section 2A before and after testing.

(a) zero w.a.

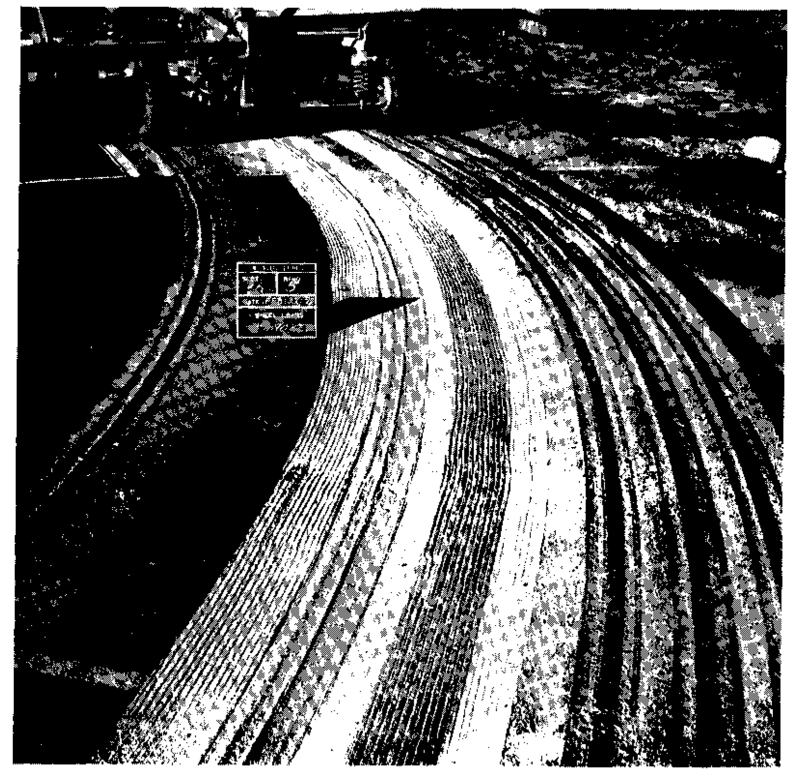


(b) After 542,321 w.a.

Figure 36: The appearance of Section 2b before and after the testing.
Note that parts of the overlay has been worn right through.

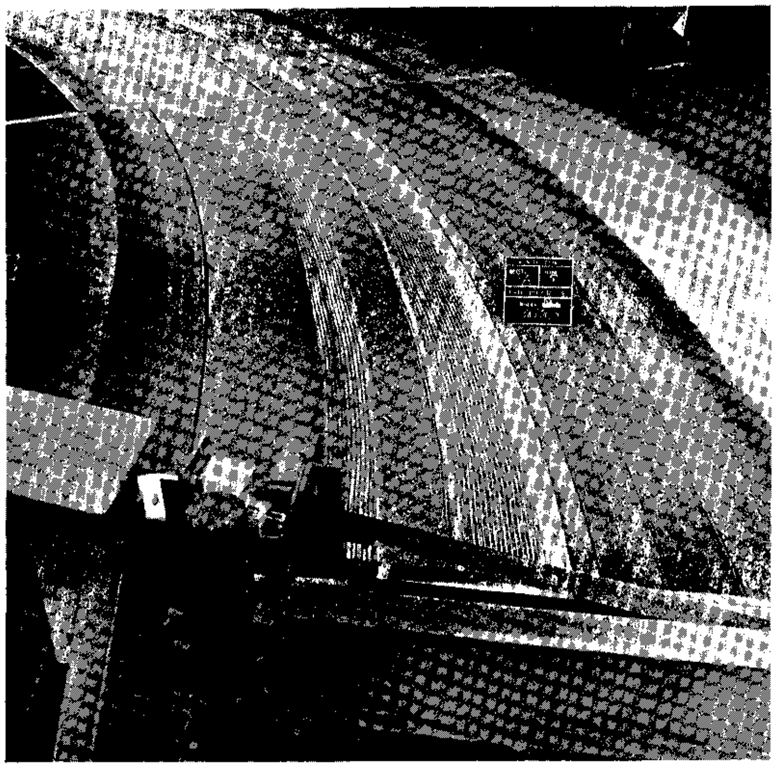


(a) After 600 w.a.

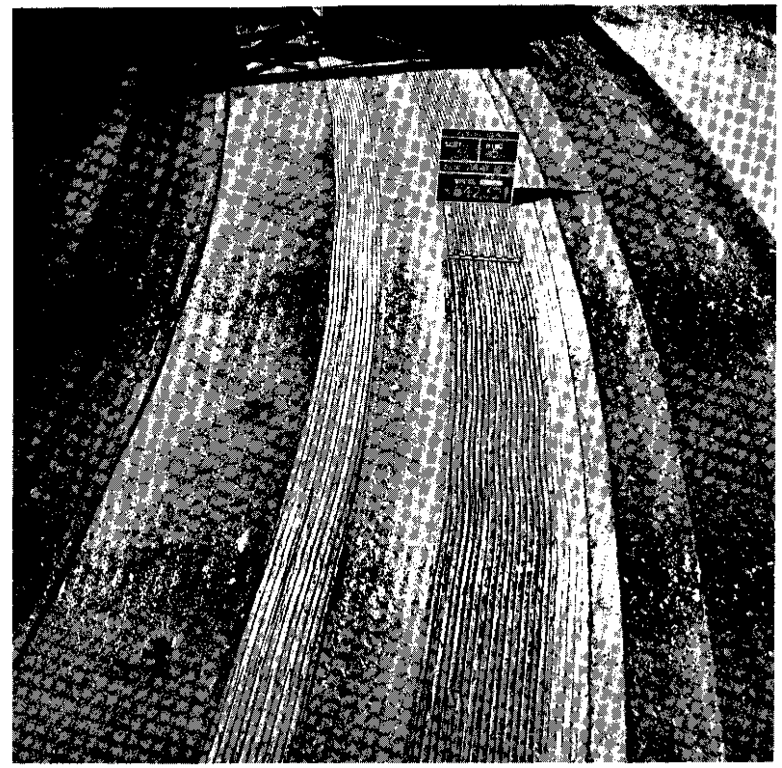


(b) After 49,190 w.a.

Figure 37: These photographs show Section 3a and the progressive wear shown on the pavement. At 600 w.a. the eccentricity was zero while at 49,190 w.a. the eccentricity was 0.50 inches. Note the center ridge in the center of the wheel paths in (b).

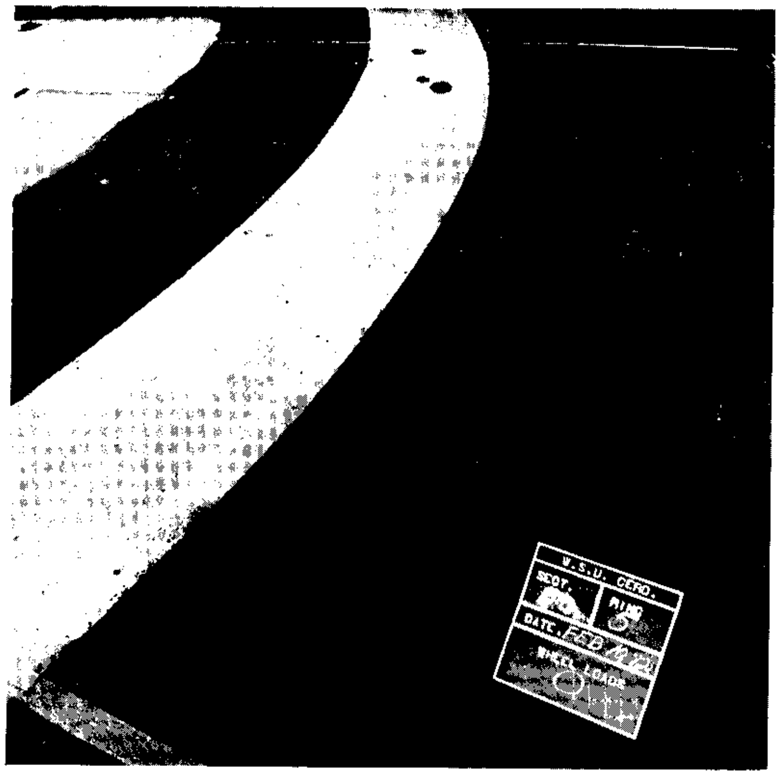


(a) After 387,503 w.a.



(b) After 542,321 w.a.

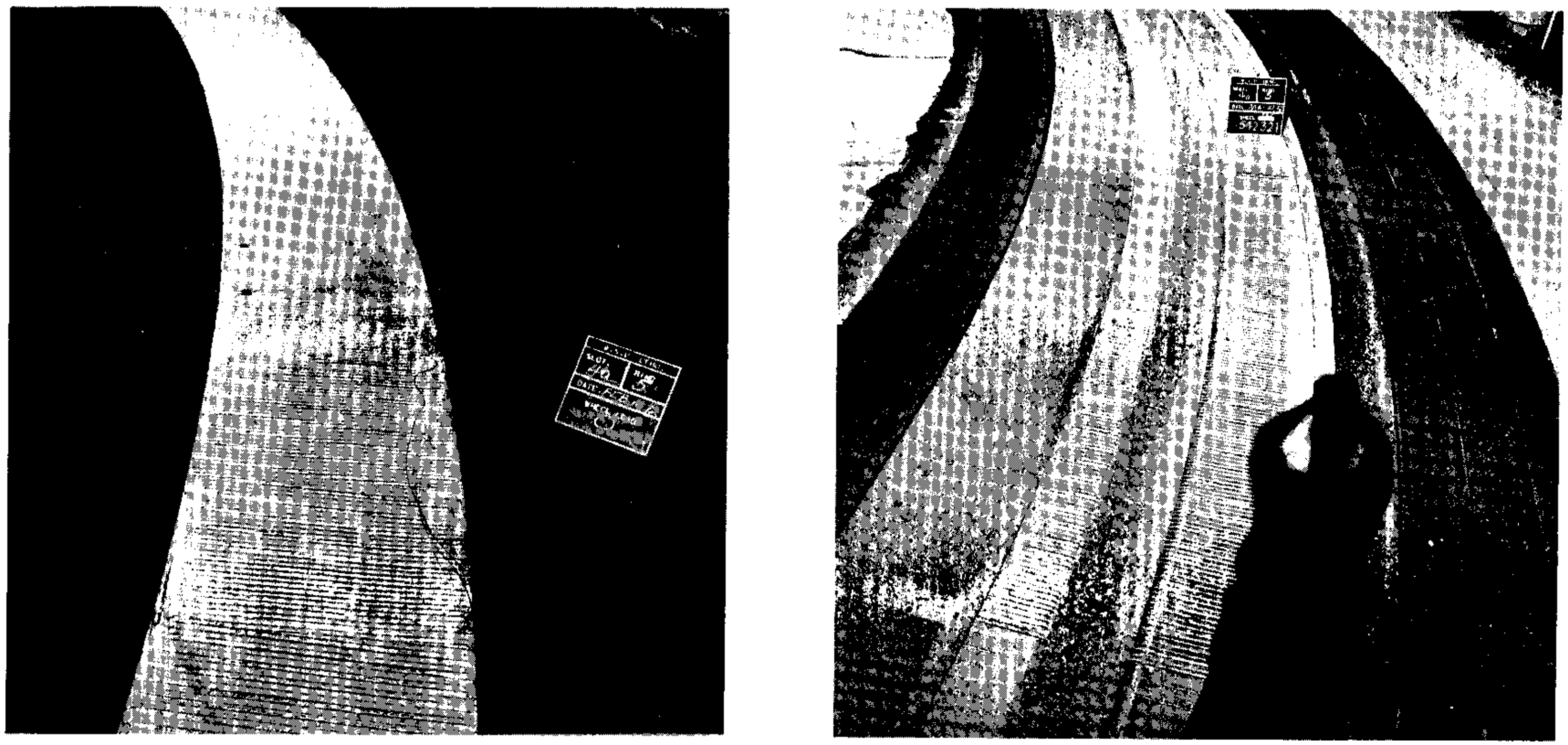
Figure 38: The appearance of Section 3a during the test and at the end of test.



(a) zero w.a.

(b) After 542,321 w.a.

Figure 39: The appearance of Section 3b before and after the test.



(a) zero w.a.

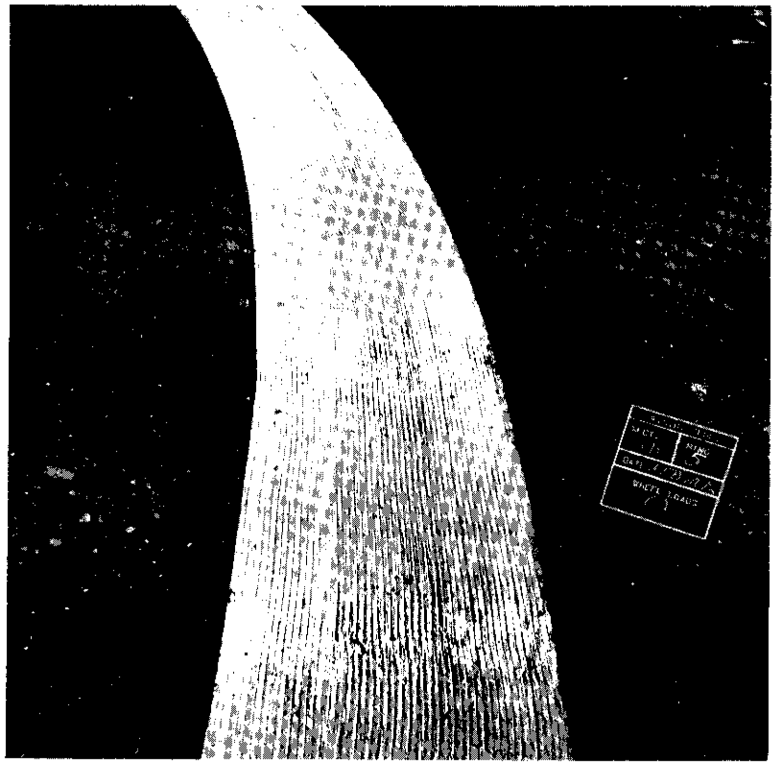
(b) After 542,321 w.a.

Figure 40: The appearance of Section 4a before and after the test.

(a) zero w.a.

(b) After 542,321 w.a.

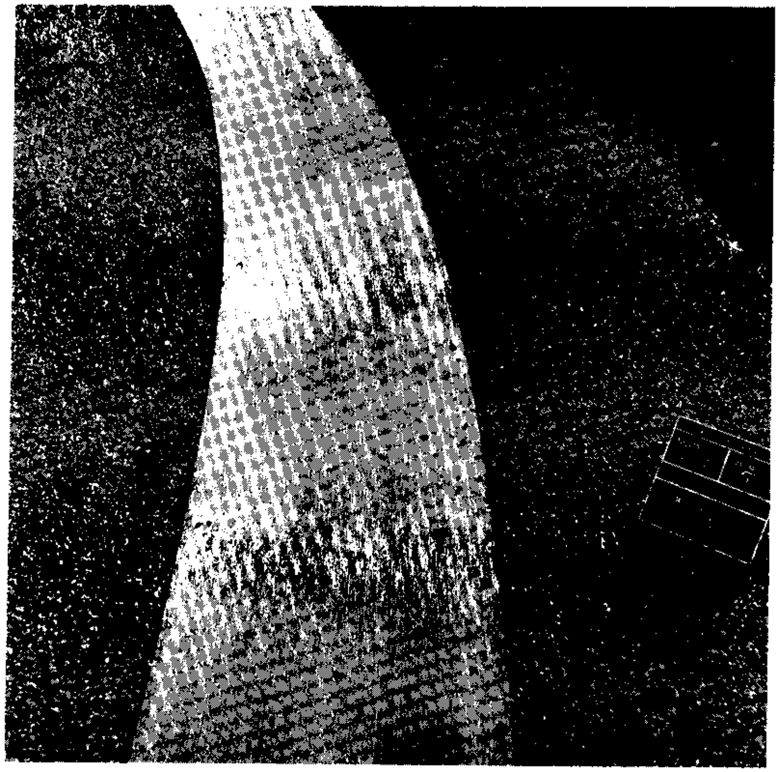
Figure 41: The appearance of Section 4b before and after the test.



(a) zero w.a.

(b) After 542,321 w.a.

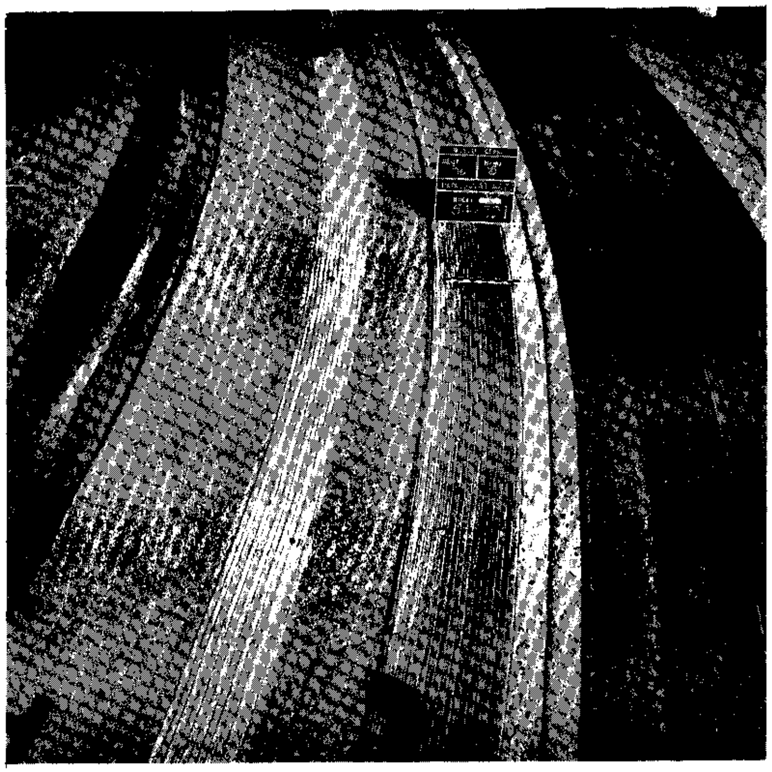
Figure 42: The appearance of Section 5b before and after the test.

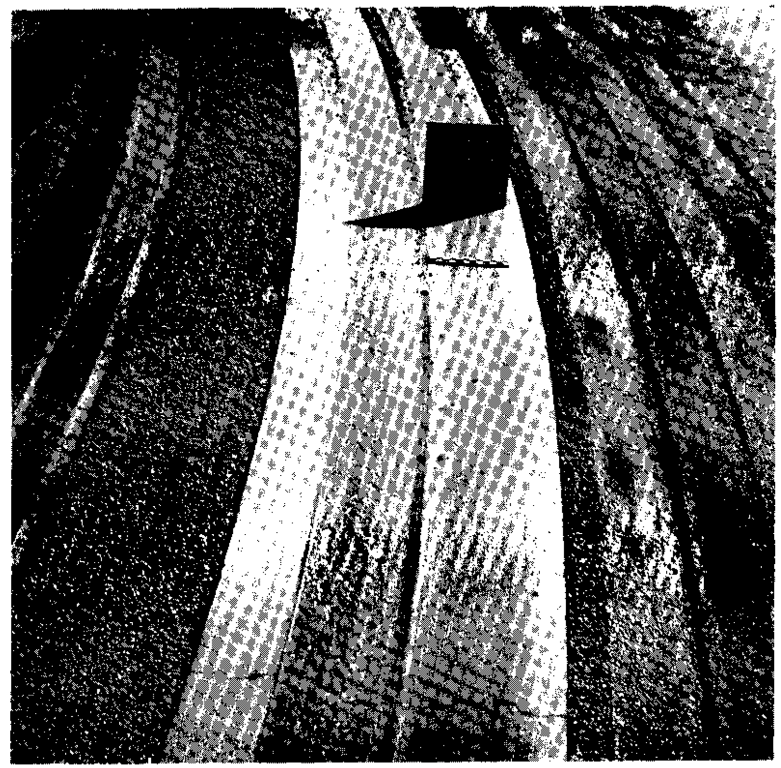


(a) zero w.a.

(b) After 542,321 w.a.

Figure 43: The appearance of Section 6a before and after the test. Note the appearance of the Idaho Chip Seal section which failed due to poor construction practices.





(a) Section 5A

(b) Section 6B

Figure 44: The appearance of the two sections after 542,321 w.a. and the end of test.

since there was an unworn ridge in the center of the wheel paths.

Cross-section views with a straight-edge at the end of test are shown in Figures 45-55. Each figure shows three different sections and the wear by the different studs and materials can be compared.

Plaster castings were taken of sections I-1a, I-4a, 0-2bB, 0-4a and C-3a and these are shown in Figure 56. These castings show the wear caused by the different types of studs and also shows how the different materials withstood the studded tires.

COMPARISON OF RESULTS

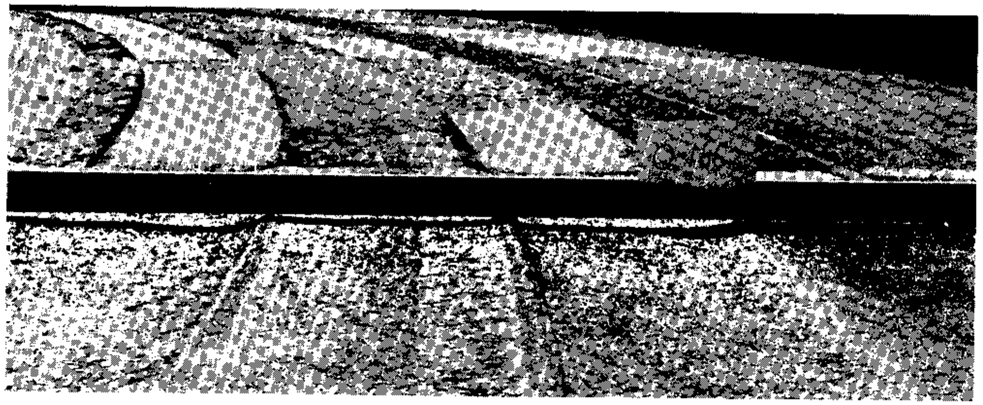
PORTLAND CEMENT AND WIRAND® CONCRETE SECTIONS

These were compared in Table 19. Since there were no portland cement concrete sections in the outside track, the portland cement concrete values had to be calculated from the inside track which only had the type #1 studs effects. With these limits in mind, the Wirand® concrete section 0-2ac, which had regular concrete aggregate, compared favorably with the portland cement concrete as far as wear was concerned and had superior skid resistance values (see Table 10).

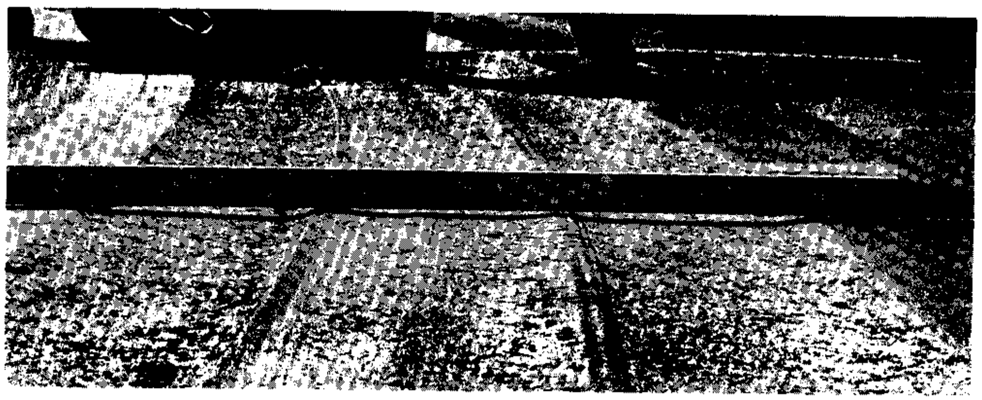
This same Wirand® concrete section was also superior to the other sections as shown in Table 11, 16 and 19 under conditions of tests and the various stud types.

