Report No. CDOT-DTD-R-93-11

COMPARISON OF 1992 COLORADO HOT MIX ASPHALT WITH SOME EUROPEAN SPECIFICATIONS

Timothy Aschenbrener
Colorado Department of Transportation
4340 East Louisiana Avenue
Denver, Colorado 80222

Final Report
June 1993

Prepared in cooperation with the
U.S. Department of Transportation
Federal Highway Administration

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ACKNOWLEDGMENTS

The author would like to express his gratitude to the many people who assisted in performing this study. CDOT Region Materials personnel identified projects and obtained samples. Kim Gilbert and Cindy Moya (CDOT-Staff Materials) performed testing on all samples. Richard Zamora (FHWA) assisted in performing the data analysis.

The CDOT Research Panel provided many excellent comments and suggestions for the study; it included Byron Lord and Kevin Stuart (FHWA-Turner Fairbank Highway Research Center), Doyt Bolling (FHWA-Region 8), Mark Swanlund (FHWA-Colorado Division), Denis Donnelly, Steve Horton and Bob LaForce (CDOT-Staff Materials), Ken Wood (CDOT-Region 4 Materials), and Donna Harmelink (CDOT-Research).

Special thanks to the panel of Colorado asphalt paving experts who provided numerous ideas and suggestions which made this study more informational: Bud Brakey (BCE), Jim Fife (Western Colorado Testing), Darrel Holmquist (CTL/Thompson), Joe Proctor (Morton International), Scott Shuler (CAPA), and Eric West (Western Mobile, Inc.).

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
CDOT-DTD-R-93-11		

4. Title and Subtitle	5. Report Date
Comparison of 1992 Colorado Hot Mix Asphalt with some European Specifications	June 1993
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Rpt.No.
Tim Aschenbrener	CDOT-DTD-R-93-11

9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Colorado Department of Transportation 4201 E. Arkansas Ave. Denver, Colorado 80222	11. Contract or Grant No.

12. Sponsoring Agency Name and Address	13. Type of Rpt. and Period Covered
Colorado Department of Transportation 4201 E. Arkansas Ave. Denver, Colorado 80222	Final Report
	14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in Cooperation with the U.S. Department of Transportation Federal Highway Administration

16. Abstract

Sixteen hot mix asphalt designs placed during 1992 in Colorado were tested with the standard CDOT test methods, the French rutting tester, the Hamburg wheel-tracking device, and the Georgia loaded-wheel tester. Hot mix asphalt was designed with the Texas gyratory compactor. These mixtures are very resistant to rutting. Some improvements need to be made to the mixtures to resist moisture damage.

Implementation:

17. Key Words		18. Distribution Statement
French rutting tester, Georgia loaded wheel tester, moisture damage,	Hamburg wheel-tracking device, rutting	No Restrictions: This report is available to the public through the National Technical Info. Service. Springfield, VA 22161

19.Security Classif. (report)	20.Security Classif. (page)	21. No. of Pages	22. Price
Unclassified	Unclassified	73	

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COMPARISON OF 1992 COLORADO HOT MIX ASPHALT
WITH SOME EUROPEAN SPECIFICATIONS

By Tim Aschenbrener

1.0 INTRODUCTION

In September 1990, a group of individuals representing AASHTO, FHWA, NAPA, SHRP, AI, and TRB participated in a 2-week tour of six European countries. Information on this tour has been published in "Report on the 1990 European Asphalt Study Tour" (1). Several areas for potential improvement of asphalt pavements were identified, including the use of performance-related testing equipment used in several European countries. Since the French equipment was commercially distributed and marketed, it was primarily selected for demonstration in the United States. The Colorado Department of Transportation (CDOT) and the FHWA Turner-Fairbank Highway Research Center were selected to demonstrate this equipment.

Since the Europeans have such a vastly different method for approving hot mix asphalt (HMA) and the component aggregates and asphalt cements for use in highway construction, it was desired to compare the quality of the standard Colorado materials to the requirements of the Europeans. The purpose of this report is to identify the relative strengths and weaknesses in the HMA specified and placed by the CDOT in 1992 as measured and compared to some of the European tests and specifications.

2.0 SITE SELECTION

During the 1992 construction season, 16 different hot mix asphalt (HMA) designs meeting Colorado Department of Transportation (CDOT) specifications were selected for comparison with the European performance-related tests. The sites are identified in Table 1.

The projects were selected to represent a wide variety of the mixtures produced throughout Colorado. There was at least one sample from each of Colorado's six Regions. HMA was selected to represent the two most commonly used aggregate gradings: Grading C is a 19.0 mm (3/4-inch) top size and Grading CX is a 12.5 mm (1/2-inch) top size.

Table 1. Site Identification.

Site	Location	Region	Plant	Grading
1	I-70 @ El Rancho	1	Drum Mixer	C
2	I-70 @ Copper Mtn.	1	Drum Mixer	C
3	Academy Blvd.	2	Drum Mixer	C
4	Delta	3	Batch	C
5	Hamilton	3	Drum Mixer	CX
6	Craig	3	Drum Mixer	CX
7	Glenwood Springs	3	Drum Mixer	CX
8	Meeker Park	4	Drum Mixer	CX
9	Stoneham	4	Drum Mixer	C
10	Telluride	5	Drum Mixer	C
11	I-25 @ Arapahoe	6	Drum Mixer	CX
12	I-76 @ Colorado	6	Drum Mixer	C
13	US-36 @ Wadsworth	6	Drum Mixer	C
14	I-25 @ Speer	6	Batch	C
15	I-25 @ Speer	6	Batch	C
16	I-25 @ Speer	6	Batch	C

A more detailed characterization of the HMA selected for this study is shown in Table 2. The gradation was measured with respect to the maximum density line. A fine (F) or coarse (C) gradation was on the fine or coarse side of the maximum density line, respectively, and a straight gradation (S) followed the maximum density line. The asphalt cement used was most commonly AC-10 or AC-20 (AASHTO M 226, Table 2). In some instances the asphalt cements were polymerized as classified by Shuler (2). Type I was typically an SB polymer, Type II was SBR, and Type III was EVA. The aggregates used in the HMA designs were crushed from sand and gravel pits (Pit) or quarried (Qua).

Table 2. Characteristics of the Hot Mix Asphalt Used in this Study.

Site	Gradation			Asphalt Cement					Aggregate	
	F	S	C	10	20	I	II	III	Pit	Qua
1	X			X						X
2	X			X					X	
3	X					X				X
4		X		X					X	
5		X					X		X	
6		X		X					X	
7		X					X		X	
8		X		X					X	
9		X			X				X	
10			X	X					X	
11		X				X				X
12	X					X			X	
13		X		X						X
14	X					X				X
15	X							X		X
16	X			X						X
Total	7	8	1	8	1	4	2	1	9	7

3.0 TESTS PERFORMED ON HOT MIX ASPHALT

3.1 Performance-Related Tests.

The relative strengths and weaknesses of HMA specified by the CDOT in 1992 were measured using the French rutting tester, Hamburg wheel-tracking device, and the Georgia loaded-wheel tester. These tests have previously been described by Aschenbrener and Stuart (3). A comparison of the testing conditions of each device is shown in Table 3.

Table 3. Test Conditions for the Performance-Related Tests.

	Performance-Related Test		
	French	Hamburg	Georgia
Test Temperature (°C)	60	50	40
Test Environment	Air	Water	Air
Load on Wheel (N)	5000	705	700
Pressure on Sample (kPa)	600	1500*	700
Loading Rate (cycles/minute)	60	25	44
Sample Mass (kg)	20	10	5
Test Time (Hours)	9	6	4
Samples per Test	2	2	1
Equipment Cost (Est.)	$80,000	$45,000	$11,000
Specification: Cycles	30,000	10,000	8,000
Rut Depth (Max)	10%	4 mm	7.6 mm

* Estimated because wheel is steel. Actual value depends on sample stiffness.

A pass is one movement of the wheel across the sample. A cycle is 2 passes, the back and forth movement of the wheel across the sample.

Other tests used by the Europeans include fatigue and thermal cracking characterization. These tests were not evaluated as part of this study.

3.2 Standard CDOT Tests.

The standard tests used by the CDOT were also performed for comparative purposes. The CDOT uses the Texas gyratory (ASTM D 4013) to compact samples. The samples are then tested using the Hveem stabilometer (AASHTO T 146) and the modified Lottman procedure (AASHTO T 283). The maximum and bulk specific gravities (AASHTO T 209 and T 166) were measured, and the air voids were calculated (AASHTO T 269). The extraction results (AASHTO

T 164, Method B) and gradations (AASHTO T 30) were also determined.

4.0 RESULTS AND DISCUSSION

A minimum of 80 kg (177 lb) of loose, project produced HMA was sampled from each project by CDOT personnel. The design and field produced material were compared using standard CDOT tests. The properties from the mixtures were also evaluated for rutting using the French rutting tester and Georgia loaded-wheel tester. Stripping was evaluated using the Hamburg wheel-tracking device.

4.1 Design Versus Field Produced Material.

The CDOT selects optimum asphalt content at 3 to 4.5 percent air voids from samples compacted using the Texas gyratory compactor at 1034 kPa (150 psi) end point stress. A minimum Hveem stabilometer value of 37 is specified, and a minimum tensile strength ratio of 0.80 from AASHTO T 283 is specified.

In some instances the properties of the material produced in the field deviate from the properties measured during the mix design. Therefore, field verification samples are tested. Field verification is defined as HMA produced in the plant for compacting and testing in the laboratory. Testing is performed for void properties, Hveem stability, and tensile strength ratio (TSR). A comparison of mix design properties and field verification properties is shown in Table 4.

D'Angelo (4) has shown that it is common for plant produced material compacted in the laboratory to have lower air voids than the design requirements. For the 16 sites studied in this experiment, 13 had air voids lower than the design air void level, and of these 7 experienced a loss of 1% or more air voids.

In order to minimize the chance of rutting, Aschenbrener (5) found that air voids of samples produced in the field and compacted in the laboratory with the Texas gyratory (ASTM D 4013) had to have air voids greater than 2%. Only Site 3 and Site 12 had field verification air voids below 2%.

Table 4. Comparison of Mix Design and Field Verification Properties.

Site	Air Voids (%)		Stability		TSR	
	Design	Field	Design	Field	Design	Field
1	4.2	4.6	53	44	1.17	1.11
2	3.0	3.4	51	57	0.96	0.61
3	3.4	1.7	47	50	1.05	1.17
4	3.8	2.8	45	49	0.93	1.12
5	3.0	2.0	40	47	1.05	1.21
6	4.4	3.5	48	42	0.96	1.12
7	3.5	3.0	59	45	1.21	0.96
8	3.3	2.9	46	31	1.09	1.09
9	3.7	2.8	47	45	1.10	1.35
10	3.0	3.5	32	42	1.06	1.19
11	3.1	2.6	49	52	1.06	0.99
12	4.3	1.9	45	48	0.98	1.07
13	3.8	2.2	37	30	1.02	0.96
14	4.0	2.6	41	49	1.04	1.16
15	4.0	3.1	45	50	1.09	1.20
16	4.0	2.2	45	35	1.09	1.07

4.2 Rutting.

Results from tests performed on material produced from the plant are reported in Table 5. The French rutting tester, Georgia loaded-wheel tester, and Hveem stabilometer produce results that relate to the expected rutting performance. Slabs of plant produced material were compacted in the laboratory to 7 $\pm$ 1% air voids for testing in the French and Georgia devices. Results from the French rutting tester are shown in Appendix A.

Table 5. Permanent Deformation Results.

Site	Georgia		French @ 60°C			Hveem Stability (Field)
	Cycles	Rut Depth	Cycles	Rut Depth	Slope	
1	8,000	3.4 mm	30,000	4.7 %	0.29	44
2	8,000	3.8	25,000	10.0	0.15	57
3	8,000	1.6	30,000	2.5	0.30	50
4	8,000	2.0	30,000	5.2	0.26	49
5	8,000	3.2	30,000	3.6	0.29	47
6	8,000	2.5	30,000	9.8	0.28	42
7	8,000	1.7	30,000	5.1	0.23	45
8	8,000	2.9	12,000	10.0	0.52	31
9	8,000	3.0	30,000	8.9	0.40	45
10	8,000	3.9	27,000	10.0	0.40	42
11	8,000	1.9	30,000	1.8	0.11	52
12	8,000	2.1	30,000	3.0	0.16	48
13	8,000	3.5	30,000	7.2	0.36	30
14	8,000	2.3	30,000	2.4	0.10	49
15	8,000	1.1	30,000	1.1	0.14	50
16	8,000	2.8	30,000	7.0	0.22	35

Unacceptable French rutting tester results are rut depths greater than 10% after 30,000 cycles or slopes (rate of rutting) greater than 0.35. Aschenbrener (6) found that slopes of 0.35 to 0.40 or greater are marginal. Aschenbrener (6) found that performing the French rutting tester at 60°C (140°F) is very severe and lower test temperatures would be appropriate for many parts of Colorado. Therefore, the test was performed at a temperature that represented the actual temperature for sites that had unacceptable results at 60°C. The results from the French rutting tester at temperatures representative of actual site conditions are summarized in Table 6.

Table 6. Results from the French Rutting Tester at the Temperature Relating to the Actual Site Conditions.

Site	French at 50°C or 55°C		
	Cycles	Rut Depth	Slope
2	30,000	2.4 %	0.15
8	30,000	3.4	0.28
9	30,000	7.0	0.21
10	30,000	5.0	0.19
13	30,000	5.6	0.30

The expected rutting performance of mixtures designed with the Texas gyratory compaction method are shown in Table 7. Results from the French rutting tester were based upon the test at the temperature representative of the actual site conditions.

Table 7. Summary of Results Relating to Rutting.

	Georgia	French	Hveem
Pass	16	16	13
Fail	0	0	3

Mixtures were designed with the Texas gyratory (ASTM D 4013) at a relatively low void range, approximately 3.0 to 4.0%. These mixtures were then produced in the field and compacted in the laboratory with the Texas gyratory and had significantly lower air voids, often 1% or more lower. Despite designing at a low air void level and losing voids in production, these mixtures still appear to be resistant to rutting based on the French rutting tester results. It is likely the 1034 kPa (150 psi) end point stress on the Texas gyratory is too great a compactive effort. A compactive effort using 680 kPa (100 psi) end point stress was determined by Aschenbrener (5) to correlate with voids in the wheel path of high trafficked pavements. HMA designed with the 680 kPa (100 psi) end point stress at 4% air voids would have higher asphalt contents but losing over 1% air voids through production would likely make a mixture susceptible to rutting. When using a 680 kPa (100 psi) end point stress, field verification of the HMA will be necessary.

4.3 Moisture Susceptibility.

The Hamburg wheel-tracking device and AASHTO T 283 (Lottman) relate to stripping performance. All samples tested were treated with hydrated lime. A summary of results relating to stripping is shown in Table 8. AASHTO T 283 results are shown in Table 4.

Samples tested in the Hamburg wheel-tracking device were prepared using the French plate compactor. Samples were 360 mm (14.2 in.) long, 180 mm (7.1 in.) wide, and 50 mm (2 in.) thick and were compacted to an air void level of 7 $\pm$ 1%. A summary of results from the Hamburg wheel-tracking device is shown in Table 9. Plots of the rutting depths versus passes and the rutting profile are shown in Appendix B.

The results from the Hamburg wheel-tracking device include the creep slope, the stripping slope and the stripping inflection point as shown in Fig. 1. The creep slope relates to rutting from plastic flow. It is the inverse of the rate of deformation in the linear region of the deformation curve, after post compaction effects have ended and before the onset of stripping. It is the number of passes required to create a 1 mm impression from rutting. The stripping slope is the inverse of the rate of deformation in the linear region of the deformation curve, after stripping begins and until the end of the test. It is the number of passes required to create a 1 mm impression from stripping. The stripping inflection point is the number of passes at the intersection of the creep slope and the stripping slope. It is related to the resistance of the HMA to moisture damage.

Table 8. Summary of Results Relating to Stripping.

	Hamburg @			Lottman
	50°C	45°C	40°C	
Pass	5	11	15	15
Fail	11	4	1	1

Five samples passed the Hamburg wheel tracking test at the 50°C test temperature: Sites 3, 4, 7, 10, and 11. Of the 11 sites that failed, two sites (Site 6 and 9) barely failed by rutting less than 7 mm. Tests were also performed at 45°C and 40°C for information.

Table 9. Summary of Results from the Hamburg Wheel Tracking Device.

Site	Temperature = 50°C			Temperature = 45°C			Temperature = 40°C		
	Creep Slope	Strip Slope	Strip Inf.	Creep Slope	Strip Slope	Strip Inf.	Creep Slope	Strip Slope	Strip Inf.
1	3,100	600	6,500	NT			10,600	---	---
2	---	200	1	NT			2,500	800	9,700
3	25,400	---	---	NT			53,500	---	---
4	14,600	---	---	32,800	---	---	22,800	---	---
5	2,600	600	7,400	12,500	---	---	7,500	---	---
6	7,000	---	17,000	9,700	---	18,500	NT		
7	19,000	---	---	12,400	---	---	NT		
8	1,900	400	2,900	9,400	2,300	11,600	8,900	---	---
9	11,800	---	---	14,800	---	---	22,600	---	---
10	12,600	---	---	13,200	---	---	NT		
11	12,000	---	---	21,300	---	---	NT		
12	5,600	1,400	12,000	12,300	---	---	35,700	---	---
13	4,900	900	7,700	6,800	---	---	NT		
14	5,800	700	11,300	9,100	---	---	16,500	---	---
15	3,700	700	9,300	NT			43,500	---	---
16	4,500	700	12,000	NT			11,300	---	---

NT = Not Tested

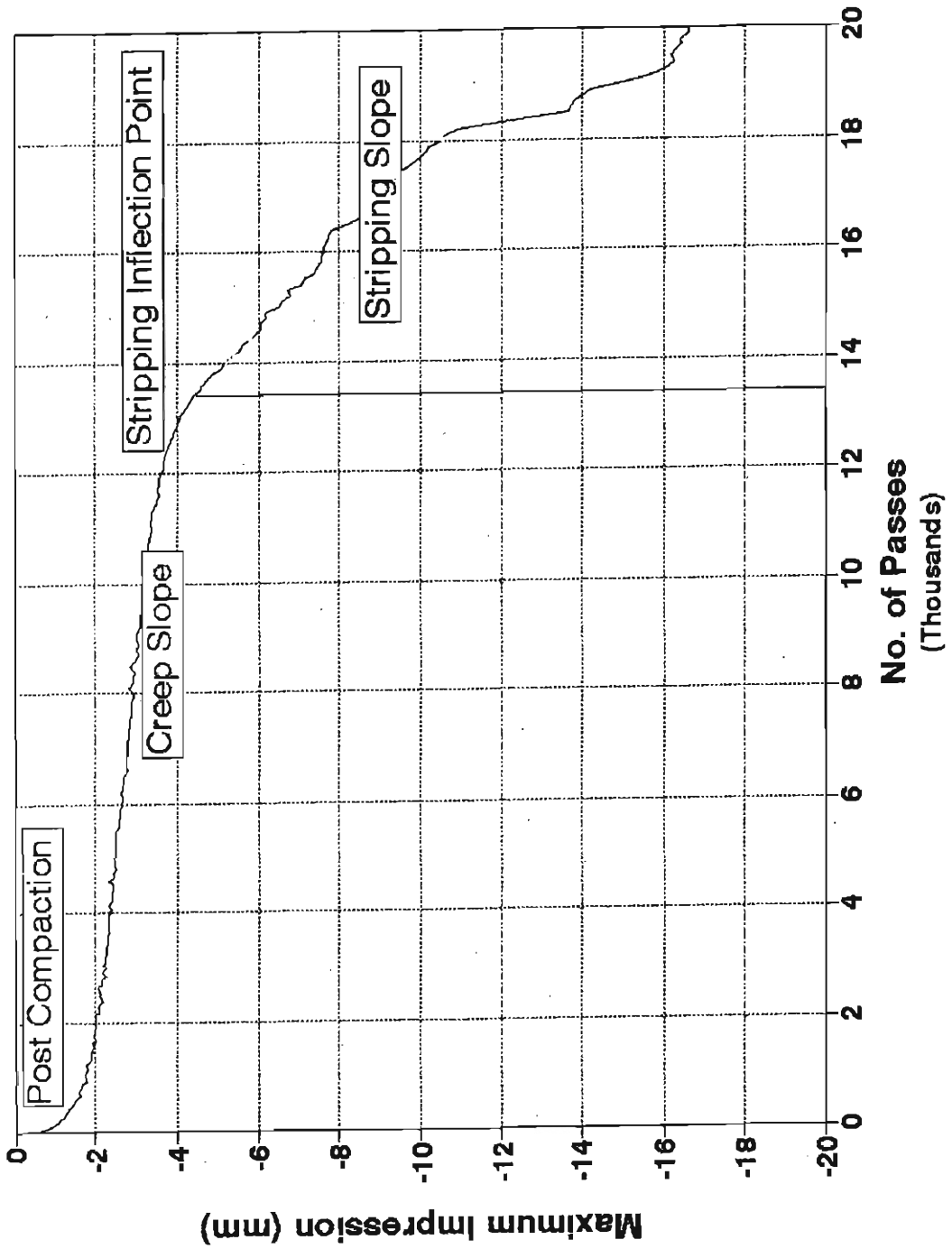

Fig. 1. Definition of Hamburg Wheel-Tracking Results.

The presence of natural fines with large amounts of clay appeared to be the primary cause of failure for most samples. Although none of the aggregates had plasticity, clay was determined to be present by the methylene blue test. The methylene blue test has previously been described by Aschenbrener (7). Of the five samples with large amounts of clay in the natural fines, all failed dramatically. Three sites contained granitic aggregates that are typically susceptible to moisture damage. Although two of the sites passed, one failed dramatically.

Failing samples did not appear to be a function of the type of asphalt cement. Of the passing samples, three were polymer modified asphalt cements and two were neat asphalt cements. Of the failing samples, four were polymer modified asphalt cements and seven were neat asphalt cements.

4.4 Comparison of Performance-Related Test Results.

With three different performance related tests from three different countries, it was desired to provide a comparison of the results from the different devices. The comparison was beneficial to identify differences and similarities in the devices.

4.4.1 French Rutting Tester Versus Georgia Loaded-Wheel Tester. Results from the French rutting tester and Georgia loaded-wheel tester were compared as shown in Figures 2 and 3. The correlation is poor (r^2 = 0.54). The poor correlation did not appear to be caused by void properties or asphalt cement stiffness. It should be noted that this study was not designed to develop a correlation between the two devices. However, based on this limited data, it appears a correlation may be difficult to establish.

4.4.2 French Rutting Tester Versus Hamburg Wheel-Tracking Device. The French rutting tester provides information that relates to the permanent deformation characteristics of the HMA pavement. The creep slope from the Hamburg wheel-tracking device also provides information relating to the permanent deformation characteristics of the HMA pavement. The results from the French rutting tester were correlated to the creep slope of the Hamburg wheel-tracking device at 50°C as shown in Figures 4 and 5. Correlation was very poor (r^2 = 0.04).

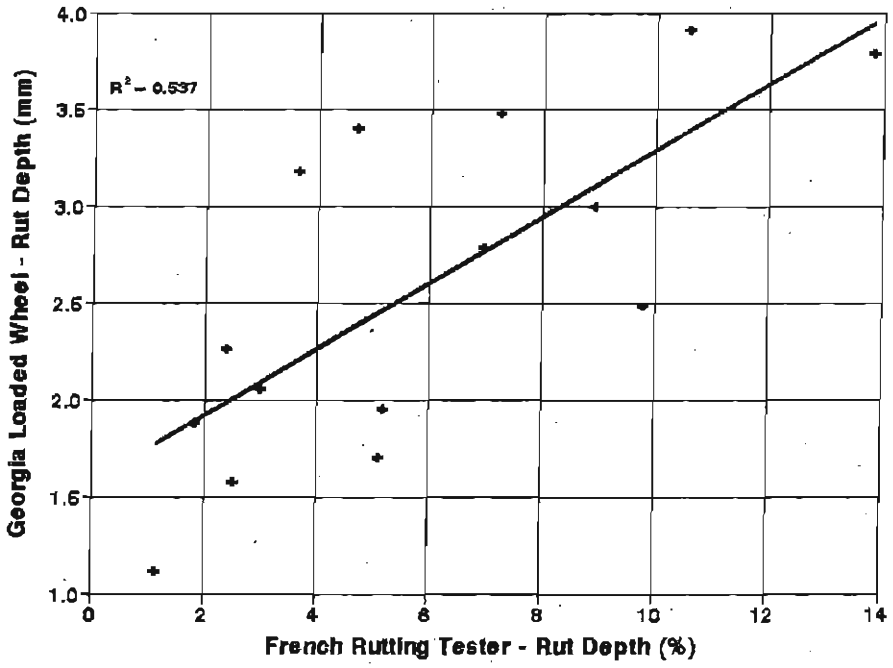

Fig. 2. Comparison of the Rut Depth (%) from the French Rutting Tester with the Rut Depth (mm) of the Georgia Loaded-Wheel Tester.

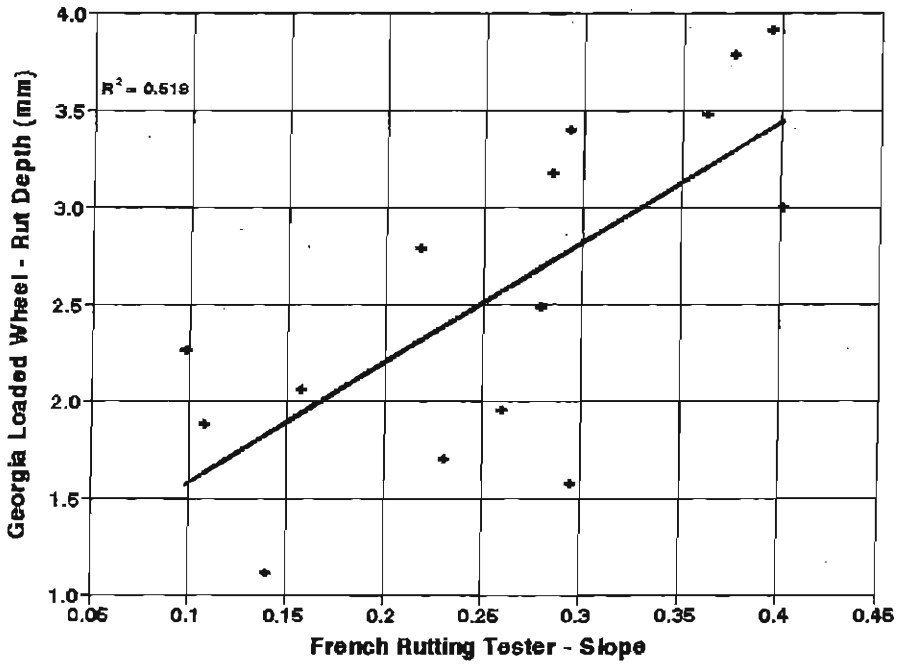

Fig. 3. Comparison of the Slope from the French Rutting Tester with the Rut Depth (mm) from the Georgia Loaded-Wheel Tester.

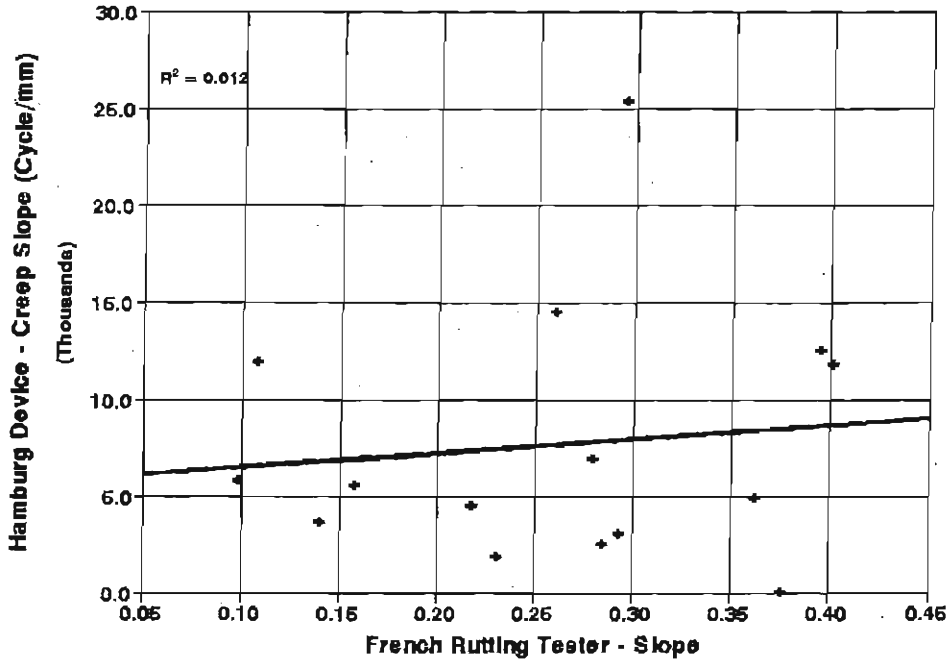

Fig. 4. Comparison of the Rut Depth (%) from the French Rutting Tester with the Creep Slope from the Hamburg Wheel-Tracking Device.

