MoDOT

Research, Development and Technology

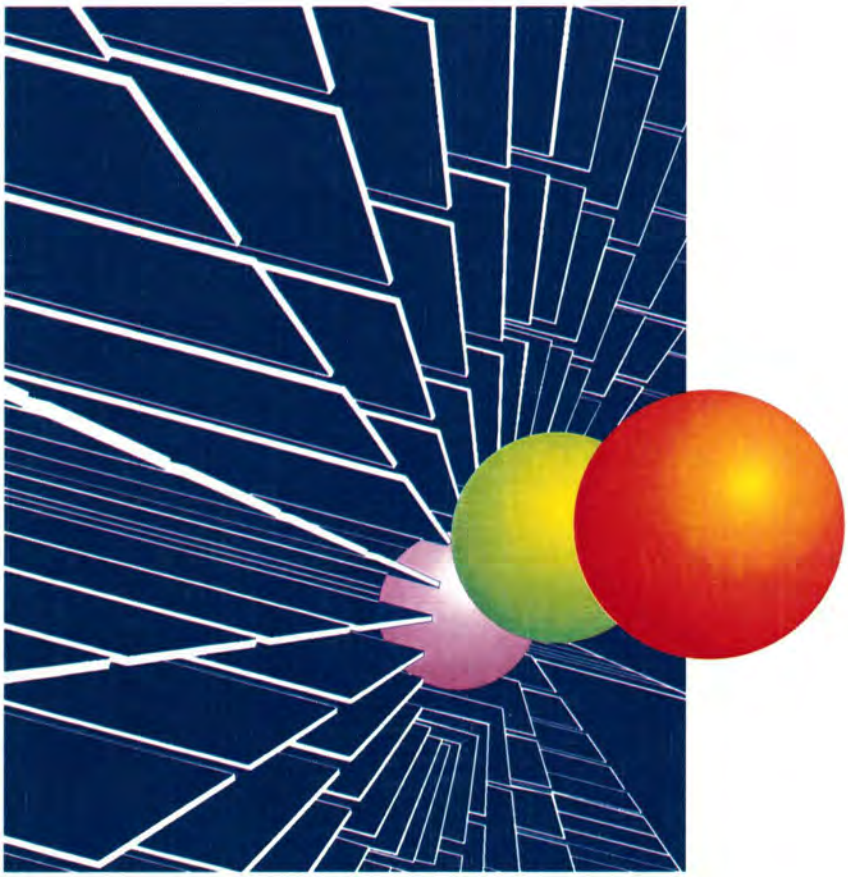
ERES Consultants

RDT 00-014

Analysis of PCC Pavement Rehabilitation in Missouri

Review of the Performance of Long-Term Pavement Performance Test Sections to Date

RI 99-023



September, 2000

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
RDT-00-014		

4. Title and Subtitle	5. Report Date
Analyses of PCC Pavement Rehabilitation in Missouri-Review of the Performance of Long-Term Pavement Performance Test Sections to Date	September 2000
	6. Performing Organization Code: Missouri DOT
7. Author(s): J. K. Ambroz and T. P. Wilson	8. Performing Organization Report No.: RDT 00-014/RI99-023
9. Performing Organization Name and Address: ERES Consultants, A Division of Applied Research Associates, Inc., 505 W. University Avenue, Champaign, IL 61820-3915	10. Work Unit No. (TRAIS)
	11. Contract or Grant No.
12. Sponsoring Agency Name and Address: Missouri Department of Transportation, 1617 Missouri Boulevard, Jefferson City, Missouri 65102	13. Type of Report and Period Covered: Final Report
	14. Sponsoring Agency Code: Missouri DOT

15. Supplementary Notes

This investigation was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. Abstract

This report details the analyses performed on rehabilitated portland cement concrete (PCC) pavement sections in Missouri that are being monitored as part of the Long-Term Pavement Performance (LTPP) program currently administered by the Federal Highway Administration (FHWA). In all, 49 test sections at 9 locations were included to determine the optimum methods of rehabilitating PCC pavements in Missouri. Rehabilitation options investigated in this effort included surface restoration techniques, standard hot-mix asphalt concrete (HMAC) overlay techniques (using both standard and SUPERPAVE design methods and materials), and HMAC overlays of fractured PCC layers (break-and-seat and rubblizing were used).

The researchers reviewed structural integrity, ride quality, and surface deterioration indicators. In addition, traffic, climate, and materials testing data were evaluated and summarized. Unit cost information on the various maintenance and rehabilitation techniques was provided by the Missouri DOT and included in the study through the calculation of cost-effectiveness values for each of the rehabilitated sections.

Findings and conclusions presented in this report are based on the data available at the time of analyses. Since all of the test sections are still in service and continue to be monitored as part of the LTPP program, it is possible that different findings and conclusions could be derived in the future.

17. Key Words	18. Distribution Statement
Pavement rehabilitation, PCC pavements, pavement surface restoration, HMAC overlays, rubblizing, break-and-seat, LTPP, cost-effectiveness	No restrictions

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No of Pages	22. Price
Unclassified	Unclassified	83	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

EXECUTIVE SUMMARY

This research effort has focused on addressing the question of how best to rehabilitate portland cement concrete (PCC) pavement in the State of Missouri, by using performance data collected by the Strategic Highway Research Program (SHRP) and the Federal Highway Administration (FHWA) over the past 10 years as part of the Long-Term Pavement Performance (LTPP) program. The 49 test sections at 9 locations throughout Missouri have been part of the LTPP program for many years, and as such have been subjected to standard pavement performance data collection efforts as part of the largest pavement research program ever undertaken.