A disadvantage of the steel fibered concrete section was that the steel fibers worked loose and spread over the track. Figure 57 shows this effect. The steel fibers in wheel paths 2, 3 and 4 stuck out of the pavement which may cause tire punctures under some conditions. It should be mentioned that

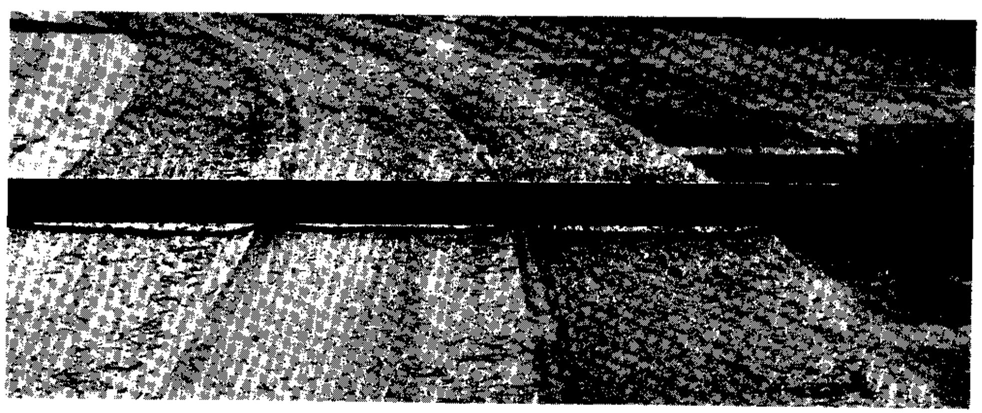
(text continued on page 88)



(a) Section 0-1bA
(sign is in error)

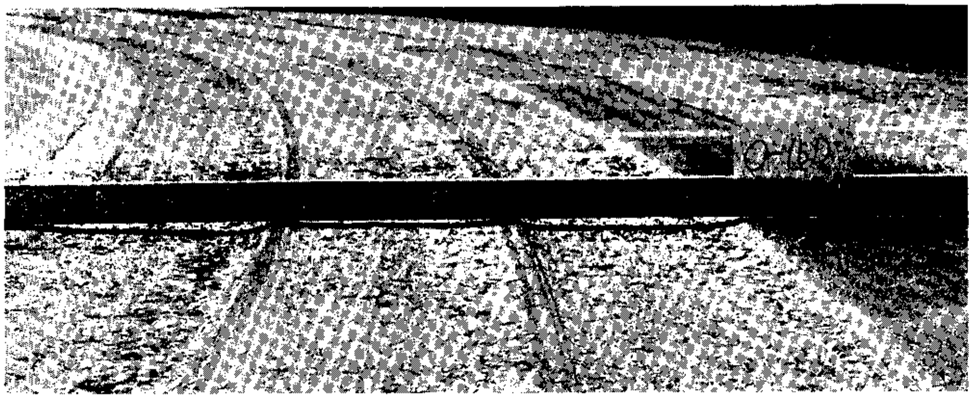


(b) Section 0-1bB



(c) Section 0-1bC

Figure 45: Cross-sections of the Wirand® Concrete Sections Final Appearance

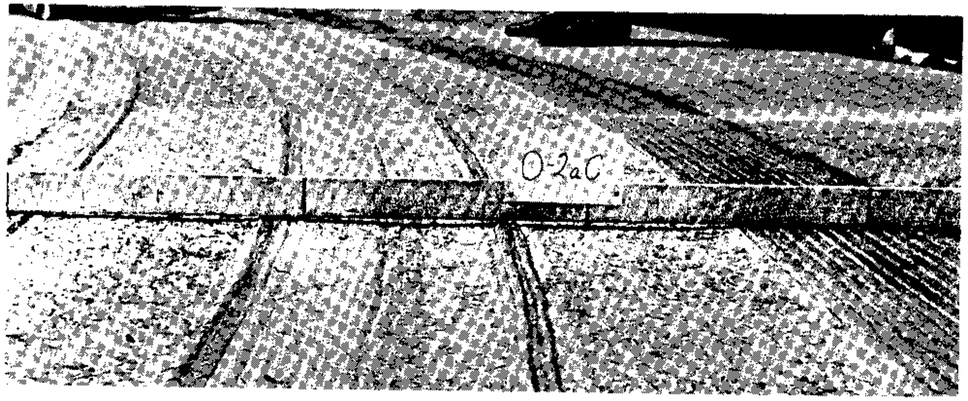


(a) Section 0-1bD

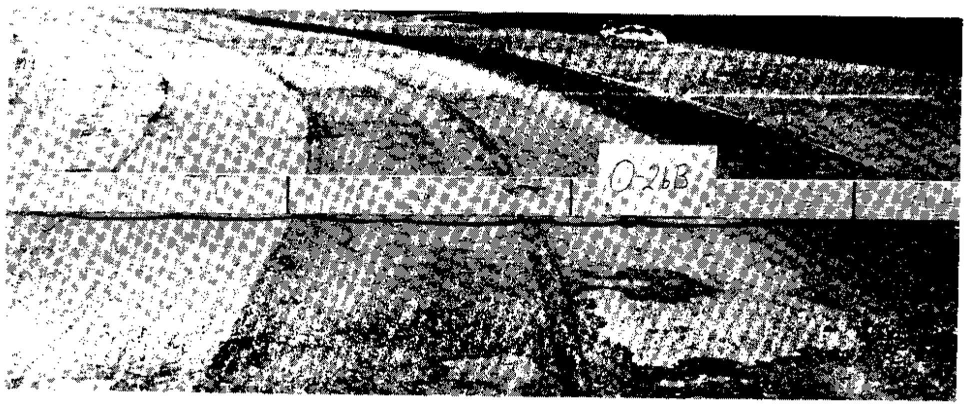
(b) Section 0-2aA

(c) Section 0-2aB

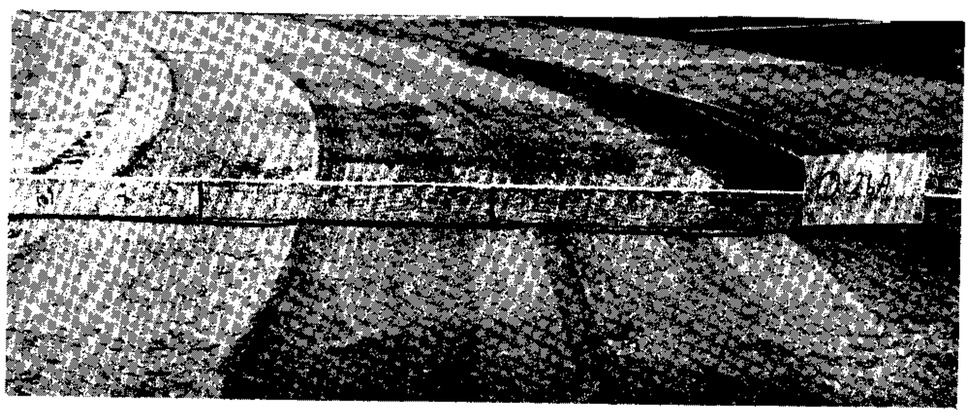
Figure 46: Cross Sections of the Wirand® Concrete Sections Final Appearance



(a) Section O-2aC Wirand R Concrete

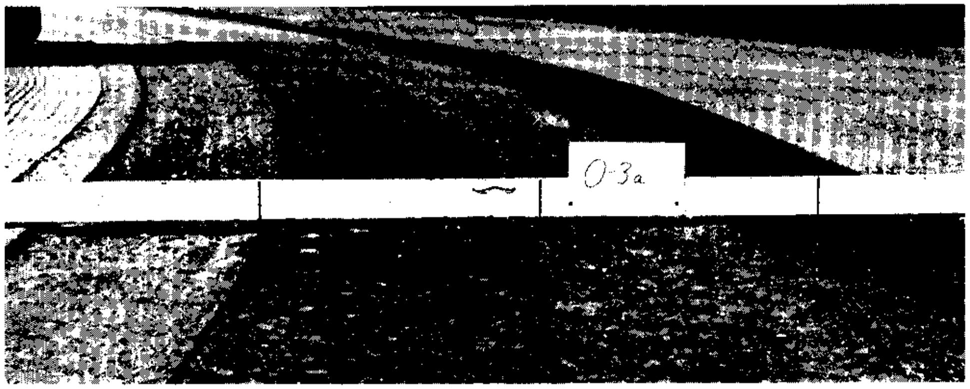


(b) Section O-2bA

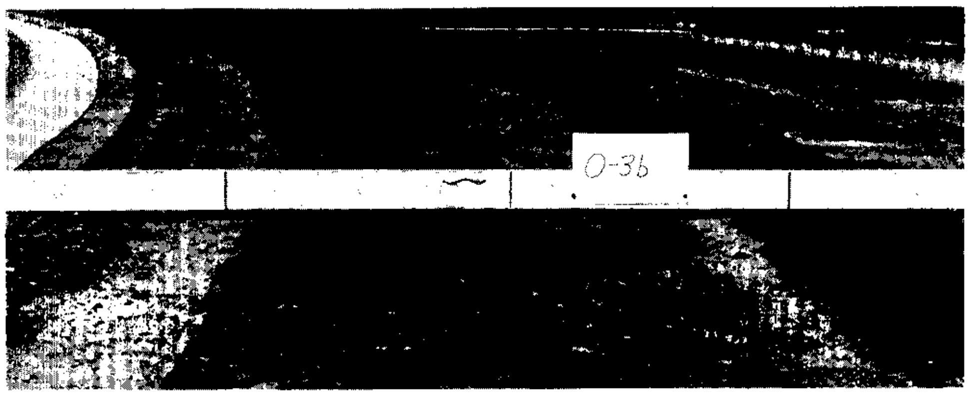


(c) Section O-2bB
Note the wear through the Polymer Concrete overlay.

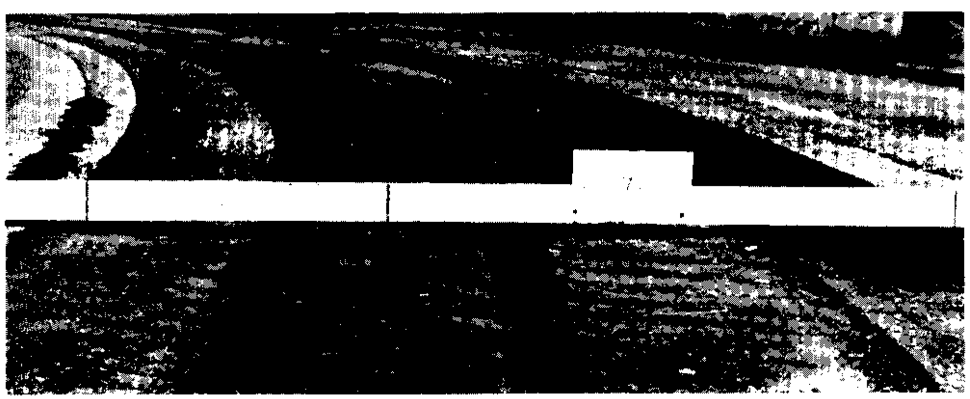
Figure 47: Cross-section views of Wirand R and Polymer Concrete Sections Final Appearance.



(a) Section 0-3a



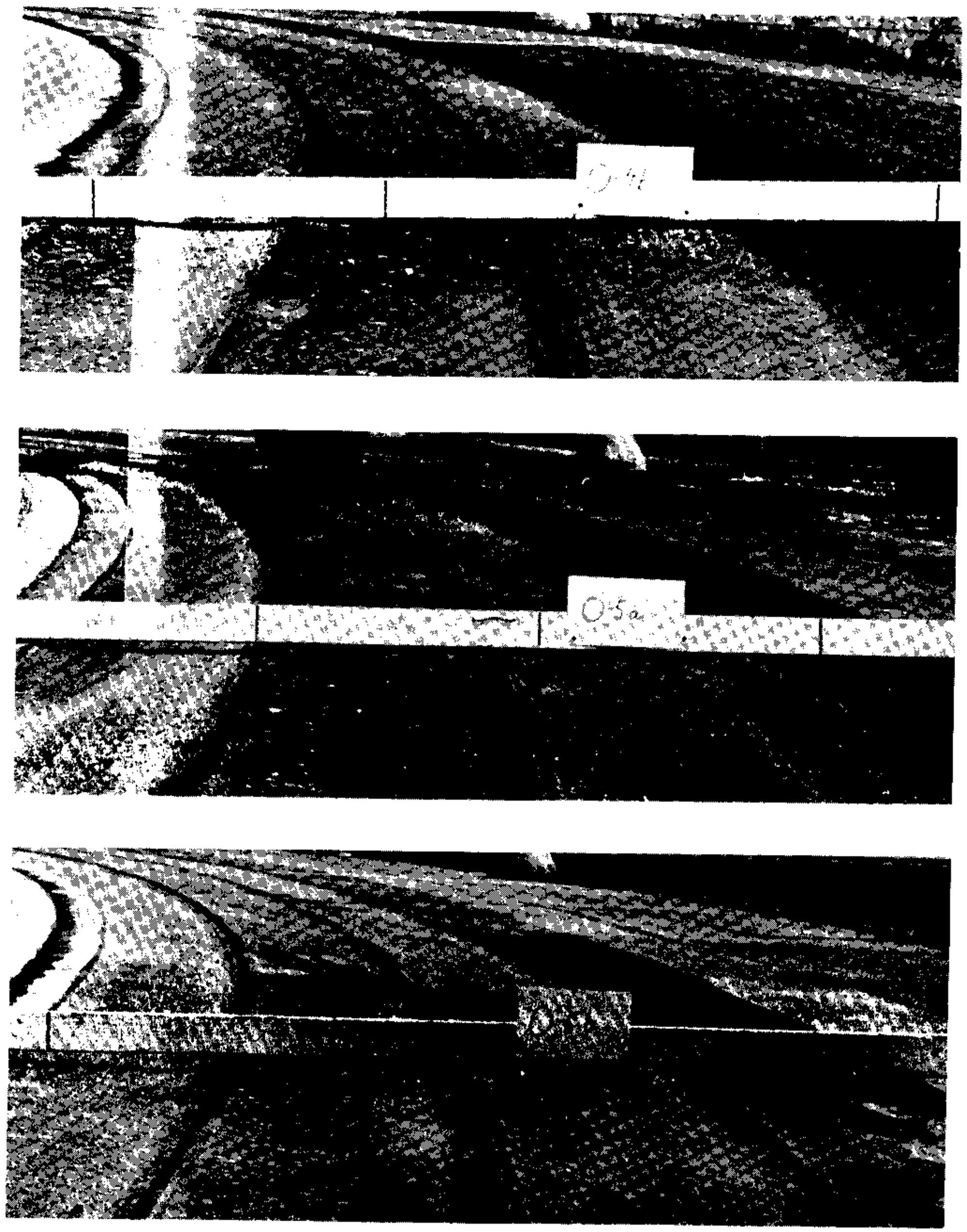
(b) Section 0-3b



(c) Section 0-4a

Figure 48: Cross-Section views of Outside Track Asphalt Concrete Sections.

Final Appearance.

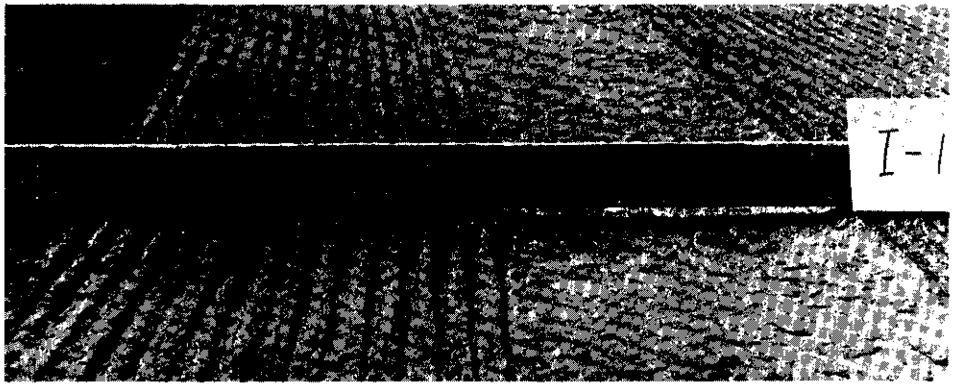


(a) Section 0-4b

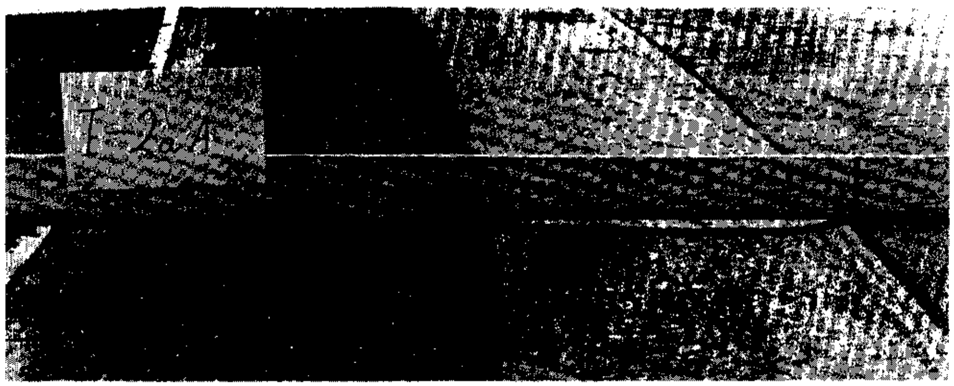
(b) Section 0-5a

(c) Section 0-5b

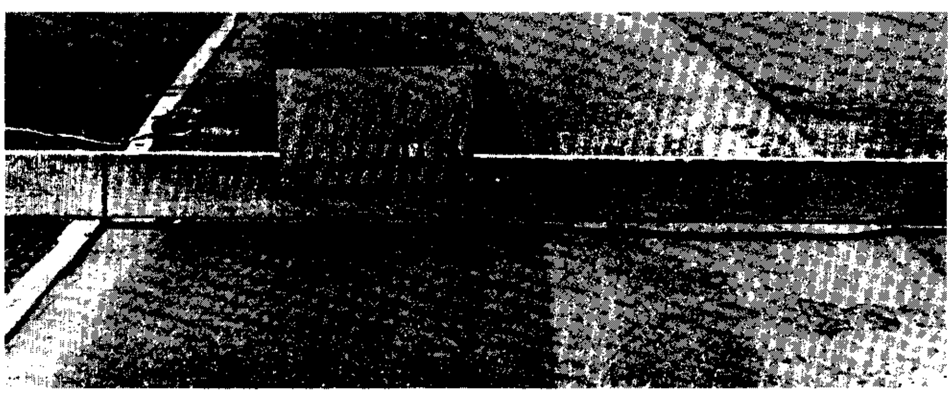
Figure 49: Cross-section views of outside track asphalt concrete sections. Final Appearance.



(a) Section I-1b
Portland Concrete Cement

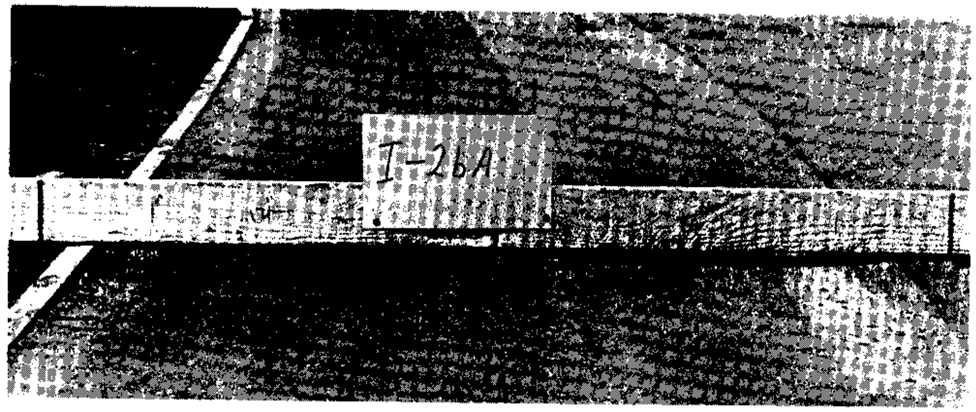


(b) Section I-2aA

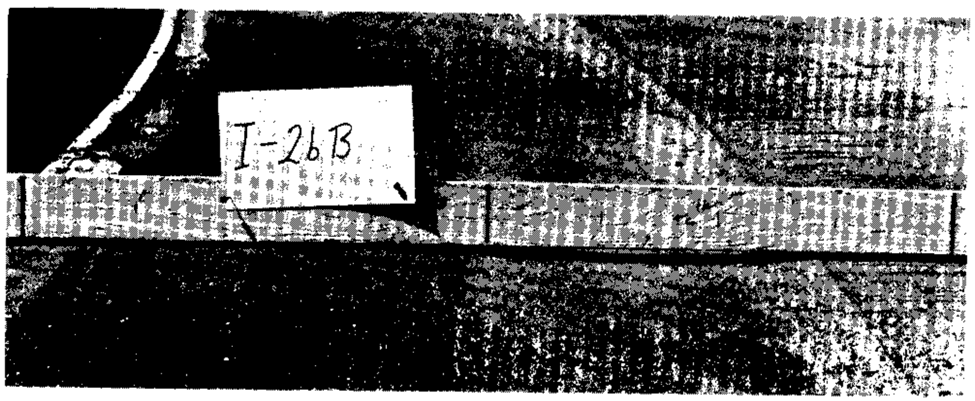


(c) Section I-2aB

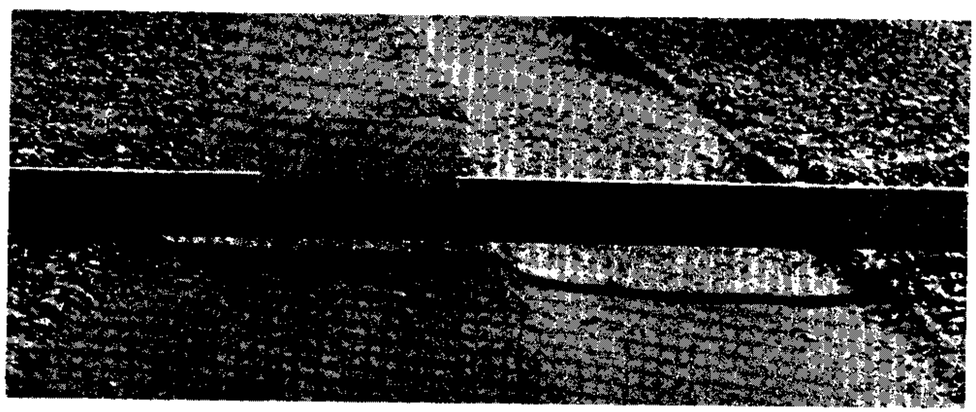
Figure 50: Cross-section views of the Portland Cement and Polymer Concrete sections on inside track.
Final Appearance



(a) Section I-2bA

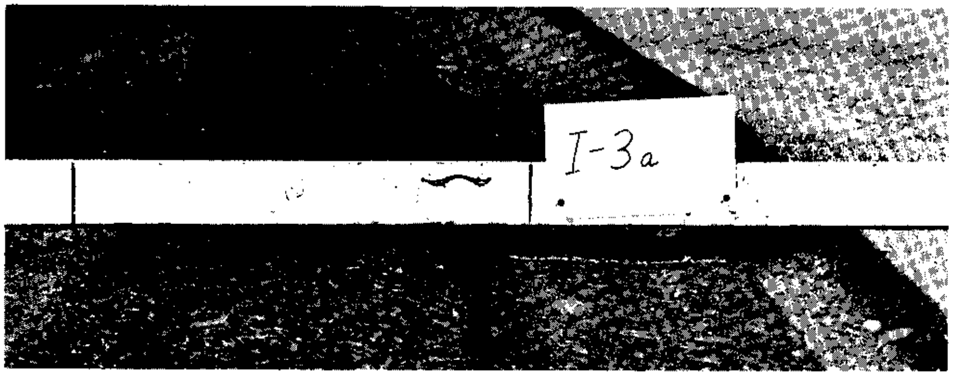


(b) Section I-2bB

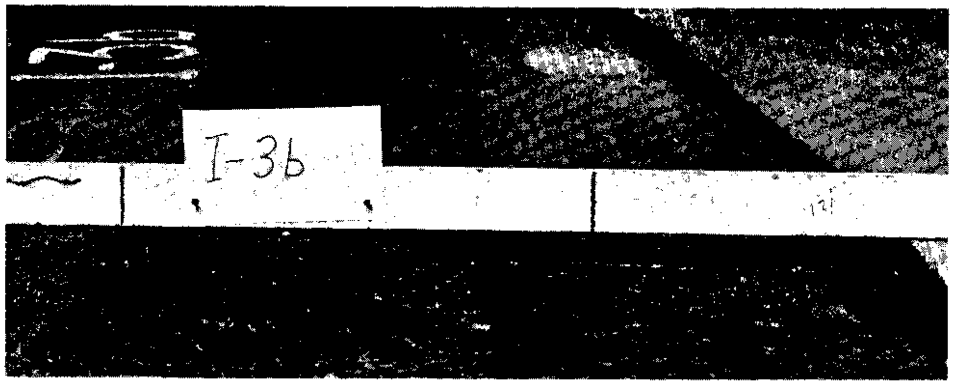


(c) Section I-6a

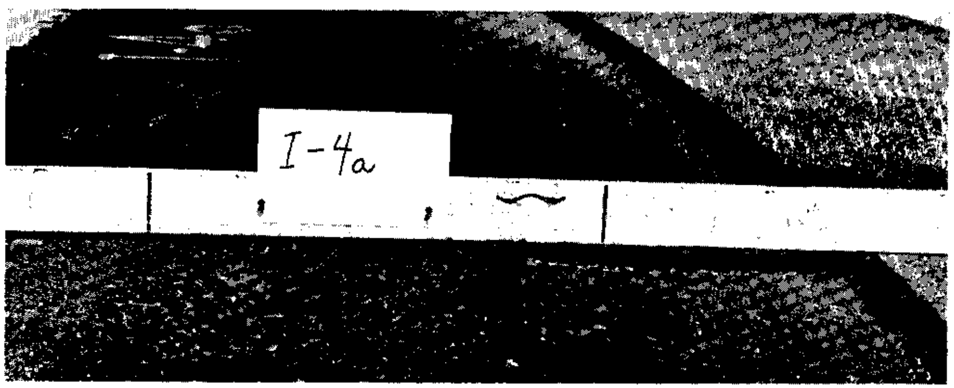
Figure 51: Cross-section views of polymer concrete and Idaho Chip Seal sections on inside track. Final Appearance.



(a) Section I-3a



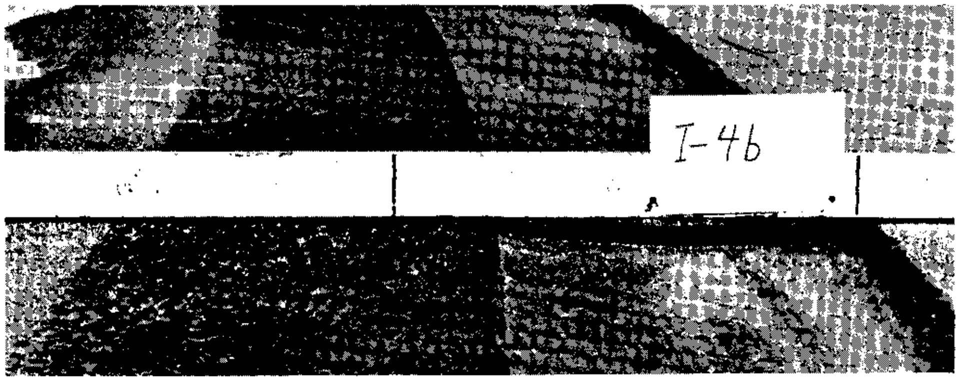
(b) Section I-3b



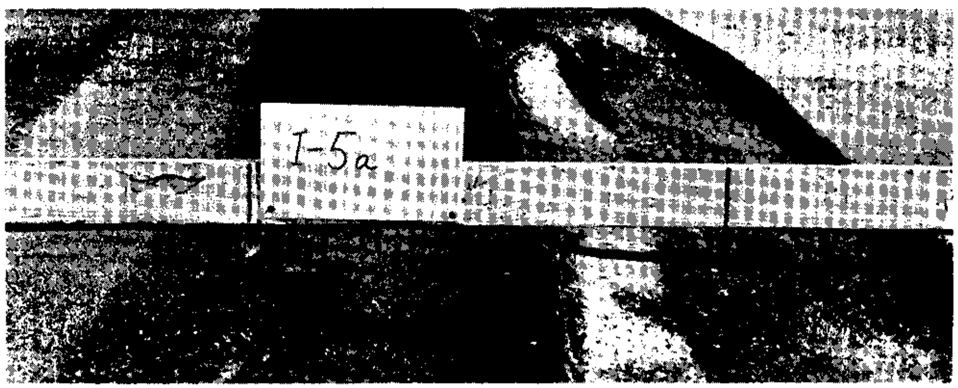
(c) Section I-4a

Figure 52: Cross-section views of the inside track asphalt concrete sections.