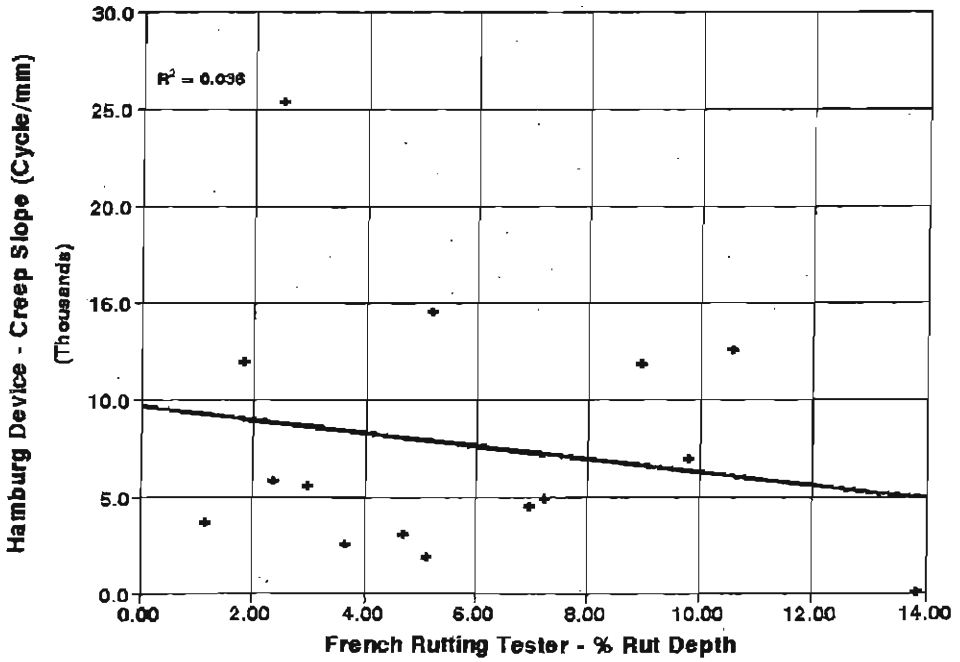

Fig. 5. Comparison of the Slope from the French Rutting Tester with the Creep Slope from the Hamburg Wheel-Tracking Device.

5.0 CONCLUSIONS

The following conclusions were based on laboratory testing of field produced material of 16 HMA mixtures designed and constructed using 1992 CDOT standards.

1. HMA mixtures designed with the Texas gyratory were designed at low air void levels. Plant produced material compacted with the Texas gyratory in the laboratory had even lower air void levels.

2. HMA mixtures designed with the Texas gyratory appear very resistant to rutting based on testing with the French rutting tester and Georgia loaded-wheel tester. This is true even though the HMA mixtures were designed at low air voids and produced at even lower air voids.

3. The 1034 kPa (150 psi) end point stress on the Texas gyratory produces asphalt mixtures with a low asphalt content. Based on the results from the rutting testers, more asphalt cement could be added to these mixtures and they would still be rut resistant. A 680 kPa (100 psi) end point stress might be more reasonable, but field verification will be more critical.

4. Five of the sixteen samples passed the Hamburg wheel-tracking test at 50°C. Two samples barely failed. Of the nine samples that failed dramatically, five probably failed because of the presence of large amounts of clay in the natural fines. Although these aggregates were not plastic, the clay was identified by the methylene blue test. Of the three granitic aggregate sources tested, one failed dramatically.

5. There was poor correlation between the French rutting tester and the Georgia loaded-wheel tester. Poor correlation also existed between the French rutting tester and the creep slope from the Hamburg wheel-tracking device.

6.0 IMPLEMENTATION

HMA designed with the 1992 CDOT standards are rut resistant. Increased asphalt contents could still produce rut resistant HMA mixtures and possibly decrease susceptibility to cracking. Data provided in this study supports higher asphalt contents, such as those that would be achieved using the 680 kPa (100 psi) end point stress on the Texas gyratory.

Resistance to moisture damage is a problem for several of the HMA mixtures tested in this study. When aggregates are from sand and gravel pits, the HMA mixtures susceptible to moisture contained natural sands with clay. The moisture resistant mixtures did not contain natural sands with clay. Atterburg limits were not effective at identifying the presence of clay. Further limits on natural sands and the quality of their P200 should be investigated. Some of the HMA mixtures using granitic aggregate were susceptible to moisture damage. Methods should be investigated to improve the adhesion of asphalt cement to some of the granitic aggregates.

7.0 REFERENCES

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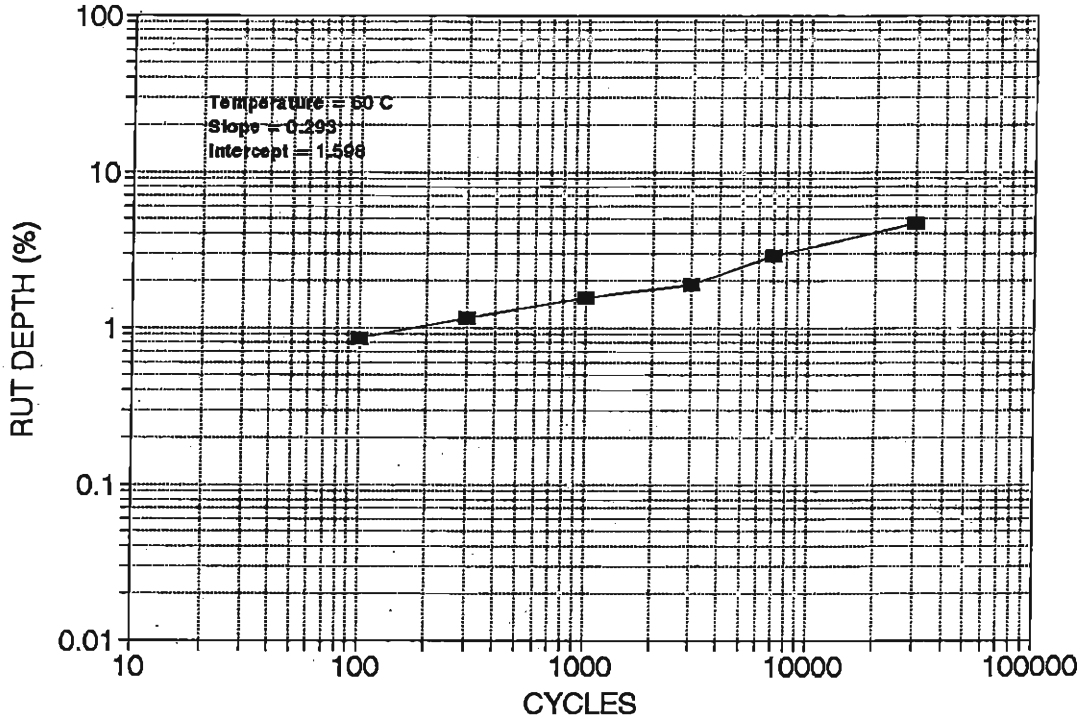
Appendix A

French Rutting Tester Results



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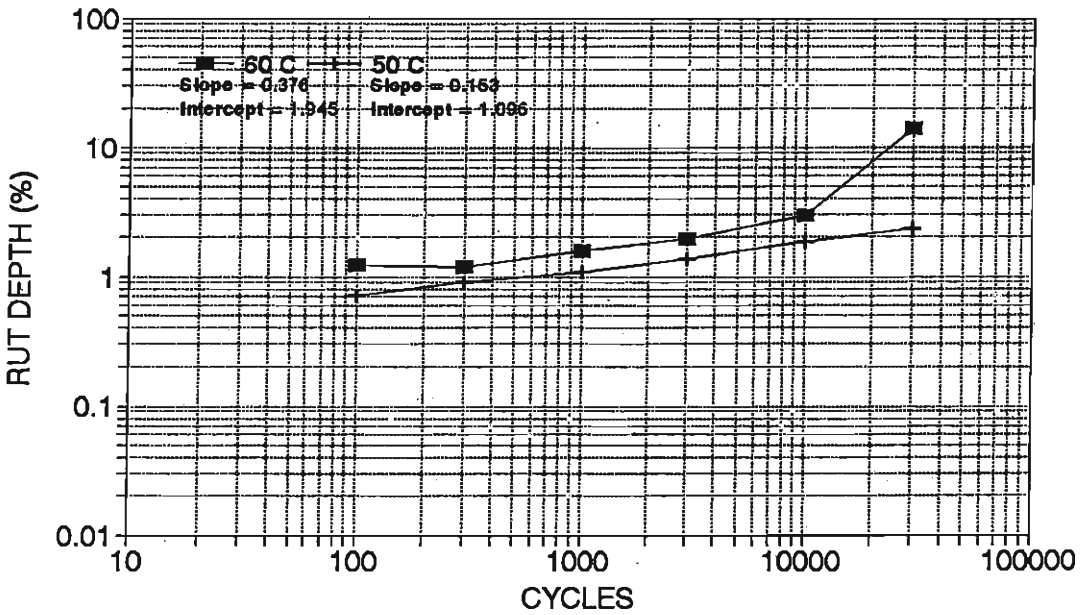

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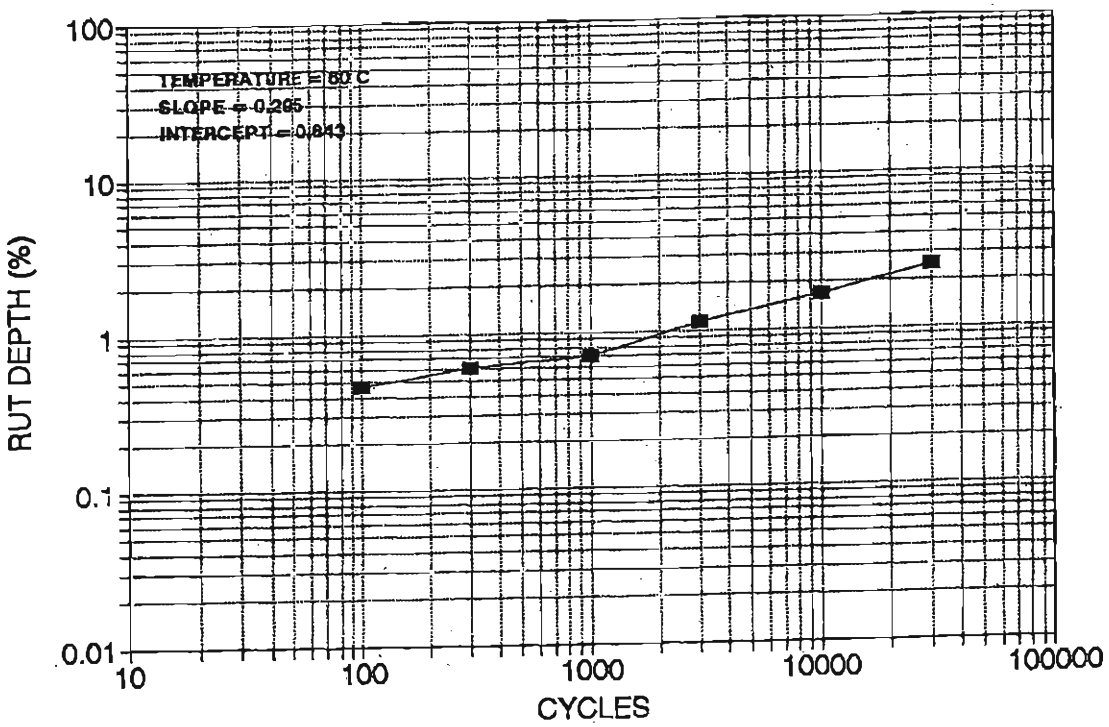

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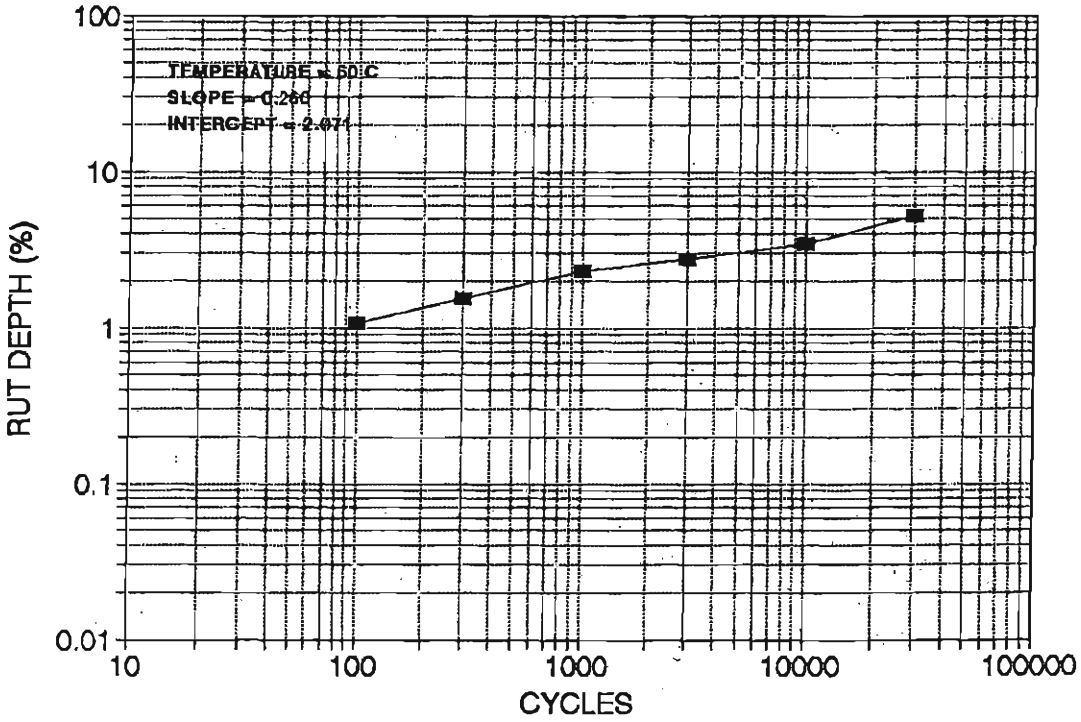
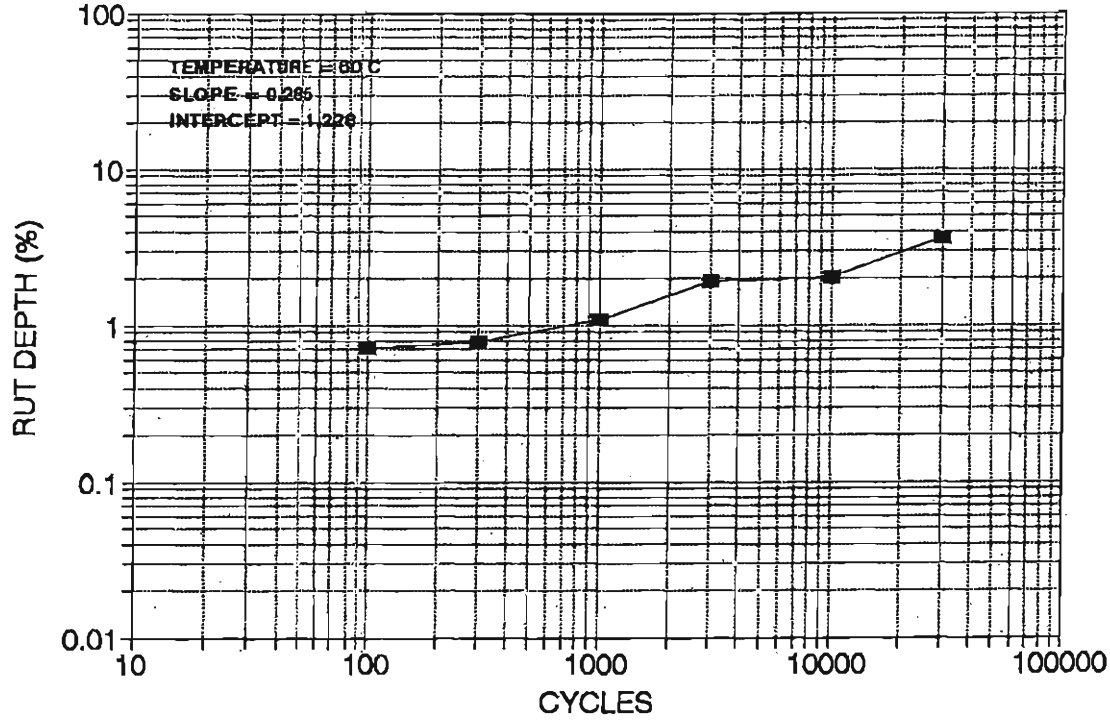
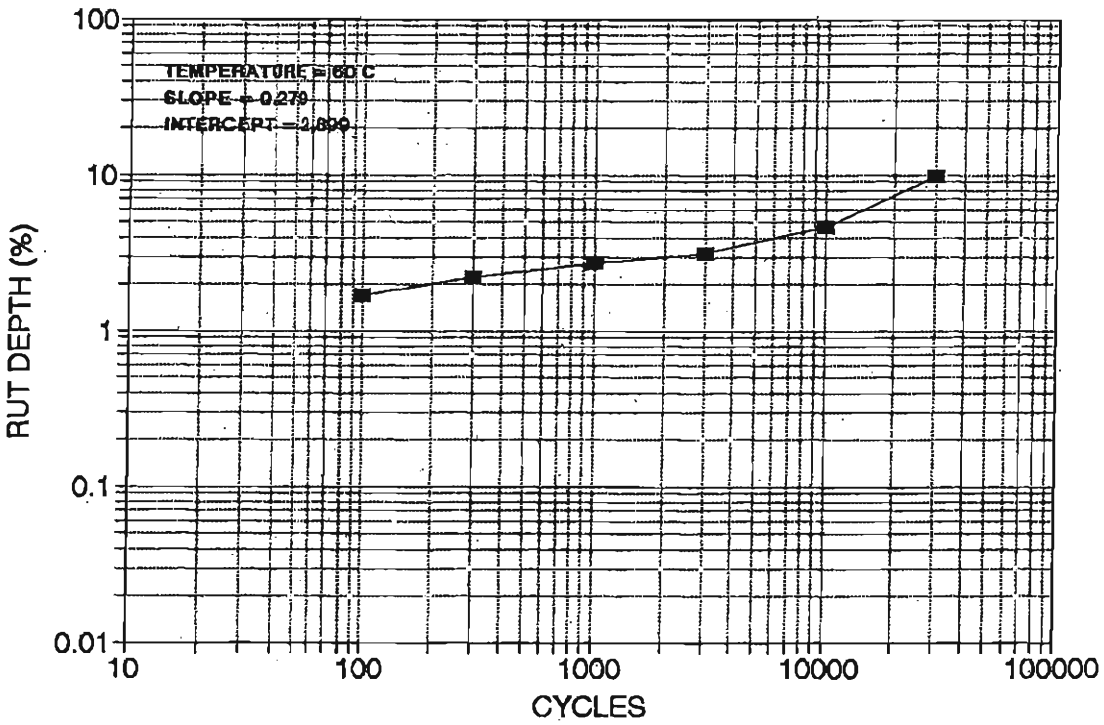


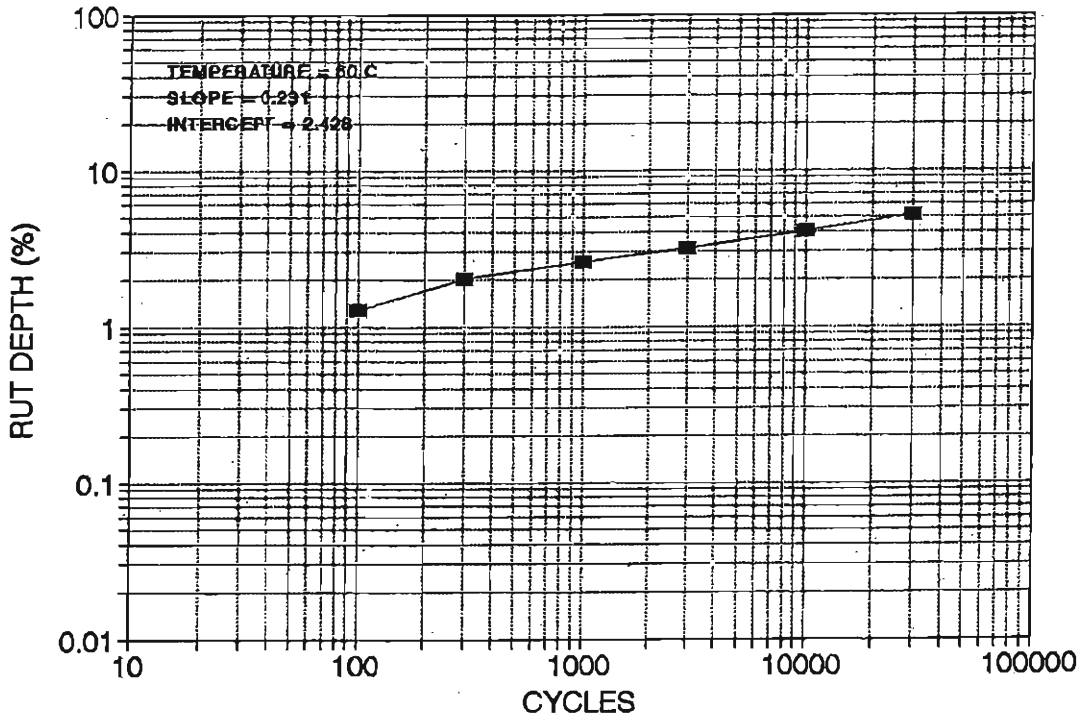
SITE NO. 4



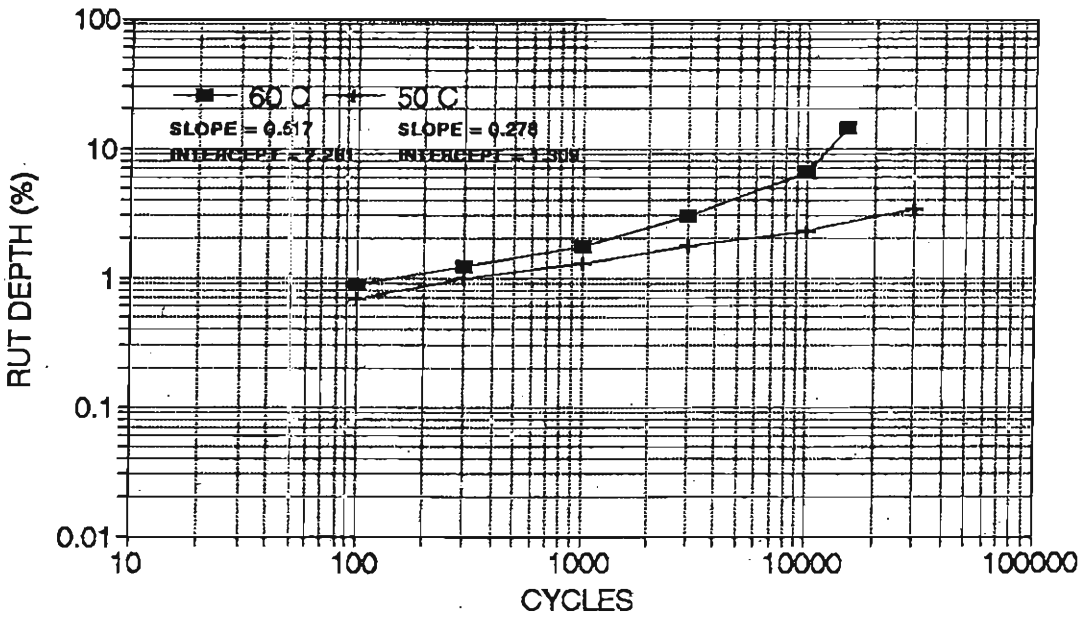
SITE NO. 5



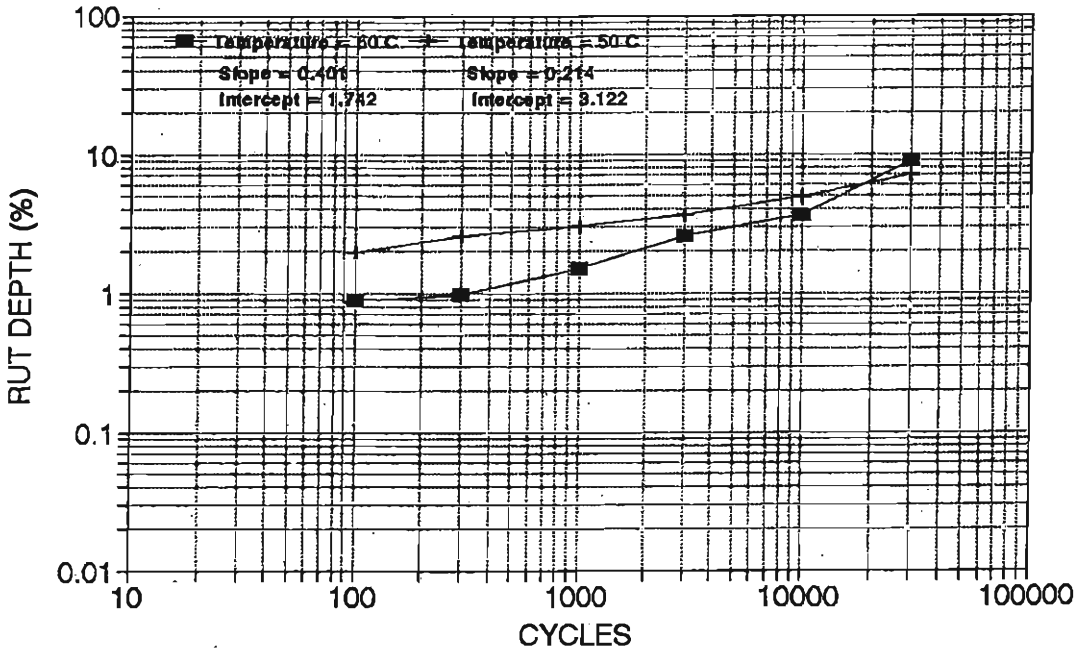
SITE NO. 6



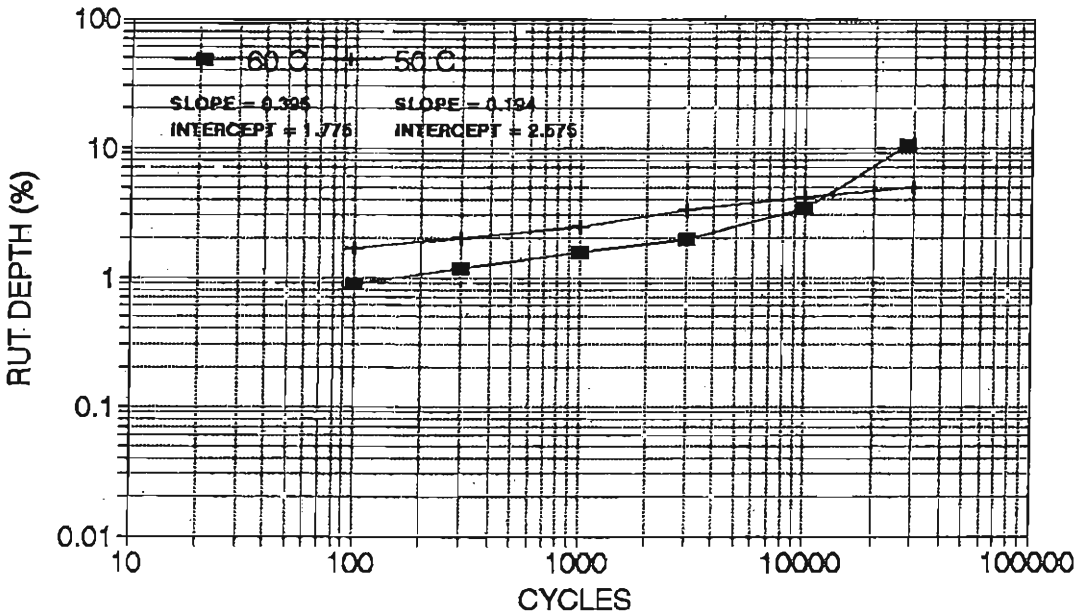
SITE NO. 7



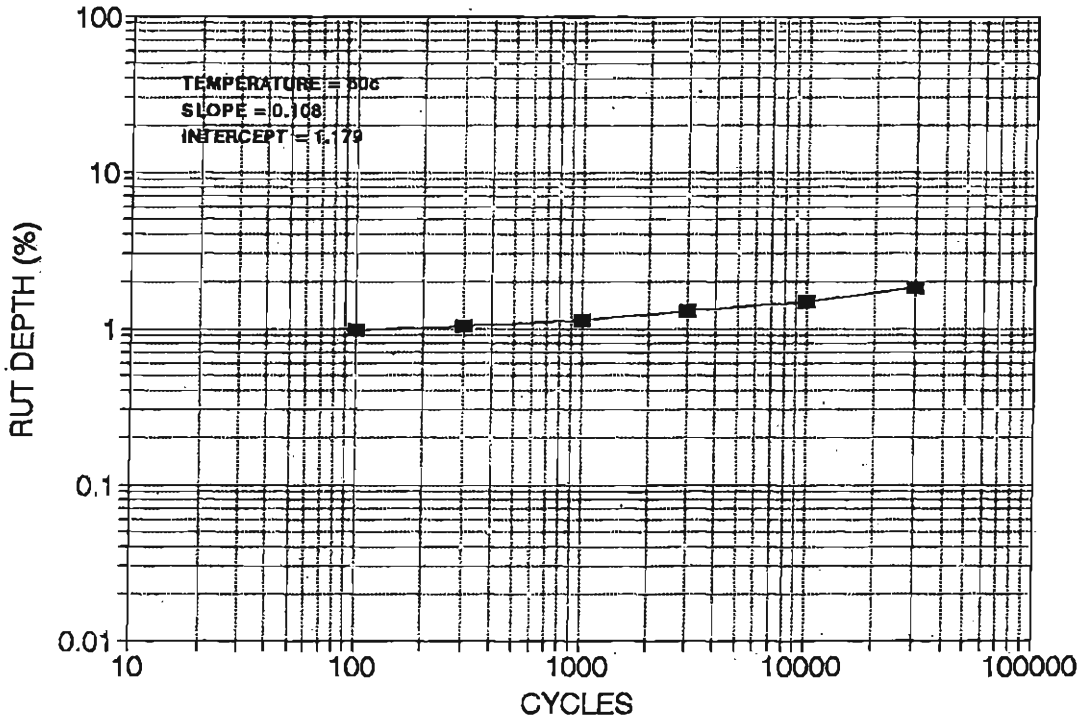
SITE NO. 8



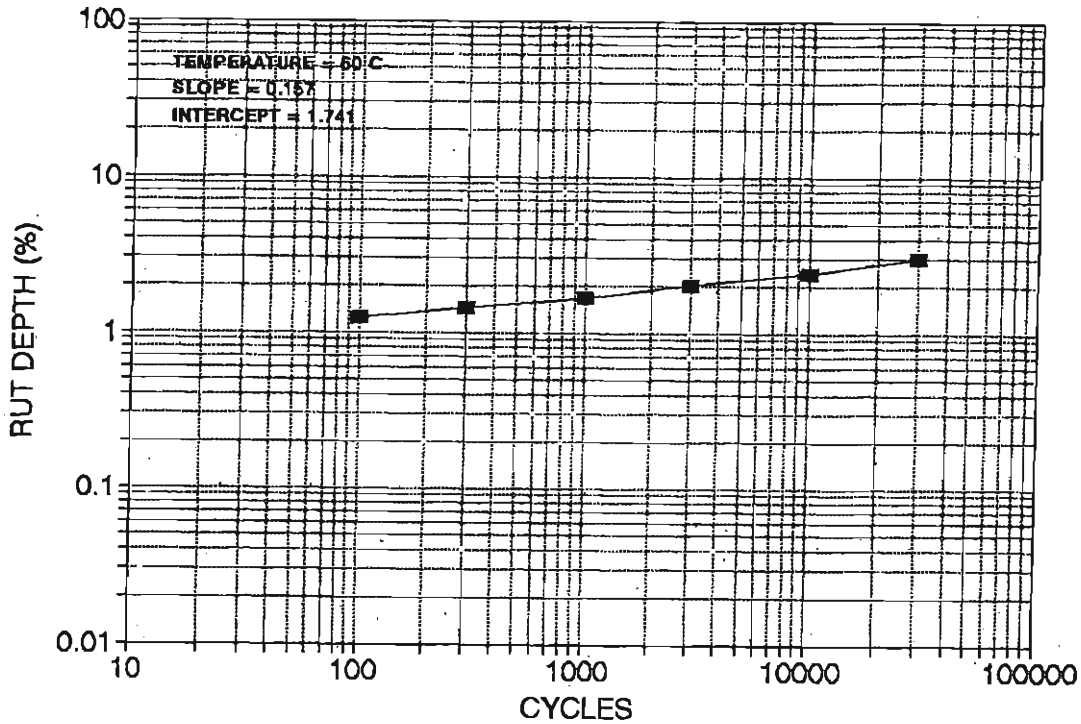
SITE NO. 9



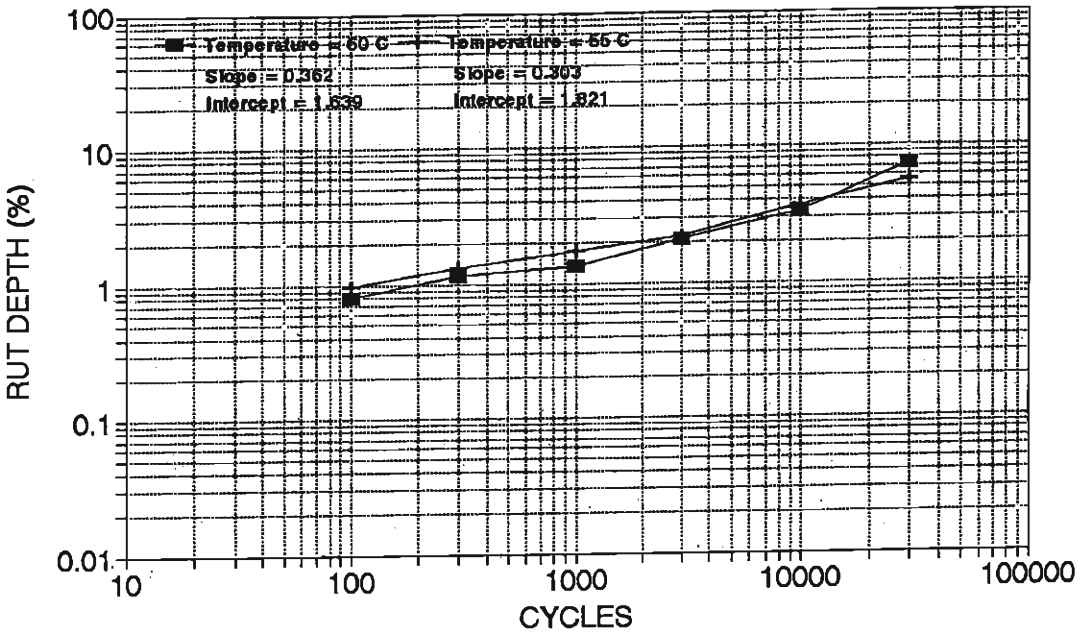
SITE NO. 10



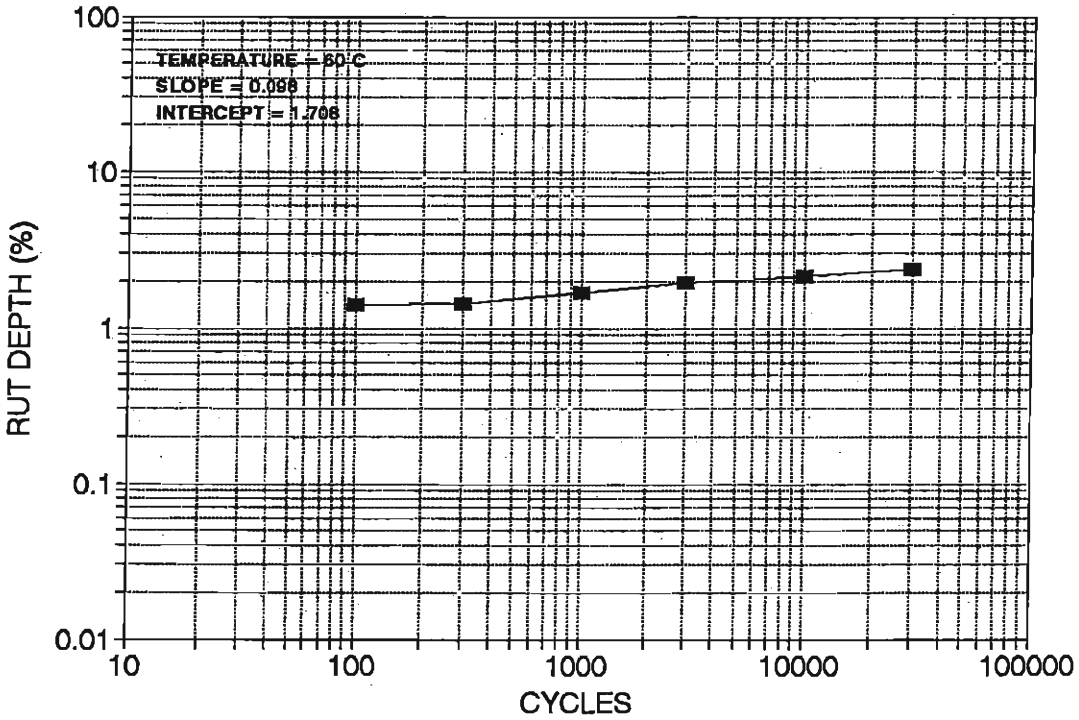
SITE NO. 11



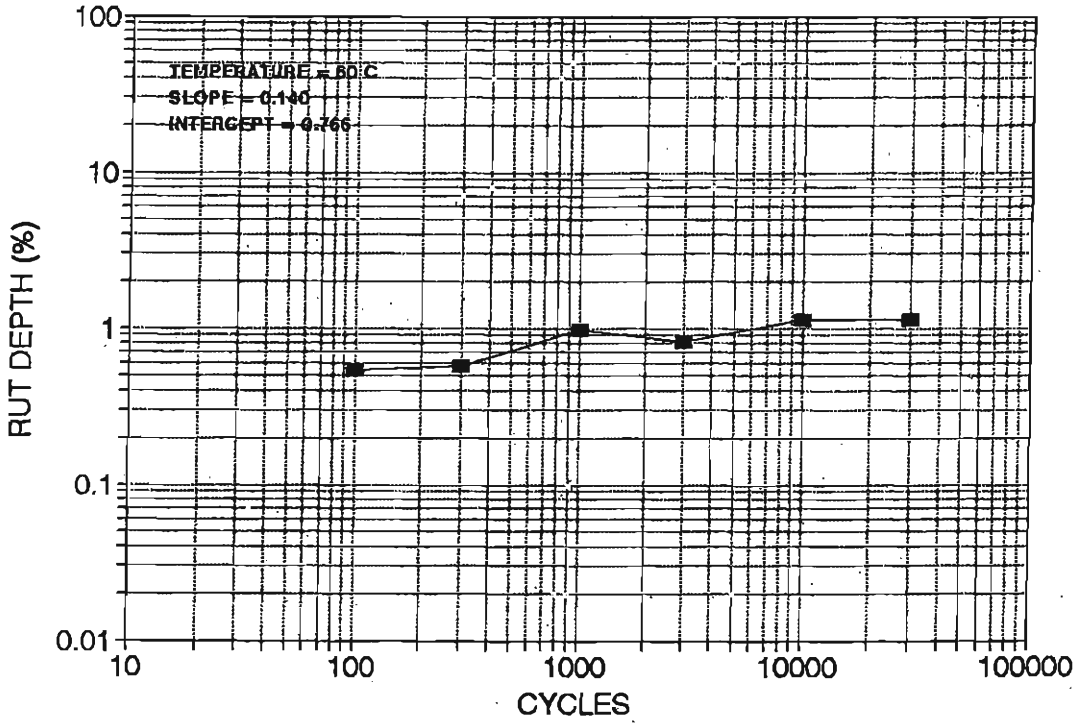
SITE NO. 12



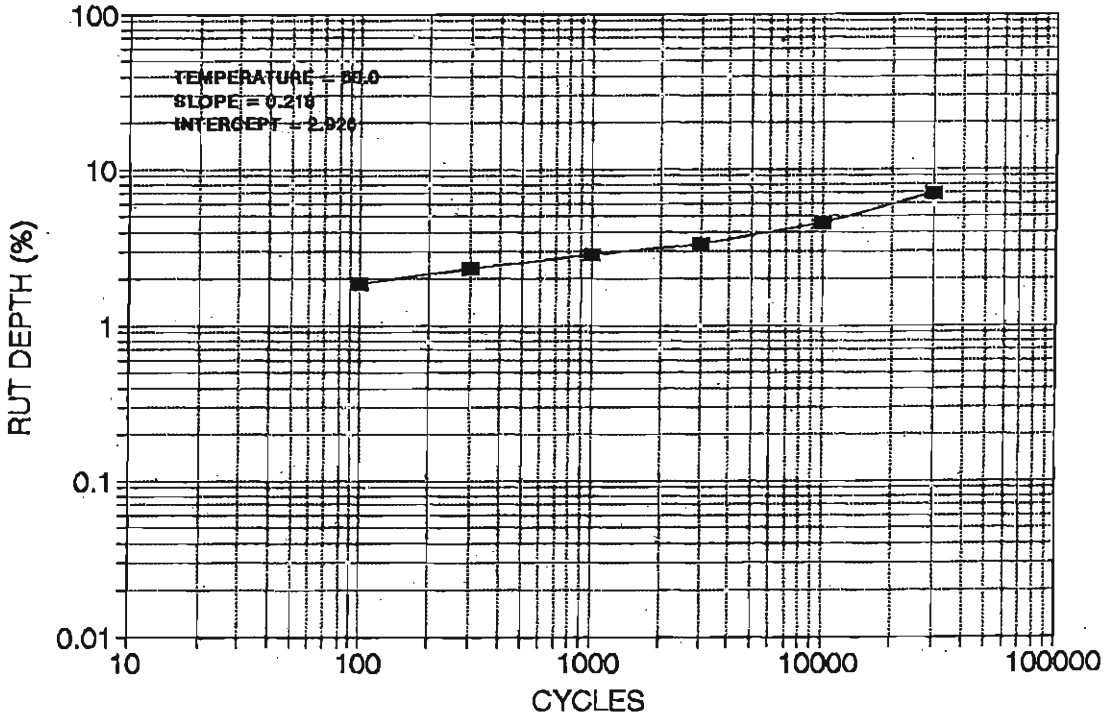
SITE NO. 13



SITE NO. 14



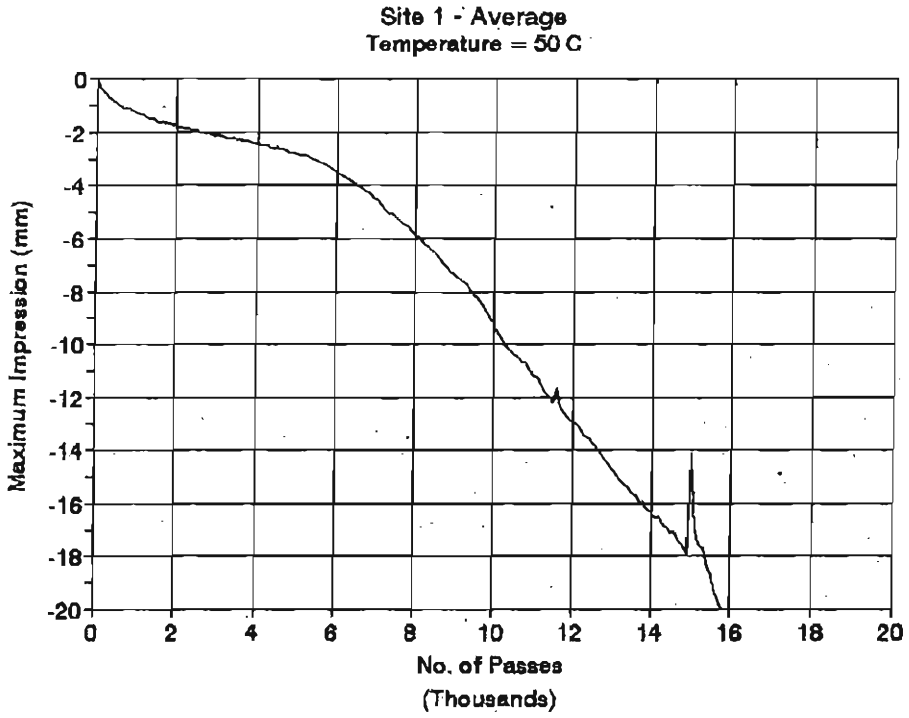
SITE NO. 15

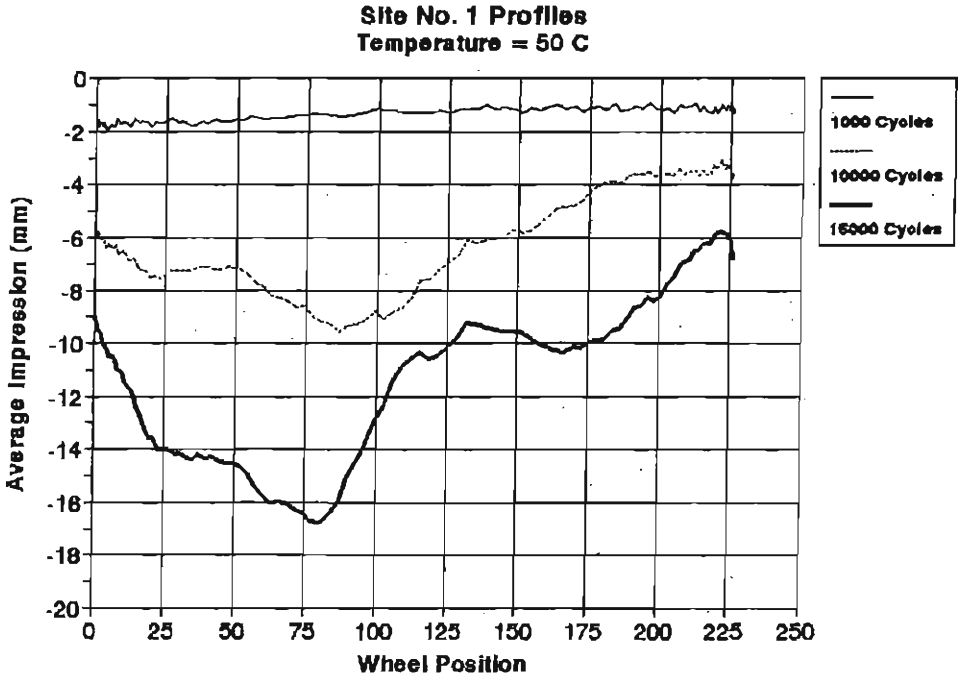


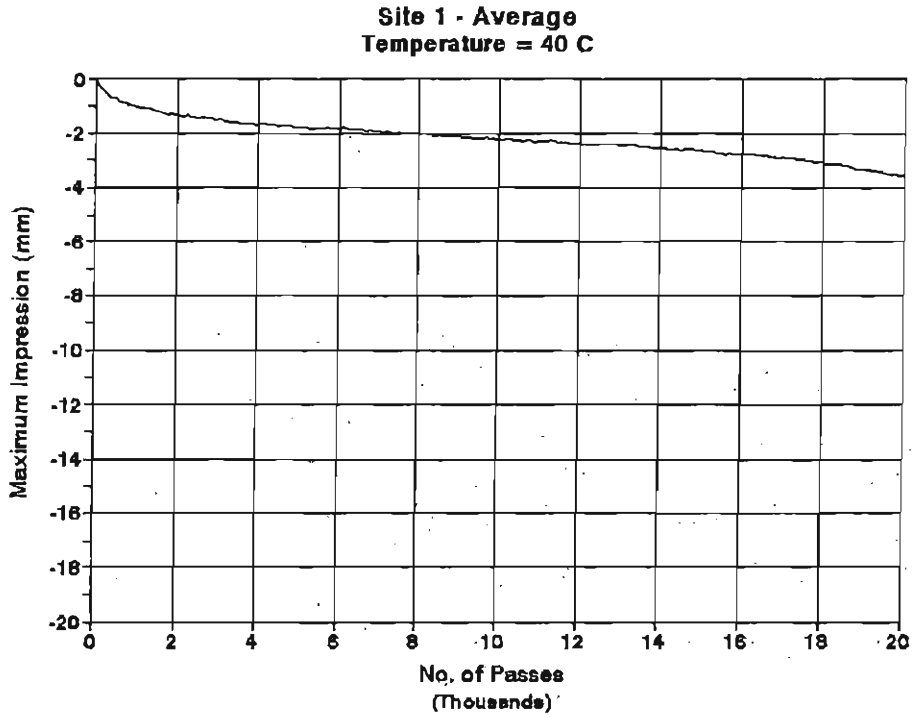
SITE 16

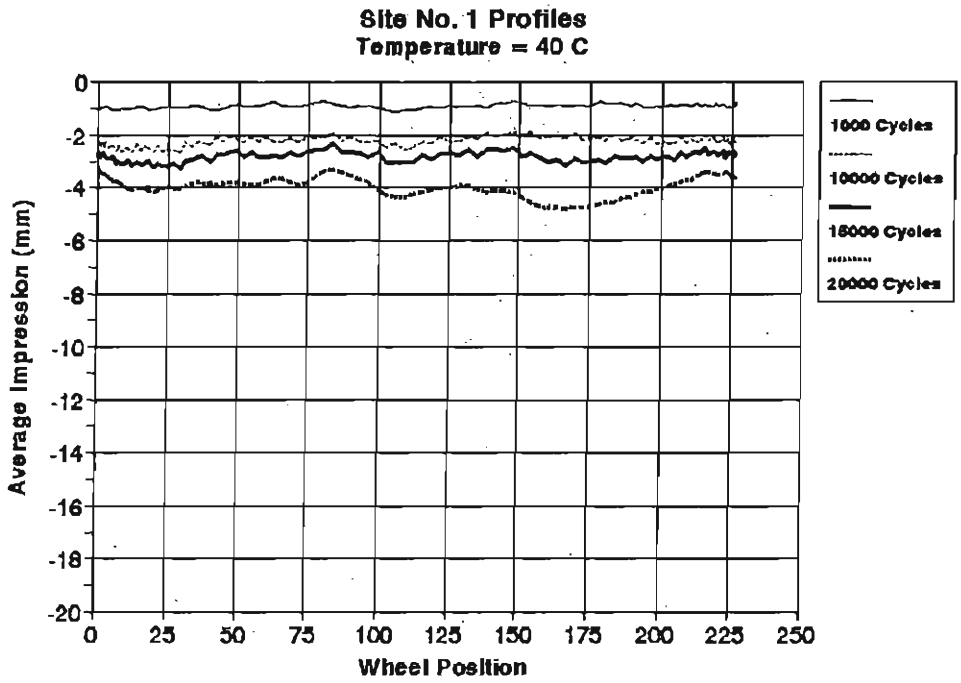
Appendix B

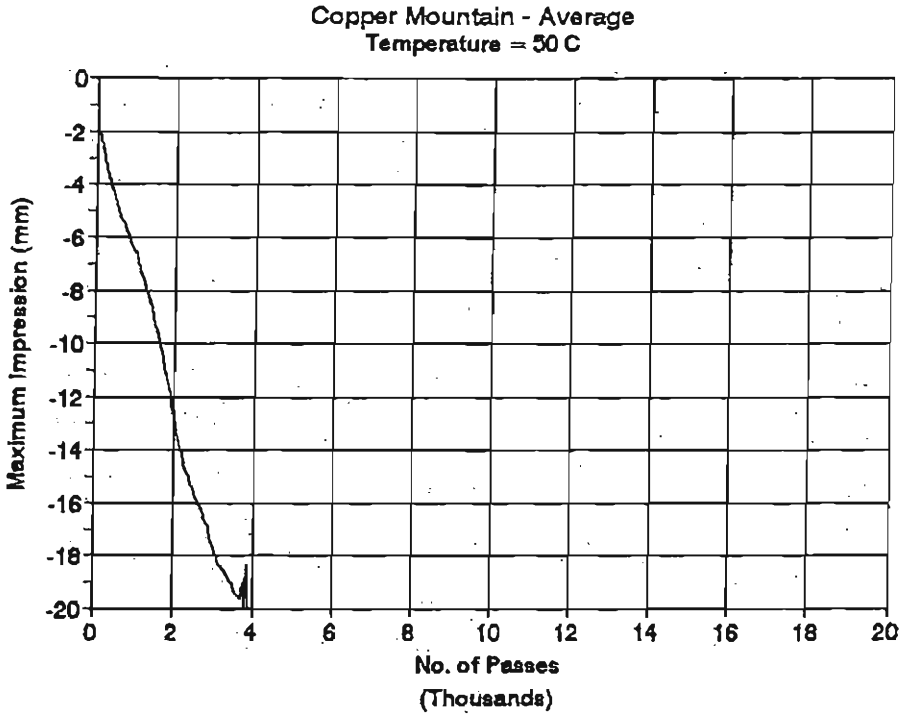
Hamburg Wheel-Tracking Device Results

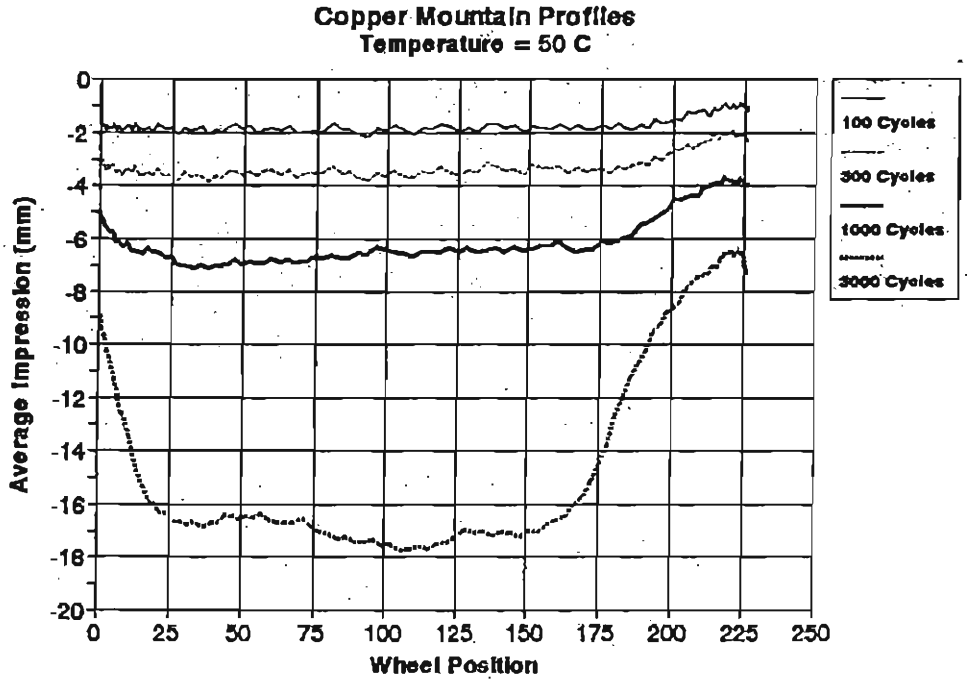

Site 1 - Average
Temperature = 50 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

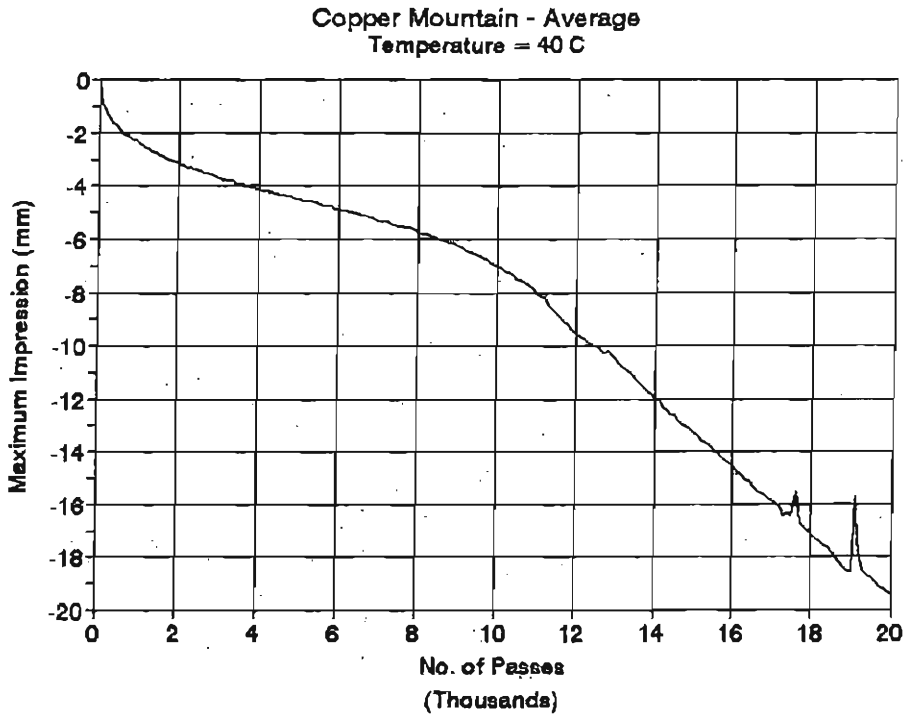

Site No. 1 Profiles
Temperature = 50 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Cycles
10000 Cycles
15000 Cycles