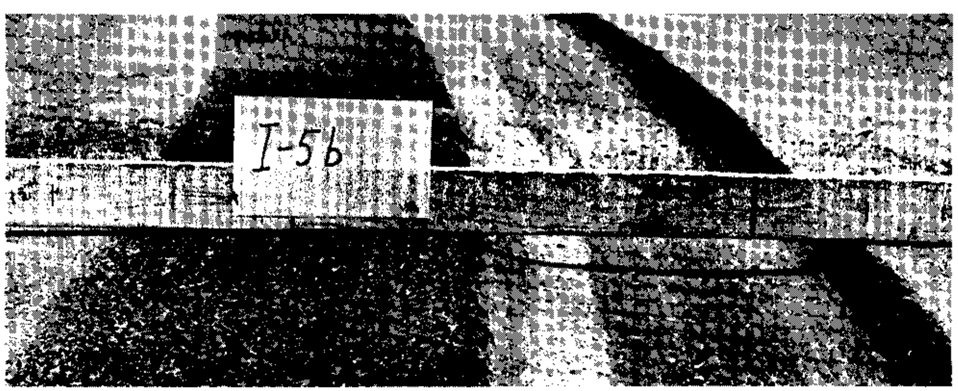
Final Appearance



(a) Section I-4b

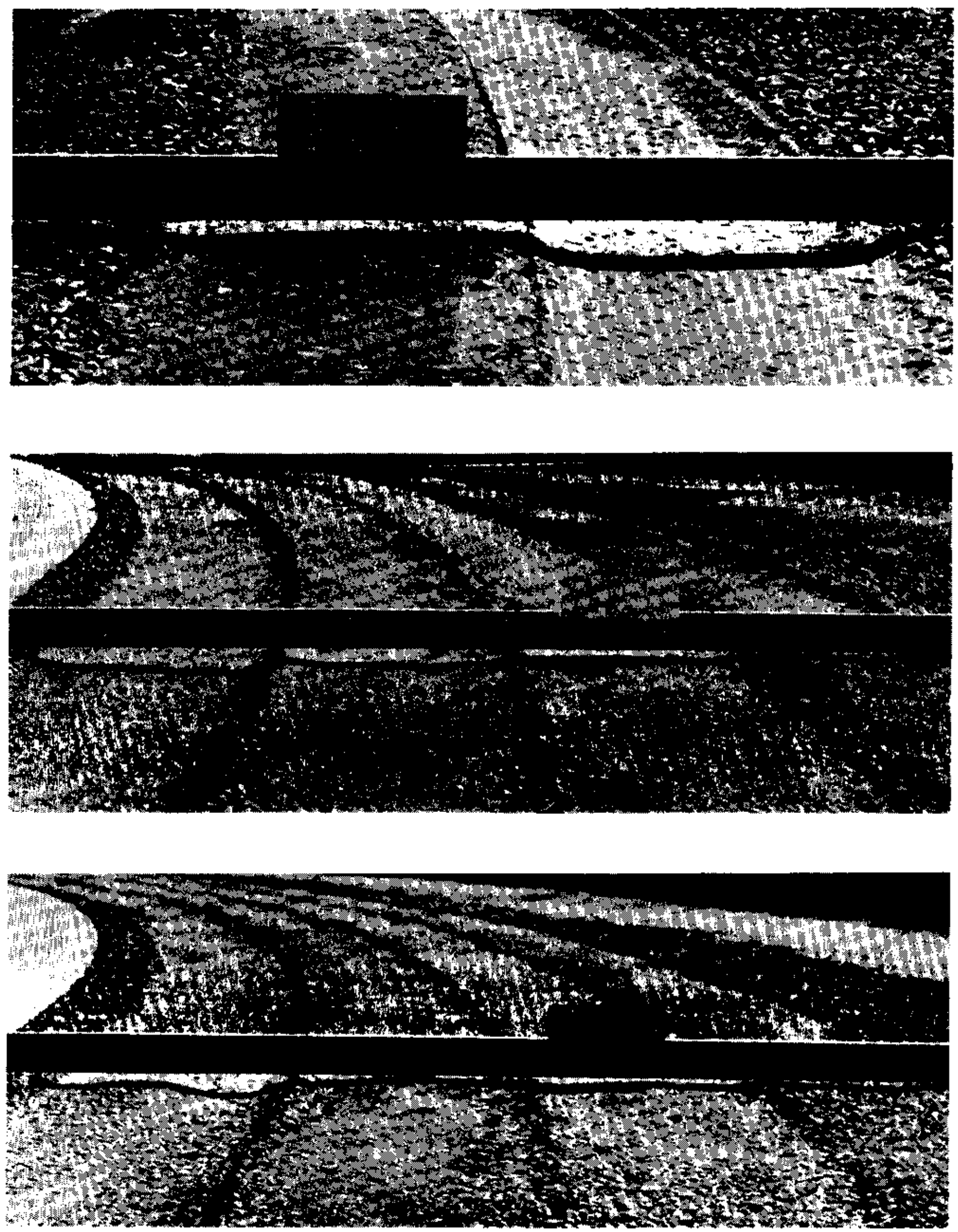


(b) Section I-5a



(c) Section I-5b

Figure 53: Cross-section views of the inside track asphalt concrete sections.
Final Appearance.



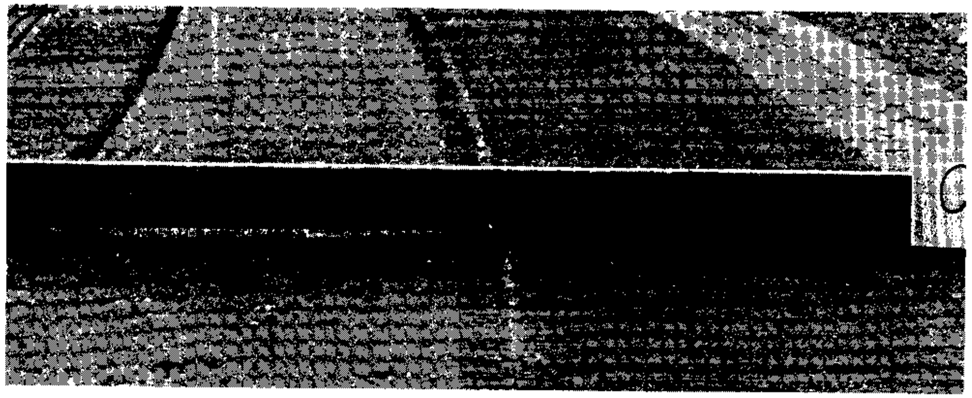
(a) Section I-6b

(b) Section 0-6a

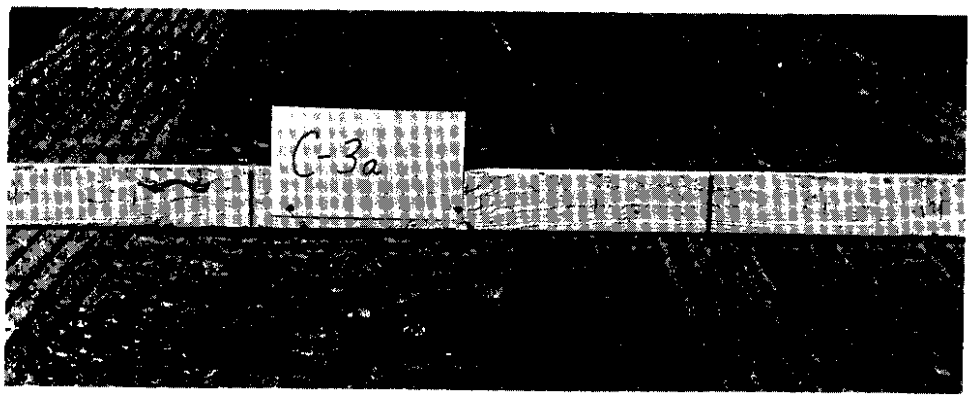
(c) Section 0-6b

Figure 54: Cross-section views of the inside and outside tracks of the Idaho Chip Seal sections.

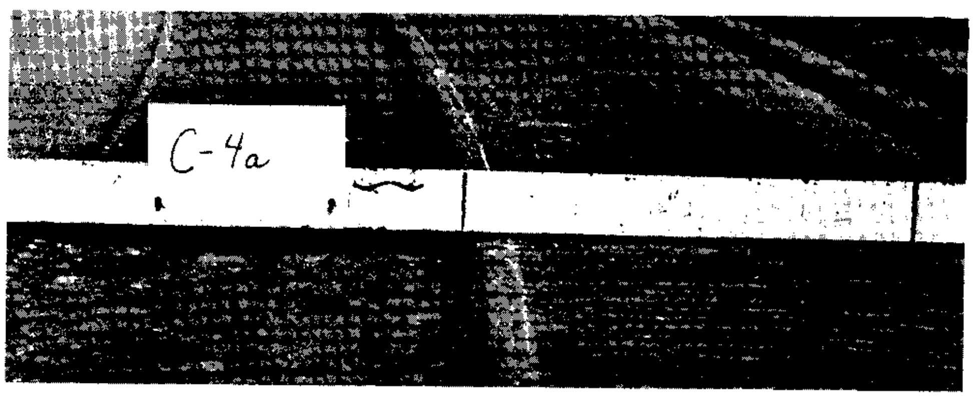
Final Appearance.



(a) Section C-1b



(b) Section C-3a



(c) Section C-4a

Figure 55: Some typical cross-sections views of the outer track portland cement concrete sections.
Final Appearance.

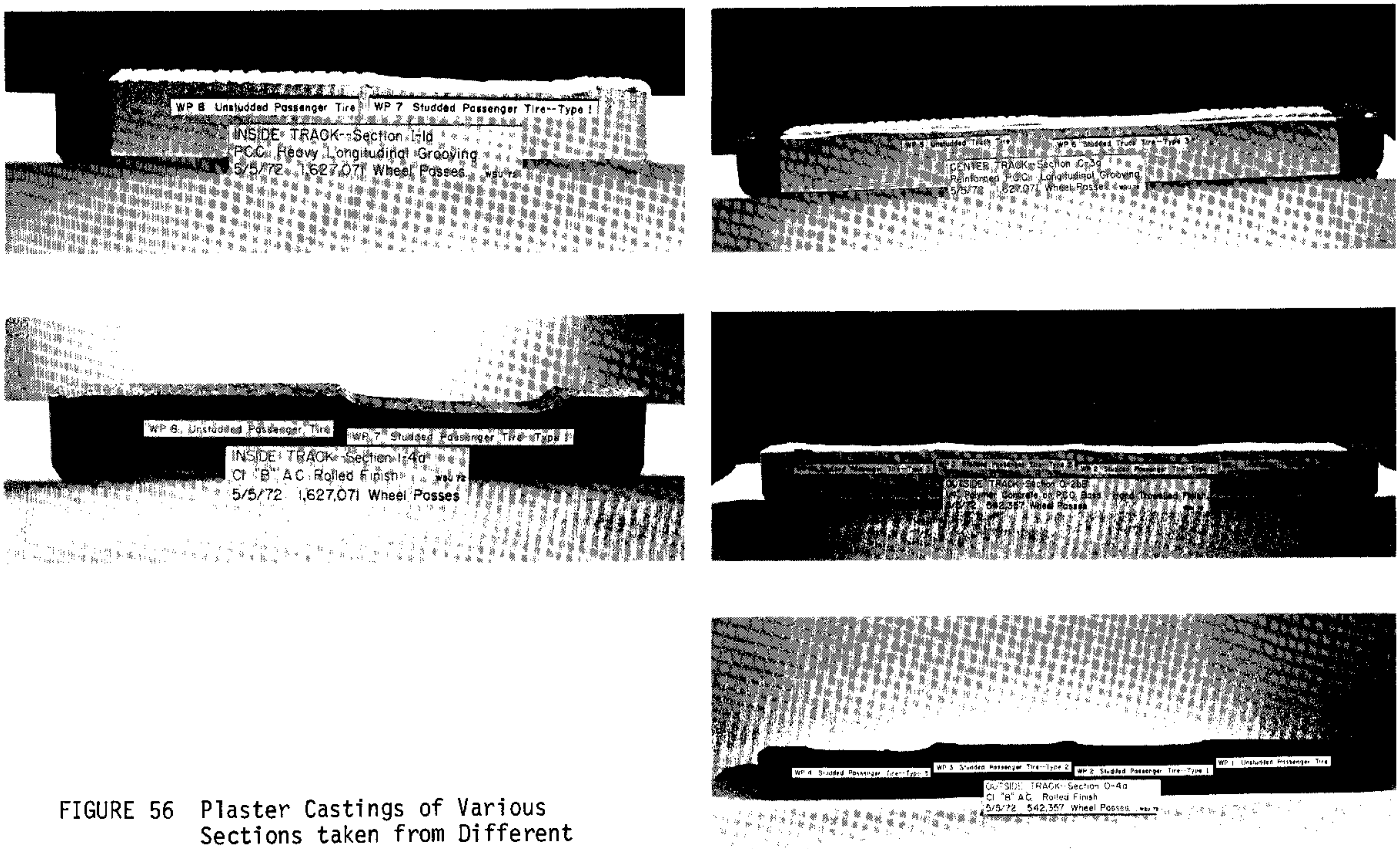


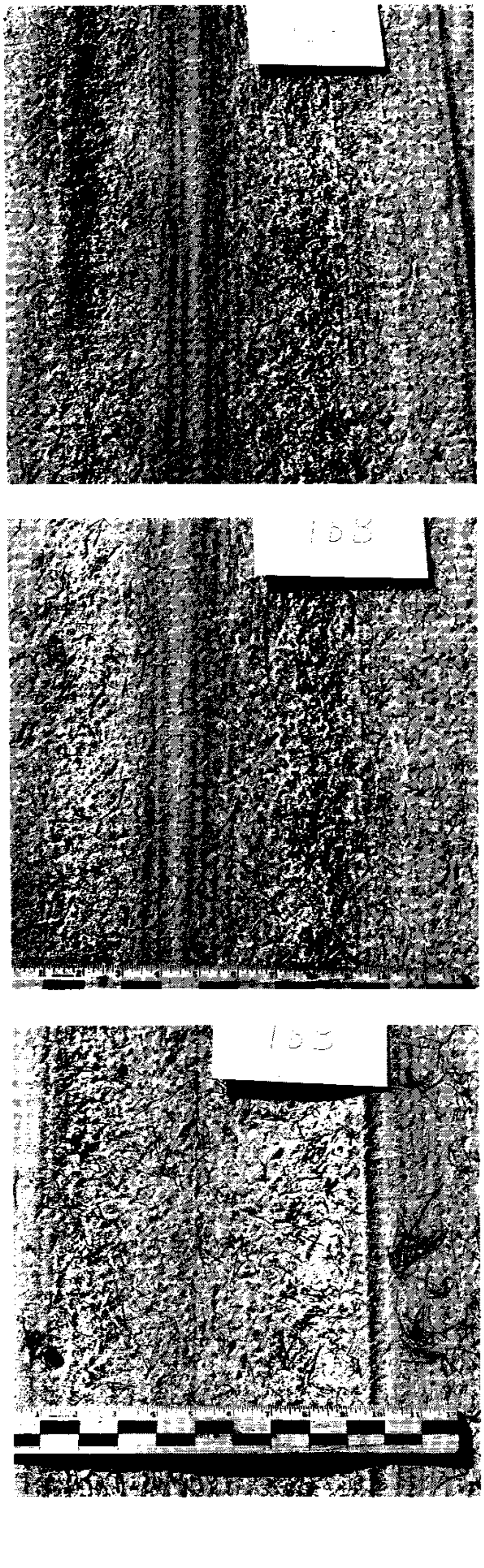
FIGURE 56 Plaster Castings of Various Sections taken from Different Tracks at end of Test.

TABLE 19 COMPARISON[1] OF P.C.C. AND WIRAND® CONCRETE SECTIONS

PARAMETERS	UNITS	PORTLAND CEMENT CONCRETE		WIRAND® CONCRETE SECTIONS						
		I-1a	I-1b	0-1bA	0-1bB	0-1bC	0-1bD	0-2aA	0-2aB	0-2aC
Area Removed	sq. inches	0.91	0.50	1.84	1.68	1.92	1.90	2.31	1.74	1.05
Rate of Wear	in./10^6 w.a.[2]	0.173	0.092	0.358	0.330	0.371	0.365	0.446	0.337	0.197
Maximum Depth	inches	0.17	0.12	0.30	0.26	0.30	0.28	0.35	0.24	0.16
Average Depth	inches	0.09	0.06	0.19	0.18	0.20	0.20	0.24	0.18	0.11

1 For 542,357 wheel applications and stud type #1

2 w.a. means wheel applications



(a) Wheel path #2 and 3 caused by stud types #1 and 2 respectively.

(b) Close up of wheel path #2 and 3 caused by stud type #1 and #2, respectively.

(c) Wheel path #4 and 3 caused by stud types #3 and #2 respectively.

FIGURE 57

Close-up top view of Wirand® Concrete Section 0-1bB after 170,000 wheel applications. Note the loose steel fibers and those sticking out of the pavement.

this effect was not noticed under the unstudded tire in wheel path #1.

POLYMER CONCRETE SECTIONS

Comparison of the different polymer concrete sections are shown in Table 20 and in Tables 11, 16, and 18. All these tables show that the inside sections were superior for wear characteristics. The polymer concrete put in Sections 0-1aA, 1aB and 1aC showed premature failure due to bonding failure. This is shown in Figures 33 (a) and (b). The mix C design, which is explained in Appendix A and Table A-6, seems to be the superior of the polymer concrete mixes tested.

Although the polymer concrete sections wear resistance was good, their skid resistance values with wear were very low as shown in Tables 7, 9 and 10. Their skid resistance characteristics have to be improved if these materials are to have any future in highway use.

PORTLAND CEMENT, WIRAND® CONCRETE AND POLYMER CONCRETE SECTION

Tables 19 and 20 show that the inside polymer concrete sections were superior to both the portland cement and outside polymer concrete sections. This is for the type #1 stud. As deduced from Table 19, the portland cement concrete sections were equal to the best Wirand® concrete section 0-2aC.

Skid resistance values show that the Wirand® concrete sections were superior with wear as compared to either the portland cement concrete and polymer concrete sections.

THE ASPHALT CONCRETE SECTIONS

Both the inside and outside tracks have to be compared. On the basis of the inside track results alone as shown in Table 14, the Class "B" asphalt concrete sections were superior in wear characteristics to the Class "E"

TABLE 20 COMPARISON[1] OF POLYMER CONCRETE SECTIONS

PARAMETERS	UNITS	I-2aA	I-2aB	I-2bA	I-2bB	0-2bA	0-2bB
Area Removed	sq. inches	0.295	0.407	0.414	0.442	2.07	0.91
Rate of Wear	in./10^6 w.a.	0.057	0.076	0.081	0.086	0.398	0.174
Maximum Depth	inches	0.081	0.095	0.097	0.098	0.30	0.20
Average Depth	inches	0.031	0.041	0.044	0.047	0.22	0.09

1 For 542,357 wheel applications (w.a.) and stud type #1.

and Class "G" asphalt concrete sections. The results are drawn in Figure 58, which shows that the Class "G" asphalt concrete was superior to the Class "E" until 1,120,000 wheel applications.

Comparing the different asphalt concrete sections from Table 12, it is difficult to say which one is best as they are fairly equal. The Class "E" asphalt concrete section may be better. Very little can be said about the effect of Gilsabind as it did not reduce wear.

From Table 21, the Class "B" asphalt concrete section was superior to the other on the inside track; while on the outside track, the Class "E" asphalt concrete was superior. Overall there was not that much difference, but since the inside track had three times more wheel applications, the values here should govern.

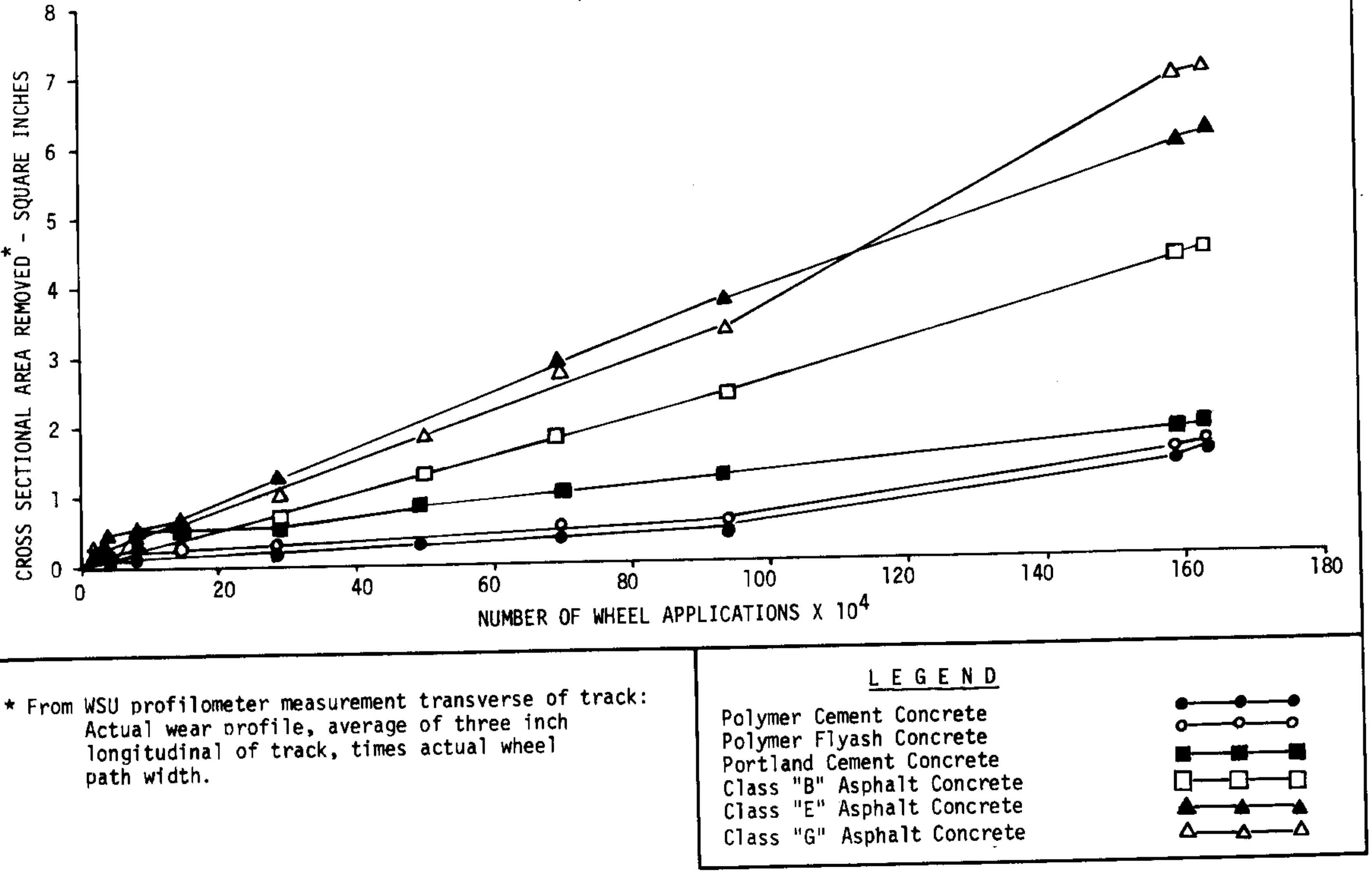
The skid resistance values, as shown in Tables 7, 9 and 10 were reduced in value but not as much as compared to the portland cement and polymer concrete sections. Of the asphalt concrete sections, the Class "G" asphalt sections seem to have suffered less reduction in skid resistance than the other two asphalt concrete types. The Gilsabind treatment initially lowered the initial skid resistance values, which after wear, seemed to be in the same range as the other asphalt concrete sections.

ALL THE SECTIONS

Figure 58, based on the inside track, shows that the polymer concrete sections showed the least wear, followed in this order by portland cement concrete, Class "B" asphalt concrete, Class "E" asphalt concrete and the Class "G" asphalt concrete. The Wirand® concrete would lie somewhere between the Class "B" asphalt concrete and the portland cement concrete.

FIGURE 58 COMPARISON OF AREA REMOVED WITH TYPE OF MATERIAL

Inside Track - Type #1 Stud
(no braking)



* From WSU profilometer measurement transverse of track: Actual wear profile, average of three inch longitudinal of track, times actual wheel path width.

TABLE 21 COMPARISON[1] OF ASPHALT CONCRETE SECTIONS

PARAMETERS	UNITS	I-3a	I-3b	0-3a	0-3b
Area Removed	sq. inches	2.30	2.64	2.22	2.25
Rate of Wear	in./10^6 w.a.	0.443	0.504	0.422	0.423
Maximum Depth	inches	0.40	0.38	0.31	0.32
Average Depth	inches	0.24	0.27	0.23	0.23
PARAMETERS	UNITS	I-4a	I-4b	0-4a	0-4b
Area Removed	sq. inches	1.44	2.01	2.66	2.74
Rate of Wear	in./10^6 w.a.	0.281	0.382	0.511	0.535
Maximum Depth	inches	0.22	0.30	0.38	0.38
Average Depth	inches	0.15	0.21	0.28	0.29
PARAMETERS	UNITS	I-5a	I-5b	0-5a	0-5b
Area Removed	sq. inches	2.07	1.56	2.15	2.82
Rate of Wear	in./10^6 w.a.	0.396	0.298	0.405	0.539
Maximum Depth	inches	0.32	0.23	0.30	0.38
Average Depth	inches	0.21	0.16	0.22	0.29

[1] For 542,357 wheel application (w.a.) and stud type #1.

BRAKING EFFECT

Brakes were applied to the inside"b" sections only. The results show that there was very little effect on wear. This is due to the few brake applications; if more had been applied, wear rates and effects would have been greater.

WEAR RATES

Wear rates were calculated for the outside, inside, and center track. Four rates were calculated in inch/10^6 wheel applications. These were Initial Average Wear Rate (IAWR) based on 0-30% wheel applications (w.a.); Middle Average Wear Rate (MAWR) based on 30-60% wheel applications; Final Average Wear Rate (FAWR) based on 60-100% wheel applications. Wear rates for the unstudded tires were insignificant as well as practically immeasureable.

The outside wear rates for the three types of studs are shown in Table 22 and in Figures 59-67. These graphs and table show that the initial rate in most cases was higher and that it decreased. This decrease is attributed to pavement-tire stud interaction as either or both change from new to used condition. The type #3 stud showed the highest wear rates, followed by the type #1 and the type #2, respectively; this was true in most cases with a few exceptions. Figure 68-71 for some selected sections show this wear and confirm the wear rates.

Table 23 shows the different wear rates for the inside track. Here too, the IAWR was usually higher than the MAWR or FAWR. The asphalt concrete sections showed the more constant wear rates throughout than the other inside sections. Figures 72-76 show that wear rates for the asphalt concrete sections was at a fairly constant rate.