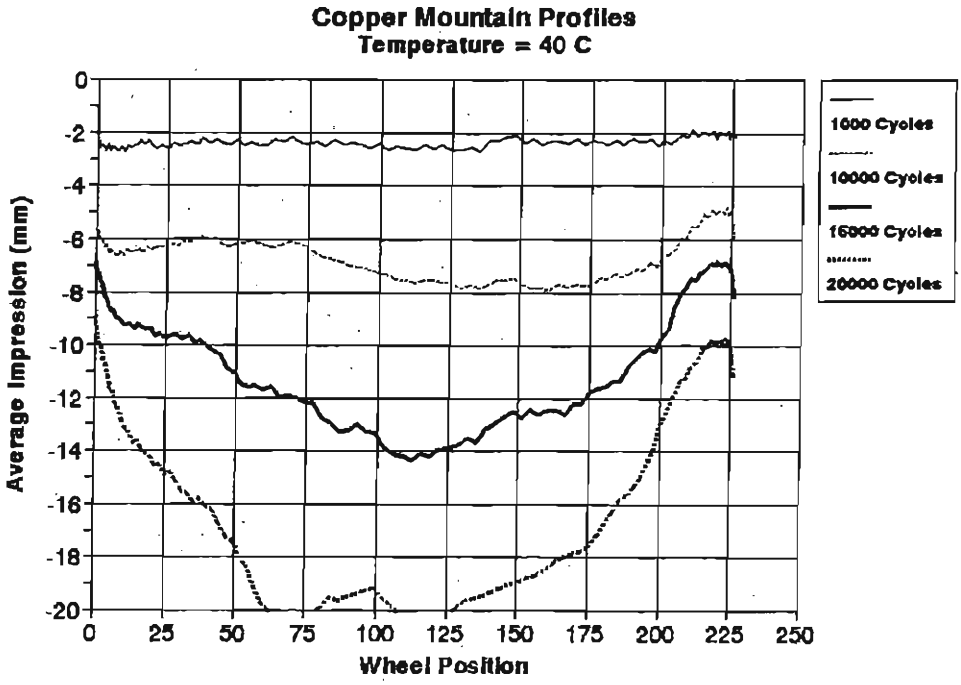

Site 1 - Average
Temperature = 40 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

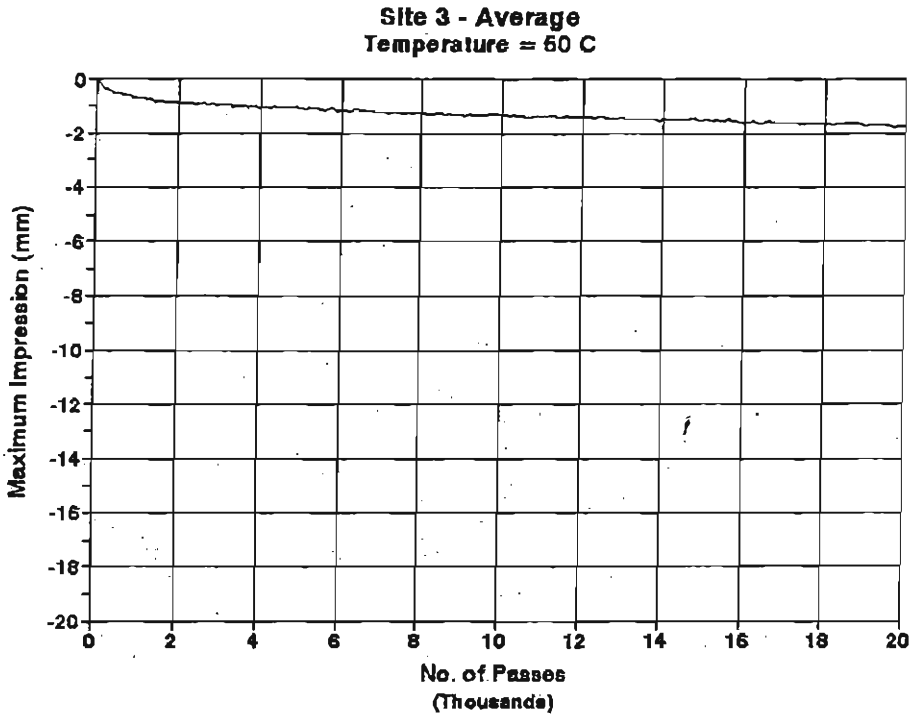

Site No. 1 Profiles
Temperature = 40 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Cycles
10000 Cycles
15000 Cycles
20000 Cycles

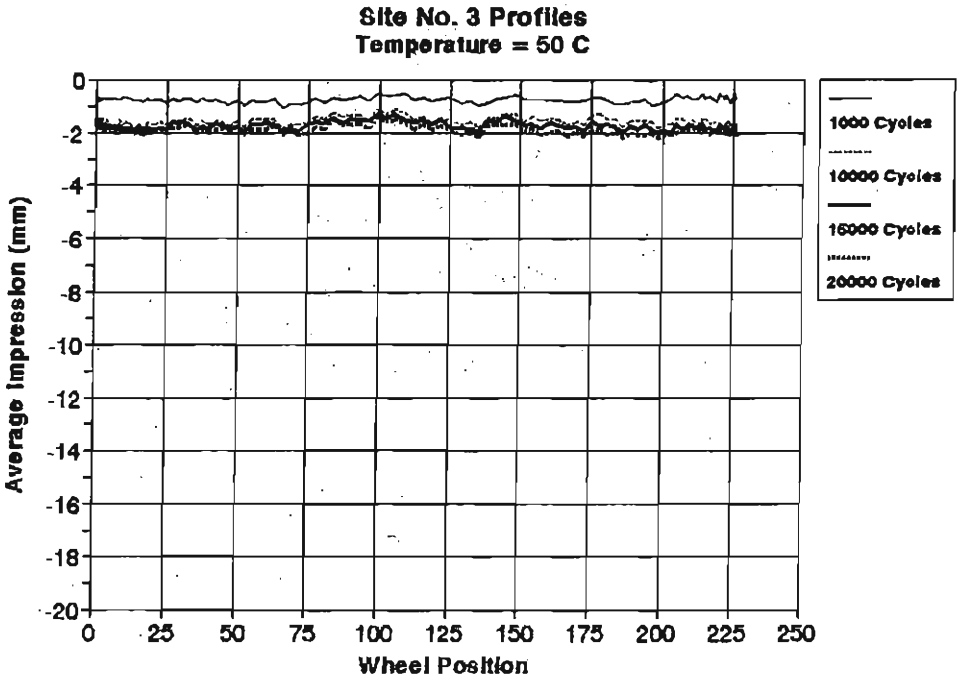

Copper Mountain - Average
Temperature = 50 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

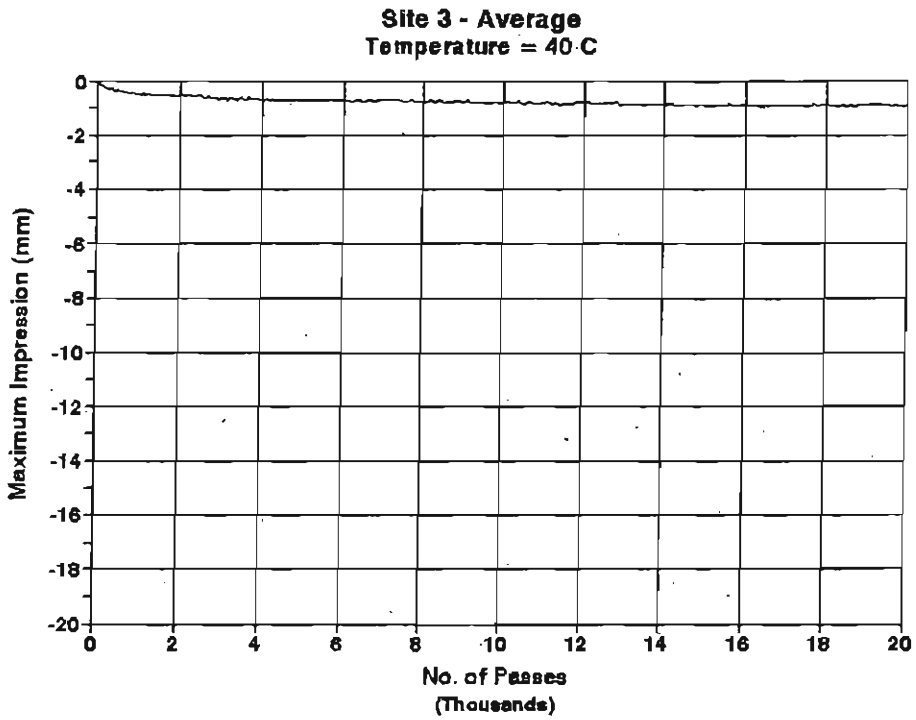

Copper Mountain Profiles
Temperature = 50 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
100 Cycles
300 Cycles
1000 Cycles
3000 Cycles

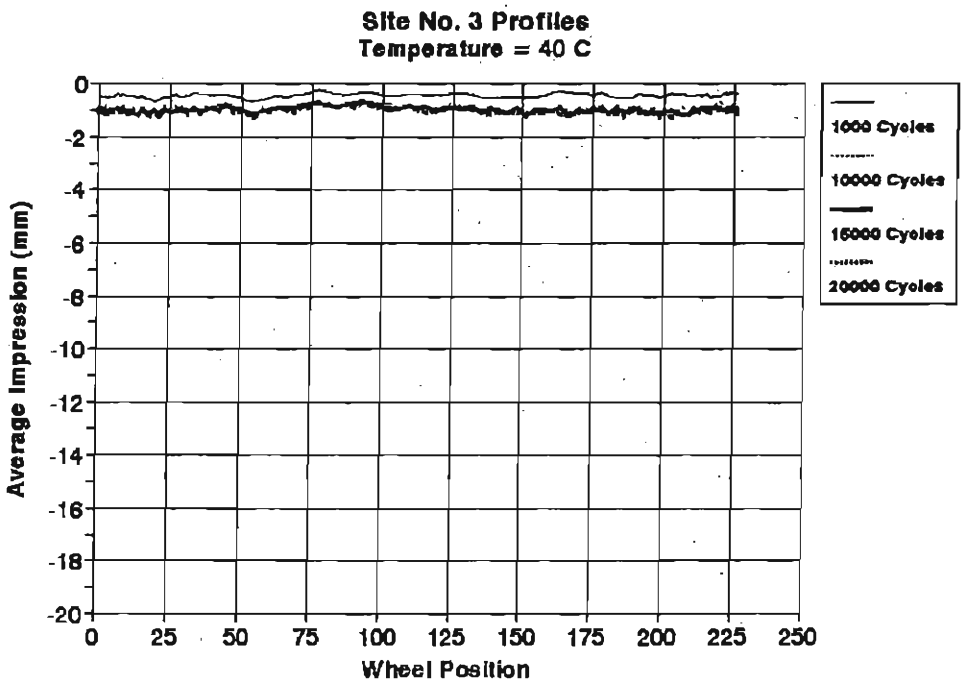

Copper Mountain - Average
Temperature = 40 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

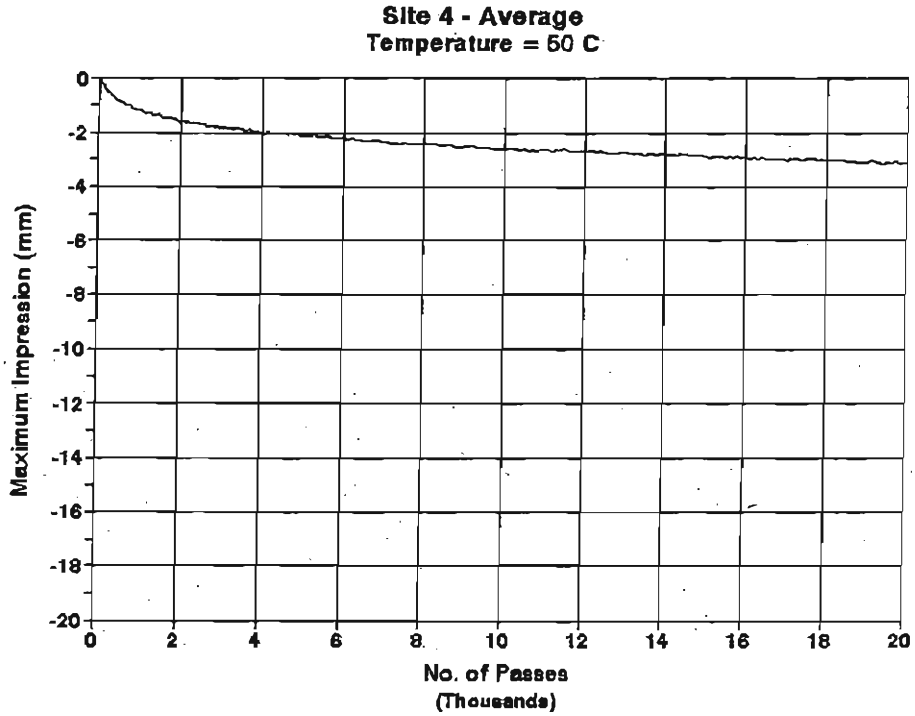

Copper Mountain Profiles
Temperature = 40 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Cycles
10000 Cycles
15000 Cycles
20000 Cycles

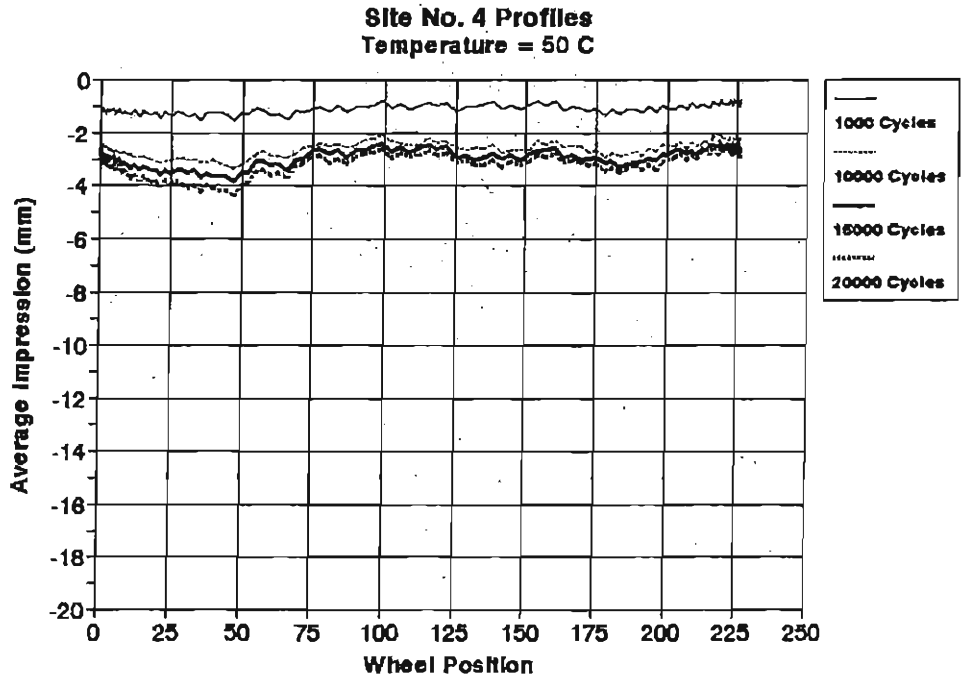

Site 3 - Average
Temperature = 50 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

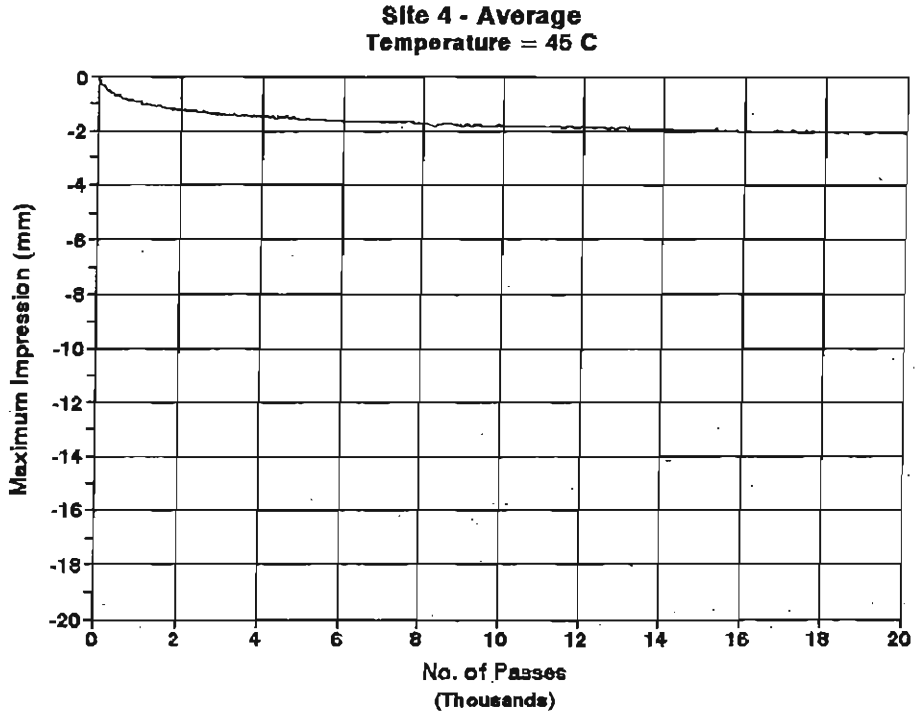

Site No. 3 Profiles
Temperature = 50 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Cycles
10000 Cycles
15000 Cycles
20000 Cycles

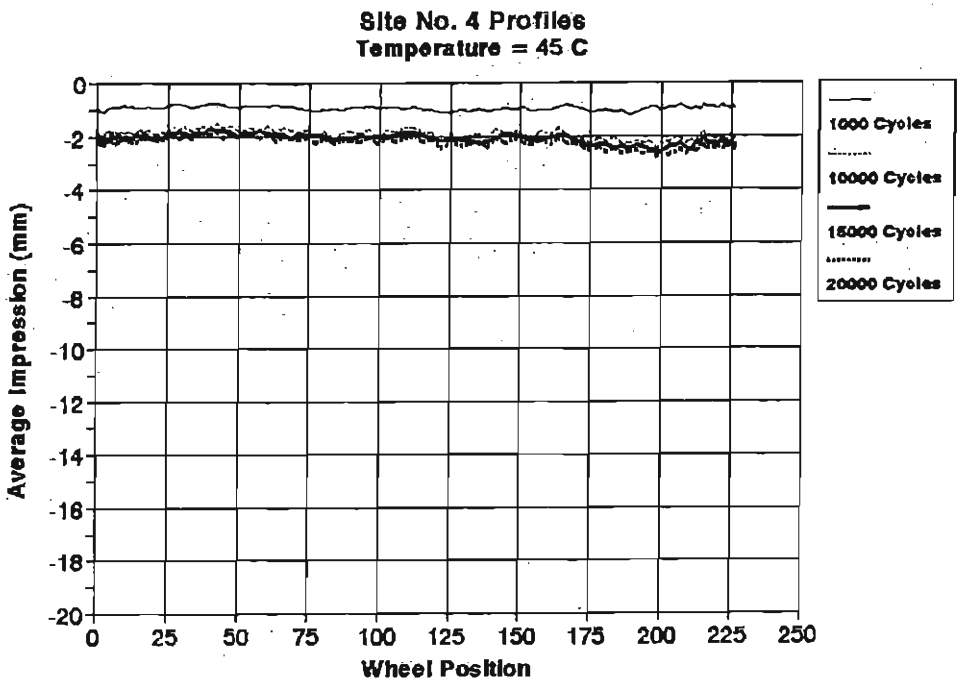

Site 3 - Average
Temperature = 40 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

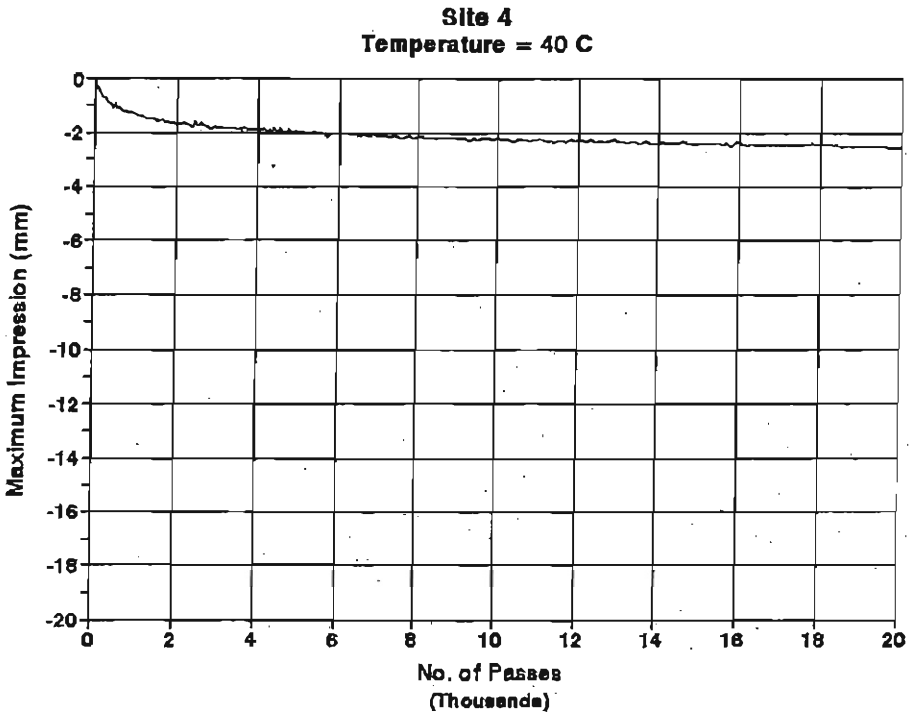

Site No. 3 Profiles
Temperature = 40 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Cycles
10000 Cycles
15000 Cycles
20000 Cycles

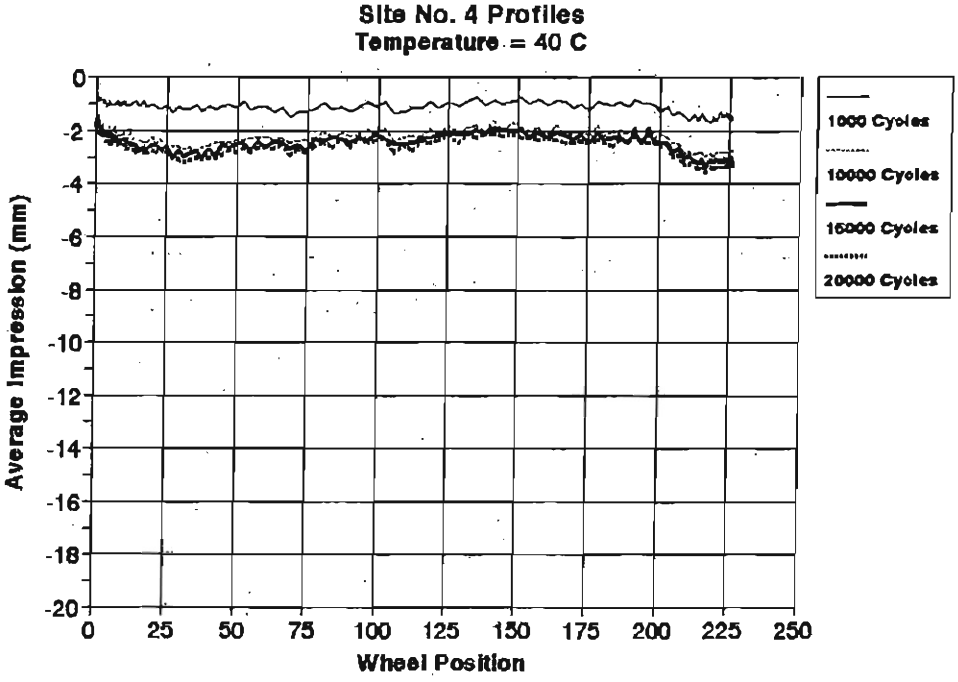

Site 4 - Average
Temperature = 50 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

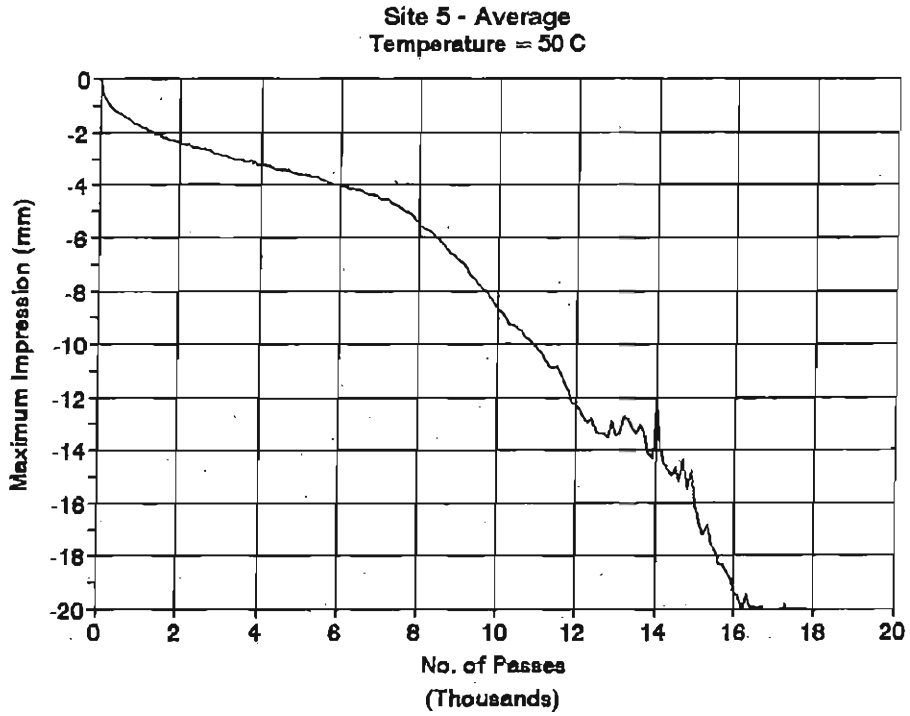

Site No. 4 Profiles
Temperature = 50 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Cycles
10000 Cycles
15000 Cycles
20000 Cycles

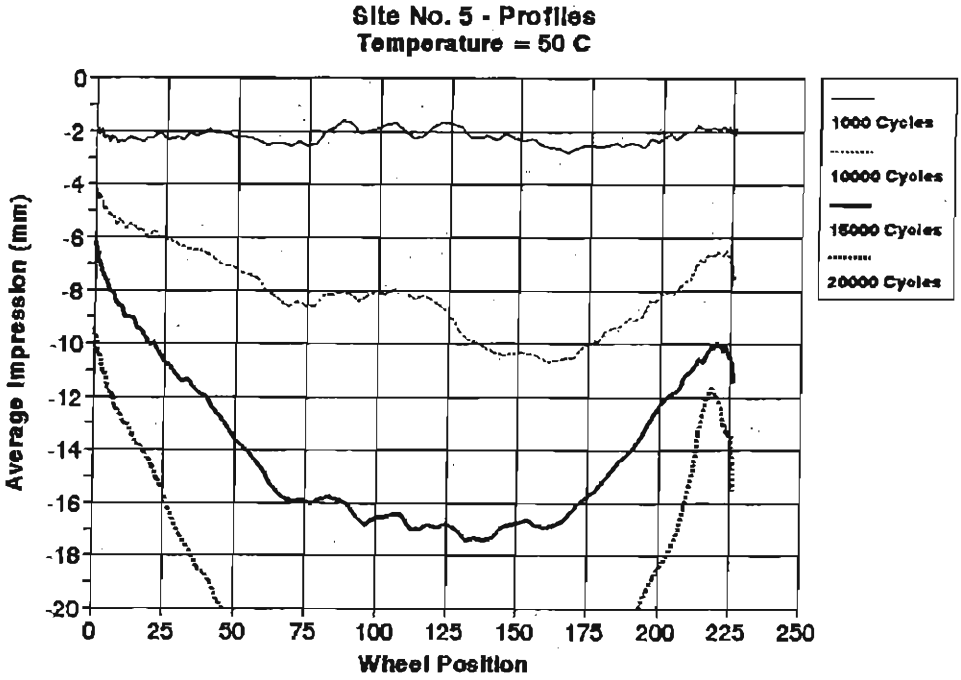

Site 4 - Average
Temperature = 45 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

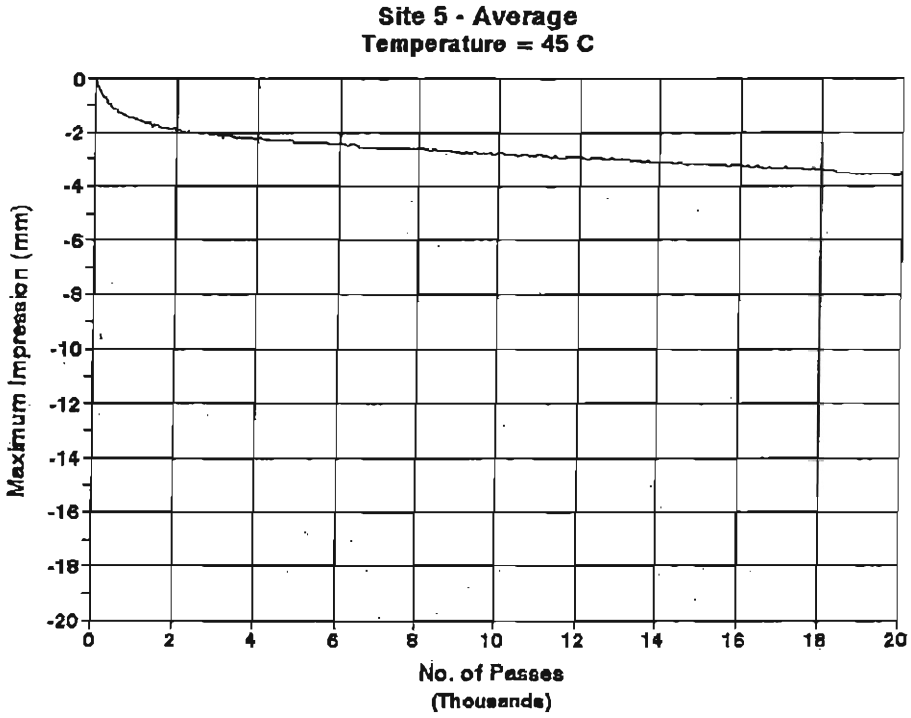

Site No. 4 Profiles
Temperature = 45 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Cycles
10000 Cycles
15000 Cycles
20000 Cycles