TABLE 22 WEAR RATES IN INCHES/10^6 WHEEL APPLICATIONS OUTSIDE TRACKS PROFILOMETER DATA

SECTION	INITIAL[1]	MIDDLE[2]	FINAL[3]	OVERALL[4]
01bA				
WP #1 U.S. WP #2 WP #3 WP #4	0 .384 .349 .603	0 .616 .165 .667	0 .185 .104 .158	0 .367 .195 .439
01bB				
WP #1 WP #2 WP #3 WP #4	0 .535 .346 .850	0 .286 .012 .278	0 .213 .082 .230	0 .330 .143 .432
01bC				
WP #1 WP #2 WP #3 WP #4	0 .514 .177 .550	0 .386 .116 .190	0 .280 .085 .252	0 .382 .121 .328
01bD				
WP #1 WP #2 WP #3 WP #4	0 .325 .352 .777	-- -- -- --	-- -- -- --	0 .365 .181 .378

1 0-30% = Initial
2 30-60% = Middle
3 60-100% = Final
4 0-100% = Overall

(all) of 5.4 x 10^5 wheel applications

TABLE 22 (Continued)
PROFILOMETER DATA

AVERAGE WEAR RATES IN IN./10^6 WHEEL APPLICATIONS

SECTION	INITIAL[1]	MIDDLE[2]	FINAL[3]	OVERALL[4]
02aA				
WP #1	--	--	0	0
WP #2	--	--	.291	.446
WP #3	--	--	.117	.177
WP #4	--	--	.269	.415
02aB				
WP #1	--	--	0	0
WP #2	--	--	.182	.337
WP #3	--	--	.034	.145
WP #4	--	--	.217	.444
02aC				
WP #1	--	--	0	0
WP #2	--	--	.086	.203
WP #3	--	--	.047	.137
WP #4	--	--	.121	.162
02bA				
WP #1	--	--	0	0
WP #2	--	--	.232	.409
WP #3	--	--	.066	.171
WP #4	--	--	--	--

[1] 0-30% = Initial
[2] 30-60% = Middle
[3] 60-100% = Final
[4] 0-100% = Overall

(all) of 5.4 x 10^5 wheel applications

TABLE 22 (Continued)
PROFILOMETER DATA

AVERAGE WEAR RATES IN IN./10^6 WHEEL APPLICATIONS

SECTION	INITIAL[1]	MIDDLE[2]	FINAL[3]	OVERALL[4]
02bB				
WP #1	0	0	0	0
WP #2	.259	.186	.111	.178
WP #3	.552	.137	.106	.254
WP #4	.334	.224	.126	.218
03a				
WP #1	0	0	0	0
WP #2	.789	.726	.178	.513
WP #3	.496	.341	.111	.295
WP #4	1.099	.407	.256	.553
03b				
WP #1	0	0	0	0
WP##2	.710	.536	.246	.472
WP #3	.392	.153	.223	.256
WP #4	.929	.712	.126	.529
04a				
WP #1	0	0	0	0
WP #2	1.044	.698	.296	.632
WP #3	.455	.221	.065	.227
WP #4	1.335	.671	.135	.645

1 0-30% = Initial
2 30-60% = Middle
3 60-100% = Final
4 0-100% = Overall

(all: of 5.4×10^5 wheel applications)

TABLE 22 (Continued)
PROFILOMETER DATA

AVERAGE WEAR RATES IN IN./10^6 WHEEL APPLICATIONS

SECTION	INITIAL[1]	MIDDLE[2]	FINAL[3]	OVERALL[4]
04b				
WP #1	0	0	0	0
WP #2	.710	.488	.218	.447
WP #3	.420	.186	.109	.228
WP #4	1.032	.549	.227	.568
05a				
WP #1	0	--	--	0
WP #2	.521	--	--	.367
WP #3	.394	--	--	--
WP #4	.880	--	--	.542
05b				
WP #1	0	0	0	0
WP #2	.783	.583	.158	.472
WP #3	.487	.201	.046	.227
WP #4	1.499	.556	.517	.826

[1] 0-30% = Initial
[2] 30-60% = Middle
[3] 60-100% = Final
[4] 0-100% = Overall

(all: of 5.4×10^5 wheel applications)

Figure 59

Section 01bA ½" Wirand Concrete - Mix 1

Summary After 542,357 Wheel Applications

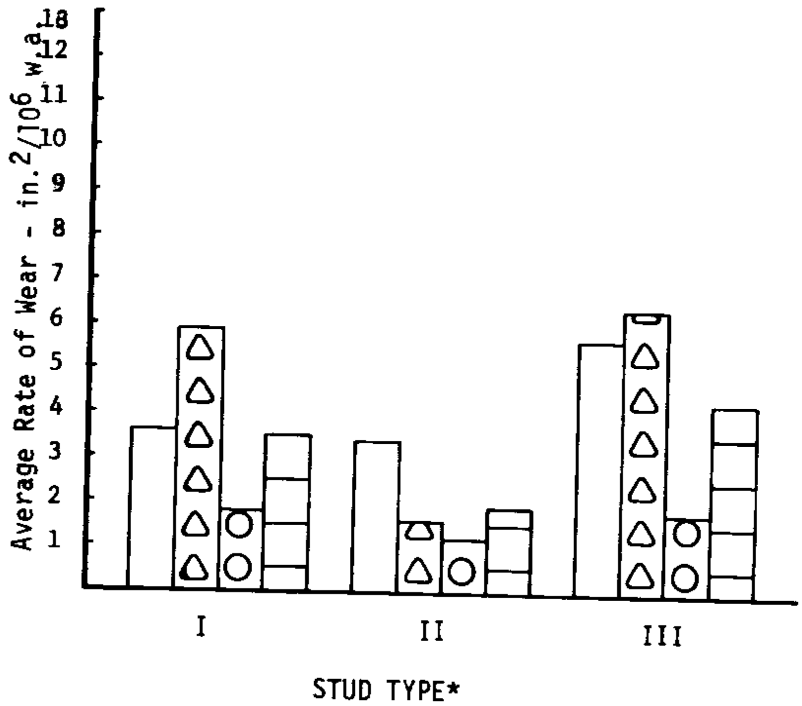
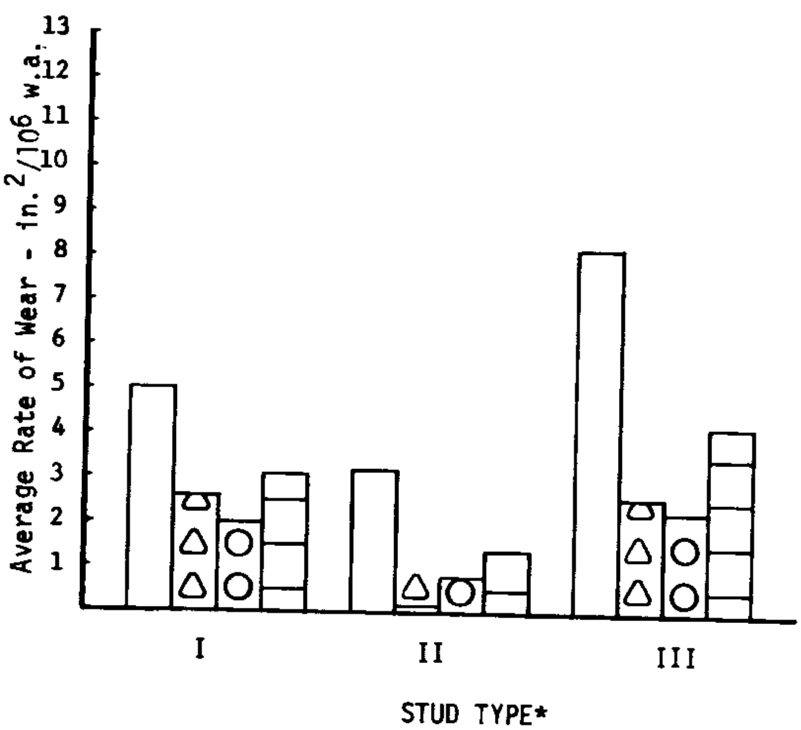
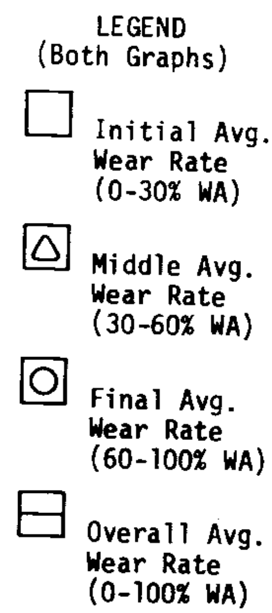


Figure 60

Section 01bB ½" Wirand Concrete - Mix 2a

Summary After 542,357 Wheel Applications





* Wear Rate Due to Unstudded Tires Insignificant or Immeasurable.

Figure 61

SEC 01bc ½" Wirand Concrete - Mix 2b
Summary after 542,357 Wheel Applications (WA)

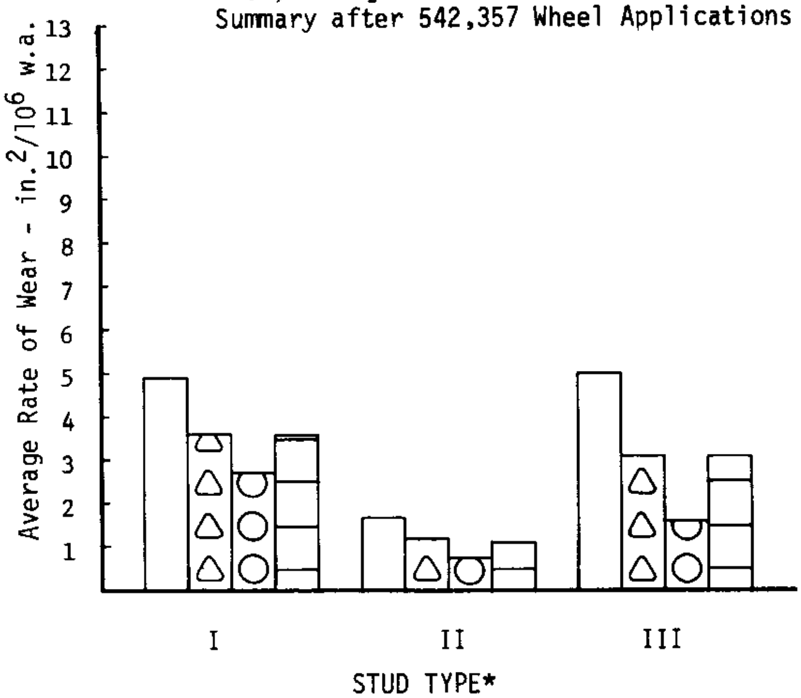
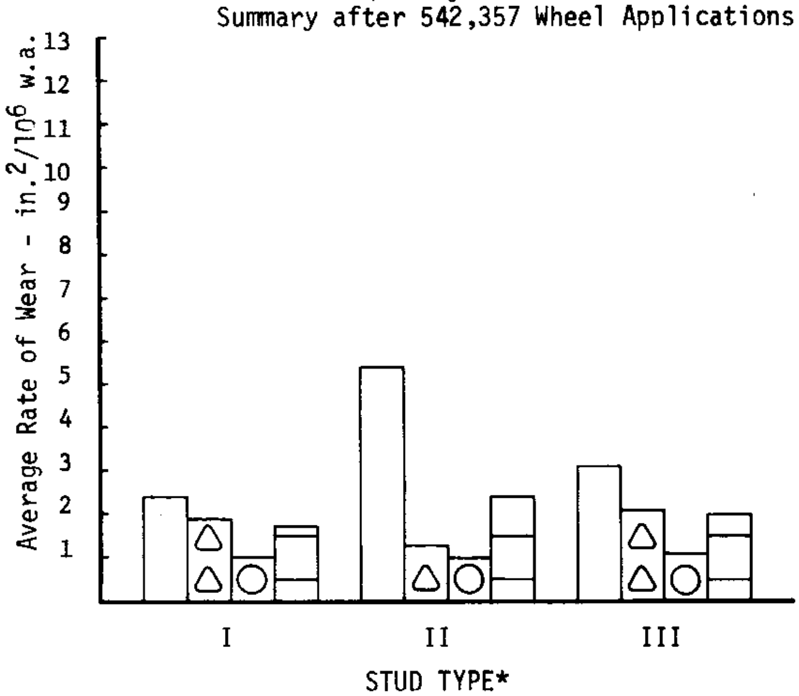
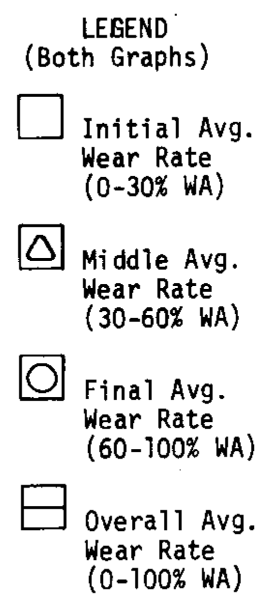


Figure 62

SEC 02bB ¼" Polymer Concrete
Summary after 542,357 Wheel Applications (WA)





* Wear Rates Due to Unstudded Tires Insignificant or Immeasurable

Figure 63

Section 03a Class "E" A.C.
Summary After 542,357 Wheel Applications (WA)

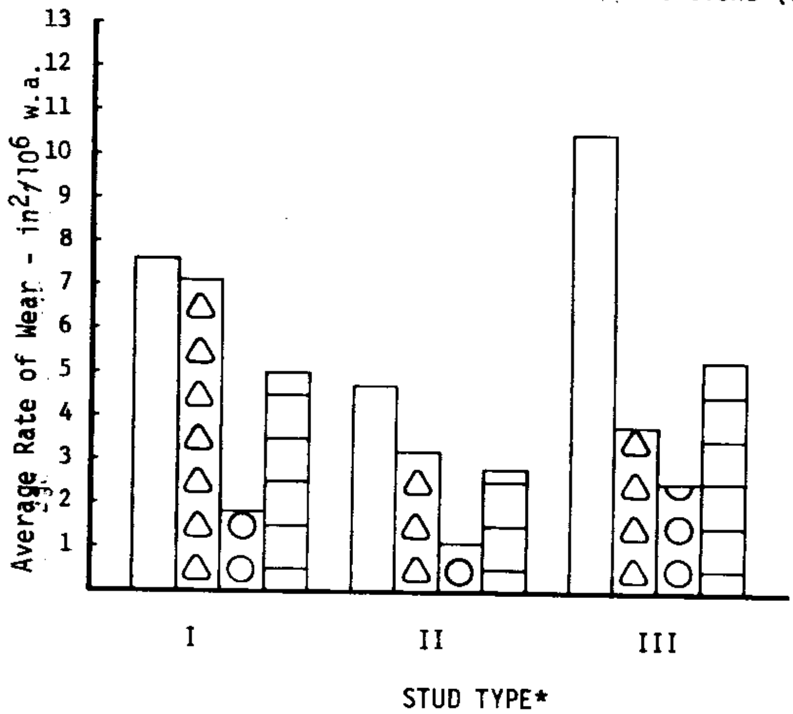
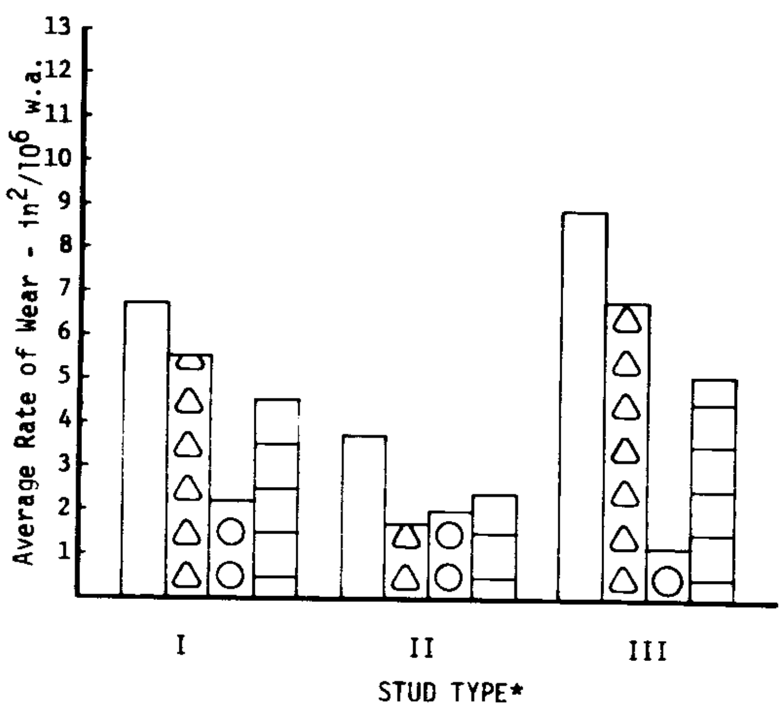
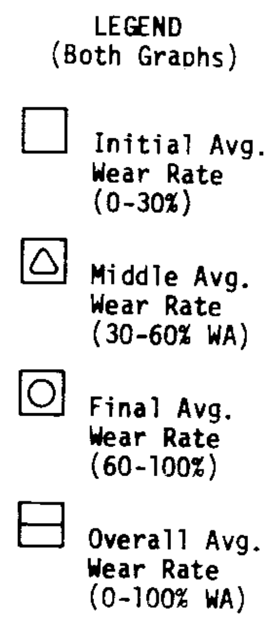


Figure 64

Section 03b Class "E" A.C. Gilsabind
Summary After 542,357 Wheel Applications (WA)





* Wear Rate Due to Unstudded Tires Insignificant or Immeasurable.

Figure 65
Section 04a Class "B" A.C.
Summary After 542,357 Wheel Applications (WA)

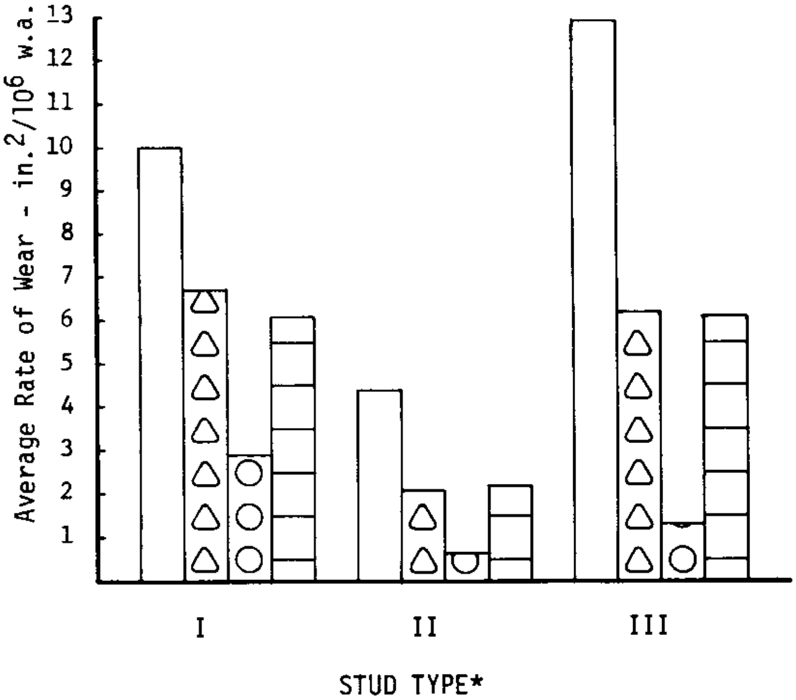
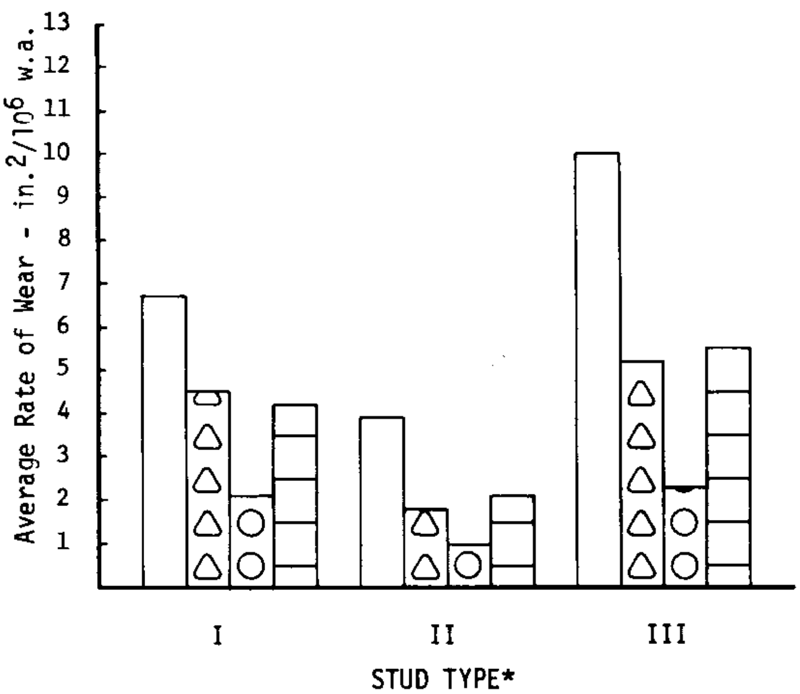
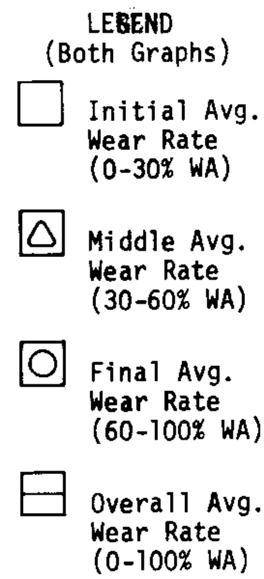


Figure 66
Section 04b Class "B" A.C. Gilsabind
Summary After 542,357 Wheel Applications (WA)

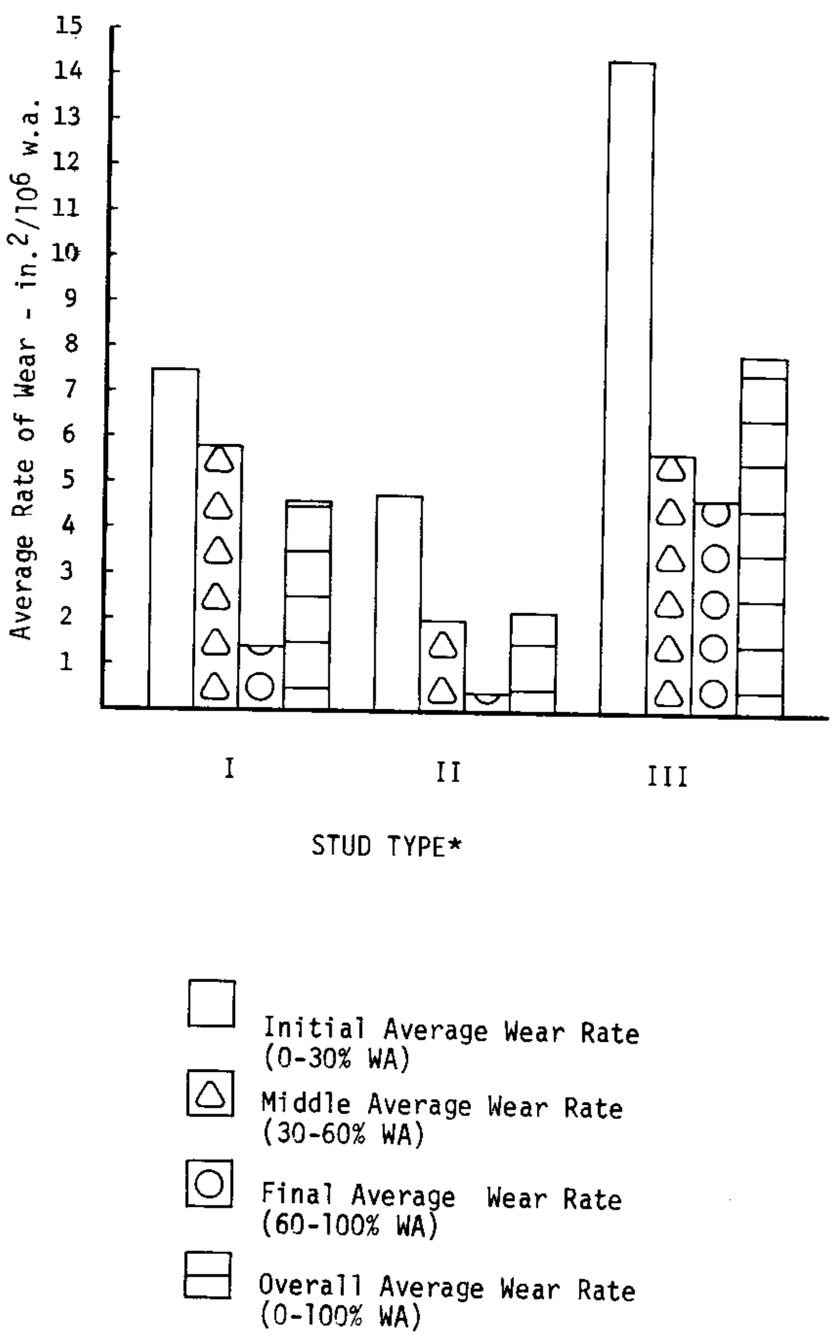




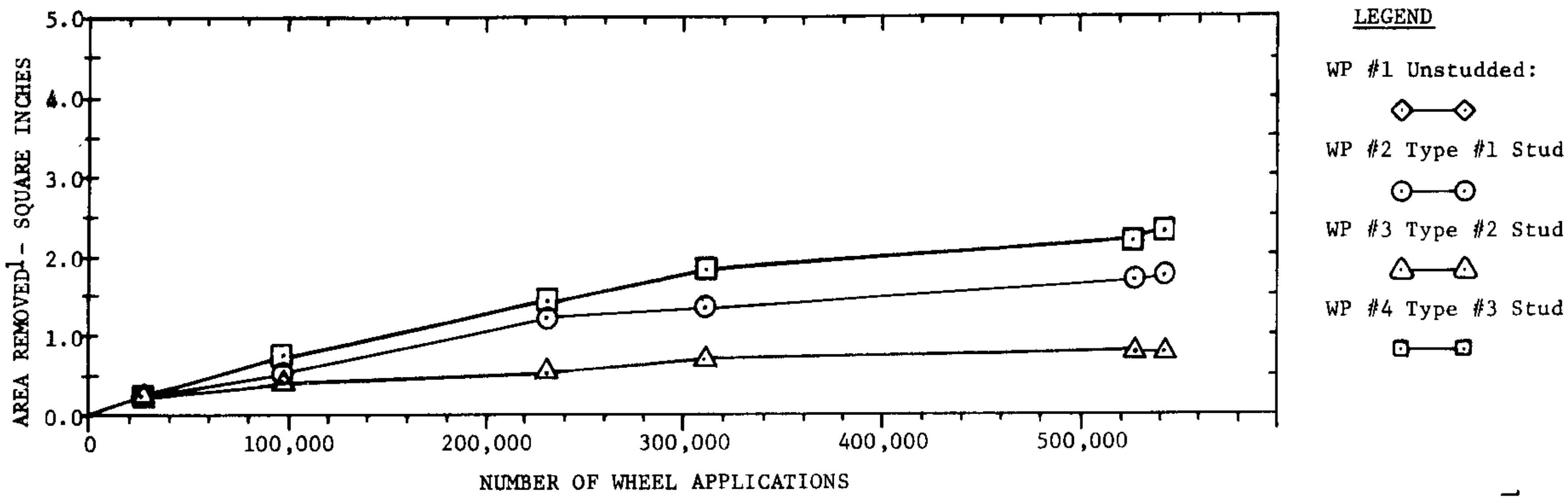
* Wear Rate Due to Unstudded Tires Insignificant or Immeasurable.

Figure 67

05a CLass "G" A.C.



* Wear Rates Due to Unstudded Tires Insignificant or Immeasurable.



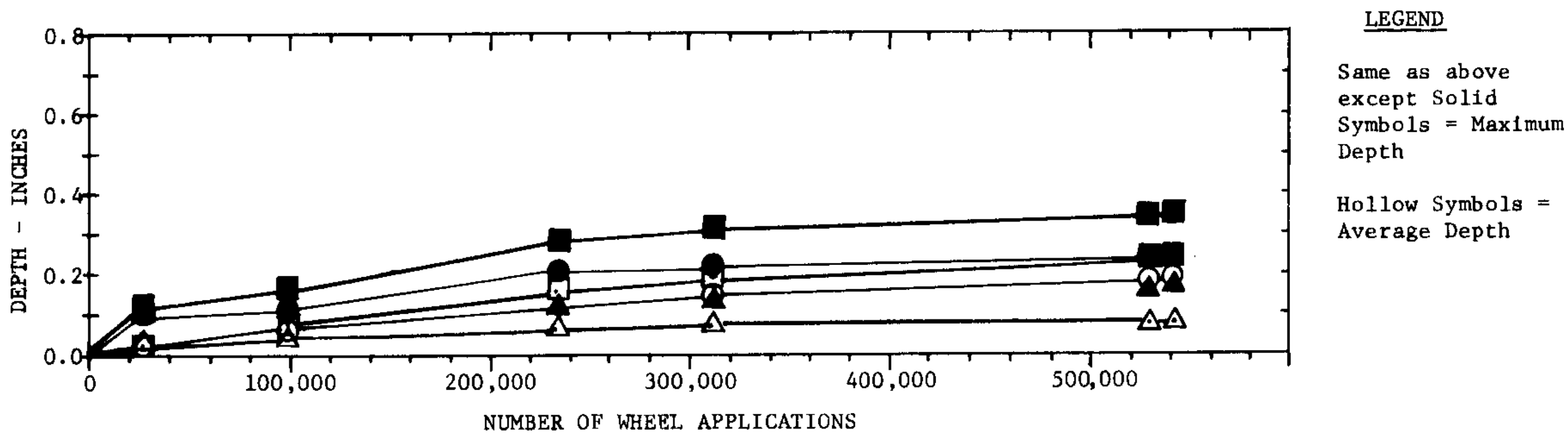


FIGURE 68 SECTION 02aB

1" WIRAND CONCRETE - MIX 4

[1] Area Removed for Unstudded Tires was so small that it could not be plotted.

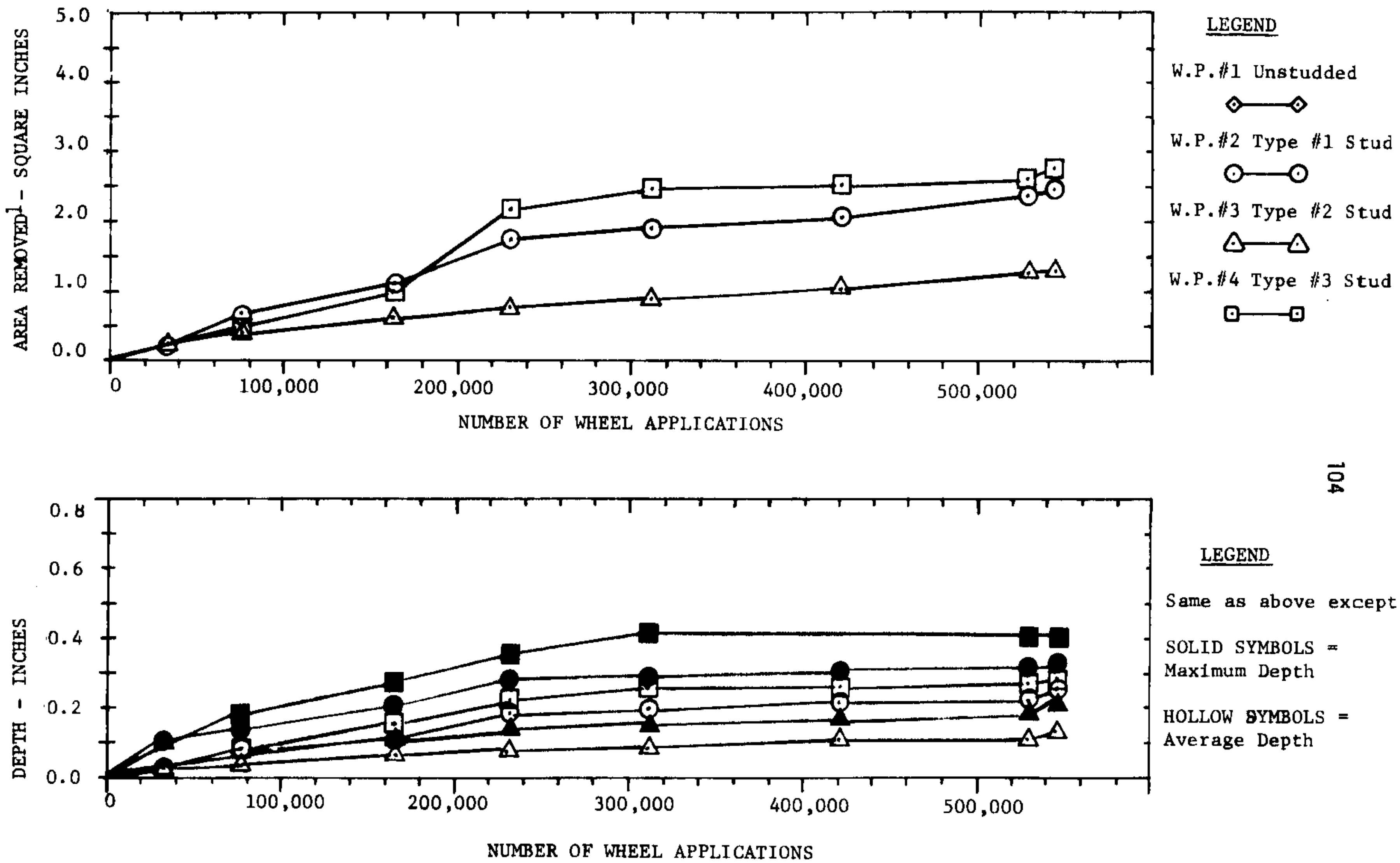


FIGURE 69 SECTION 0-3b

CLASS "E" A.C. GILSABIND

[1] Area Removed for Unstudded Tires was so small that it could not be plotted.

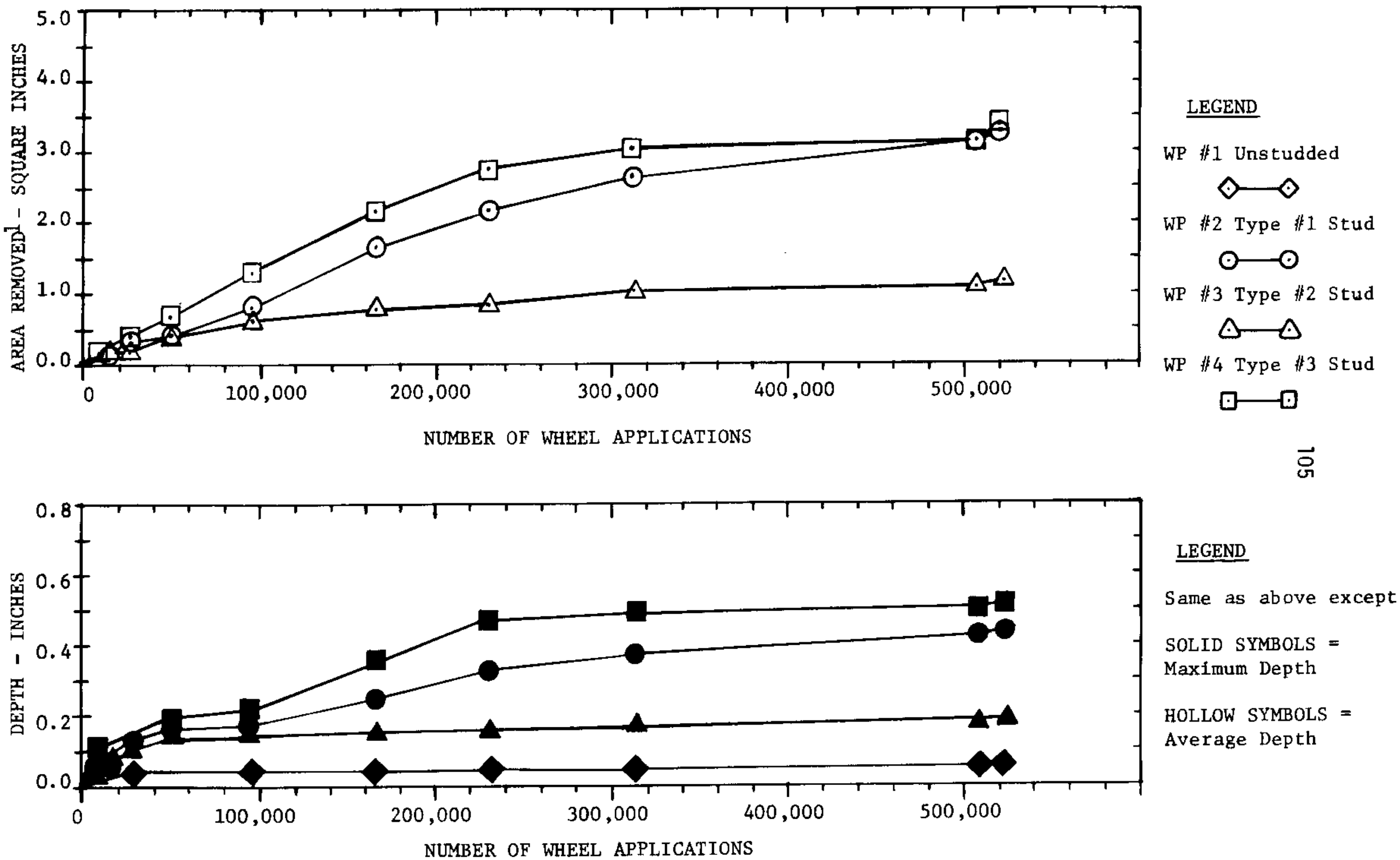


FIGURE 70 SECTION 0-4A

CLASS "B" AC

1 Area Removed for Unstudded Tires was so small that it could not be plotted.

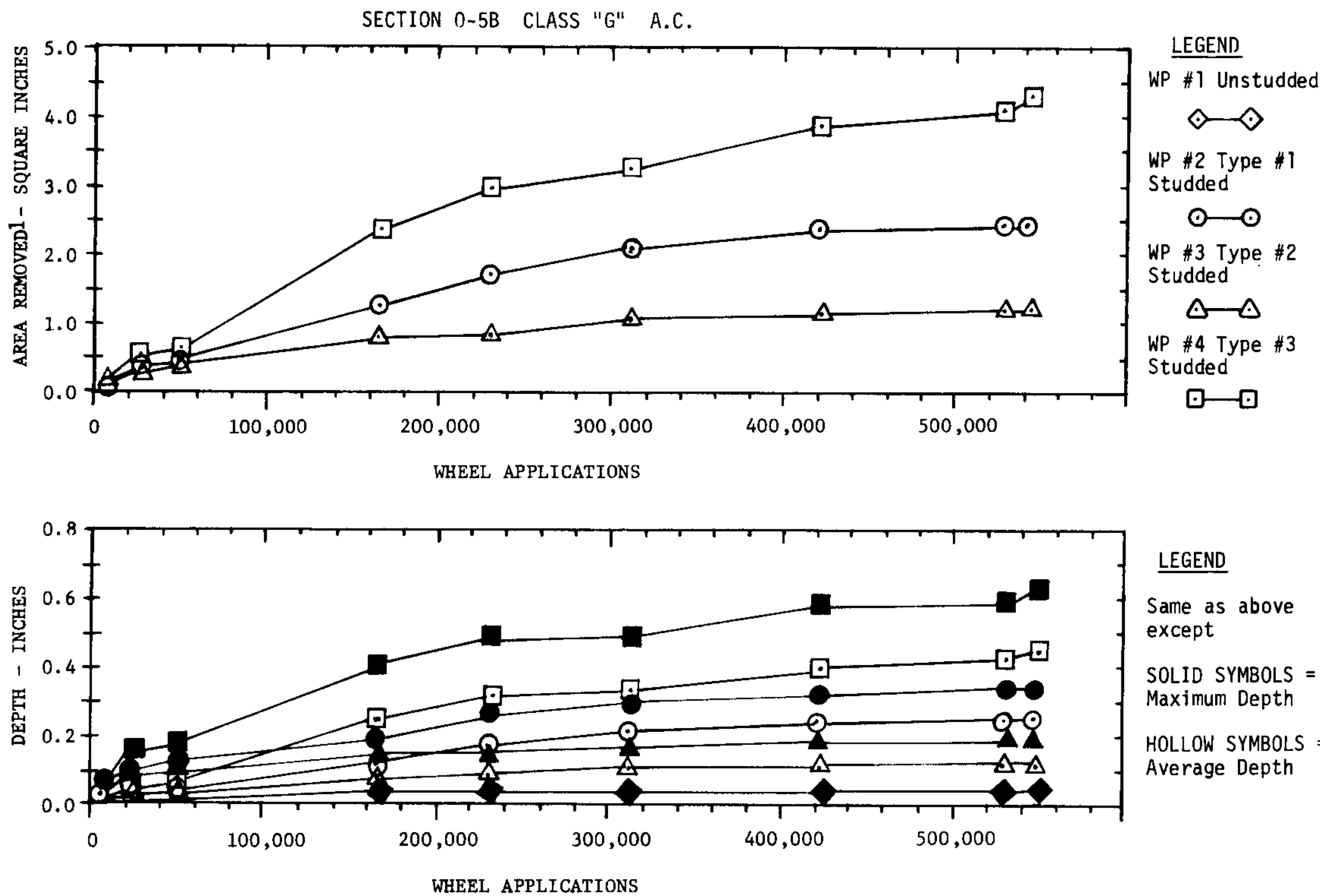


FIGURE 71

1 Area Removed for Unstudded Tires was so small that it could not be plotted.

TABLE 23 PROFILOMETER DATA IN AVERAGE WEAR RATES IN IN./10^6 WHEEL APPLICATIONS FOR INSIDE TRACK

SECTION	INITIAL[1]	MIDDLE[2]	FINAL[3]	OVERALL[4]
I-1a				
WP #7	.181	.079	.101	.120
WP #8	0	0	0	0
I-1b				
WP #7	.078	.117	.076	.088
WP #8	0	0	0	0
I-2aA				
WP #7	.058	.055	.158	.104
WP #8	0	0	0	0
I-2aB				
WP #7	--	--	.146	.98
WP #8	--	--	0	0
I-2bA				
WP #7	--	--	--	.592
WP #8	--	--	--	0
I-2bB				
WP #7	.092	.056	.092	.082
WP #8	0	0	0	0
I-3a				
WP #7	--	--	.342	.385
WP #8	--	--	0	0
I-3b				
WP #7	.484	.486	.340	.424
WP #8	0	0	0	0

1 Initial = 0-30%
2 Middle = 30-60%
3 Final = 60-100%
4 Overall = 0-100%

(all: of 1.6 X 10^6 wheel applications)

PROFILOMETER DATA

AVERAGE WEAR RATES IN INCHES/10^6 WHEEL APPLICATIONS

SECTION	INITIAL[1]	MIDDLE[2]	FINAL[3]	OVERALL[4]
I-4a				
WP #7	.284	.261	.301	.285
WP #8	0	0	0	0
I-4b				
WP #7	.406	.255	.338	.336
WP #8	0	0	0	0
I-5a				
WP #7	.380	.348	.531	.435
WP #8	0	0	0	0
I-5b				
WP #7	.261	.541	.379	.387
WP #8	0	0	0	0