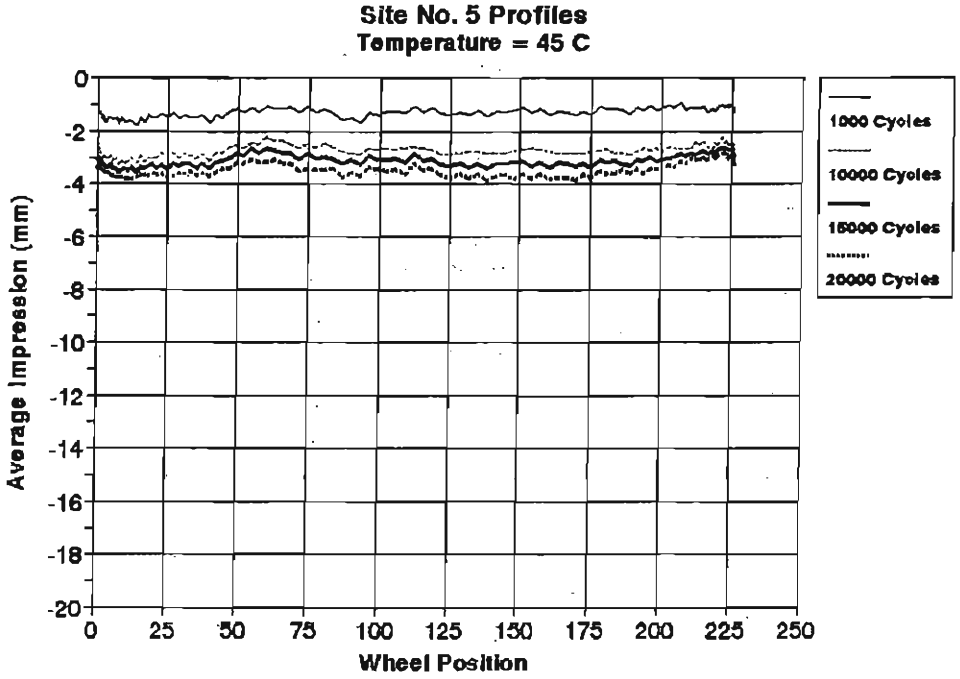

Site 4
Temperature = 40 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

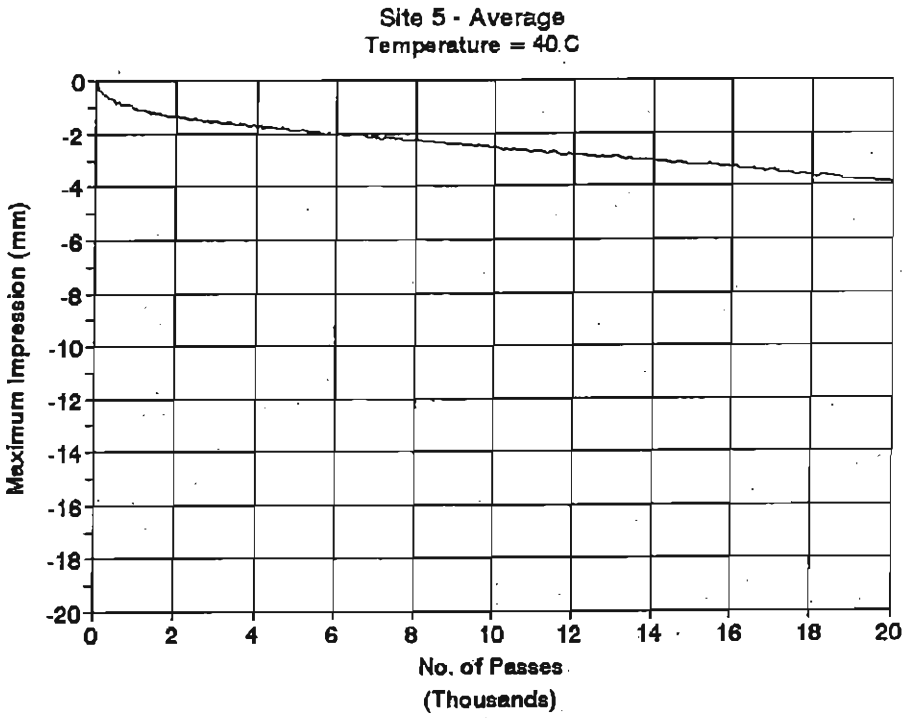

Site No. 4 Profiles
Temperature = 40 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Cycles
10000 Cycles
16000 Cycles
20000 Cycles

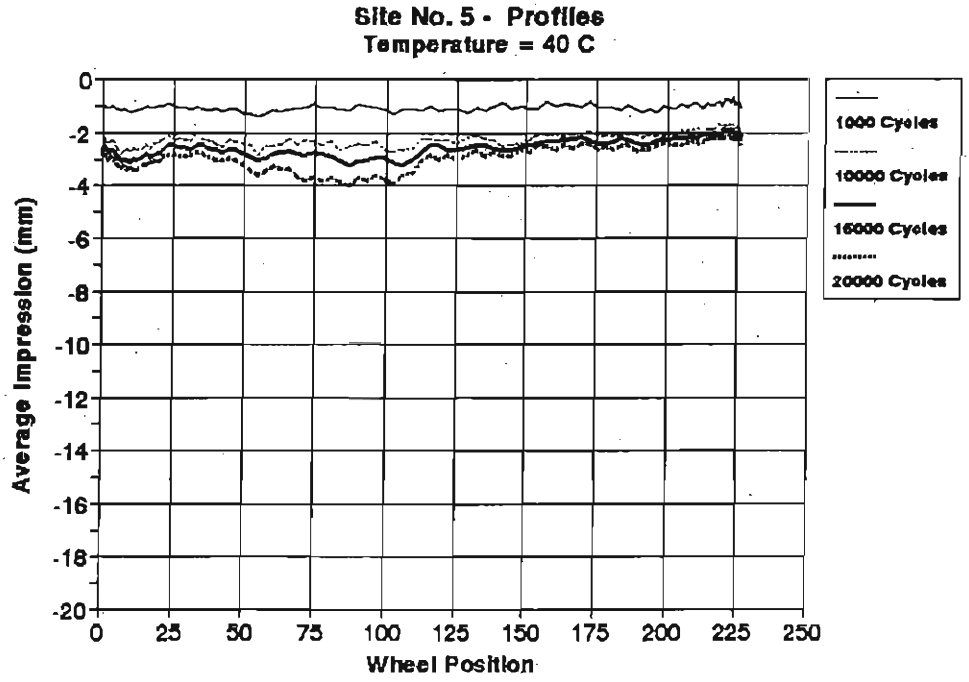

Site 5 - Average
Temperature = 50 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

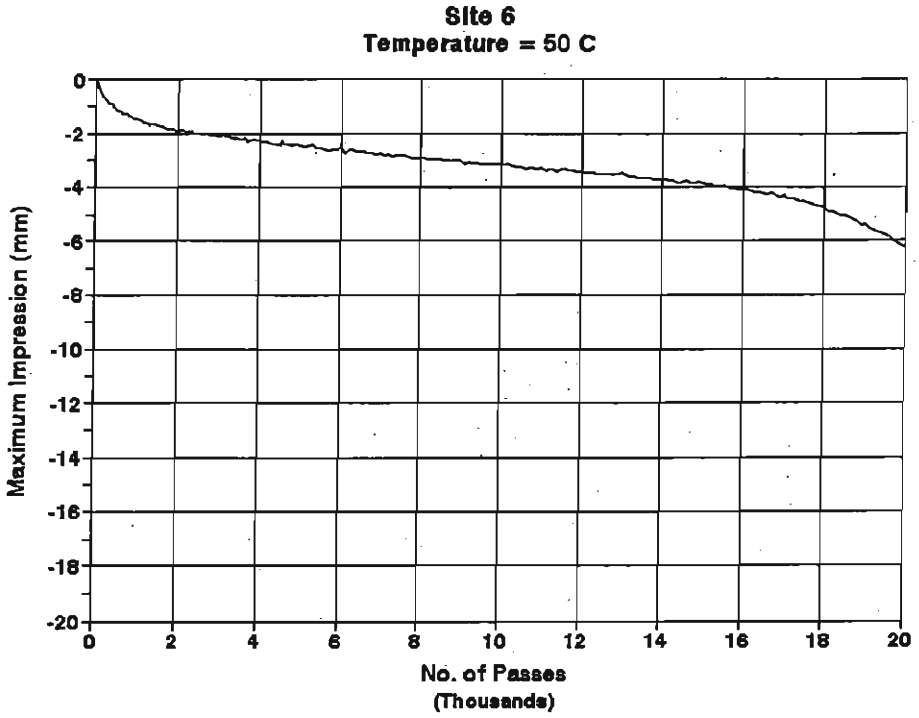

Site No. 5 - Profiles
Temperature = 50 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Cycles
10000 Cycles
15000 Cycles
20000 Cycles

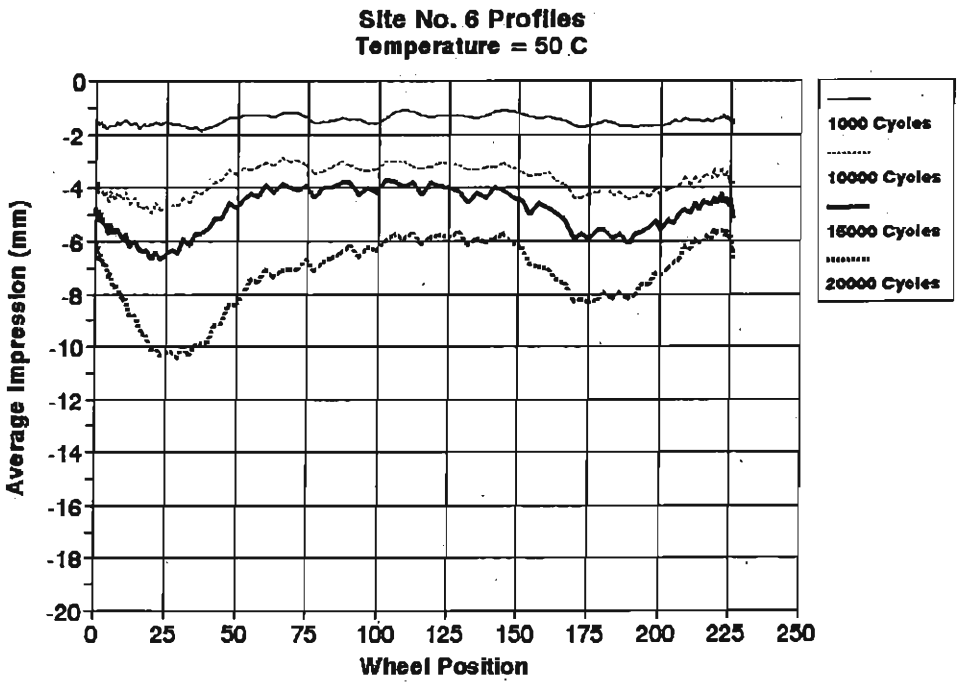

Site 5 - Average
Temperature = 45 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

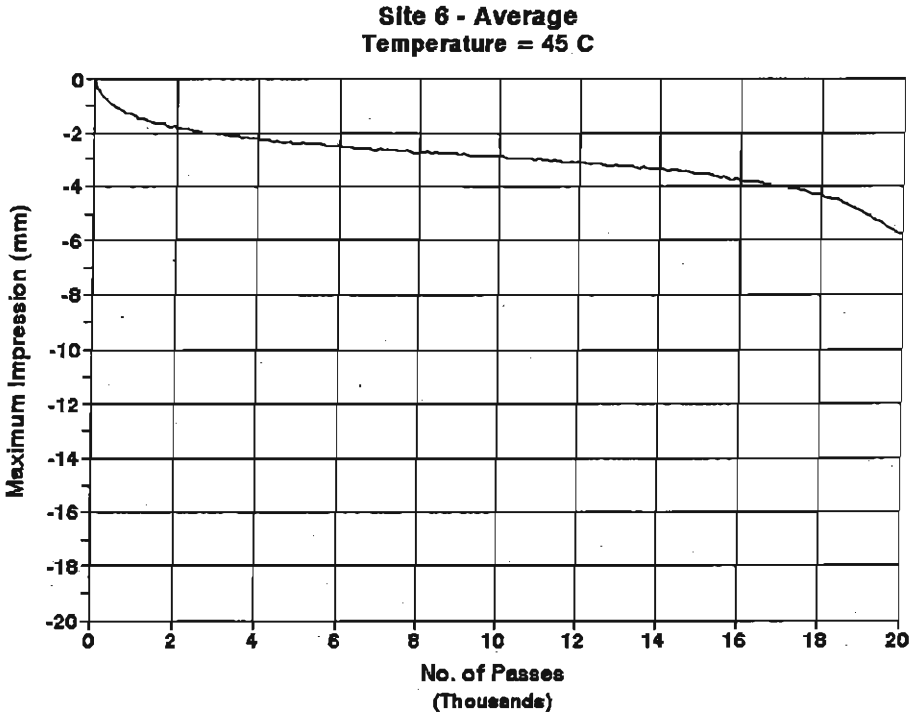

Site No. 5 Profiles
Temperature = 45 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Cycles
10000 Cycles
15000 Cycles
20000 Cycles

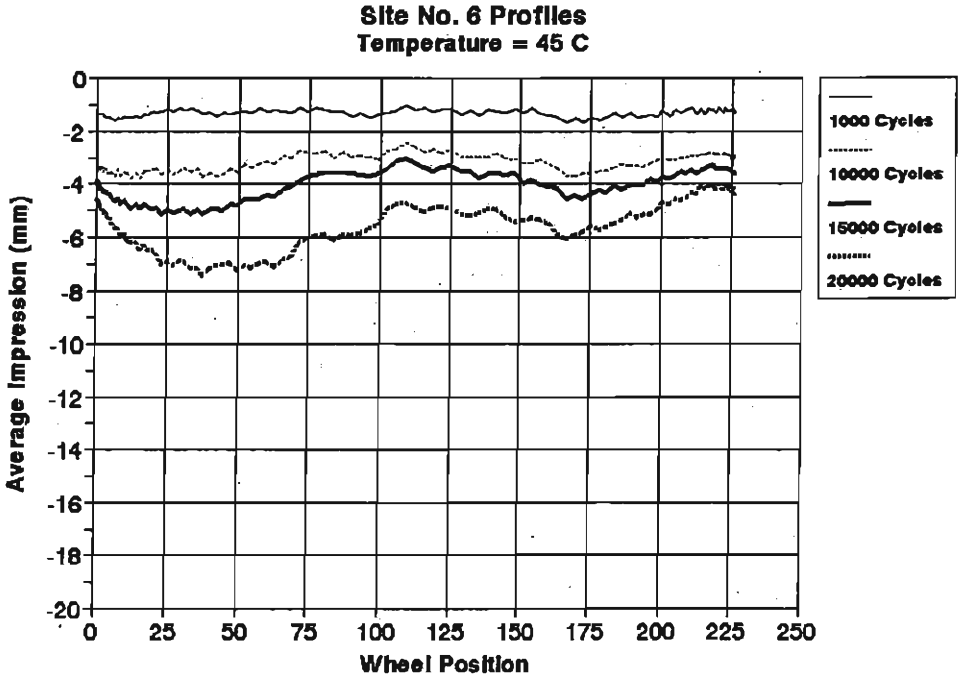

Site 5 - Average
Temperature = 40 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

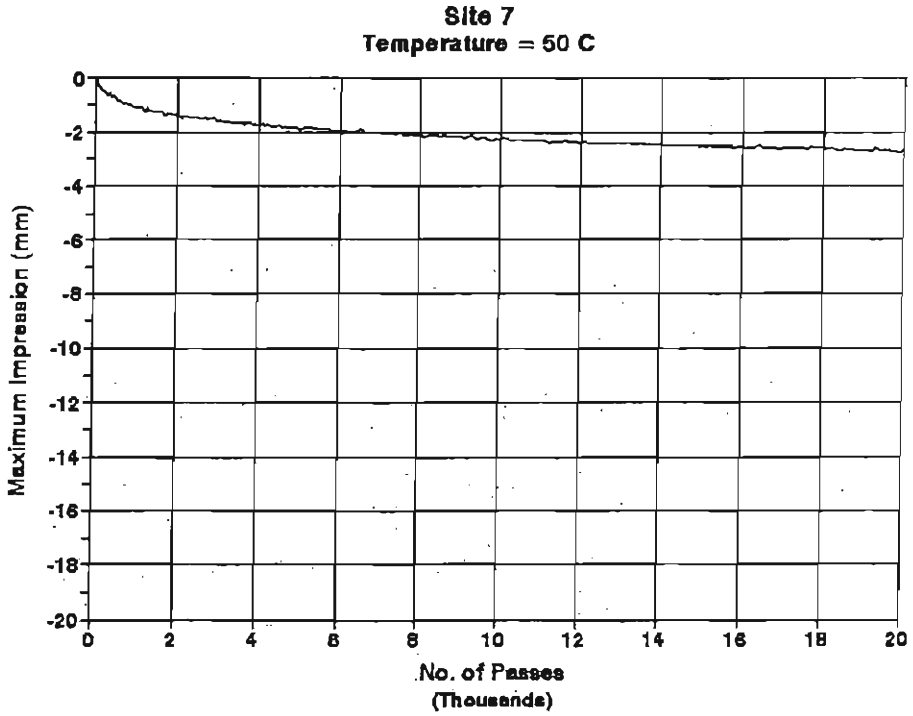

Site No. 5 - Profiles
Temperature = 40 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Cycles
10000 Cycles
16000 Cycles
20000 Cycles

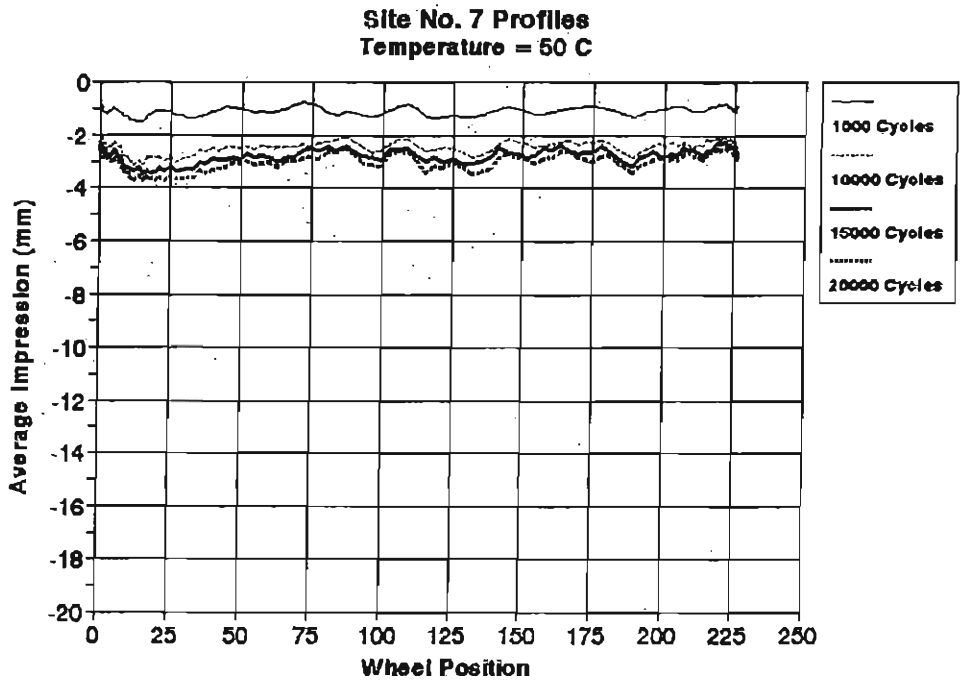

Site 6
Temperature = 50 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

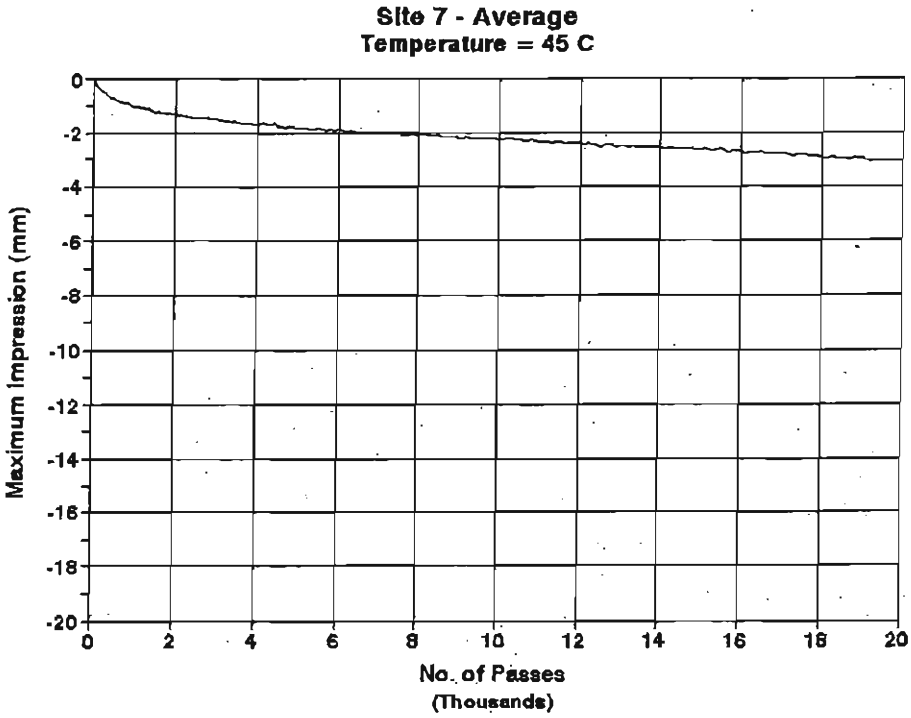

Site No. 6 Profiles
Temperature = 50 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Cycles
10000 Cycles
15000 Cycles
20000 Cycles

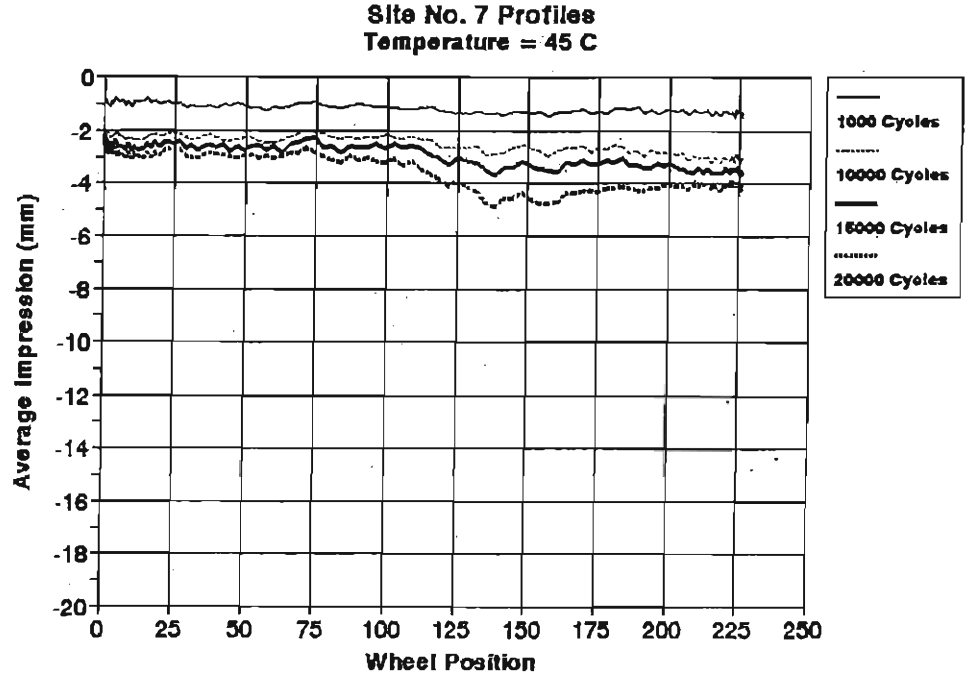

Site 6 - Average
Temperature = 45 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

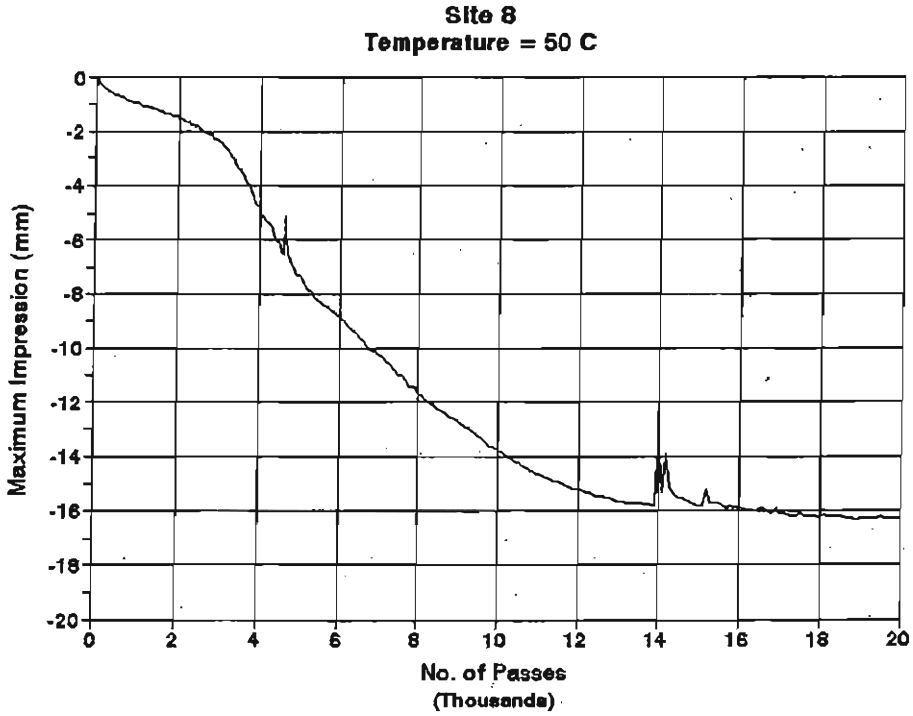

Site No. 6 Profiles
Temperature = 45 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Cycles
10000 Cycles
15000 Cycles
20000 Cycles

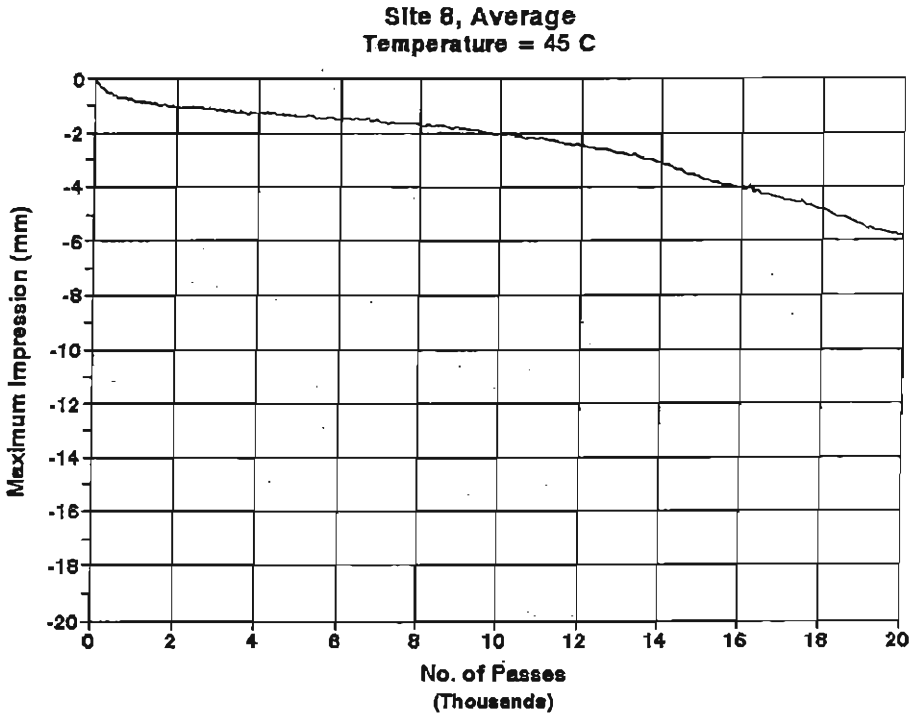

Site 7
Temperature = 50 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

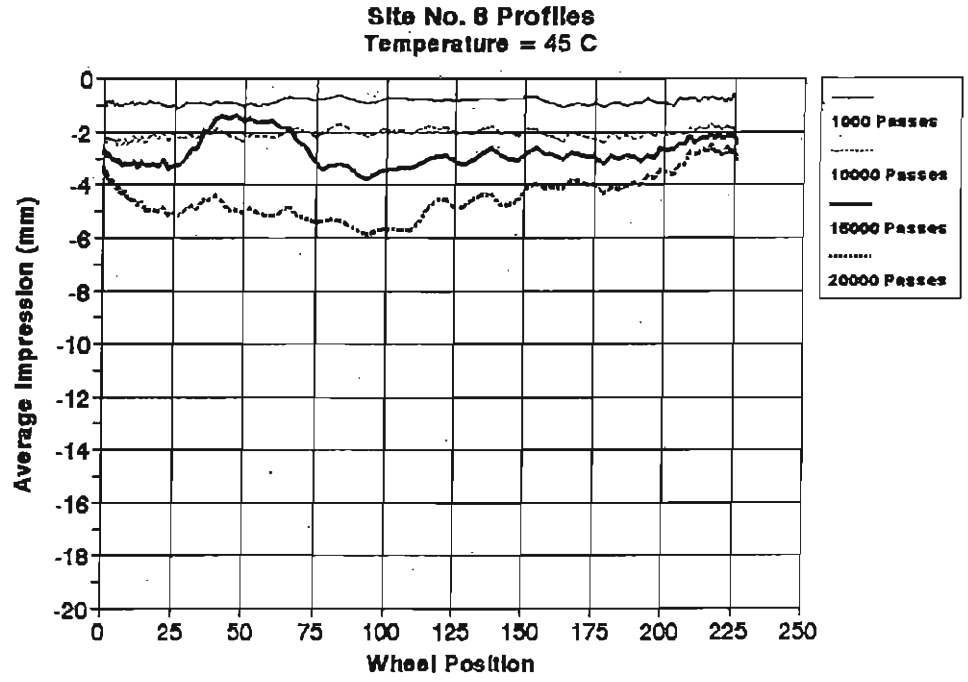

Site No. 7 Profiles
Temperature = 50 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Cycles
10000 Cycles
15000 Cycles
20000 Cycles

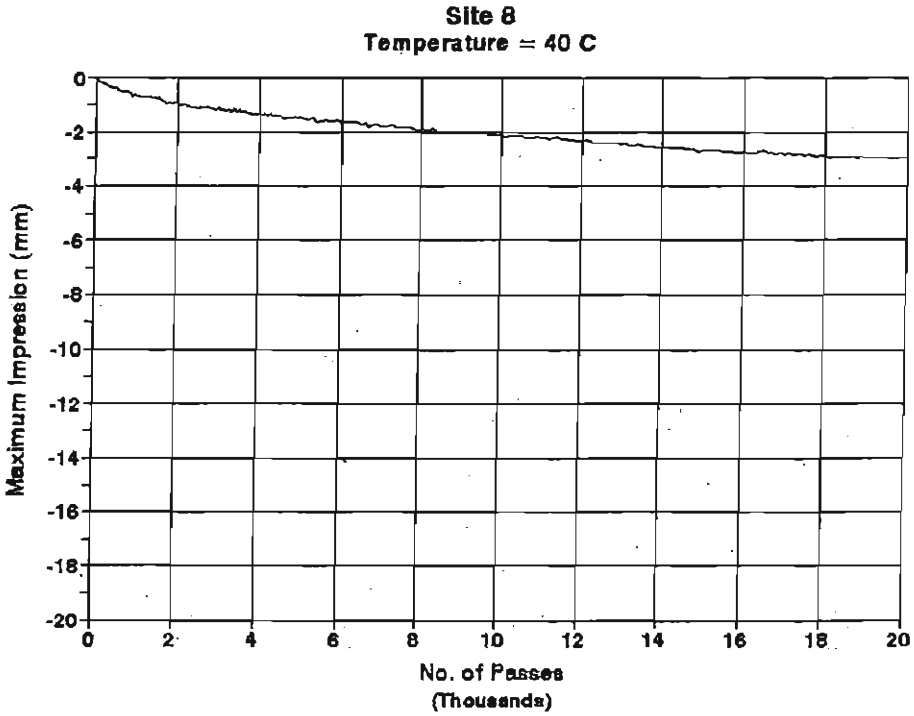

Site 7 - Average
Temperature = 45 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

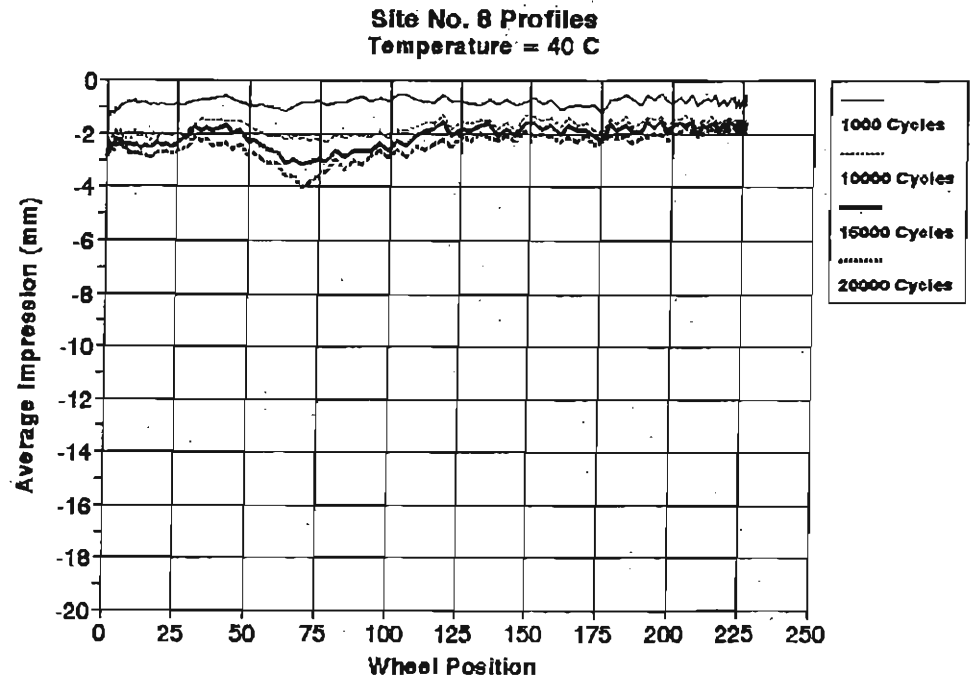

Site No. 7 Profiles
Temperature = 45 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Cycles
10000 Cycles
15000 Cycles
20000 Cycles

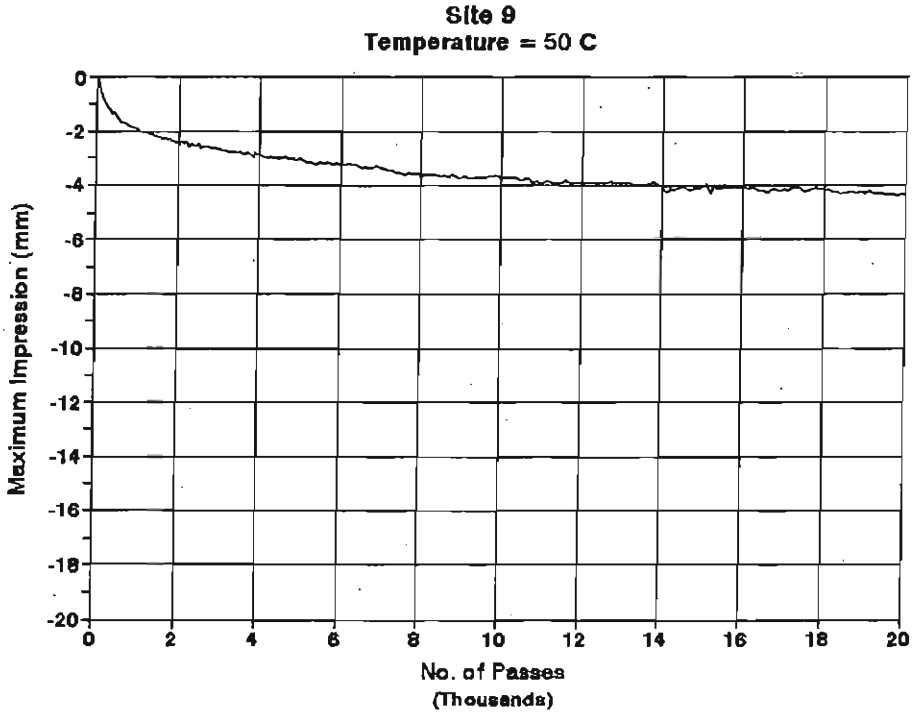

Site 8
Temperature = 50 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

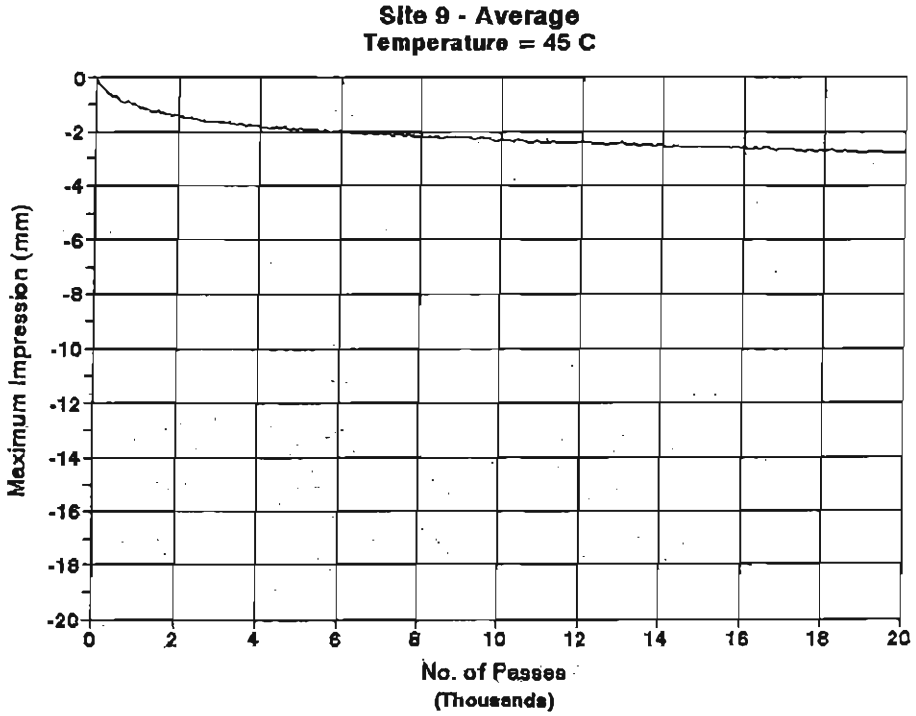

Site 8, Average
Temperature = 45 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

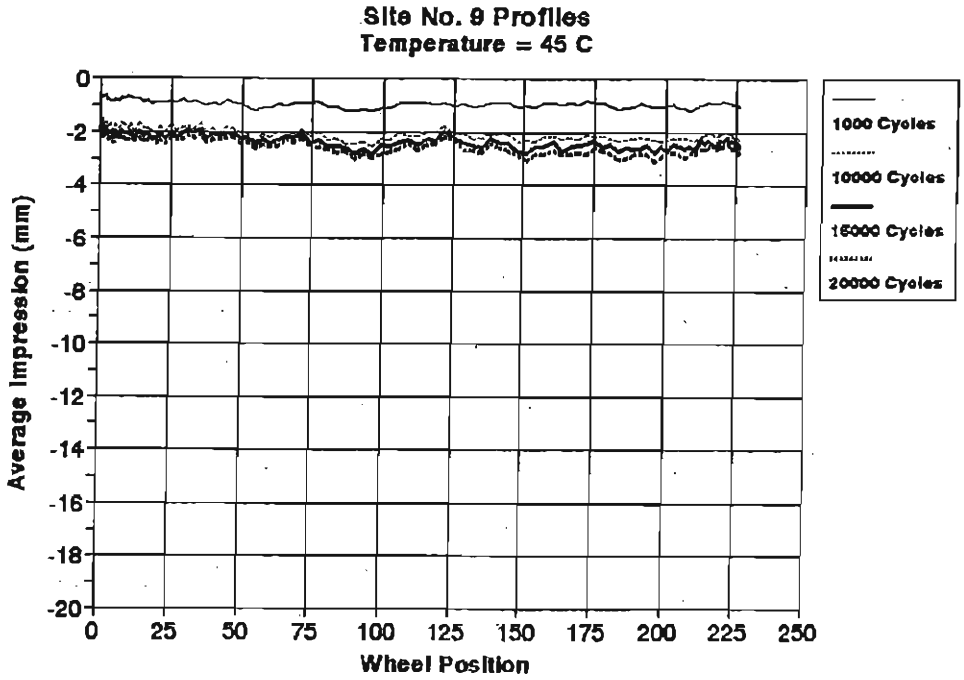

Site No. 8 Profiles
Temperature = 45 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Passes
10000 Passes
15000 Passes
20000 Passes

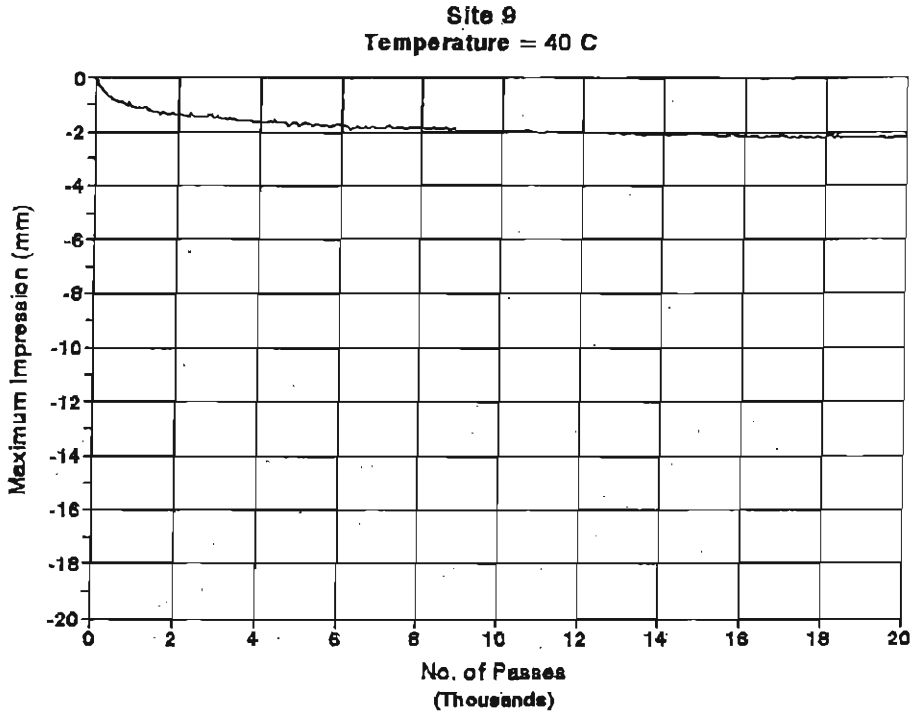

Site 8
Temperature = 40 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

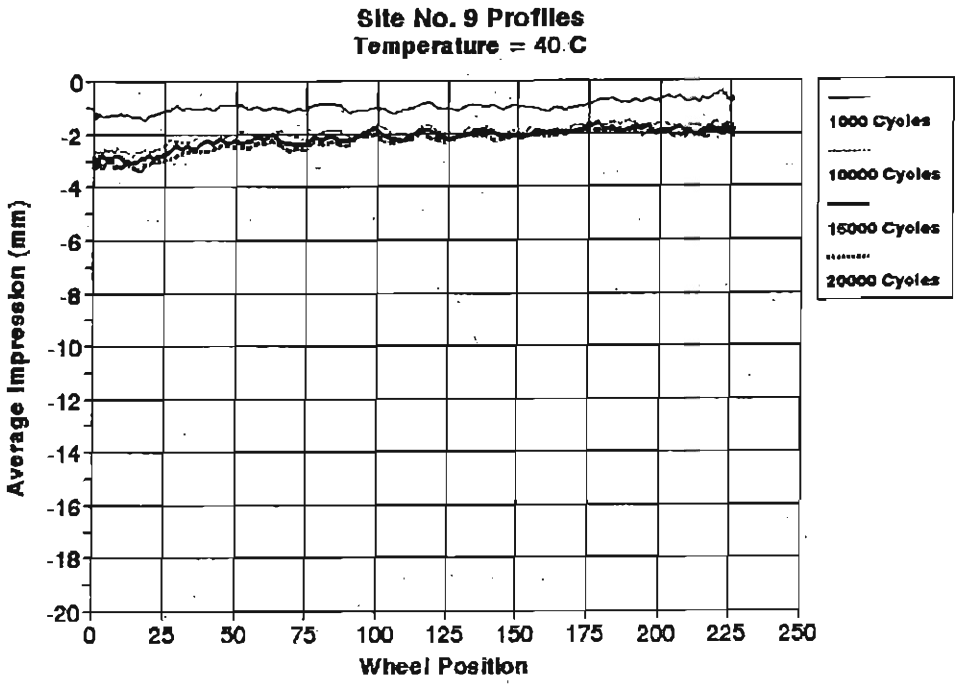

Site No. 8 Profiles
Temperature = 40 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Cycles
10000 Cycles
15000 Cycles
20000 Cycles

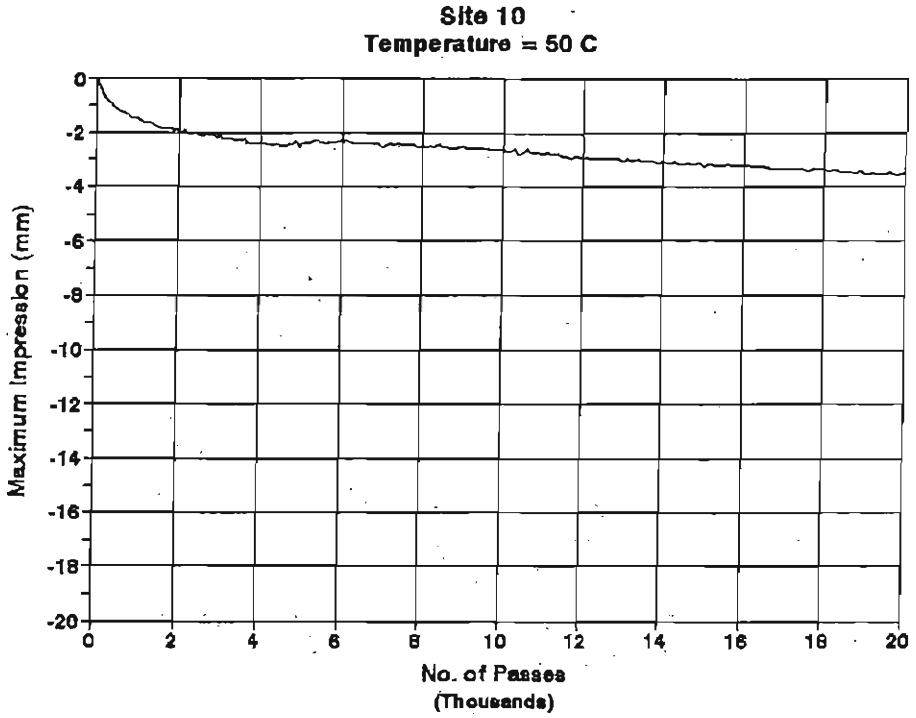

Site 9
Temperature = 50 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

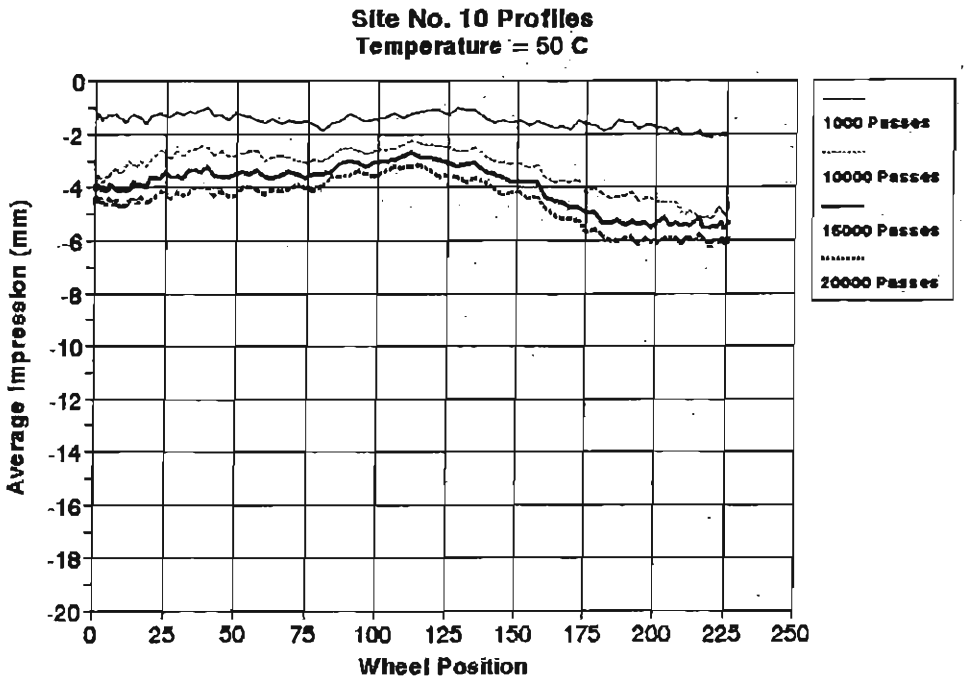

Site 9 - Average
Temperature = 45 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

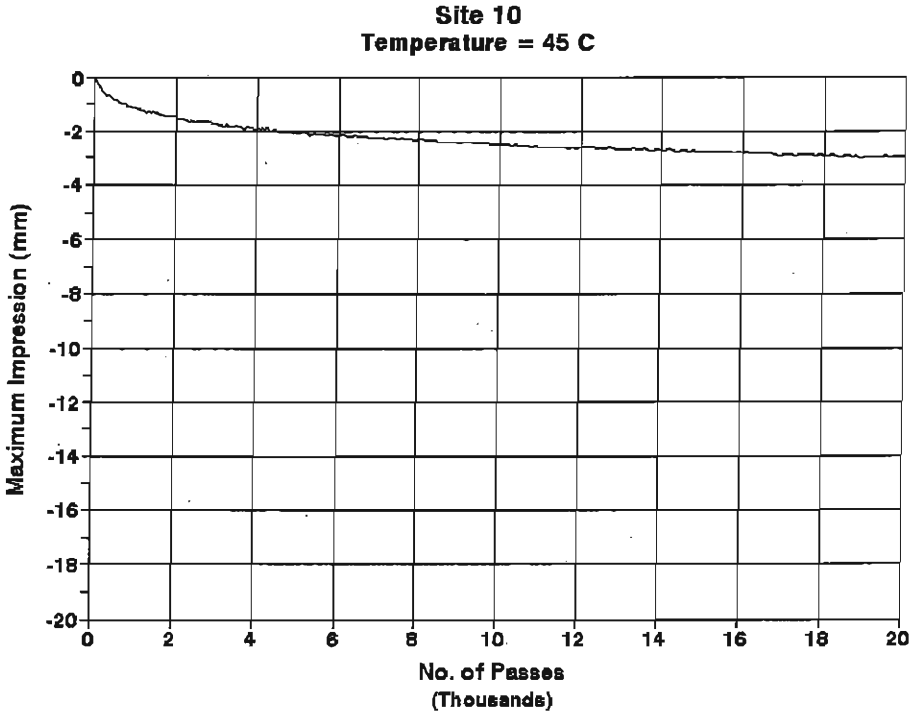

Site No. 9 Profiles
Temperature = 45 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Cycles
10000 Cycles
15000 Cycles
20000 Cycles

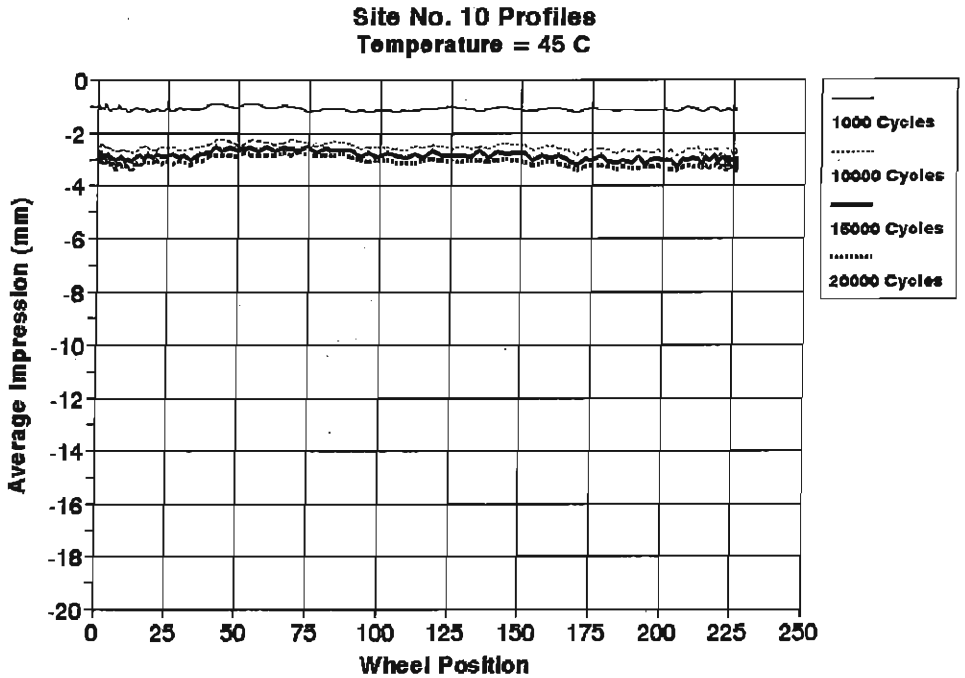

Site 9
Temperature = 40 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

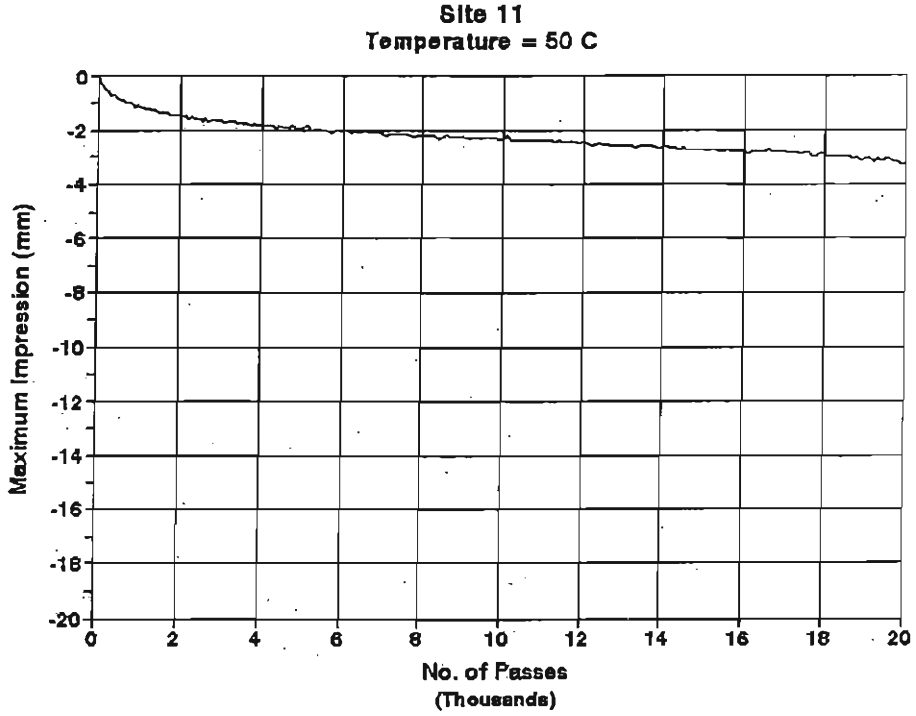

Site No. 9 Profiles
Temperature = 40 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Cycles
10000 Cycles
15000 Cycles
20000 Cycles