[1] Initial = 0-30%
[2] Middle = 30-60%
[3] Final = 60-100%
[4] Overall = 0-100%

(all) of 1.6 X 10^6 wheel application

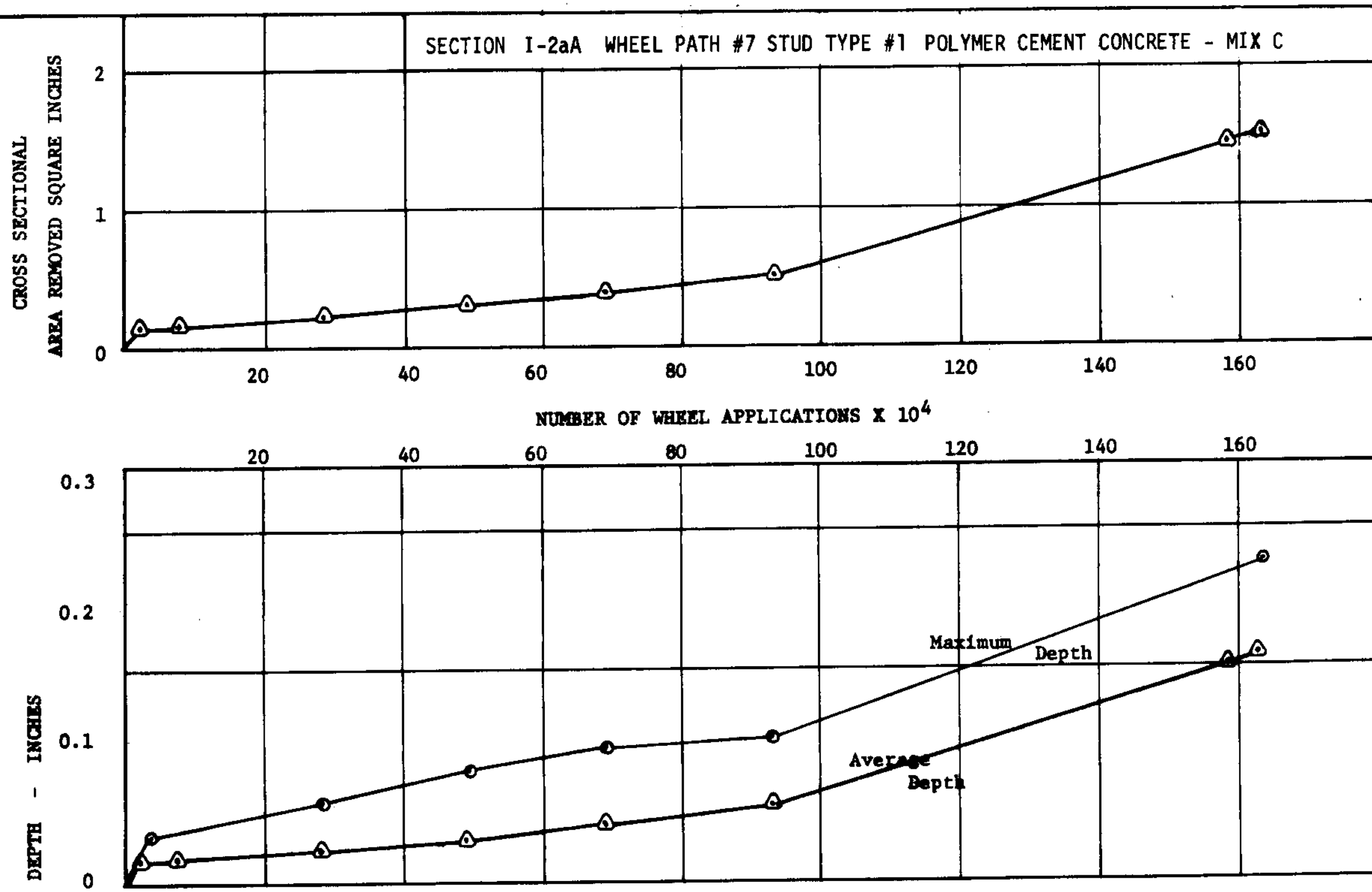


FIGURE 72 AREA REMOVED, MAXIMUM AND AVERAGE DEPTH MEASUREMENTS VERSUS WHEEL APPLICATIONS

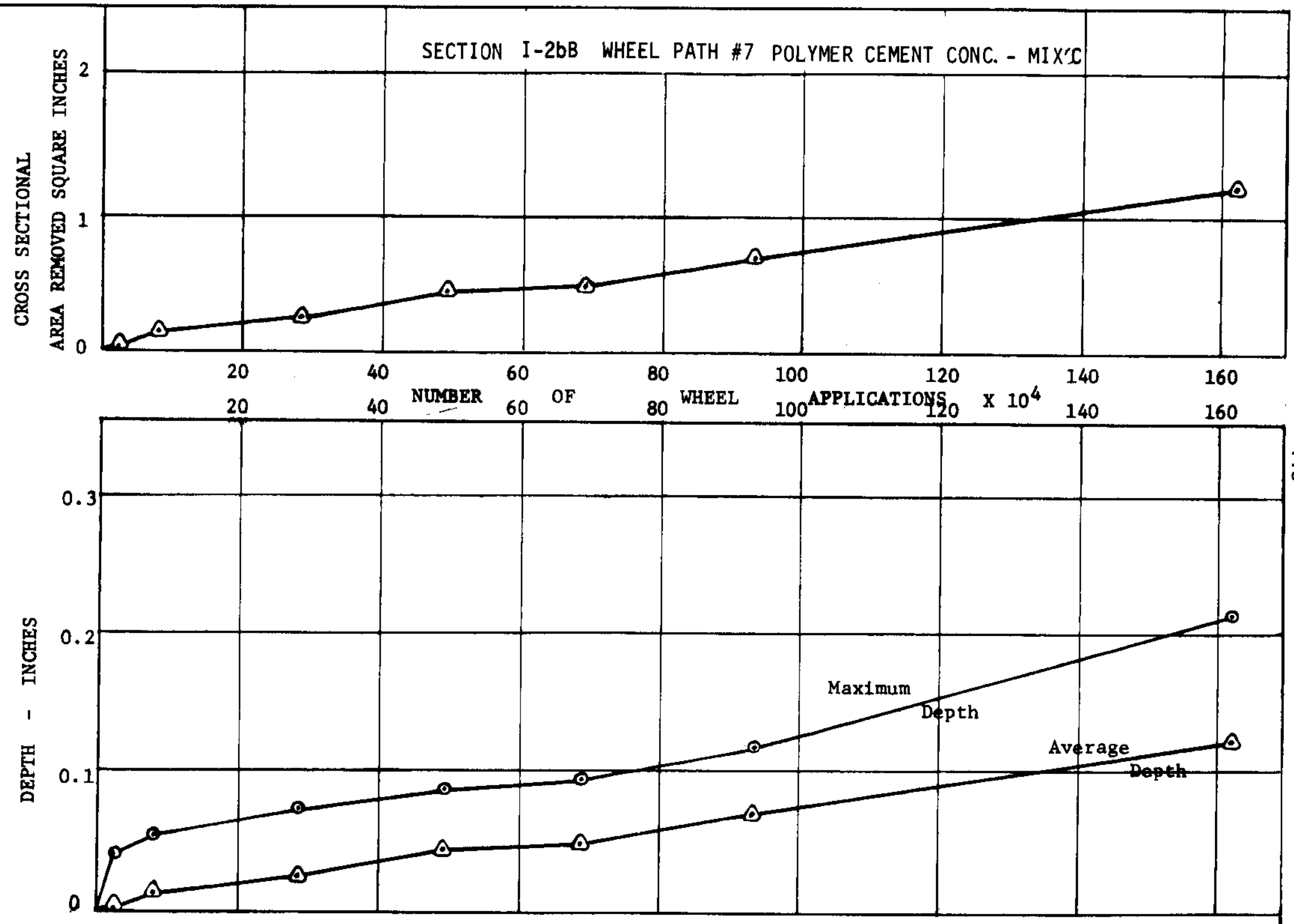


FIGURE 73 AREA REMOVED, MAXIMUM AND AVERAGE DEPTH MEASUREMENTS VERSUS WHEEL APPLICATIONS

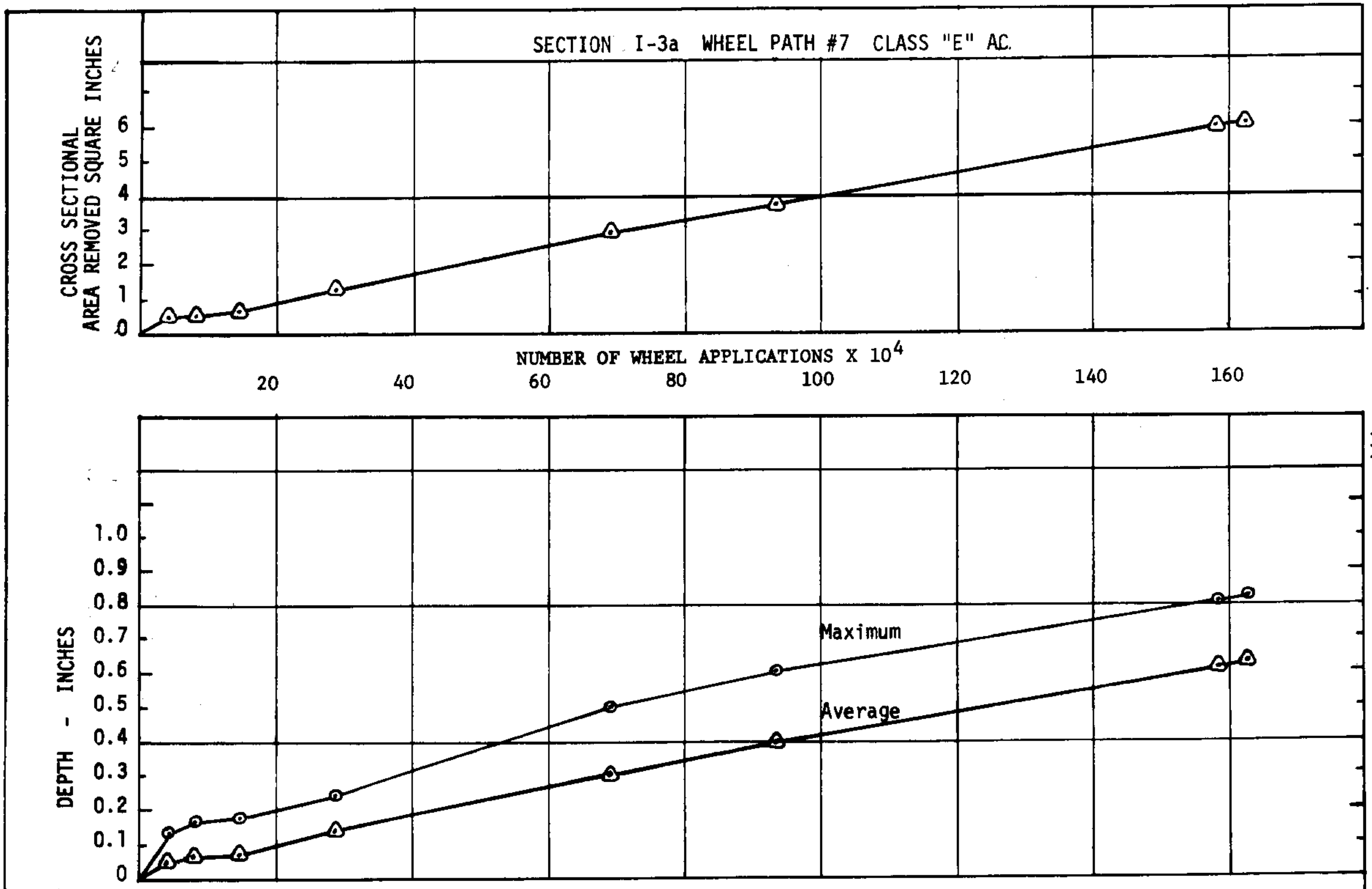
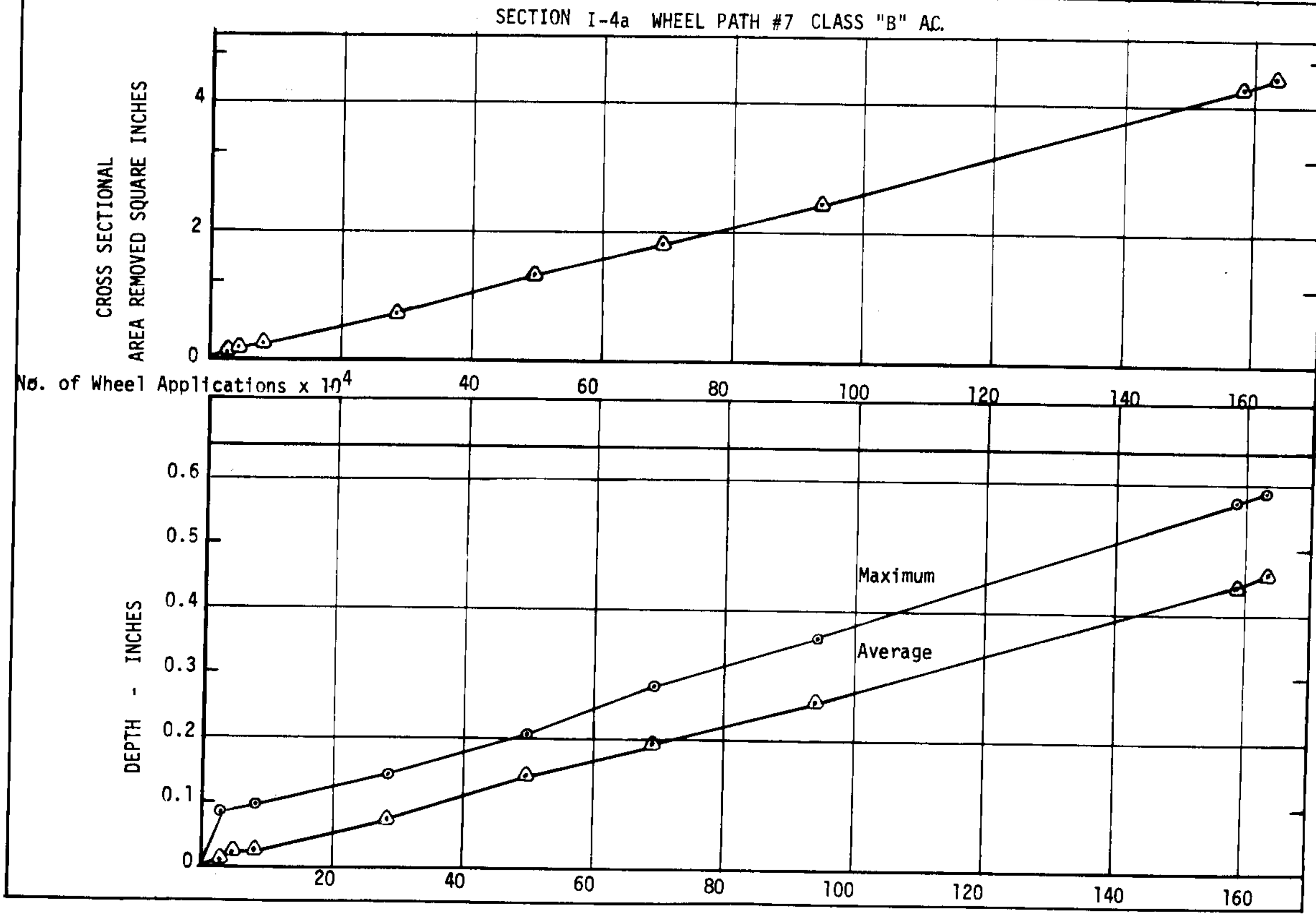


FIGURE 74 AREA REMOVED, MAXIMUM AND AVERAGE DEPTH MEASUREMENTS VERSUS WHEEL APPLICATIONS

FIGURE 75 AREA REMOVED, MAXIMUM AND AVERAGE DEPTH MEASUREMENTS VERSUS WHEEL APPLICATIONS



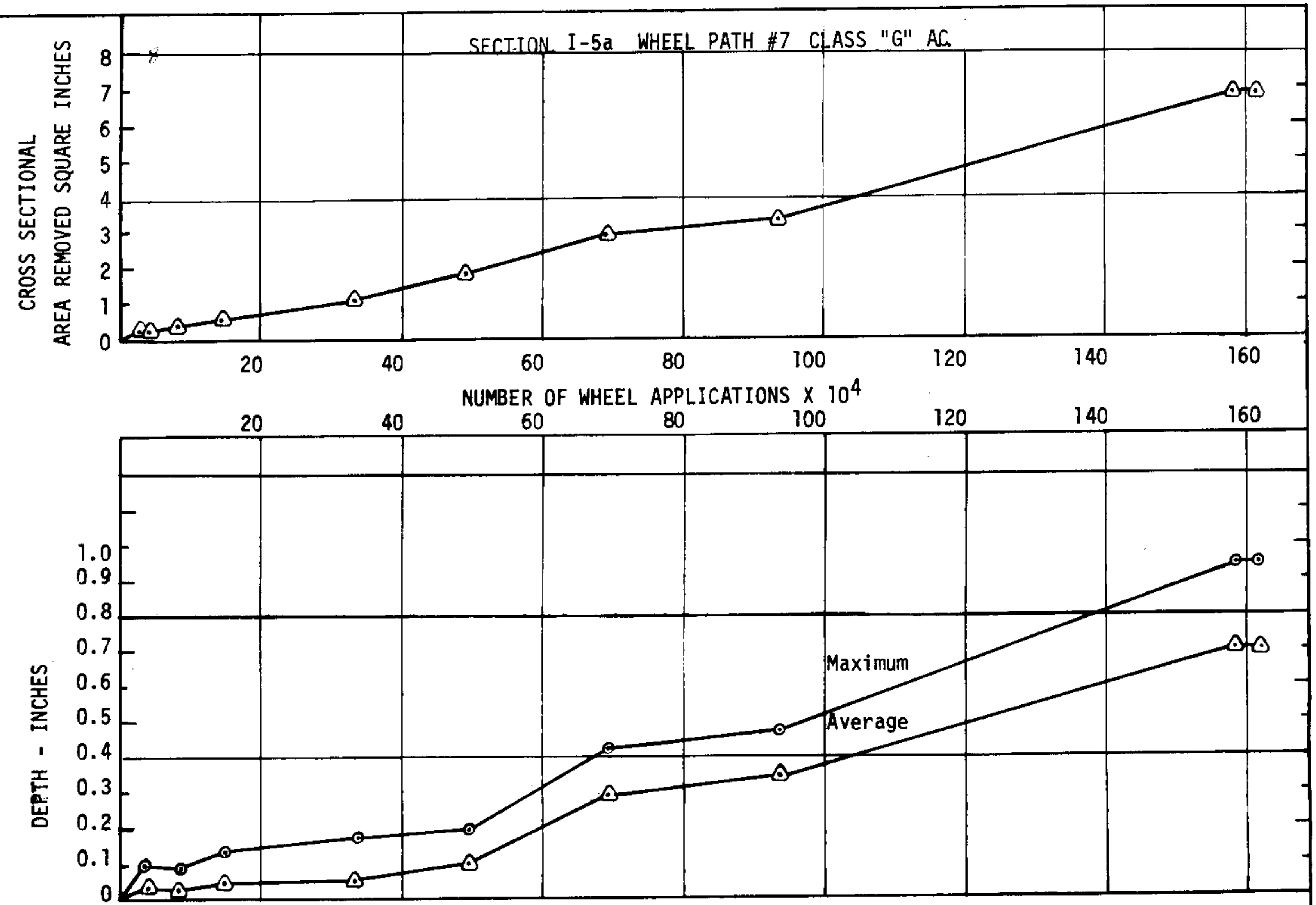


FIGURE 76 AREA REMOVED, MAXIMUM AND AVERAGE DEPTH MEASUREMENTS VERSUS WHEEL APPLICATIONS

Table 24 shows the different wear rates for the center track. It can be seen that the initial wear rates are very high compared to the other wear rates. This can be definitely correlated to the time the studded truck tires stopped wearing the pavement and there was shift in truss weight to the outside truck tire. It is difficult to say which of the surface textures resisted the stud effect the best. The final values shown in Table 15 do not allow for definite conclusions. It can be said the different surface textures, formed while the portland cement concrete was plastic, showed no great advantage for wear resistance. The reason is that the textures probably consisted of sand cement mortar deficient in coarser aggregate, and thus little strength to resist the tire studs.

THE DIFFERENT TYPES OF STUDS AND WEAR

All studded tires tested caused abnormal wear on all surfaces of the test track. A table was made using comparative pavement wear. The type #3 stud was used as 100% wear and the wear from the other types was calculated as a percentage of type #3 wear. This was called Percentage Wear (P.W.). Wear ratios (W.R.) were calculated on the basis of Percentage Wear (P.W.). The results are shown in Table 25. The unstudded tire wear was not used as standard since the wear was so slight that much error was involved.

Table 25 shows that type #2 and type #1 studs reduced wear on the pavement in that order. Although type #1 studs were not tested under manufacturer's conditions for pin movement and controlled protrusion, it still showed considerable reduction in pavement wear as compared to type #3 studs. Type #2 studs, in most cases,on the outside track showed the most reduction in wear.

TABLE 24 AVERAGE WEAR RATES FOR CENTER TRACKS[7] - INCHES/10^6 WHEEL APPLICATIONS

SECTION	SURFACE TEXTURE	INITIAL[1]	MIDDLE[2]	FINAL[3]	OVERALL[4]
C-1a	Heavy Long. Brooming	.214	.0339	.0065	.089
C-1b	Light Transverse Brooming	.162	.103	.065	.112
C-2a	Heavy Transverse Brooming	.144	.031	.016	.066
b	Burlap	.207	.0154	.0083	.081
C-3a	Longitudinal Grooving	.224	.0179	.0096	.088
b	Light Long. Brooming	.257	.016	.0191	.102
C-4a	Transverse Grooving	.256	.0102	.0130	.098
b	Light Transverse Brooming	.256	.0099	.0182	.100
C-5a	Light Plastic Grooving	.219	.0027	.0148	.080
b	Light Plastic Grooving	.119	.0599	.0126	.065
C-6a	Med. Long. Brooming	.261	.0260	0	.099
b	Light Long. Brooming	.289[5]	--[6]	--[6]	.082

[1] 0-494,220 wheel applications

[2] 494,220 - 936,663 wheel applications

[3] 936,663 - 1,390,935 wheel applications

[4] 0 - 1,390,935 wheel applications

[5] Initial rate 0 - 287,520 wheel applications

[6] Data not available

[7] Wear rates are insignificant for unstudded truck tires in wheel path #5

TABLE 25 COMPARATIVE PAVEMENT WEAR[1]

SECTION	PAVEMENT TYPE	PERCENTAGE WEAR[2] AND WEAR RATIO[3] WITH RESPECT TO TYPE 3 STUDS							
		WP #1 No Studs		WP #2 Type #1		W.P. #3 Type #2		W.P. #4 Type #3	
		P.W.[2]	W.R.[3]	P.W.[2]	W.R.[3]	P.W.[2]	W.R.[3]	P.W.[2]	W.R.[3]
0-1bA	½" Wirand Concrete	6.1	16.4	83.6	1.2	47.8	2.1	100	1
B	½" Wirand Concrete	0.7	142.9	78.3	1.3	34.8	2.9	100	1
C	½" Wirand Concrete	2.4	41.7	117.6	0.8	41.2	2.4	100	1
D	½" Wirand Concrete	11.0	9.1	95.2	1.0	47.6	2.1	100	1
0-2aA	1" Wirand Concrete	3.0	33.3	109.0	0.9	40.9	2.4	100	1
B	1" Wirand Concrete	3.1	32.4	75.0	1.3	33.3	3.0	100	1
C	3" Wirand Concrete	1.7	60.0	122.2	0.8	77.8	1.3	100	1
0-2bA	1" Polymer Concrete[4]	0.75	133.3	183.3	0.6	80.0	1.2	100	1
B	¼" Polymer Concrete	.83	120.5	75.0	1.3	108.3	0.9	100	1
0-3a	Class "E" A.C.	10.4	9.7	82.1	1.2	50.0	2.0	100	1
b	Cl. "E" A.C. Gilsabind	2.1	47.1	71.9	1.4	46.9	2.1	100	1
0-4a	Class "B" A.C.	4.5	22.3	96.6	1.0	41.4	2.4	100	1
b	Class "B" A.C. Gilsabind	4.7	21.4	96.7	1.0	43.3	2.3	100	1
0-5a	Class "G" A.C.	6.7	15.0	73.3	1.4	46.7	2.1	100	1
b	Class "G" A.C.	2.4	40.8	76.3	1.3	39.5	2.5	100	1
0-6a	Idaho Chip Seal	--	--	--	--	--	--	100	1
b	Idaho Chip Seal	19.5	5.1	30.0	3.3	55.0	1.8	100	1

1 Passenger tires and outside track only

2 Percentage Wear (P.W.) = $\frac{\text{Stud Type Y Average Wear}}{\text{Stud Type 3 Average Wear}} \times 100\%$

4 Some of the wear was due to poor bond

3 Wear Ratio (W.R.) = $\frac{100}{\text{Percentage Wear}}$

COMPARISONS WITH OTHER STUDIES

THE MINNESOTA STUDY

It is difficult to compare different tests. The Minnesota study (29) done by American Oil Company was completely different than that done by WSU. The American Oil Company test track is smaller and completely inside where the environment can be controlled. The WSU test track was completely open to all elements. The test speeds were completely different--35 mph for the Minnesota study versus 20-25 mph for the WSU study. The temperature was 25°F ± 5 and continuously wet for the Minnesota; the WSU temperature varied with the weather. The pavements were different to some extent as those at WSU were built using normal construction equipment whenever possible compared to the Minnesota study where the pavements were built in the laboratory. The edges of the channels were ground down in the Minnesota study while WSU's channels' edges were left to develop naturally. Tires were changed frequently in the Minnesota study as compared to those at the WSU test track. All these differences in conditions naturally contributed to results which cannot be directly compared but can be relatively. Minnesota study was done on the type #3 stud.

Another study was done by the American Oil Company (30) for the State of Minnesota Department of Highways on the type #1 stud. They had the same problem in obtaining the stud protrusion characteristics of 0.040 inch as did the WSU study. This, too, was due to the inability of the American Oil Traffic Simulator to reach speeds of 40-60 mph on bare pavements.

Tables 26, 27 and 28 show comparisons on channeling rates for the type #3, type #1 studs, and average rut depth for the type #3 studs respectively. The comparisons are relative only and show fair comparisons. The differences,

TABLE 26 COMPARISON OF WEAR RATES FROM THE MINNESOTA[1] AND WASHINGTON STATE UNIVERSITY TESTS

Type #3 Studs

PAVEMENT TYPE	CHANNELING RATES - INCHES/10^6 WHEEL APPLICATIONS					
	MINNESOTA STUDY			W.S.U. STUDY		
	INITIAL	INTERMEDIATE	TERMINAL	INITIAL	INTERMEDIATE	TERMINAL
Asphalt Concrete (High Type)	0.96	0.510	0.408	1.335	0.671	0.645
Asphalt Concrete (Regular)	1.04	1.019	0.790	1.499	.556	0.826
Portland Cement	1.50	0.689	0.347	--	0.121	0.162
Epoxy Mortar	0.60	0.200	0.159	--	0.066	0.171

[1] Reference 29

TABLE 27 COMPARISON OF WEAR RATES FROM THE MINNESOTA[1] AND WASHINGTON STATE UNIVERSITY TEST - Type #1 Studs

PAVEMENT TYPE	CHANNELING RATES - INCHES/10^6 WHEEL APPLICATIONS					
	MINNESOTA STUDY			W.S.U. STUDY		
	INITIAL	INTERMEDIATE	TERMINAL	INITIAL	INTERMEDIATE	TERMINAL
Portland Cement Concrete	0.61	0.34	0.18	0.130	0.099	0.104
Asphalt Concrete	1.39	0.72	0.352	0.284	0.562	0.281

1 Reference 30

TABLE 28 COMPARISON OF AVERAGE RUT DEPTH - MINNESOTA[1] & W.S.U. TESTS ON STUD TYPE #1

PAVEMENT TYPE	MINNESOTA	W.S.U.
	RUT DEPTH - INCHES	RUT DEPTH
Asphalt - regular	0.40	0.38
Asphalt - high type	0.25	0.28
Portland Cement	0.25	0.16
Epoxy Mortar	0.127	0.14

[1] Reference 29

no doubt, reflect the different conditions of tests.

OTHER STUDIES

It is difficult to compare results obtained with the Ontario studies (25,26,31) because their results are from the field. Rates of wear were estimated by assuming some ADT with a percentage of cars having studded tires.

The Swedish Road Research Laboratory (24,32) with their traffic simulater obtained average wear depths of 6.9 mm per 200,000 wheel passes; this is equivalent to 0.272 inches per 200,000 wheel passes and 1.15 inches /10^6 wheel passes. Since the type of studs used and conditions of tests were different or not mentioned, it is very difficult to make any meaningful comparisons, except that WSU rates were considerably lower.

Hode Keyser (33) found wear rates of 0.11 inches per 100,000 wheel applications for bituminous concrete and 0.10 inches per 100,000 wheel applications for concrete wear rates. Unfortunately, if one assumes that the wear rates continue to be the same, the rut depth would be quite high after a million wheel passes. The WSU results are lower which may be due to the conditions of test.

COMPARISON WITH NORMAL HIGHWAYS

The wheel paths on a highway are larger than those on the test track. The WSU researchers measured a few Washington State highways and found that the tire wheel path measured about 36 inches. Since the test track wheel path as shown in Figures 22 and 23 was 9.50 inches, this means that the rates of wear should be divided by 3.8 to obtain the proper rate of wear for one million wheel passes. This factor would give a fair estimate of the rate of wear for the different pavement types. It should be remembered that in areas of acceleration and deceleration, the wear rates should be increased by a factor of 3 and 2 respectively, as found in other studies (33). Other adjustment factors for estimating "real world" effects would include accurate information on number and type of studded tires in use for time periods involved. Temperature effects should also be considered.

REFERENCES

1. Carlstedt, R. L. "Report on Tire Studs for Passenger Cars 1964," Kennametal Inc.: Latrobe, Pa., October 1964.

2. Miller, W. P. II. "The Winter Tire Stud," Highway Research Record, No. 136, Highway Research Board: Washington D.C., 1966, p. 1-6.

3. Miller, W. P. II. "Principles of Winter Tire Studs," Highway Research Record No. 171, Highway Research Board: Washington, D.C., 1967,p. 1-13.

4. Rosenthal, P., Haselton, F.R., Bird, K.D. and P.J. Joseph. "Evaluation of Studded Tires--Performance Data and Pavement Wear Measurement," NCHRP Report 61, Highway Research Board: Washington, D.C., 1969, 66 pages.

5. Burke, J. E. and L. J. McKenzie. "Some Tests of Studded Tires in Illinois," Highway Research Record No. 136, Highway Research Board: Washington, D.C., 1966, p. 42-58.

6. Whitehurst, E. A. and A. H. Easton. "An Evaluation of Studded Tire Performance," Highway Research Record No. 171, Highway Research Board: Washington, D.C., 1967, p. 14-27.

7. Bellis, W. R. and J. T. Dempster, Jr. "Studded Tire Evaluation in New Jersey," Highway Research Record No. 171, Highway Research Board: Washington, D.C., 1967, p. 28-51.

8. Smith, R. W., Ewens, W. E. and D. J. Clough. "Effectiveness of Studded Tires," Highway Research Record No. 352, Highway Research Board: Washington, D.C., 1971, p. 39-49.

9. Bird, K. D. and F. R. Haselton. "Evaluation of Studded Tire Performance," CAL Report No. 159, Cornell Aeronautical Laboratory, Inc.: Buffalo, New York, September 1967, 72 pages.

10. "Winter Testing of Tires," Report on Research Conducted for the Canada Safety Council, Damas and Smith Limited, 1971, 70 pages.

11. Normand, J. "Influence of Studded Tires on Winter Driving Safety in Quebec," Highway Research Record No. 352, Highway Research Board: Washington, D.C., 1971, p. 50-61.

12. Perchonok, K. "Safety Effectiveness of Studded Tires," CAL Report No. VJ-2915-V-2, Cornell Aeronautical Laboratory, Inc.: Buffalo, New York, September 1971, 78 pages.

13. Overend, R. B. "The Great Studded Tire Controversy," Traffic Safety, Vol. 71, No. 12, December 1971, p. 8-10,35-39.

14. Dale, J. M. "Studded Tires Versus Pavement Markings," Highway Research News, No. 38, Highway Research Board, Washington, D.C., Winter 1970, p. 25-29.

15. Jensen, P.A. and Korfhage, G. R. "Studded Tires--Their Effect on Pavement Wear and Performance Characteristics," Special Study No. 290, Minnesota Department of Highways, 1968.

16. Hode Keyser, J. "The Effect of Studded Tires on the Durability of Road Surfacings," Highway Research Record No. 331, Highway Research Board: Washington, D. C. 1970, p. 41-53.

17. Jensen, P. A. and Korfhage, G.R. "Preliminary Studies of Effect of Studded Tires on Highway Pavements," Highway Research Record No. 136, Highway Research Board: Washington, D.C., 1966, p. 8-23.

18. Burnett, W. B. and Kearney, E. J. "Studded Tires - Skid Resistance and Pavement Damage," Highway Research Record No. 136, Highway Research Board: Washington, D.C., 1966, p. 24-30.

19. White, O. A. and Jenkins, J. C. "Test of Steel Studded Snow Tires," Highway Research Record No. 136, Highway Research Board: Washington, D.C., 1966, p. 31-41.

20. Lee, A., Page, T. A. and R. Decarrera. "Effects of Carbide Studded Tires On Roadway Surfaces," Highway Research Record No. 136, Highway Research Board: Washington, D.C., 1966, p. 59-77.

21. Hogbin, L.E. "Damage to Roads by Studded Tyres," RRL Report LR 208, Road Research Laboratory, Ministry of Transport, Crowthorne, Berkshire, Great Britain, 1968, 9 pages.

22. Rosengren, A. "An Investigation Concerning Studded Tyres With Special Reference to Pavement Wear, Based on Litterature Studies," Special Report No. 81A, The National Swedish Road Research Institute, Stockholm, Sweden, 1969, 26 pages.

23. Requirand, R. and Leger, Ph. "Usure des revêtements par les pneus ā clous," Bulletin Liason Labo. Routien P. et Ch., No. 49, December 1970, p. 139-149.

24. Andersson, O., Lilja, B., Rosengren, A., Astrom, T., and Orbom, B. "Pavement Wear Due to Studded Tyres Measured in the Test Road Machine of the National Swedish Road Research Institute," Special Report No. 83A, The National Swedish Road Research Institute, Stockholm, Sweden, Nov. 1969, 30 pages.

25. Smith, P. and Schonfeld, R. "Pavement Wear Due to Studded Tires and the Economic Consequences in Ontario," D.H.O. Report No. RR152, Department of Highways, Ontario, Canada, January 1970, 28 pages.

26. Smith, P. and Schonfeld, R. "Studies of Studded - Tire Damage and Performance in Ontario - Winter 1969-70," D.H.O. Report No. RR 165, Department of Highways, Ontario, Canada, August 1970, 18 pages.

27. "Effects of Studded Tires," A Research Progress Report, Minnesota Department of Highways, December 1970, 37 pages.

28. "Effects of Studded Tires," A Research Summary Report, Minnesota Department of Highways, March 1971, 47 pages.

29. Speer, T. L. and J. W. Gorman. "Laboratory Evaluation of Pavement Damage Caused by Studded Tires, Salt and Abrasive Sand," Final Report, American Oil Company, May 25, 1971, 77 pages + Appendix.

30. Speer, T. L. and J. W. Gorman. "Laboratory Evaluation of Pavement Damage Caused by Studded Tires, Salt and Abrasive Sand," Supplemental Report - Test 5A/B, American Oil Company, June 15, 1971, 28 pages.

31. Smith, P. and Schonfeld, R. "Thoughts on Tolerable Pavement Wear," M.T.C. Report No. RR179, Ministry of Transportation and Communications, Ontario, Canada, May 1972, 9 pages.

32. "Winter Damage to Road Pavements," A Report by an OECD Road Research Group, Organization for Economic Co-operation and Development, Paris, May 1972, 99 pages.

33. Hode Keyser, J. "Resistance of Various Types of Bituminous Concrete and Cement Concrete to Wear by Studded Tires," Highway Research Record No. 352, Highway Research Board: Washington, D.C., 1971, p. 16-38.

34. Hode Keyser, J. "Design Criteria for Wear Resistant Bituminous Pavement Surfaces," Paper presented at 51st Annual Meeting, The Highway Research Board, Washington, D.C., January 1972, 58 pages.

35. Fromm, H. J. and J. T. Corkill. "An Evaluation of Surface Course Mixes Designed to Resist Studded Tire Wear," D.H.O. Report No. RR 171, and in Proceedings, The Association of Asphalt Paving Technologists, Oklahoma City, Oklahoma, Feb. 15-17, 1971, p. 358-382.

36. Santucci, L. E. "Resistance of Pavement Surfacings to Studded Tire Wear," Internal Report, Chevron Research Company: Richmond, California, August 8, 1971, 23 pages.

37. Rennie, D. "Status of Studded Tire Legislation," Kennametal Inc.: Latrobe, Pa., October 20, 1972, 8 pages.

38. "Studded Tires," Washington Highway News, Olympia, Washington, October 1972, p. 8.

39. Andrews, G. H. "Annual Report of Highway Department Progress," Speech before the Washington State Good Roads Association, Spokane, Washington, September 21, 1972.

40. Krukar, M. and J. C. Cook. "The Effect of Studded Tires on Different Pavement and Surface Textures," Transportation Systems Section Publication H-36, Washington State University, Pullman, July 1972, 32 pages.

41. Cantz, R. "New Tire Stud Developments," paper presented at 51st Annual Meeting, The Highway Research Board, Washington, D.C., January 1972, 25 pages.

42. Baum, C. S. "The Tire Stud Controversy and A New Concept--The Perma-T-Grip," Permanence Corporation, Detroit, Michigan, April 19, 1972, 18 pages.

LIST OF CONTRIBUTORS

Kennametal - passenger car and truck tires, with and without studs.

Permanence - passenger car tire, studded.

Battelle Pacific Northwest Laboratories - various types of steel fibers for the Wirand ^{R} Concrete.

Central Pre-Mix Concrete - concrete for Wirand sections.

C & C Distributors - equipment and Gilsabind treatment.

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.

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

Central Pre-Mix Concrete Co. Inc., 237 West 8th, Moscow, ID 83843
Sherman Dionne, Manager.

C & C Distributors, N. 3430 Cook, Spokane, WA 99207.
Carl Carbon, Jr., Technical Representative.

APPENDIX A

CONSTRUCTION SCHEDULE - RING 5

October 1, 1971

This month was spent removing the old existing pavement and bases, and preparing the subgrade. The density was checked by nuclear methods. Due to the poor weather, crushed rock was used to improve the subgrade characteristics.

A 6.0" deep layer and 10 foot wide section of Class "F" asphalt concrete base was laid with a Blaw-Knox paver throughout the whole ring. This was done in two lifts.

During the last week of October, wooden forms for the center track and part of the inside and outside track was built for portland cement concrete sections. Reinforcing steel was put in the center track.

November 2, 1971 Tuesday

Portland cement concrete was poured in the center and inside ring. The surface textures were put in. Curing compound was put on and the portland cement concrete was insulated with layers of straw and polymer plastic sheets. Air temperature varied between 35-45°F.

November 3, 1971 Wednesday

Poured portland cement concrete in the outside track in sections 0-1a, 1b, 0-2a 1 & 2 and 0-2b. In 0-2a3, three inches of Class "E" asphalt concrete was put in. All regular portland cement concrete work was finished.

Chuck Henager of Battelle worked with putting in the Wirand® Concrete in Sections 0-1bA,B,C,D and in 0-2aA and B. Air temperature hovering about 40°F and overcast. The Wirand® Concrete materials was hand weighed and then mixed in 1/4 cu. yard electric mobile mixer. No curing compound was put on the Wirand® Concrete as they were too wet. No curing compound was put on the portland cement concrete sections which will have polymer concrete topping. All sections were insulated from the cold.

November 4, 1971 Thursday

It was raining very hard in the morning. Roger LeClerc and Ray Dinsmore of Washington State Highway Department visited the track. The weather cleared by 10:30 a.m. and the 3" Wirand® section was poured at 11:15 a.m. It was mixed in a Central Pre-Mix transit truck. Longitudinal grooves, using the Washington State Highway Department's tools, were put in this section at 1:30 p.m. Then it was covered with insulation.

November 9, 1971

The insulation cover on portland cement concrete was removed and all the straw was swept off the track. United Paving, Inc. put on tack coat on the inside and outside rings.

November 10, 1971

Air temperature at 2 p.m. = 50°F

1) The portland cement concrete was swept.
2) Plastic lined cardboard was put over the portland cement concrete to protect it from asphalt concrete.
3) United Paving, Inc. crew laid crushed rock in shoulders to bring them up to the level of the asphalt treated base.
4) The Class "B" asphalt concrete in sections 0-6a & b and I-6a & b was put in three layers of 2 inch thickness because the asphalt concrete was compacted with a wacker. By 1:15 p.m., the asphalt concrete temperature was 150° F.
5) At 1:30 p.m., started laying the Class "G" asphalt concrete in three layers in section I-5 and 0-5a & b. Temperature of first layer was 290°F.

   A Vibro-Plus Compactor CL21 and a motor driven hand tamper was used to compact the sections.
6) The second layer of Class "G" was laid at 2:10 p.m. with the asphalt concrete temperature = 370°F. Density was checked with a nuclear density equipment.
7) At 3:30 p.m., started laying the Class "B" asphalt concrete in section I-4 and 0-4a & b.

First lift at 3:30 p.m. asphalt concrete temperature = 325°F
air temperature = 48°F

The Class "B" was coarse looking and much segregation was occurring due to the hand work required.

Second lift at 4:05 p.m. asphalt concrete temperature = 280°F
air temperature = 47°F

Third lift at 4:15 p.m. asphalt concrete temperature = 330°F
air temperature = 47°F

8) The compaction was completed using a small steel roller by 5:30 p.m.

November 11, 1971

At nine a.m. and air temperature = 44°F with no wind, we started laying the Class "E" asphalt concrete at 8:30 a.m. in three layers of 2 inch lifts. Temperature of Class "E" asphalt concrete in truck and first lift = +300°F.

At 9:00 a.m., second lift put on, asphalt concrete temperature = 230°F

At 9:00 a.m. second batch from plant arrived and was put on the inside track. The asphalt concrete temperature in truck was 275°F. The temperature lift was 200°F.

At 10:00 a.m., the last lift on the inside ring was laid. The air temperature was 48°F with a slight wind coming up.

At 10:25 a.m., started rolling the outside ring and finished at 11 a.m. The surface looked coarse with voids. It was difficult to get good nuclear density readings. Some of this may have been due to the cold asphalt concrete which made it difficult to obtain optimum compaction.

November 22, 1971

Air temperature = 36°F. The Gilsabind was sprayed in the mornings on sections 0-3b and 0-4b at 0.11 gallon/square yard a5 90°F.

At 4 p.m. the Idaho Chip Seal was put on in the inside section I-6. Air temperature = 32°F. Temperature of the RC800 with Pliopave 190°F and sprayed at 0.25 gallon/square yard. Both the aggregate and pavements were heated. The aggregates were put on at 25#/sq. yd.

The asphalt seal coat started to cool off near the portland cement concrete inside track. The job was finished at 4:40 p.m. as it was too cold to do the outside track.

Max Huffaker and his staff from Materials Chemistry laid a short section of polymer concrete in the 1" section and 1/8" overlay in the other (see construction schedule for the polymer concrete sections).

November 23, 1971

Air temperature = 33°F, wind blowing at 5-10 mph.
Temperature of RC800 = 210°F.
10 a.m. sprayed it too thick on the pavement and ran out; had to heat up a new batch. Too much was sprayed and more aggregate was heated to put on it to soak up the excess asphalt RC800 at 10:30 a.m.

A batch of 1" thick polymer concrete was put in.

12:30 p.m. Air temperature = 35°F with 15 mph wind.
Temperature of RC800 = 240°F.
The aggregate and pavement were heated. Sprayed the RC800 and put on the aggregate and rolled the rest of the outside sections.

The polymer concrete was put in O-1a, 2 inches thick; section looked very rough. They also put in part of the 1" polymer cement in O-2bA and O-2bB. 1:45 p.m. it started snowing.

November 29, 1971

Laid some more polymer concrete in O-1a.

POLYMER CONCRETE SCHEDULE

Each section was covered with a special insulated box which was heated with a bank of lights for at least 24 hours before the polymer concrete was placed.

SECTION 0-1a 2" THICK X 22 FT. X 3.5 FT.

This section cast using 1 part by wt. epoxy, 1 part portland cement, 4.8 parts sand, 6.9 parts rock as the basic mix with the addition of approximately 1 part water.

The first three feet was placed on November 23, however the lights had been turned off the day before and the concrete was cold. This gave trouble with priming the surface with epoxy.

The next 10 feet was placed on November 29 with the surface somewhat warmer but wet. When priming the concrete surface a trowel was used to spread the epoxy and it was worked into the surface. When water was standing on the surface it was forced off to the side by the epoxy.

The last nine feet was placed on November 29; however, the basic mix was altered in that 50% of the portland cement was replaced by an equal weight of flyash from the Centralia Power Plant. Water was reduced to approximately 3/4 parts by weight.

The finish on the entire length was accomplished by use of a 2" x 4" x 4'. The 2 x 4 was used to strike off the concrete to the proper level and as a tamping tool to work the large aggregate into the surface. This mix was very hard to lay. Warmer weather would have helped.

SECTION O-2b 1" THICK X 11 FT. X 3.5 FT.

This section was cast using 1 part by weight epoxy, 1 part portland cement, 5 parts sand. Approximately 1 part water was required to give the desired workability.

The first 18 inches (one Mix) was placed on November 22; by the next morning this piece had hardened and the rest of the section was cast on the November 23. This entire section was warm and dry when the topping was applied; however the air temperature did get down to 33°F by the end of the afternoon.

All of section O-2b was primed with epoxy the same as section O-1a.

The finish was achieved by working the epoxy concrete down approximately the proper level and then placing a sheet of polyethylene over the surface and troweling it flat. When the polyethylene was removed enough of the epoxy clung to the sheet that a rough surface remained.

SECTION O-2b 1/8" THICK X 11 FT. X 3.5 FT.

This section was applied by troweling the same mixture used for the 1" topping into the epoxy priming coat. This seemed to work very well. Some of the area required greater than 1/8" to bring the surface up to the proper grade. This caused great difficulty because of the low temperature since the mix had lots of time to cool and because the thin layer was cooled rapidly in the air. The pre-warmed surface was getting quite cool by the end of the day. As a result somewhat of a poor surface was left over part of the area.

TABLE A-1 ASPHALT CONCRETE MIX DESIGNS[1]

GRADING AND ASPHALT REQUIREMENTS

Percentages by Weight Passing Sieves			
	Class B	Class E	Class G
1¼" sieve (square opening)		100	
1" sieve (square opening)		90-100	
3/4" sieve (square opening)			
1/2" sieve (square opening)	90-100	60-80	100
5/8" sieve (square opening)	100	67-86	
3/8" sieve (square opening)	75-90		97-100
1/4" sieve (square opening)	55-75	40-62	55-82
U.S. No. 10 sieve	32-48	25-40	32-48
U.S. No. 40 sieve	11-24	10-23	11-24
U.S. No. 80 sieve	6-15	6-14	6-15
U.S. No. 200 sieve	3-7	2-9	3-7
Mineral Filler	0-2		0-2
Asphalt % of total mixture	4.0-7.5	3.5-7	4-7.5

[1] These mix designs were taken from Standard Specifications of the State of Washington.

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 WIRAND® MIX DESIGNS

INGREDIENT[1]	MIX NUMBERS						
	1	2a	2b	3	4	5	6
Cement Type II, lbs	952	992	992	975	975	882	886
Sand, lbs.	2382	2477	2477	2436	2436	1845	1840
3/8" Aggregate, lbs.	--	--	--	--	--	756	756
Wires, lbs.	3/4" x 0.16"	1" x .016"	1" x .016"	1" x .016"	1" x .016"	1" x .016"	1.5" x .020
	540	285	65	265	265	265	221
Water, lbs.	306	285	285	298	280	270	283
WRDA[2], oz.	71.5	72	72	72	72	72	--
Pozzolith[3], oz.	--	--	--	--	--	--	28
Darex AEA, oz.	12.5	12.5	12.5	12.5	12.5	12.5	12.5
PROPERTIES							
Slump	3", 4"	2-3/4"	2-3/4"	4"	3-½",3-½"	4", 4"	3"
W/C Ratio	.40	.36	.36	.39	.36	.37	.39
No. of Batches	2	1	1	1	2	2	1

NOTES:

1 Expressed as quantities per cubic yard, corrected for moisture content of 4% and 1% absorption sand, (1% moisture 0.5% absorption on 3/8" aggregate).

2 W. R. Grace Co. WRDA, Water Reducing Densifying Additive.

3 Master Builder Co., Water Reducing Agent.

TABLE A-4 PORTLAND CEMENT AND WIRAND® CONCRETE STRENGTH TEST RESULTS - RING #5

TYPE OF CONCRETE	SAMPLE NUMBER	SECTION	DATE POURED	CURING TIME - DAYS		STRENGTH - PSI				
				TUNNEL[1]	HUMIDITY CHANNEL[2]	COMPRESSIVE[3]	SPLITTING TENSILE[4]	CALCULATED FLEXURAL[5] STRENGTH	LAB. FLEXURAL STRENGTH	F/T
P.C.C.	#1	Center Ring	11-02-71	44	5	3730				
Type II	#2	" "	"	44	5	4270				
	#3	" "	"	44	5	--	455	705	--	1.54
	#4	" "	"	44	5	--	470	720	--	1.52[5]
	#5	" "	11-03-71	43	5	3160				
	#6	" "	"	43	5		415	665		1.60
Wirand®	#10	Outside 3	11-03-71	43	5	4370			870[6]	
	#11	" 4	"	43	5		735	985	870[6]	1.34
	#12	" 5	"	43	5		475	725	945[6]	1.52
Wirand®	#7	Outside 6	11-04-71	42	5	6060			947[6]	
	#8	" 6	"	42	5		825	1065	1000[6]	1.29
	#9	" 6	"	42	5		940	1170	1042[6]	1.24

® Registered trademark of Battelle Development Corporation.

1 Kept at the G.A. Riedesel Pavement Research Center in the sample can at room temperature of 55 F.

2 Kept at the Civil Engineering Department Humidity Chamber at 70 F. The can was stripped off the concrete cylinders.

3 Standard ASTM Compression Test procedures followed. Cylinders capped before testing. Tested 12/21/71.

4 Standard ASTM C-496-69 Test procedure followed. Tested on 12/21/71.

5 Israel Narrow and Erik Ullberg. "Correlation Between Tensile Splitting Strength and Flexural Strength of Concrete", ACI Proceedings, American Concrete Institute, Vol. 60, No. 1, Jan. 1963.

6 From Battelle Pacific Northwest Laboratories - yield strength.

TABLE A5-1 WASHINGTON STATE UNIVERSITY TEST TRACK TOPPING SPECIMENS

SPECIMEN IDENT.	MIX DESIGN[1] AND WIRE CONTENT	CURING CONDITIONS	28 DAY TEST[2]	
			YIELD STRENGTH PSI	ULTIMATE STRENGTH PSI
Section 1 Batch 1	Mortar mix, 530#/yd. .016" x 3/4"	1 day moist 14 days immersion[3] 13 days air dry	720	768
Section 1 Batch 2	Mortar mix, 530#/yd. .016" x 3/4"	1 day moist 14 days immersion[3] 13 days air dry	840	2016
Section 1 Batch 2	Mortar mix, 530#/yd. .016" x 3/4"	1 day moist 14 days immersion[3] 13 days air dry	1100[4]	1482[4]
Section 2 Batch 1	Mortar mix, 285#/yd. .016" x 1"	1 day moist 14 days immersion[3] 13 days air dry	900	1590
Section 2 Batch 2	Mortar Mix, 65#/yd. .016" x 1"	1 day moist 14 days immersion[3] 13 days air dry	840	930
Section 3 Batch 1	Mortar mix, 265#/yd. .016 x 1"	1 day moist 14 days immersion[3] 13 days air dry	870	1170
Section 4 Batch 3	Mortar mix, 265#/yd. .016 x 1"	1 day moist 14 days immersion[3] 13 days air dry	870	1440
Section 5	Aggregate Mix (3/8" max.) 265#/yd. .016" x 1"	Same as above[3]	945	1101

1 10 sack type II cement for mortar mixes; 9 sack type II for aggregate mix. 3 Immersed in tap water at 60°F
2 Center point loading on 2½"x 3" x 16" beams, 15" span, 2½" depth dimension, except as noted.
4 These results are from 3rd point loading on a 9" span using a 3" depth. Test beam broke sufficiently off center in the center point load test to allow a third point test.

TABLE A5-2 WASHINGTON STATE UNIVERSITY 3" SLAB AT TEST TRACK

SPECIMEN IDENT.	MIX DESIGN AND WIRE CONTENT	CURING CONDITIONS	30 DAY TEST[1]	
			YIELD STRENGTH PSI	ULTIMATE STRENGTH PSI
0176 Section 6	9 sack Type II cement, aggregate mix (3/8") 221 #/yd. .020" x 1.5"	1 day moist 14 days immersion[2] 15 days air dry	947	2140
0176[2] Section 6	9 sack Type II cement, aggregate mix (3/8") 221 #/yd. .020" x 1.5"	1 day moist 14 days immersion[2] 15 days air dry	1000[3]	1742[3]
0177 Section 6	9 sack Type II cement, aggregate mix (3/8") 221 #/yd. .020" x 1.5"	1 day moist 14 days immersion[2] 15 days air dry	898	1819
0178 Section 6	9 sack Type II cement, aggregate mix (3/8") 221 #/yd. .020" x 1.5"	1 day moist 14 days immersion[2] 15 days air dry	1042	2036

1 Center point loading on nominal 2 1/2" x 3" x 16" beams, 2 1/2" depth dimension, except as noted.

2 Tap water at 60°F.

3 These results are from 3rd point loading on a 7 1/2" span using a 2 1/2" depth.

TABLE A-6 POLYMER CONCRETE MIX DESIGNS

INGREDIENTS	PARTS BY WEIGHT			
	MIX A[1]	MIX B[2]	MIX C[3]	MIX D[4]
Epoxy	1	1	1	1
Portland Cement	1	1/2	1	1/2
Sand[5]	4.8	4.8	5	5
3/4" - Aggregate[5]	6.9	6.9	--	--
Flyash[6]	--	1/2	--	1/2
Water	1	3/4	1	1

1 Mix "A" was used in sections O-1aA and O-1aB.

2 Mix "B" was used in section O-1aC.

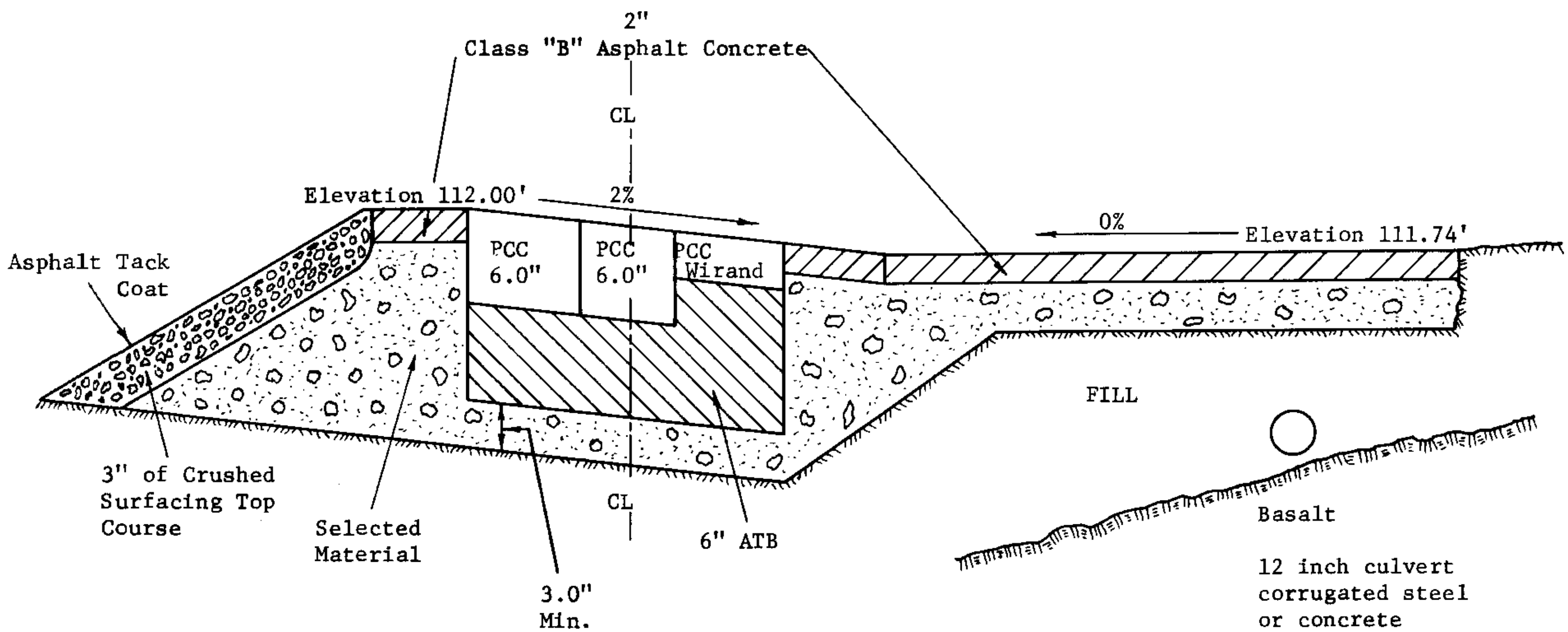
3 Mix "C" was used in sections O-2bA, O-2bB, I-2aA and I-2bB.

4 Mix "D" was used in sections I-2aB and I-2bA.

5 Sand and 3/4" - aggregate conformed with standard specifications of the State of Washington for fine and coarse aggregates for portland cement concrete mix designs.

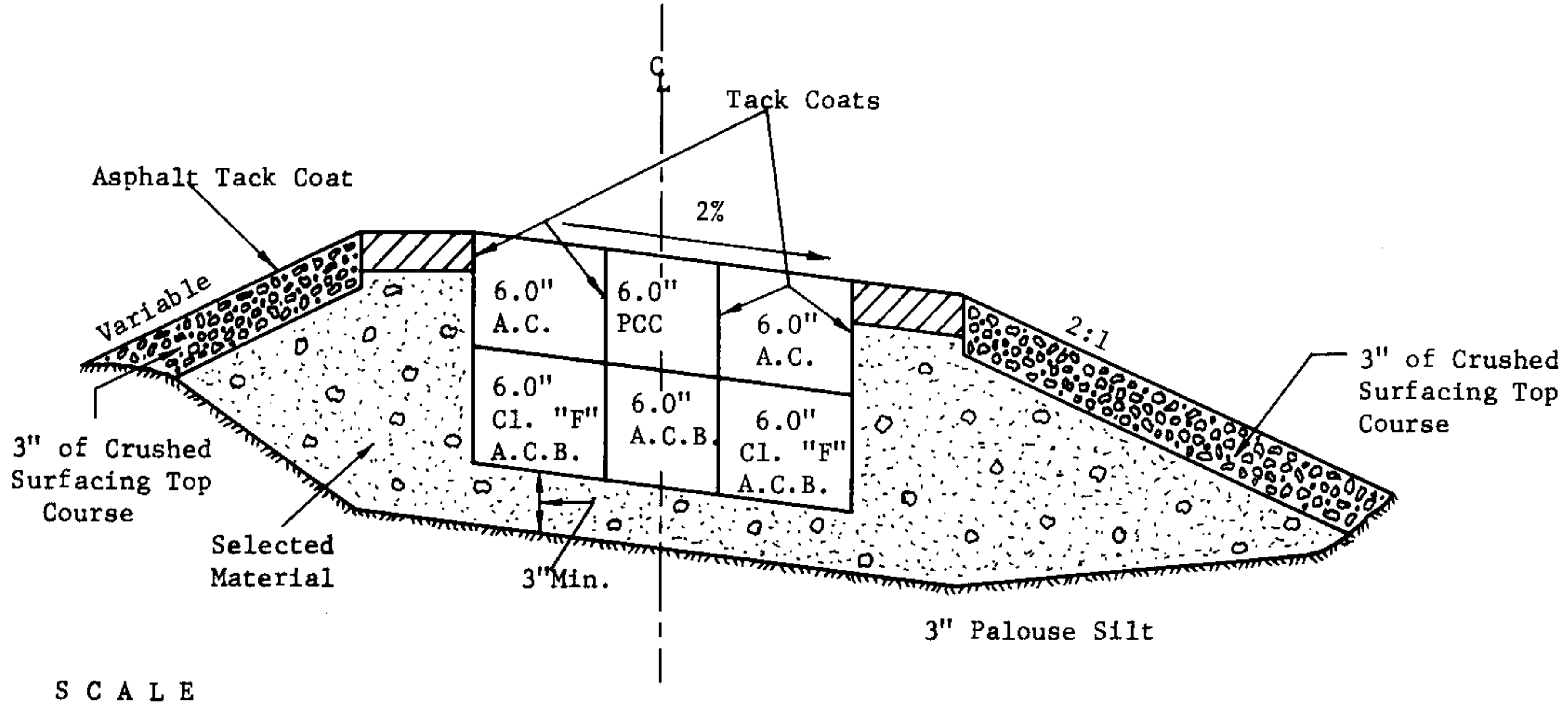
6 Flyash used was obtained from the Centralia Power Plant, Centralia, Washington.