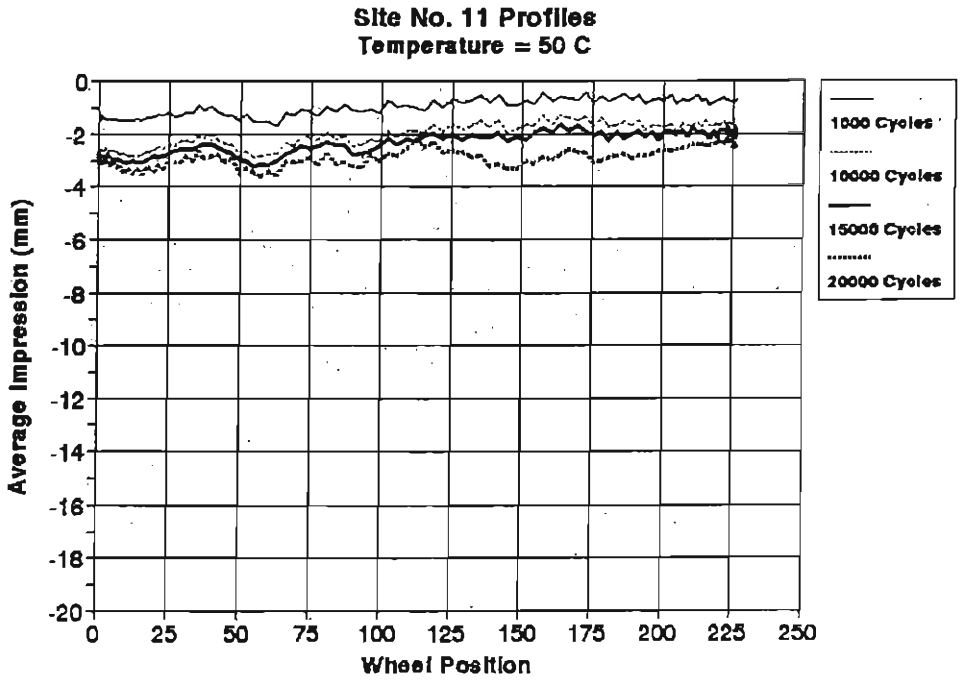

Site 10
Temperature = 50 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

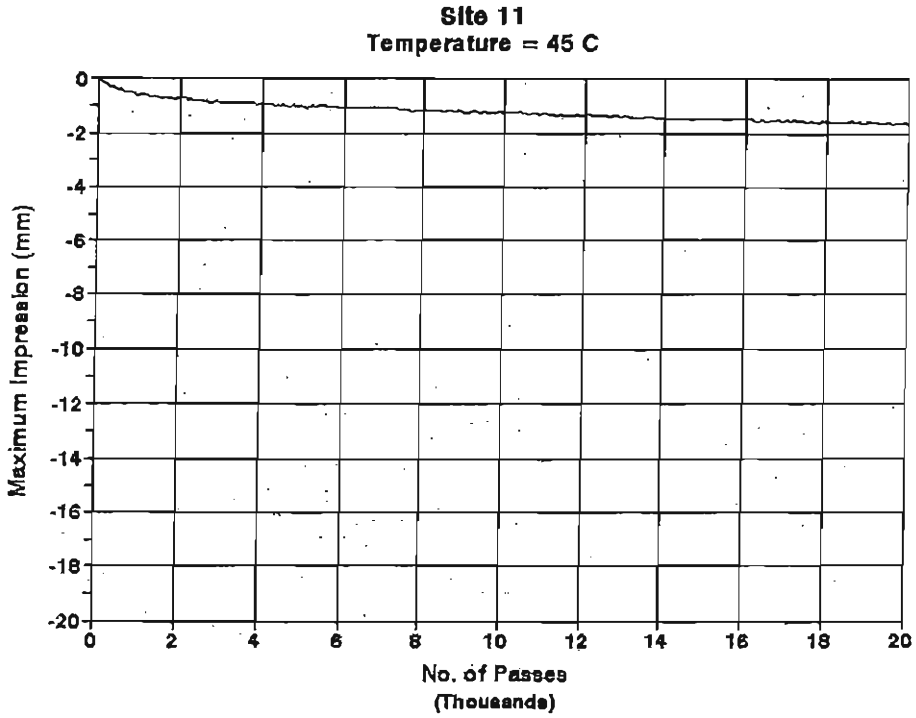

Site No. 10 Profiles
Temperature = 50 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Passes
10000 Passes
16000 Passes
20000 Passes

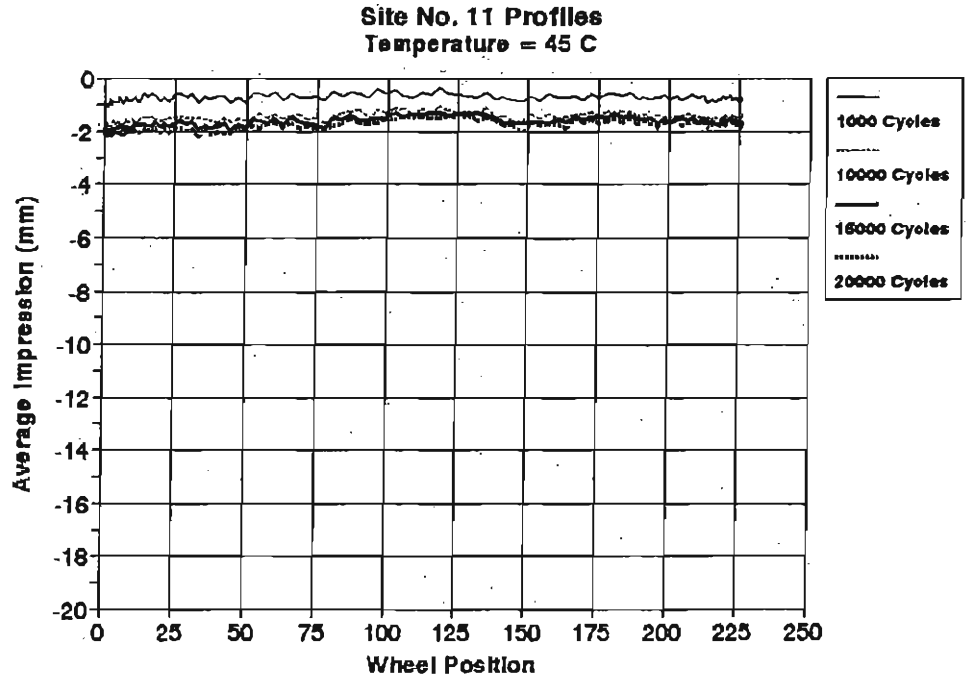

Site 10
Temperature = 45 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

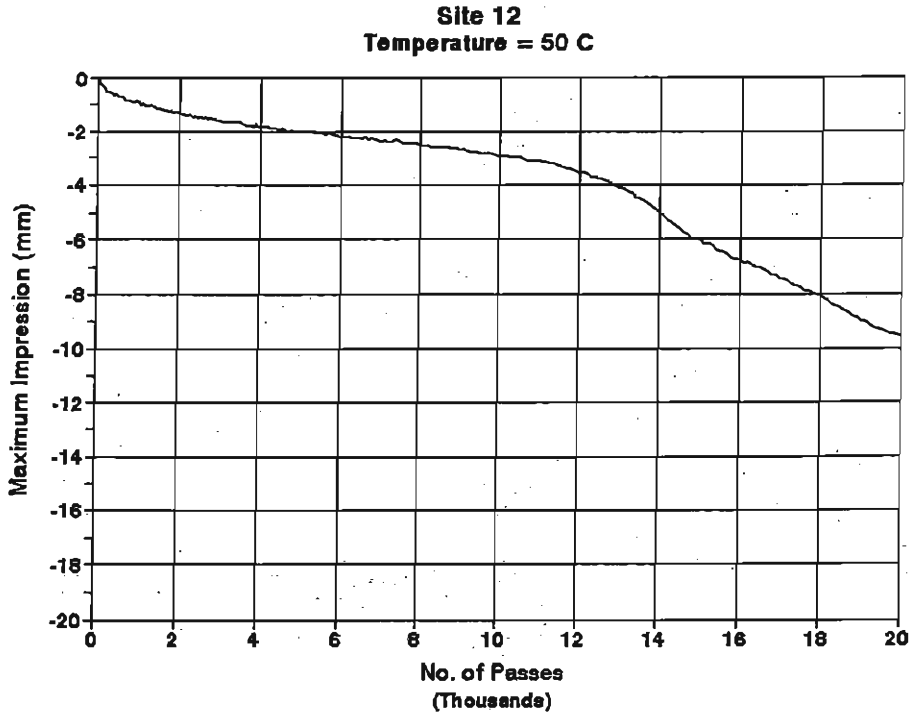

Site No. 10 Profiles
Temperature = 45 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Cycles
10000 Cycles
15000 Cycles
20000 Cycles

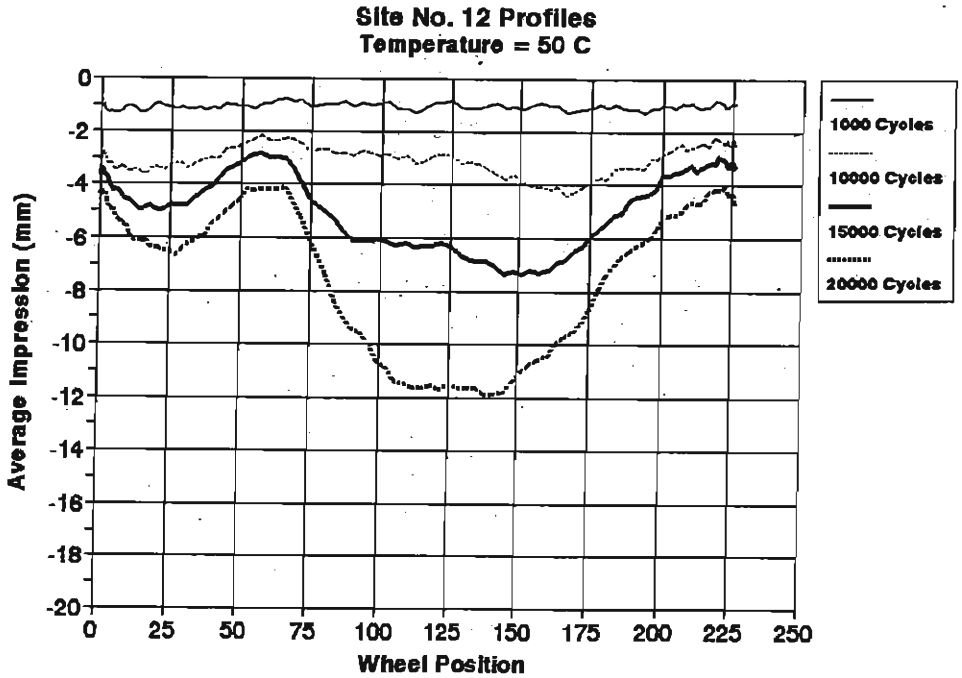

Site 11
Temperature = 50 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

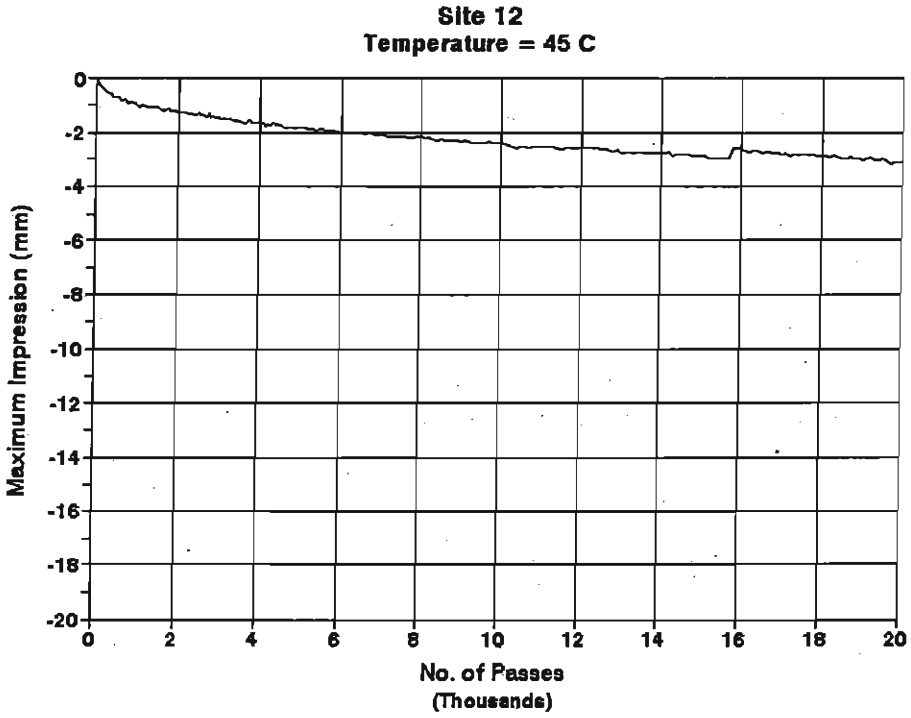

Site No. 11 Profiles
Temperature = 50 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Cycles
10000 Cycles
15000 Cycles
20000 Cycles

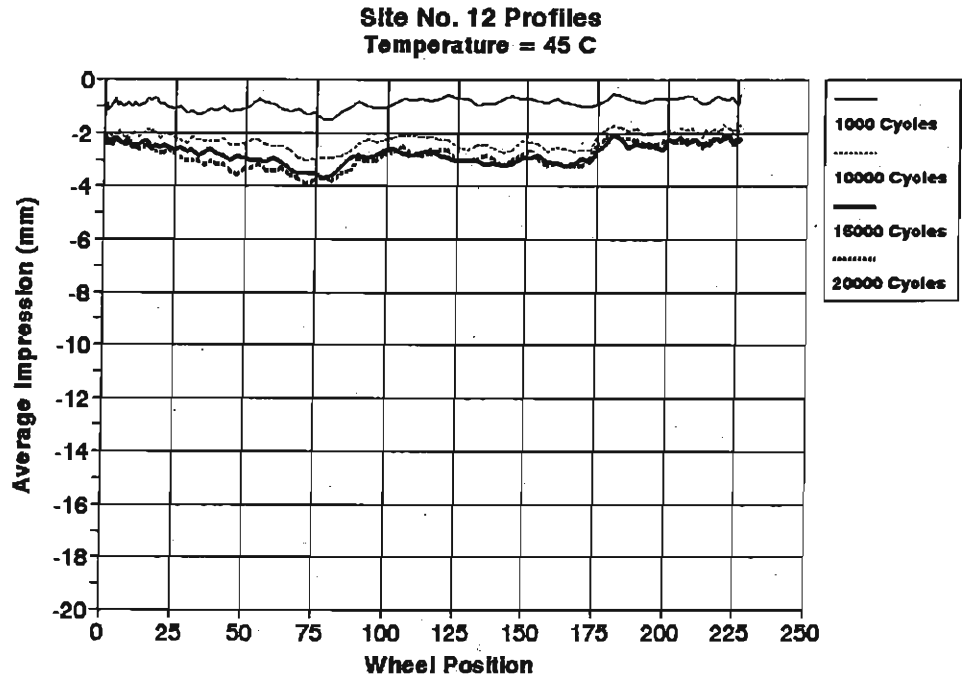

Site 11
Temperature = 45 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

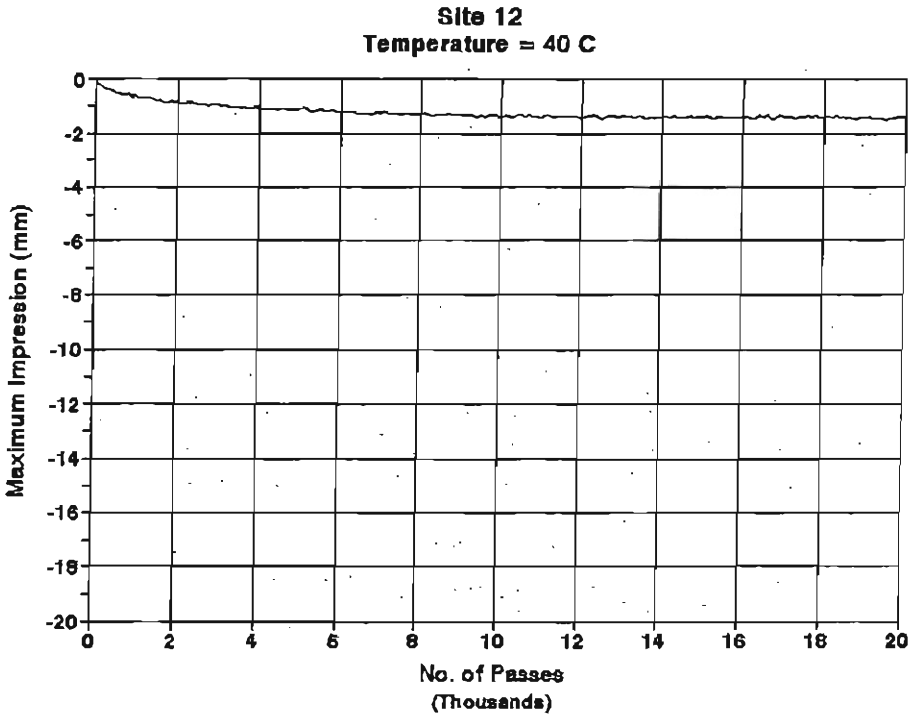

Site No. 11 Profiles
Temperature = 45 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Cycles
10000 Cycles
16000 Cycles
20000 Cycles

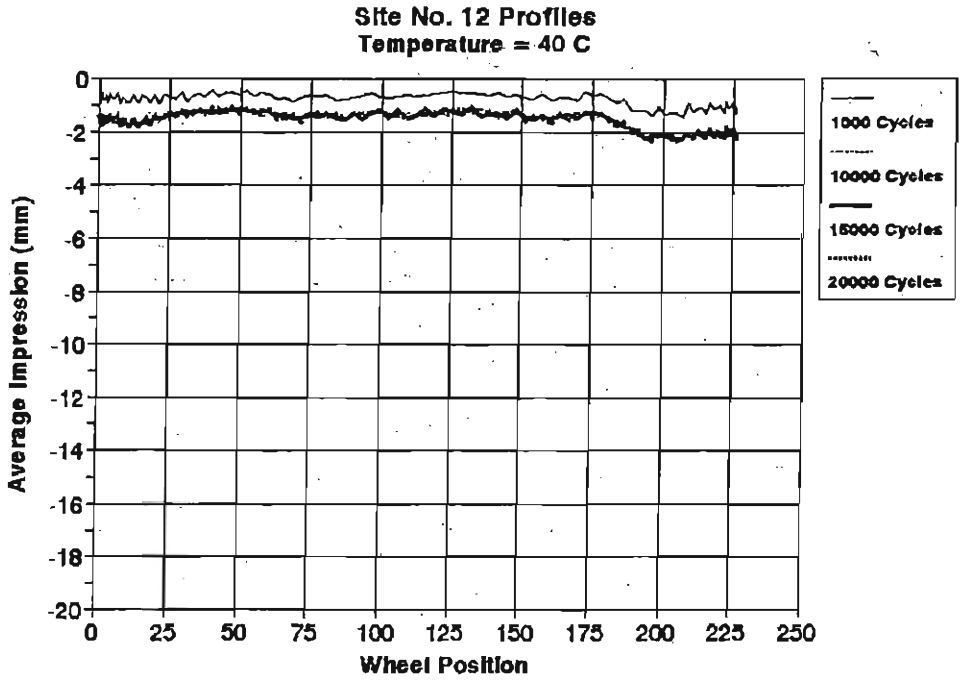

Site 12
Temperature = 50 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

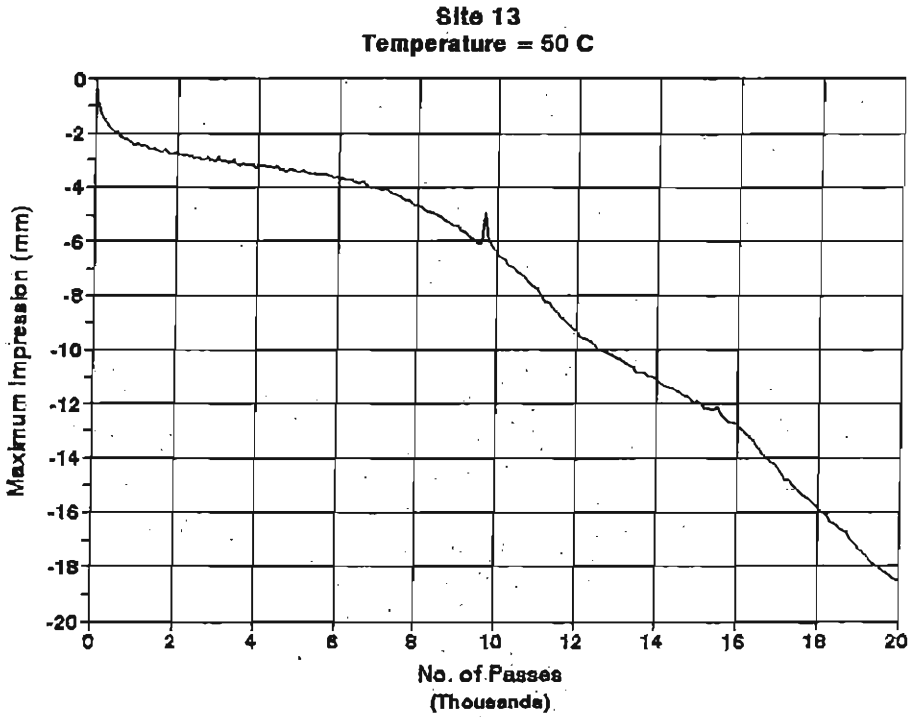

Site No. 12 Profiles
Temperature = 50 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Cycles
10000 Cycles
15000 Cycles
20000 Cycles

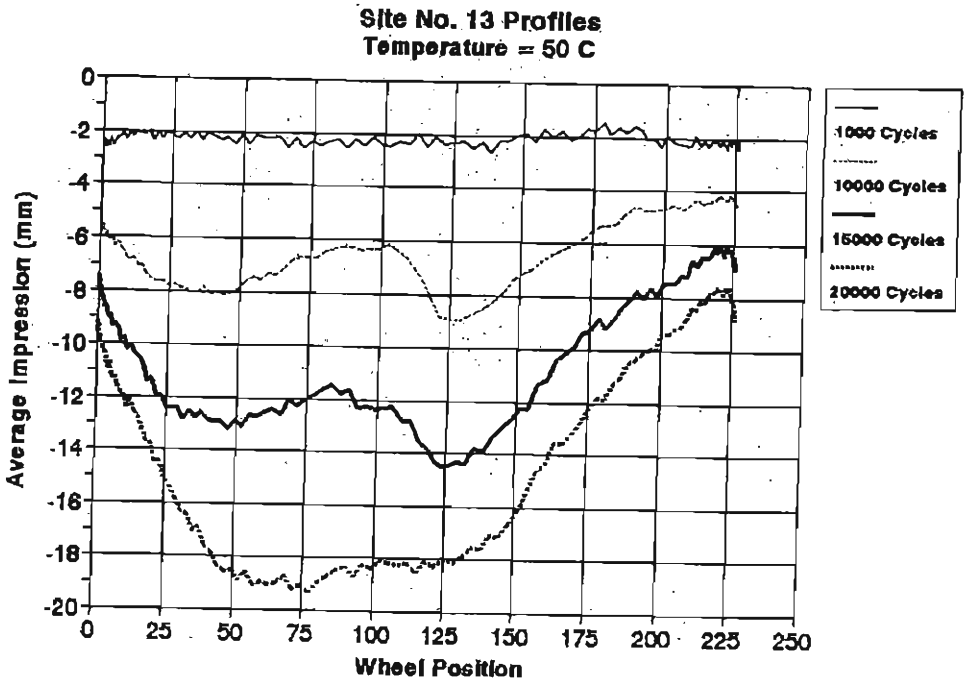

Site 12
Temperature = 45 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

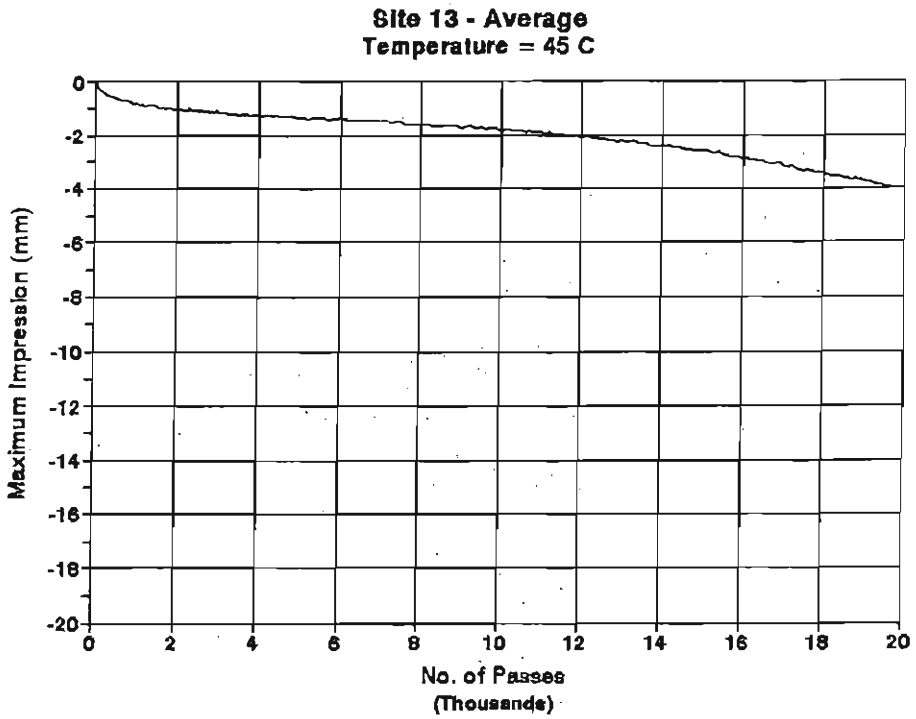

Site No. 12 Profiles
Temperature = 45 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Cycles
10000 Cycles
15000 Cycles
20000 Cycles

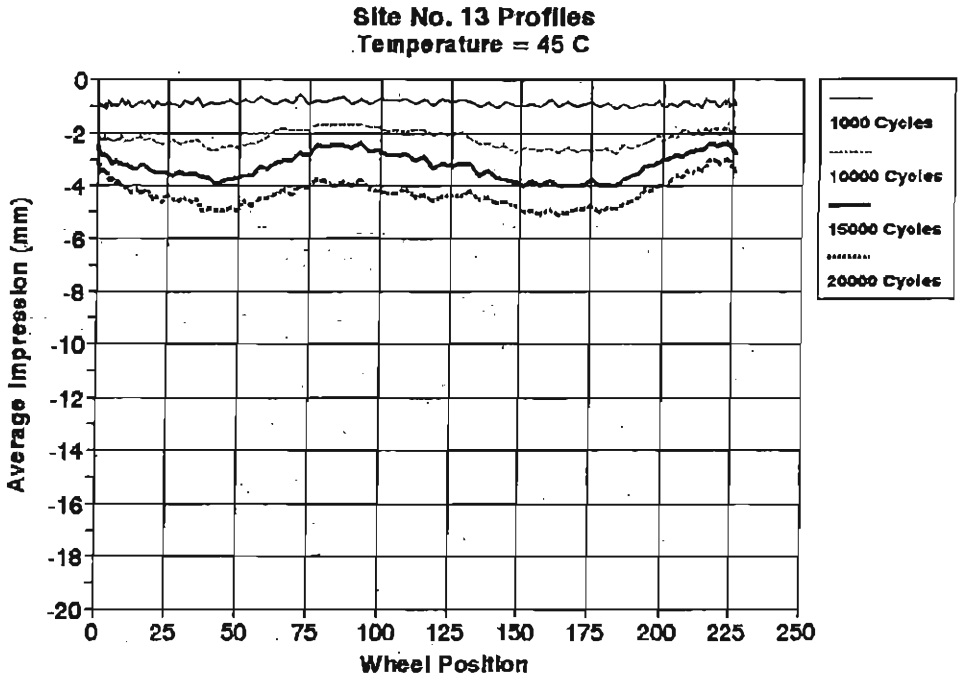

Site 12
Temperature = 40 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

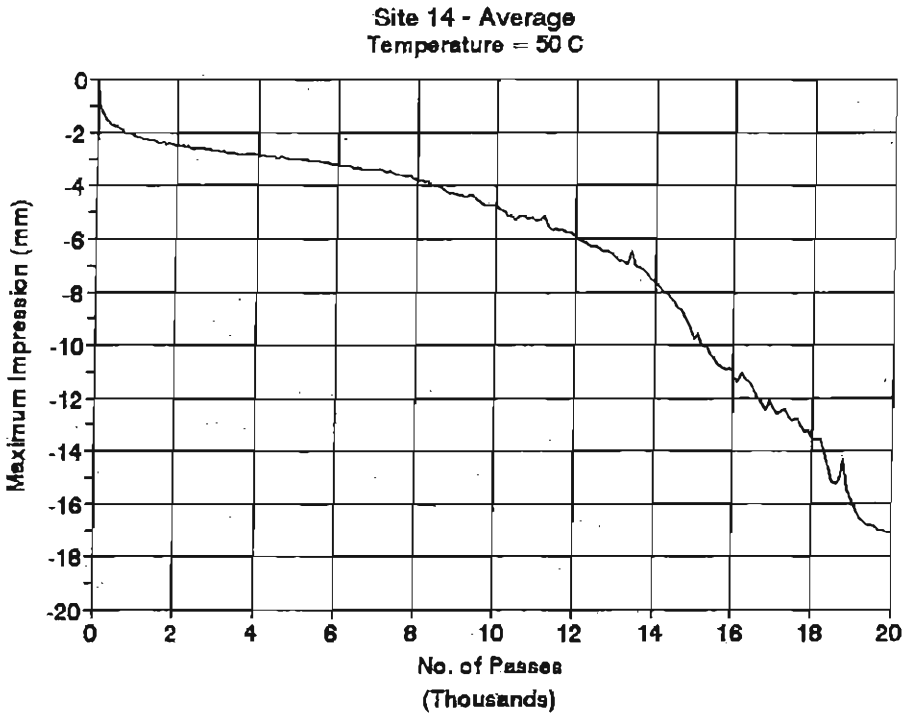

Site No. 12 Profiles
Temperature = 40 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Cycles
10000 Cycles
15000 Cycles
20000 Cycles