FIGURE A-1 TYPICAL CROSS-SECTION OF SECTIONS 1b and 2a



S C A L E
Horizontal: 1" = 5.0'
Vertical: 1" = 10.0"

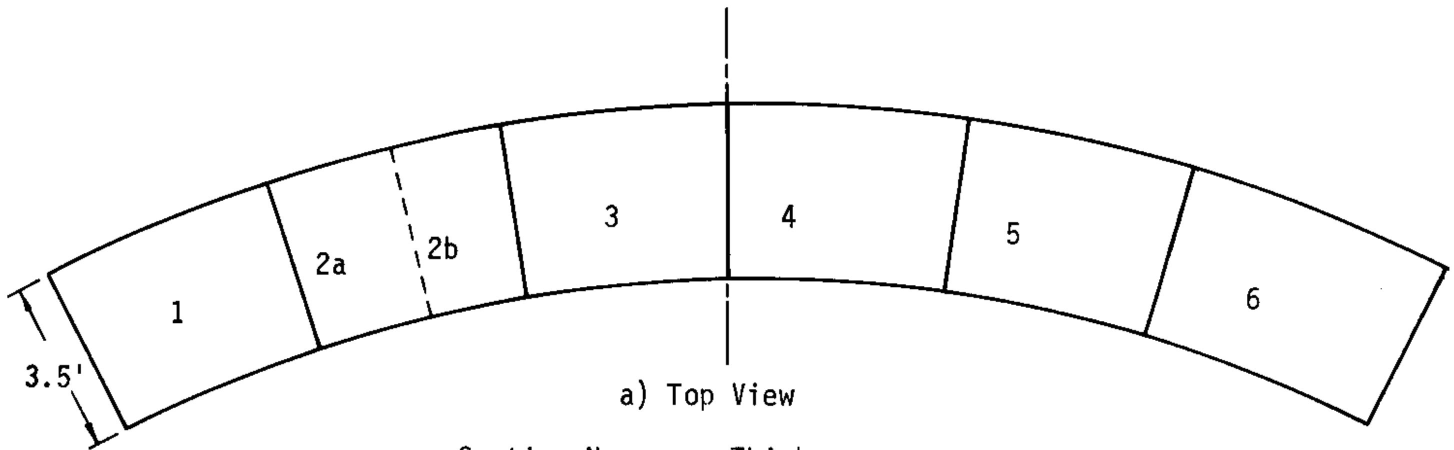
FIGURE A-2 TYPICAL CROSS-SECTION OF 3a to 6b



S C A L E

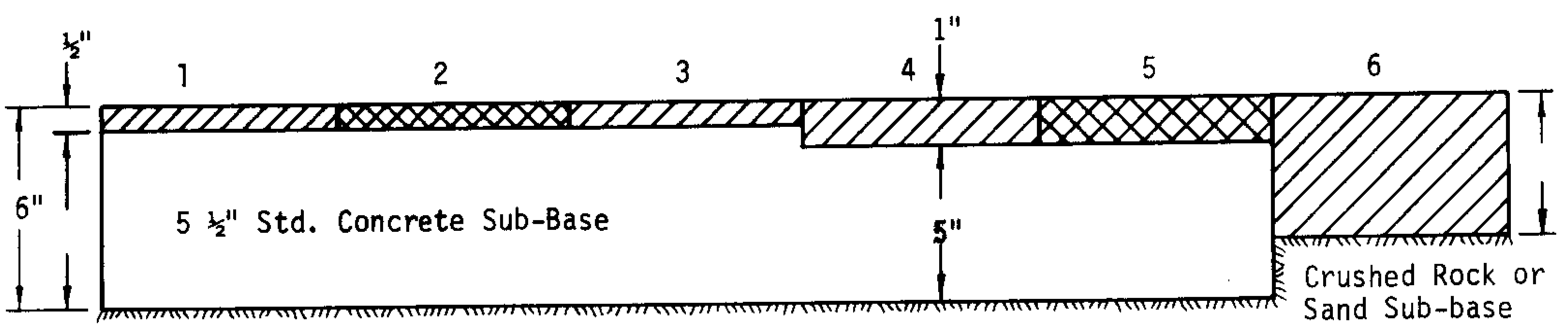
Horizontal: 1" = 5.0'
Vertical: 1" = 10.0"

FIGURE A-3 TYPICAL VIEWS FOR THE DIFFERENT WIRAND® CONCRETE



a) Top View

Section No.	Thickness
1	1/2" overlay
2a	1/2" overlay
2b	1/2" overlay
3	1/2" overlay
4	1" overlay
5	1" overlay
6	3" slab



b) Longitudinal Cross-Section

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 volgage 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

A few corrections are to be incorporated into the next models to eliminate minor problems. These are as follows:

1. Structural changes in support beam to eliminate errors due to beam sag, presently being removed from data by computer techniques.
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 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 we demand 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 data is reduced to computer punch cards. The pavement wear data is reduced with the help of a Benson-Lehner, Model F Decimal Converter, that is tied directly to an IBM 026 card punch. This is an excellent high accuracy method for converting graphic or plotted data to computer compatible form. 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 plots 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 our requirements.

HIGHWAY COMPUTER PROGRAM

This program was written in Fortran IV programming language and is designed to be able to grow 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 stud wear, pavement wear, and multiple site average pavement wear for each of the 13 types of pavement. All data is available to the program as further calculations and outputs are anticipated.

APPENDIX D

LOG OF OPERATIONS FOR RING NO. 5 - 1972

Month	Day	Total Operating Time		Speed MPH	Revolutions		Air Temperature Range	
		Hours	Minutes		Daily	Accumulated	High	Low
February	11	2	20	10-15	597	597		
	14	11	28	20	4588	5187	32	31
	15	11	55	20	5053	10240	42	32
	16	15	27	20	6315	16555	44	28
	17	17	40	20	7262	23817	34	31
	18	15	02	20	6160	29977	44	34
	19	10	12	20-22	4354	34331	46	37
	20	15	56	20	6636	40967	39	28
	21	5	43	20	2376	43343	36	30
	22	20	06	20-22	9049	52392	36	27
	23	14	53	20	6573	58965	38	30
	24	20	53	20	8709	67674	36	29
	25	19	06	20	7984	75658	35	26
	26	18	43	20-21	7298	82956	36	28
	27	21	25	20	9597	92553	52	35
	28	17	30	20	6656	99209	50	42
	29	22	28	20	9361	108570	38	27
March	01	19	51	20	8327	116897	32	28
	02	22	33	20	8761	125658	42	30
	03	20	14	20-25	9219	134877	40	26
	04	23	55	25	11913	146790	43	28
	05	24	00	25	12051	158841	53	32
	06	20	54	25	10017	168858	46	26
	07	8	09	25	4402	173260	34	27
	08	6	42	25	3392	176652	56	40
	09	16	55	25	8446	185098	62	40
	10	21	45	25	10915	196013	57	38

LOG OF OPERATIONS FOR RING NO. 5 - 1972

Month	Day	Total Operating Time		Speed MPH	Revolutions		Air Temperature Range	
		Hours	Minutes		Daily	Accumulated	High	Low
March	11	23	13	25	11676	207689	55	36
	12	8	26	25-20	3677	211366	47	38
	13	22	48	20	9307	220673	48	38
	14	16	23	20	6680	227353	49	35
	15	18	12	20	7367	234720	52	31
	16	22	23	20	8881	243601	66	39
	17	18	42	20	7605	251206	65	44
	18	22	39	20	9193	260399	48	39
	19	22	18	20	9219	269618	50	37
	20	20	34	20	8560	278178	53	32
	21	18	31	20	8450	286628	57	34
	22	21	06	20	8688	295316	62	40
	23	21	46	20	9357	304673	40	29
	24	19	14	20	7548	312221	46	29
	31	10	14	20	4221	316442	63	36
April	01	21	00	20	8633	325075	58	36
	02	22	18	20	8631	333706	49	23
	03	6	49	20	2728	336434	42	20
	08	13	16	20	5219	341653	44	31
	09	22	11	20	8073	349726	47	26
	10	19	43	20	7971	357697	57	26
	11	21	53	20	9054	366751	43	35
	12	20	13	20	8616	375367	40	28
	13	22	07	20	8994	384361	44	27
	14	8	52	20	3645	388006	48	30
	15	7	24	20	2942	390948	46	38
	16	22	24	20	8917	399865	42	29

LOG OF OPERATIONS FOR RING NO. 5 - 1972

Month	Day	Total Operating Time		Speed MPH	Revolutions		Air Temperature Range	
		Hours	Minutes		Daily	Accumulated	High	Low
April	17	22	06	20	9085	408950	38	22
	18	20	10	20	8240	417190	46	20
	19	19	17	20	8049	425239	54	32
	20	22	00	20	8943	434182	53	32
	21	22	20	20	9130	443312	46	28
	22	19	28	20-15	8218	451530	48	24
	23	22	09	15	6788	458318	66	31
	24	20	32	15-20	8105	466423	55	36
	25	23	06	20	9390	475813	52	34
	26	21	05	20	8425	484238	60	26
	27	21	08	20	8449	492687	70	34
	28	22	05	20	7876	500563	50	36
	29	22	36	20	8972	509535	48	29
	30	22	42	20	8603	518138	53	21
May	1	14	30	20	6231	524369	61	25
	2	18	14	20	6463	530832	68	39
	3	21	33	20	7985	538817	74	34
	4	8	32	20	3504	542321	70	36
	5		15	5-20	36	542357	80	40
TOTAL		1304	12					

APPENDIX E

HIGH AND LOW DAILY SURFACE PAVEMENT TEMPERATURES - °F - 1972

Month	Day	Portland Cement Concrete		Asphalt Concrete	
		High	Low	High	Low
February	11	39	29.5	42	29
	14	43	30.5	50	31.5
	15	47.5	33	50.5	33
	16	50	42.5	56.5	42.5
	17	39	35.5	42	36
	18	60	36.5	74	36.5
	19	54	36	59.5	35
	20	47.5	31	51.5	30.5
	21	50.5	27.5	55	27.5
	22	51	32.5	59	36.5
	23	56	31.5	65.5	32
	24	45.5	31.5	50	31.5
	25	54.5	31	53	31
	26	41.5	30	42.5	30.5
	27	45.5	37.5	50	39
	28	70.5	42.5	69	46
	29	55.5	30	57.5	29
March	01	37.5	29	42	28
	02	47	32.5	44.5	33
	03	46.5	28	52	28
	04	50.5	29	55	30.5
	05	53.5	35.5	58.5	38.5
	06	53.5	29.5	59.5	29
	07	67	27.5	78.5	27.5
	08	61.5	31.5	64	31
	09	82	41.5	91.5	40
	10	64.5	41.5	68.5	42

HIGH AND LOW DAILY SURFACE PAVEMENT TEMPERATURES - °F - 1972

Month	Day	Portland Cement Concrete High	Portland Cement Concrete Low	Asphalt Concrete High	Asphalt Concrete Low
March	11	47.5	43	48.5	43.5
	12	48.5	45	43	46
	13	54	40	57	32
	14	74.5	33.5	86	33.5
	15	70	33.5	79.5	34
	16	81	40.5	87.5	41
	17	80	41	90	40.5
	18	50	40.5	53	39
	19	56.5	39	60	39
	20	72.5	35.5	75	36
	21	67	41	76	40
	22	74.5	44	84	44
	23	63.5	33	67.5	32.5
	24	62.5	33	70	32.5
	31	58.5	26.5	66.5	25
April	01	76	45	80	44
	02	74	29.5	84	29.5
	03	87.5	26	97	26
	08	51	32	58	30
	09	68.5	28.5	76	29
	10	67	31	77.5	31
	11	47.5	39.5	48.5	39.5
	12	--	--	--	--
	13	54	35	58	34.5
	14	67.5	36.5	73.5	36.5
	15	59.5	41	67.5	41
	16	62	33.5	68.5	33.5

HIGH AND LOW DAILY SURFACE PAVEMENT TEMPERATURES -°F - 1972

Month	Day	Portland Cement Concrete High	Portland Cement Concrete Low	Asphalt Concrete High	Asphalt Concrete Low
April	17	55	27.5	66.5	27
	18	78.5	25.5	83.5	26
	19	81.5	28	93	24.5
	20	72.5	36	82	35.5
	21	54	33	66.5	31.5
	22	78	26.5	94	27.5
	23	91	34	91.5	34.5
	24	65	43	74	40.5
	25	70	38.5	70	37.5
	26	90.5	31.5	100	28.5
	27	95.5	39.5	105	39.5
	28	54	40	63	38
	29	71	32	86.5	30
	30	74	28.5	92	26
May	1	101	30.5	112	28
	2	102	42	112	40
	3	101.5	39.5	109	34
	4	104.5	42	124	38
	5	106	45	122.5	36
AVERAGE		64.4	34.8	71.2	34.3

APPENDIX F

TABLE F-1 COMPUTER READOUT FOR SITE NO. I-1A, WHEEL PATH NO. 7

PASS NUMBER	AREA REMOVED SQ. INCH	RATE OF WEAR SQ. INCH/PASS	MAX. DEPTH INCH	AVE. DEPTH INCH	AREA/WD. INCH
0.	0.0	0.0	0.0	0.0	0.0
40650.	0.106041E 00	0.260863E-05	0.06705	0.00874	0.01116
80550.	0.492559E 00	0.968716E-05	0.12998	0.04992	0.05185
147510.	0.512311E 00	0.294990E-06	0.13330	0.05128	0.05393
287520.	0.546202E 00	0.242058E-06	0.11454	0.05479	0.05749
494220.	0.867683E 00	0.155530E-05	0.16580	0.08962	0.09134
692550.	0.103402E 01	0.838666E-06	0.19365	0.10736	0.10884
936663.	0.120824E 01	0.713717E-06	0.20963	0.12461	0.12718
1584300.	0.185748E 01	0.100247E-05	0.29994	0.19148	0.19552
1627071.	0.189263E 01	0.821831E-06	0.31557	0.19507	0.19922

WHEEL PATH NUMBER 8

0.	0.0	0.0	0.0	0.0	0.0
40650.	0.0	0.0	0.0	0.0	0.0
80550.	0.0	0.0	0.0	0.0	0.0
147510.	0.0	0.0	0.0	0.0	0.0
287520.	0.0	0.0	0.0	0.0	0.0
494220.	0.0	0.0	0.0	0.0	0.0
692550.	0.0	0.0	0.0	0.0	0.0
936663.	0.0	0.0	0.0	0.0	0.0
1584300.	0.0	0.0	0.0	0.0	0.0
1627071.	0.0	0.0	0.0	0.0	0.0

TABLE F-2 COMPUTER READOUT FOR SITE NO. 0-4A, 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
0.	0.0	0.0	0.0	0.0	0.0
600.	0.578732E-01	0.964553E-04	0.01557	0.00920	0.00942
8500.	-0.129306E 00	0.0	0.01932	-0.01070	-0.02105
13550.	-0.132696E-01	0.0	0.02688	-0.01213	-0.00216
26850.	0.761843E-01	0.672585E-05	0.02878	0.01256	0.01240
49170.	0.0	0.0	0.03512	0.01599	0.00000
95840.	0.0	0.0	0.04192	0.01419	0.00000
164740.	0.0	0.0	0.04306	-0.01211	-0.00000
230850.	0.0	0.0	0.04609	0.01199	0.00000
312221.	0.0	0.0	0.04956	0.01828	0.00000
528100.	0.0	0.0	0.05556	0.01973	0.00000
542357	0.0	0.0	0.05842	0.02291	0.00000

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
0.	0.0	0.0	0.0	0.0	0.0
600.	-0.220894E-01	0.0	0.03599	-0.00207	-0.00233
8500.		0.117613E-04	0.06002	0.00768	0.00746
13550.	0.411862E-01	-0.586900E-05		0.00538	0.00434
26850	0.290542E 00	0.187486E-04	0.13256	0.02889	0.03058
49170.	0.400475E 00	0.492528E-05	0.16625	0.04235	0.04216
95840.	0.798863E 00	0.853629E-05	0.16471	0.08391	0.08409
164740.	0.164896E 01	0.123381E-04	0.24482	0.17234	0.17357
230850.	0.217905E 01	0.801841E-05	0.32723	0.22731	0.22937
312221.	0.263753E 01	0.563443E-05	0.37238	0.27508	0.27763
528100.	0.314411E 01	0.234658E-05	0.42370	0.32833	0.33096
542357.	0.329519E 01	0.105972E-04	0.44075	0.34282	0.24686

TABLE F-2 COMPUTER READOUT FOR SITE NO. 0-4A

WHEEL PATH 3

PASS NUMBER	AREA REMOVED SQ. INCH	RATE OF WEAR SQ INCH/PASS	MAX. DEPTH INCH	AVE. DEPTH INCH	AREA/WD INCH
0.	0.0	0.0	0.0	0.0	0.0
600.	0.268024E-01	0.0	0.03565	-0.00600	-0.00598
8500.	0.331300E-01	0.113838E-04	0.05417	0.00409	0.00349
13550	0.514331E-01	0.362438E-05	0.08672	0.00701	0.00541
26850.	0.182747E 00	0.987324E-05	0.09566	0.02017	0.01924
49170.	0.378436E 00	0.876742F-05	0.14346	0.04027	0.03984
95840.	0.624050E 00	0.526279E-05	0.14458	0.06574	0.06569
164740.	0.720012E 00	0.139276E-05	0.15300	0.07490	0.07579
230850.	0.851884E 00	0.199474E-05	0.15376	0.08851	0.08967
312221.	0.102595E 01	0.213918E-05	0.16424	0.10752	0.10799
528100.	0.107309E 01	0.218359E-06	0.17696	0.11146	0.11296
542357.	0.117436E 01	0.710316E-05	0.18592	0.12321	0.12362

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
0.	0.0	0.0	0.0	0.0	0.0
600.	0.0	0.0	0.0	0.0	0.0
8500.	0.113308E 00	0.143428E-04	0.10968	0.01364	0.01193
13550	0.0	0.0	0.0	0.0	0.0
26850.	0.375028E 00	0.281976E-04	0.13122	0.04101	0.03948
49170.	0.641537E 00	0.119404E-04	0.18835	0.06785	0.06753
95840.	0.128692E 01	0.138287E-04	0.21337	0.13350	0.13547
164740.	0.212663E 01	0.121873E-04	0.35874	0.21963	0.22386
230850.	0.275934E 01	0.957067E-05	0.46950	0.28843	0.29046
312221.	0.303977E 01	0.344631E-05	0.49701	0.31866	0.31998
528100.	0.313504E 01	0.441282E-06	0.48845	0.32831	0.33000
542357	0.333406E 01	0.139596E-04	0.50896	0.34960	0.35095

TABLE F-3 COMPUTER READOUT FOR C-4b

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
0.	0.154959E 01	0.295092E-06	0.20753	0.13919	0.13929
0.	-0.127483E-01	0.0	0.02589	-0.00106	-0.00110
1800.	0.567754E-01	0.386242E-04	0.03591	0.00536	0.00488
25500.	0.223323E-01	-0.145329E-05	0.03457	0.00215	0.00192
40650.	0.164834E-01	-0.386066E-06	0.03174	0.00107	0.00142
80550.	0.724258E-01	0.140207E-05	0.04371	0.00582	0.00623
147510.	0.162340E 00	0.134281E-05	0.03823	0.01390	0.01396
287520.	-0.526280E-01	0.0	0.03013	-0.00457	-0.00453
494220.	-0.258898E-01	0.0	0.02503	-0.00236	-0.00223
692550.	0.811019E-01	0.539463E-06	0.03474	0.00694	0.00698
936663.	0.480064E-01	-0.135574E-06	0.03174	0.00421	0.00413
1262040.	0.846362E-01	0.112576E-06	0.03272	0.00710	0.00728
1584300.	0.110865E 00	0.813886E-07	0.03923	0.00916	0.00954
1627071.	0.155993E 00	0.105511E-05	0.04177	0.01351	0.01342

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
0.	0.0	0.162707E 07	0.0	0.0	0.0
0.	0.467737E-01	0.467737E-01	0.03664	0.00433	0.00420
1800.	0.146902E 00	0.556269E-04	0.05286	0.01326	0.01320
25500.	0.238184E 00	0.385154E-05	0.07988	0.02146	0.02141
40650	0.317199E 00	0.521556E-05	0.08783	0.02891	0.02851
80550.	0.631448E 00	0.787591E-05	0.12290	0.05698	0.05676
147510.	0.767439E 00	0.203093E-05	0.13552	0.06882	0.06898
287520.	0.112356E 01	0.254346E-05	0.17553	0.10058	0.10099
494220.	0.140692E 01	0.137088E-05	0.19746	0.12642	0.12647
692550.	0.146467E 01	0.291170E-06	0.19775	0.13081	0.13166
936663.	0.148101E 01	0.669411E-07	0.20063	0.13106	0.13312
1153581.	0.154117E 01	0.444853E-06	0.20697	0.13671	0.13853
1368421.	0.154959E 01	-0.169130E-06	0.20753	0.13919	0.13929
1396935.	0.157751E 01	0.295092E-06	0.21104	0.14061	0.14180

APPENDIX F

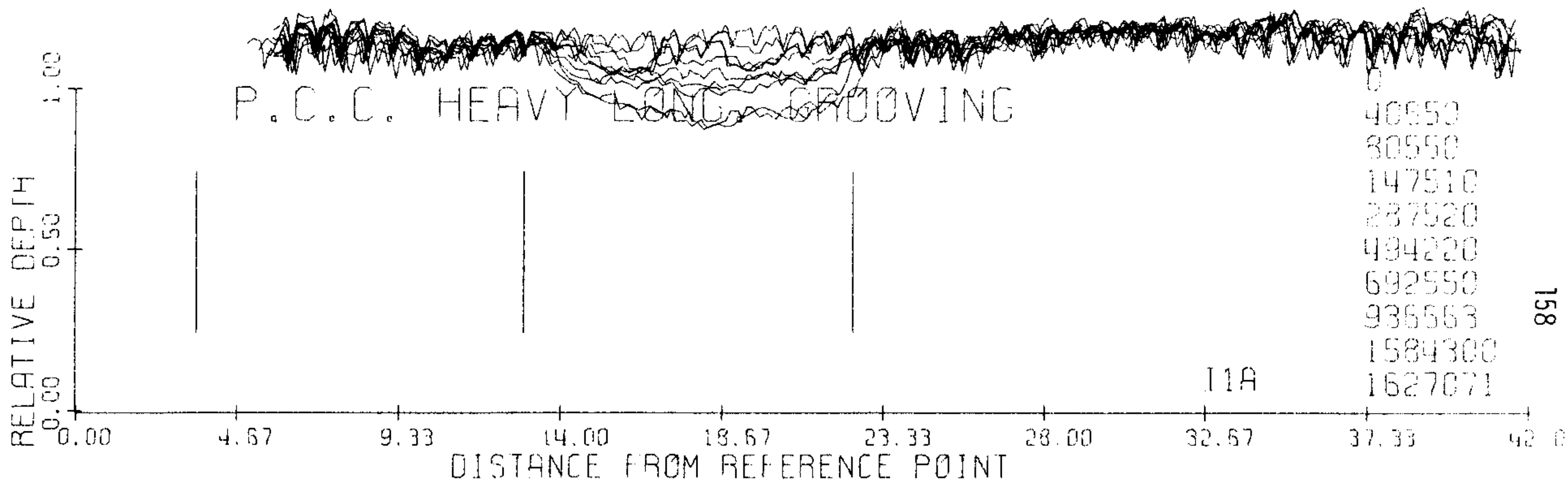


FIGURE F-1 Computer Plotted Transverse Cross-sections of I-1a for Various Wheel Passes

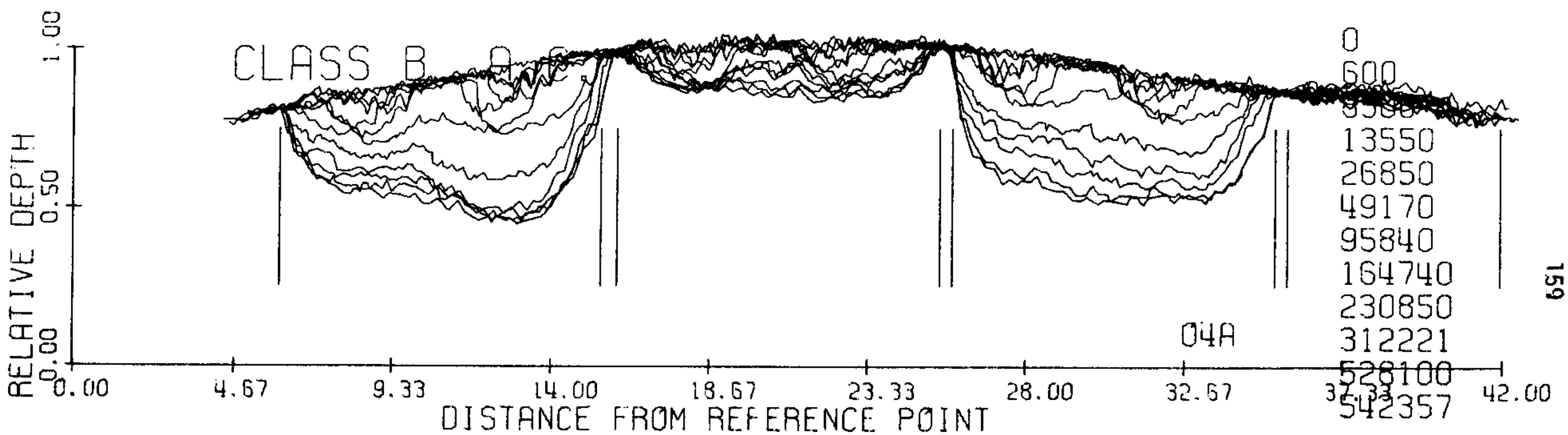


FIGURE F-2 Computer Plotted Transverse Cross Section Profile of Section O-4A for Various Wheel Passes.

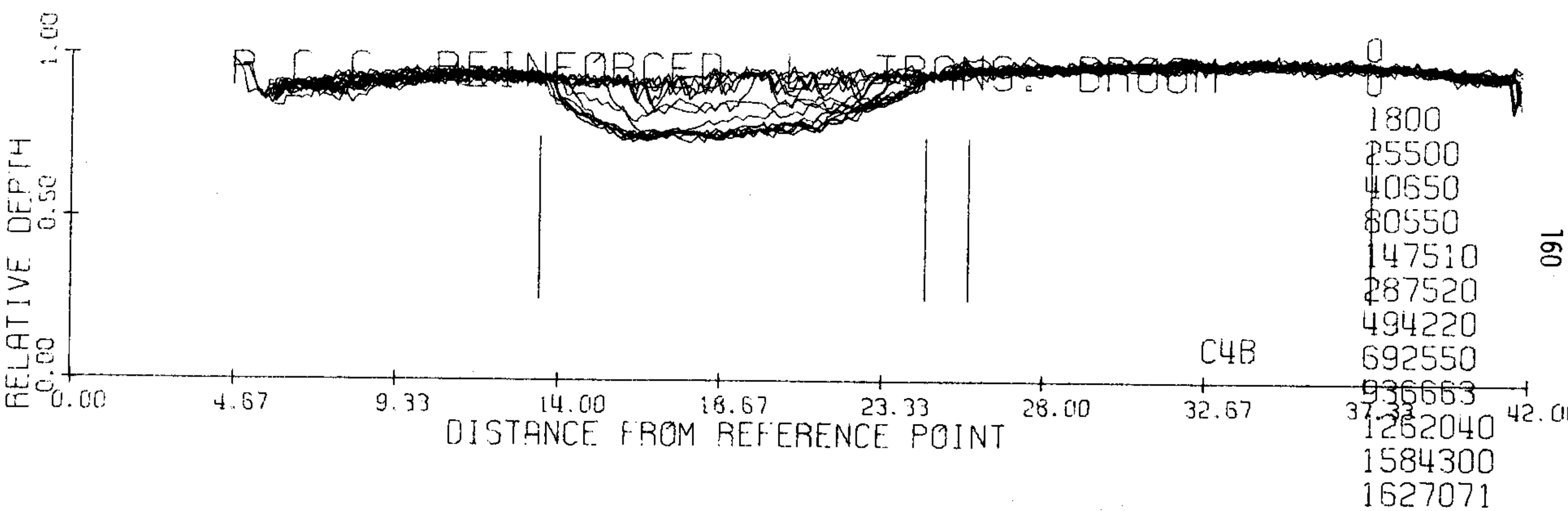


FIGURE F-3 COMPUTER PLOTTED TRANSVERSE CROSS-SECTION FOR C-4b FOR VARIOUS WHEEL PASSES.