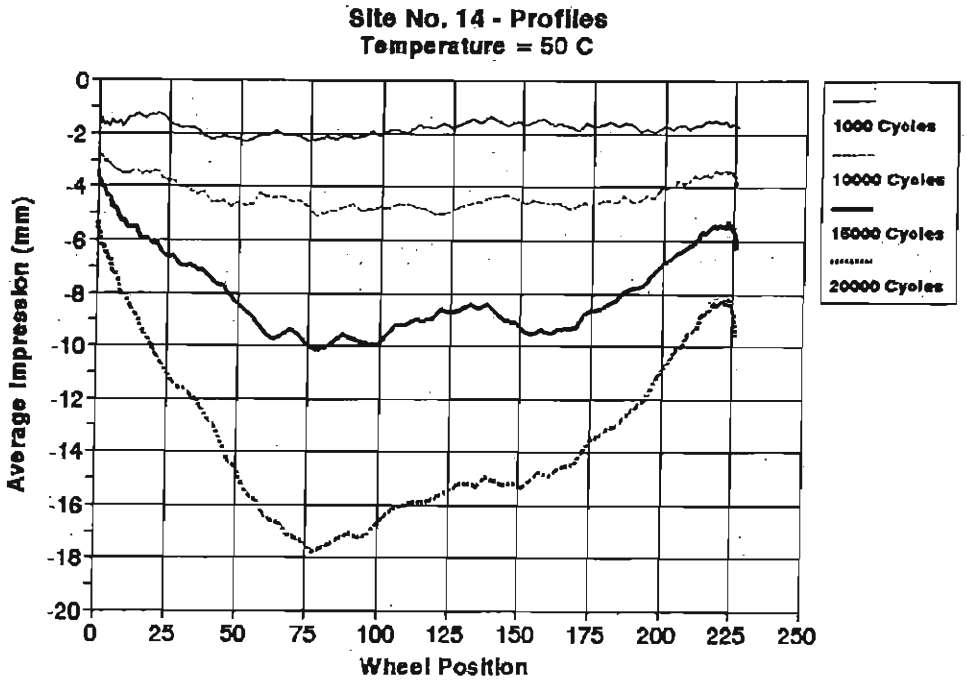

Site 13
Temperature = 50 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

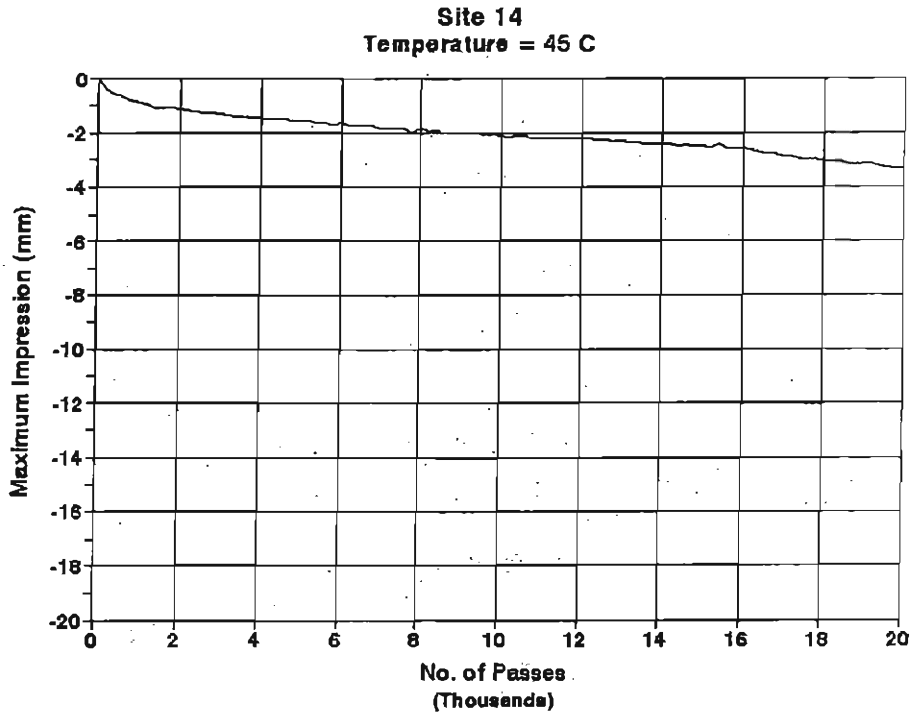

Site No. 13 Profiles
Temperature = 50 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Cycles
10000 Cycles
15000 Cycles
20000 Cycles

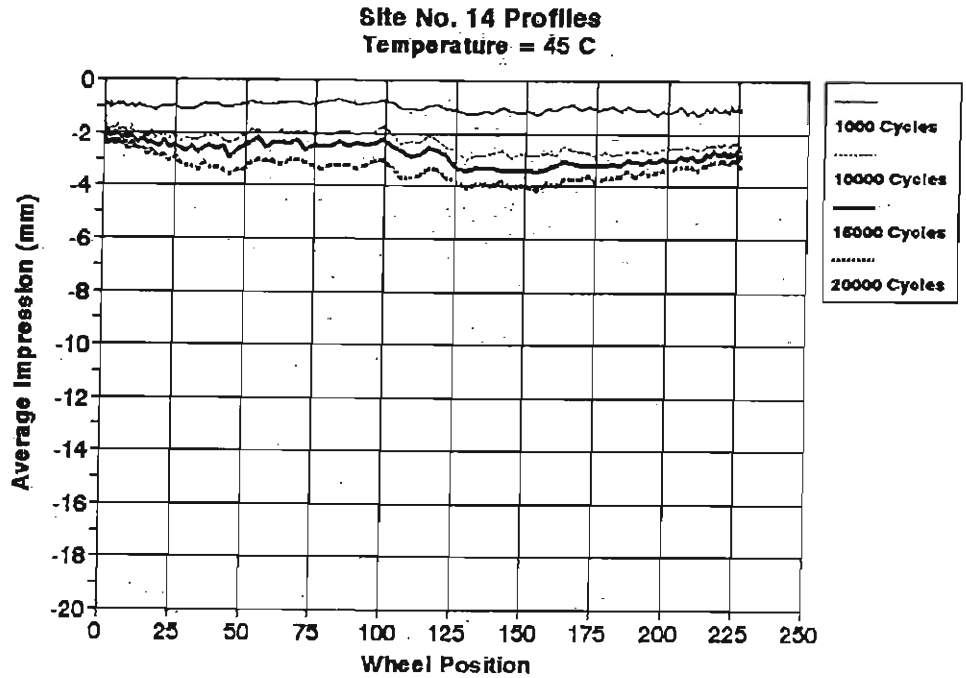

Site 13 - Average
Temperature = 45 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

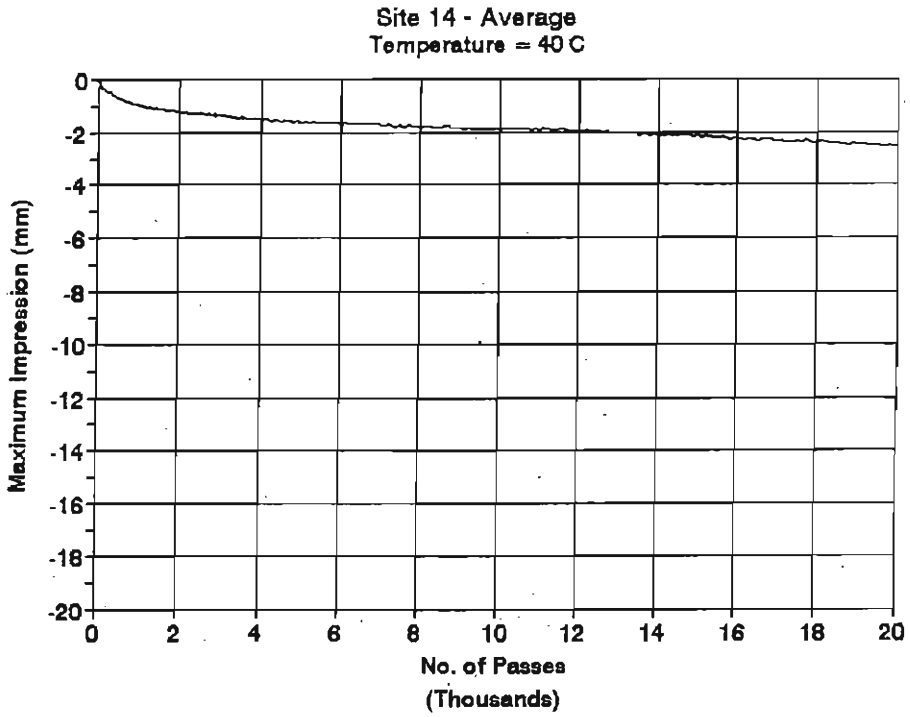

Site No. 13 Profiles
Temperature = 45 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Cycles
10000 Cycles
15000 Cycles
20000 Cycles

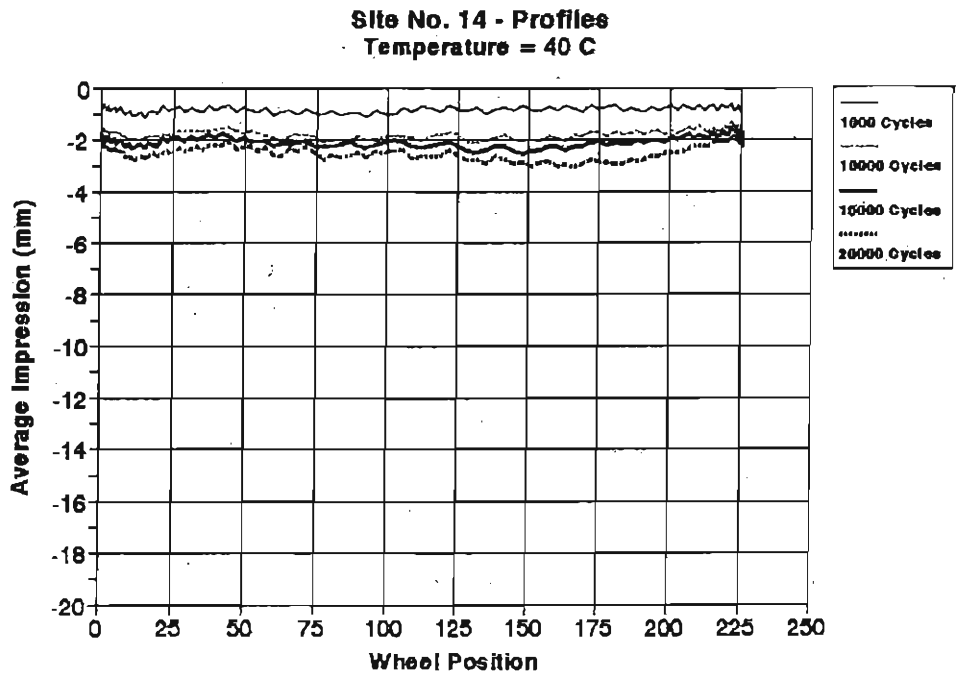

Site 14 - Average
Temperature = 50 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

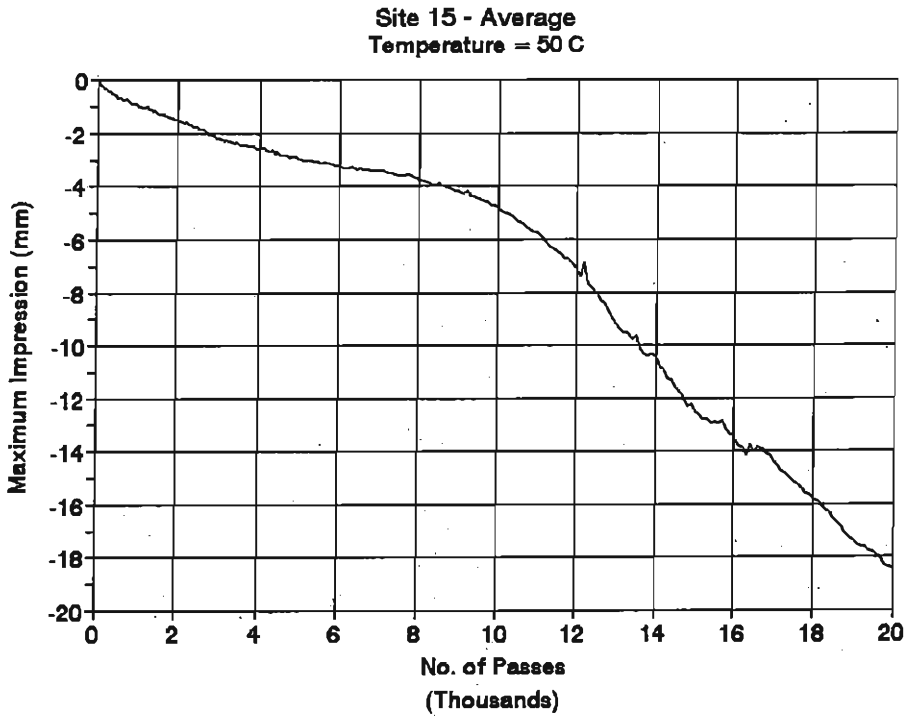

Site No. 14 - Profiles
Temperature = 50 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Cycles
10000 Cycles
15000 Cycles
20000 Cycles

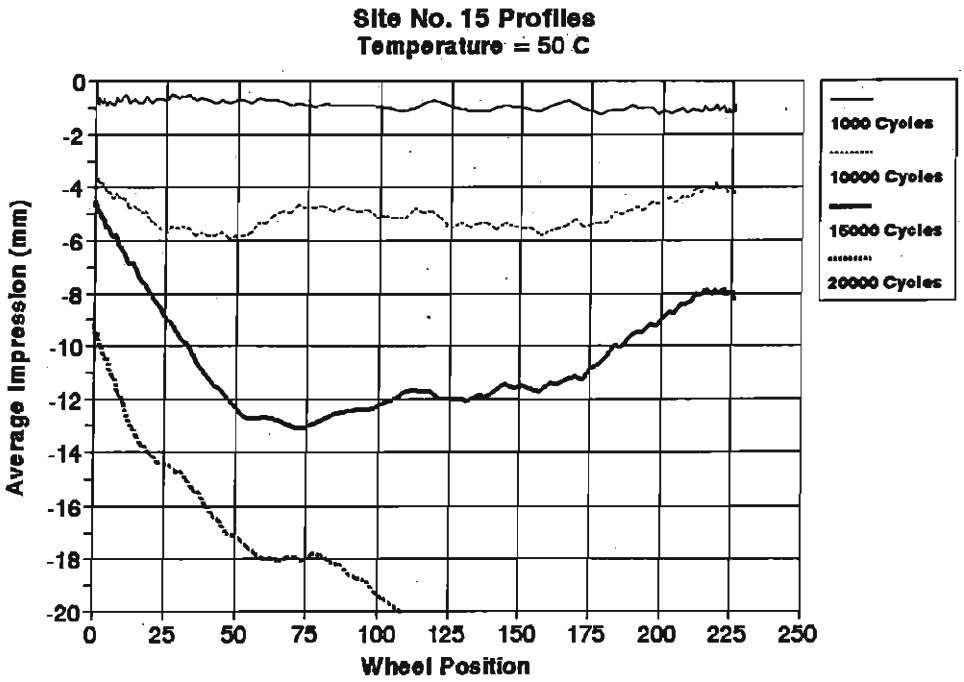

Site 14
Temperature = 45 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

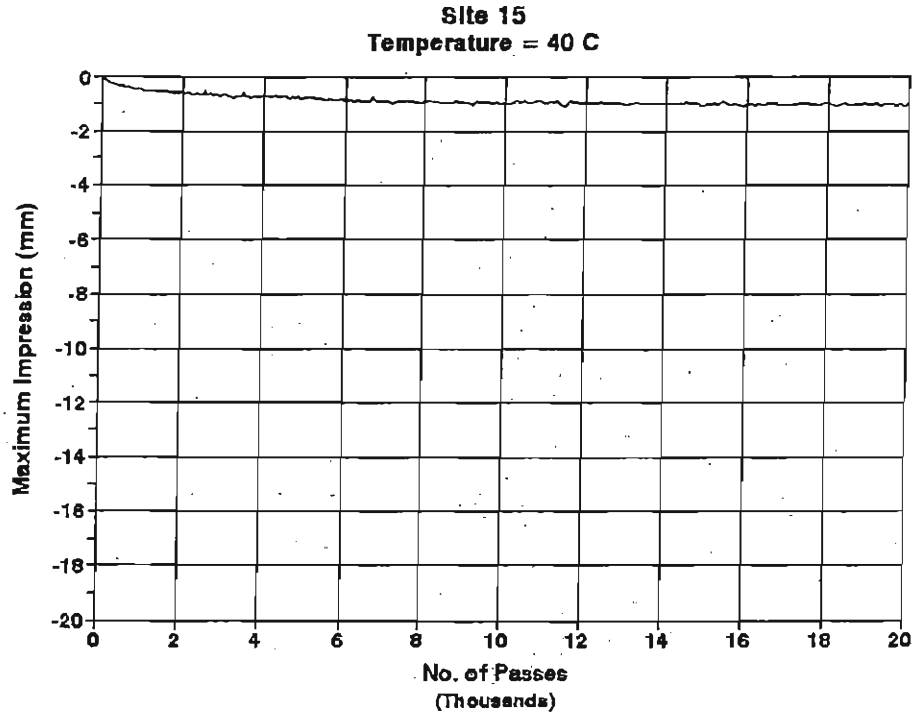

Site No. 14 Profiles
Temperature = 45 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Cycles
10000 Cycles
15000 Cycles
20000 Cycles

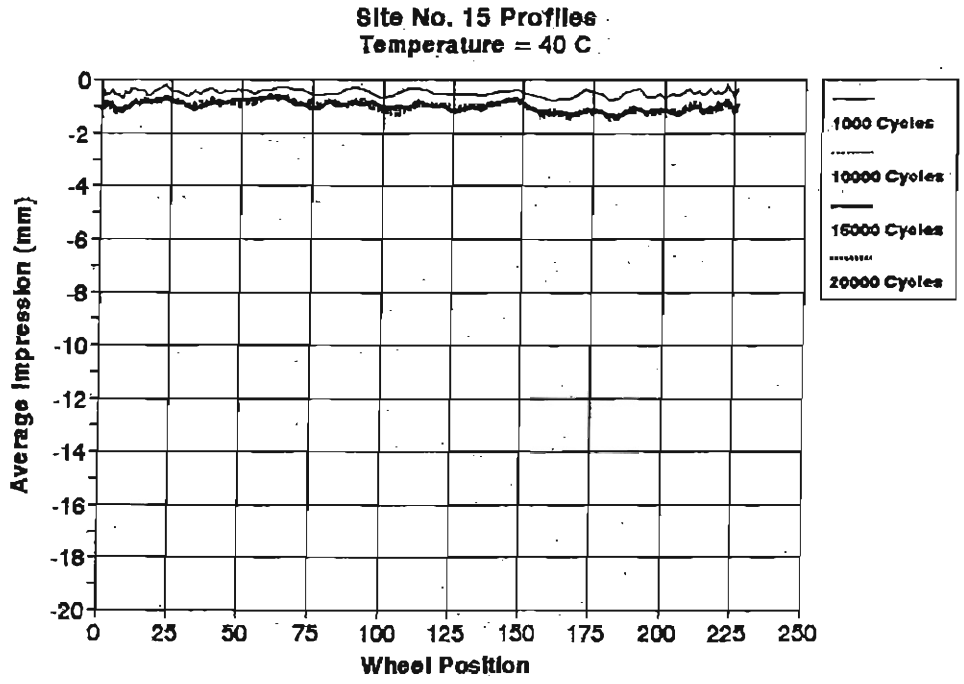

Site 14 - Average
Temperature = 40 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

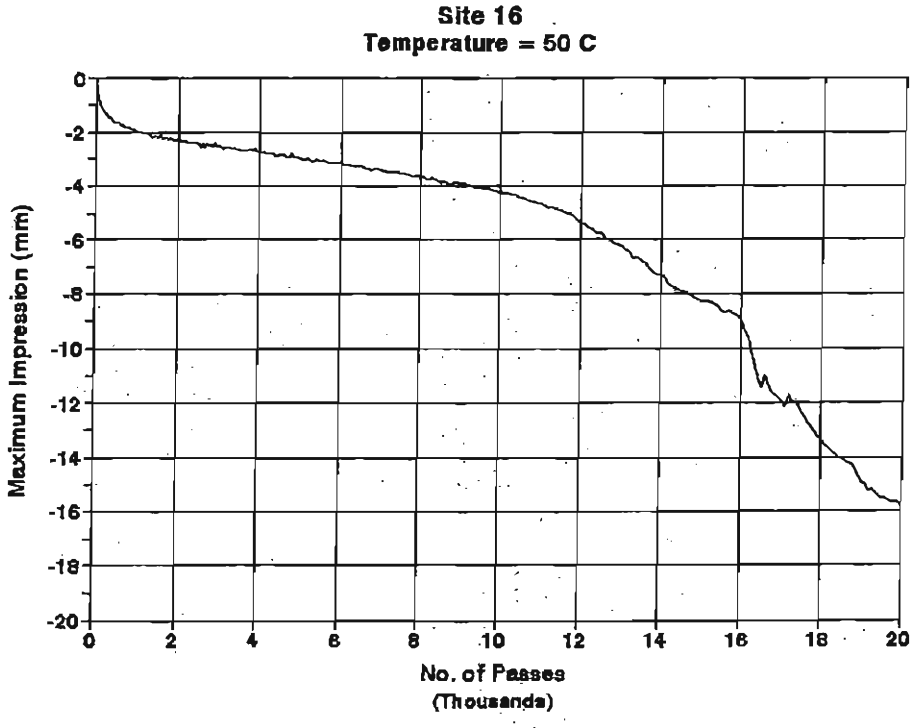

Site No. 14 - Profiles
Temperature = 40 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Cycles
10000 Cycles
15000 Cycles
20000 Cycles

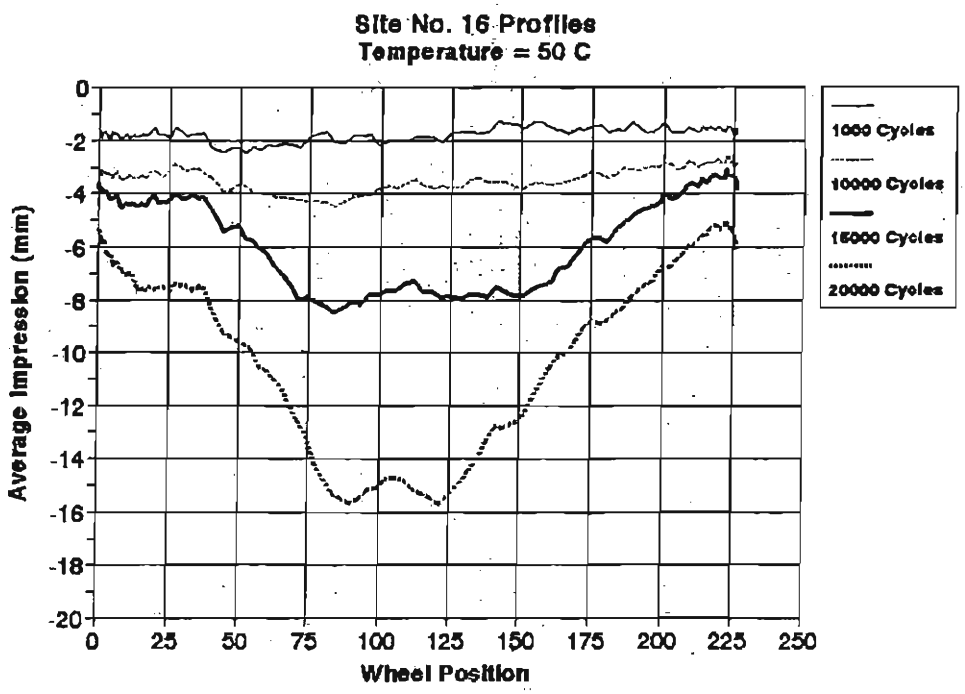

Site 15 - Average
Temperature = 50 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)

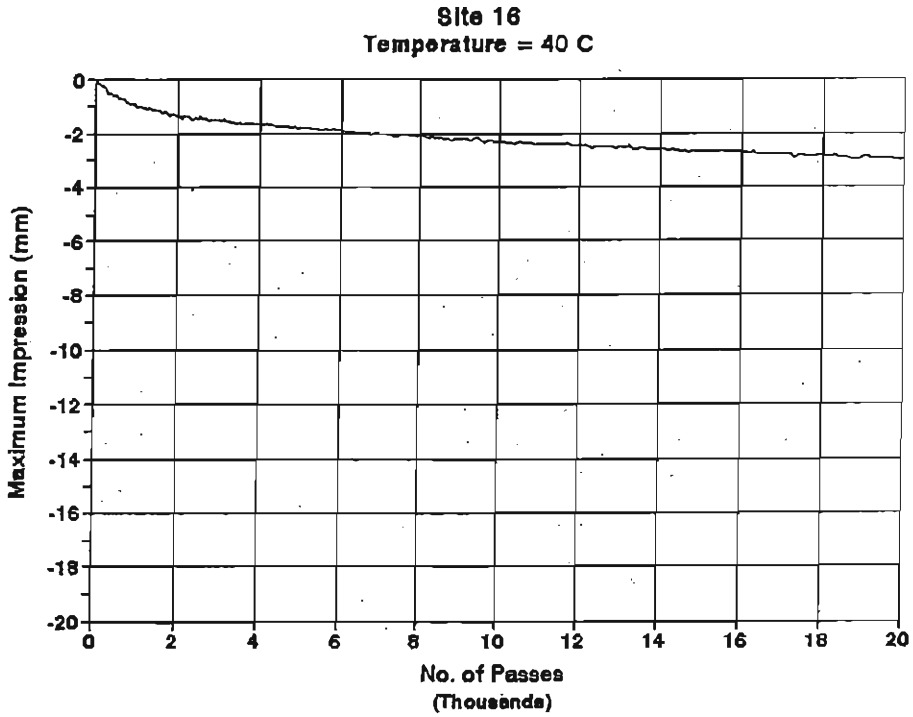

Site No. 15 Profiles
Temperature = 50 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Cycles
10000 Cycles
15000 Cycles
20000 Cycles

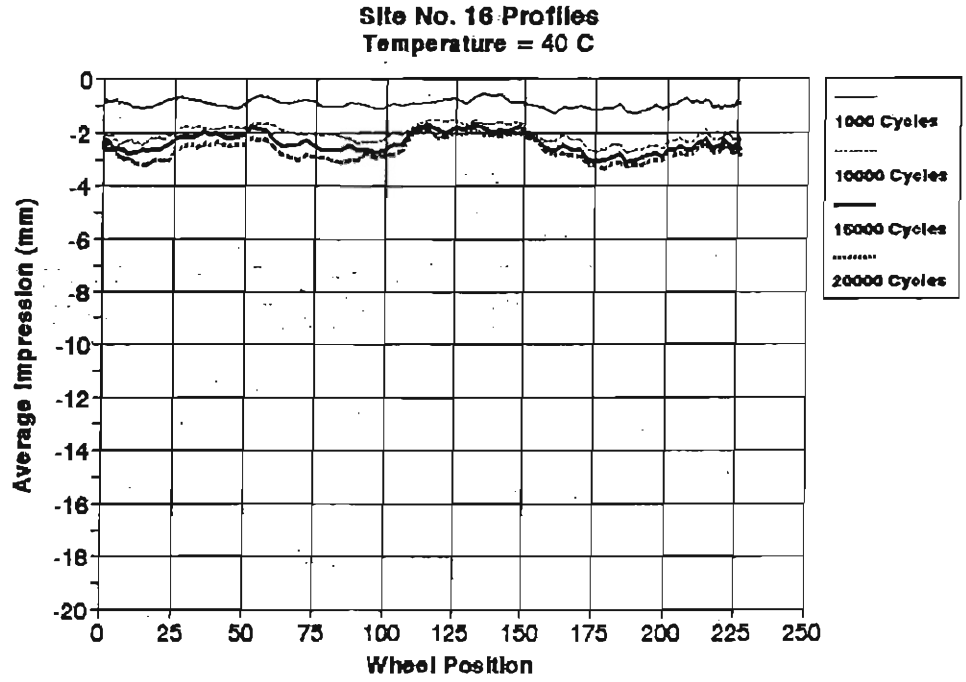

Site 15
Temperature = 40 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)


Site No. 15 Profiles
Temperature = 40 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Cycles
10000 Cycles
15000 Cycles
20000 Cycles


Site 16
Temperature = 50 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)


Site No. 16 Profiles
Temperature = 50 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Cycles
10000 Cycles
15000 Cycles
20000 Cycles


Site 16
Temperature = 40 C
Maximum Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2
4
6
8
10
12
14
16
18
20
No. of Passes
(Thousands)


Site No. 16 Profiles
Temperature = 40 C
Average Impression (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
25
50
75
100
125
150
175
200
225
250
Wheel Position
1000 Cycles
10000 Cycles
15000 Cycles
20000 Cycles