The methods of PCC pavement rehabilitation included at these sites ranged from surface restoration techniques (patching, crack/joint sealing, diamond grinding), to overlays with additional bonded PCC layers, to standard overlays with hot-mix asphalt concrete (HMAC) materials (using both standard and SUPERPAVE design methods), to HMAC overlays of fractured PCC (using both rubblization and break and seat operations).

Throughout this investigation, various performance indicators have been reviewed including structural integrity (using deflection data); ride quality (using the International Roughness Index [IRI]), and surface deterioration (using surface distress types and severities developed by and for the LTPP program). In addition to the pavement performance indicators, additional data collected by the LTPP program were evaluated and summarized in the areas of traffic, climate, and materials testing properties. The intent of all of this data review and analyses was to determine which were the optimum rehabilitation alternatives for PCC pavements based on the available test sites.

While many different trends and performance differences were noted for the various rehabilitation alternatives, the final component in determining which were the most desirable—or conversely those alternatives which should be avoided—was completed using the relative performance and estimated costs for performing each rehabilitation. While the majority of the performance data were collected as part of LTPP program, the cost information included in the cost-effectiveness calculations was provided by the Missouri DOT, and represents the costs associated with performing the different activities at the present time. This coupling of performance data collected over the past several years, and the costs associated with performing various repair activities at the present time, was intended to provide the answers which could benefit the decision making process in the Missouri DOT today, and into the future. LTPP has identified those alternatives which perform better, Missouri DOT knows how much it would cost to perform those alternatives today, and the result is a series of relative rankings which help to indicate which rehabilitation options are the ones which will be most cost-effective. The best cost-effectiveness rankings for the different test sites.

For the Specific Pavement Studies (SPS) test site on I-35 near Bethany, Missouri, the best cost-effectiveness rankings were for a bare PCC section which had minimal surface preparation and undersealing of the slabs (low cost for repair and little change in pavement roughness over time) and HMAC overlays of fractured PCC (very little pre-overlay repair to original PCC; and good reduction in pavement roughness over time). For the SPS test site on US 67 near Festus,

Missouri, the best cost-effectiveness rankings were for a 3-in bonded PCC overlay (with original PCC surface cold-milled), a standard 3-in HMAC overlay, and a 4-in bonded PCC overlay, while the 5-in bonded PCC overlays had the lowest rankings to due increases in roughness over time.

The two other SPS test sites—US 69 near Sedalia, Missouri, and Rt. 9 near Potosi, Missouri—were also reviewed during this effort, but as they are newer sites, the differences in performance needed to begin identifying the best alternatives have not yet materialized. It is expected that these sites will yield results which can be used by the Missouri DOT within the next 5-6 years.

The final set of test sites included in this study were the 5 General Pavement Studies (GPS) test sites of rehabilitated PCC located throughout Missouri. Each of these sites consisted of an HMAC overlay of the PCC, and each has performed well since their rehabilitation. Because these sites contain only a single test section, their value does not lie in the comparisons of many different alternatives at a single location as with the SPS sites, but these sites should provide useful information on the expected service lives of the HMAC overlays under different traffic and climatic conditions, and provide information on the distress development and the failure modes to help identify those areas where design of the rehabilitations should focus in the future.

TABLE OF CONTENTS

Executive Summary i

1.0 INTRODUCTION 1
LTPP PROGRAM BACKGROUND 1
MISSOURI LTPP INVOLVEMENT 1

2.0 INVENTORY 5

3.0 CONSTRUCTION DATA 8
SECTION DESCRIPTIONS 8
Bethany (SPS-6 1992) 8
Potosi (SPS-6 1998) 12
Festus (SPS-7) 14
Sedalia (SPS-9A) 17
GPS-7 Experimental Sections 20
CONSTRUCTION SUMMARIES 21

4.0 TRAFFIC, CLIMATE, AND MATERIALS 27
TRAFFIC 27
CLIMATIC DATA 29
MATERIALS TESTING DATA 30

5.0 PAVEMENT PERFORMANCE INDICATORS 35
SURFACE DISTRESS 35
RIDE DATA 36
STRUCTURAL RESPONSE 37

6.0 PERFORMANCE TRENDS 39
ROUGHNESS TRENDS 39
Bethany and Potosi (SPS-6) 39
Festus (SPS-7) 43
Sedalia (SPS-9A) 45
GPS-7 45
SURFACE DISTRESS 46
Bethany (SPS-6) 46
Festus (SPS-7) 51
STRUCTURAL EVALUATION 56
Bethany (SPS-6) 56
Potosi (SPS-6) 56
Festus (SPS-7) 58
Sedalia (SPS-9A) 58

PERFORMANCE TRENDS SUMMARY 58
Bethany (SPS-6) 58
Potosi (SPS-6) 63
Festus (SPS-7) 64
Sedalia (SPS-9A) 64
GPS-7 65

7.0 COST DATA 66

8.0 COST-EFFECTIVENESS FINDINGS 74

9.0 FINDINGS AND CONCLUSIONS 80

REFERENCES 83

Appendix A—Summary of performance data included in report

Appendix B—Distributions of traffic by single- and tandem-axle, and vehicle classification.

Appendix C—Climatic data plots for all test sites.

Appendix D—Materials testing data plots for all test sites.

Appendix E—Plots of OUTER Area pavement support data.

Analyses of PCC Pavement Rehabilitation in Missouri
Review of the Performance of Long-Term Pavement Performance Test Sections

1.0 INTRODUCTION

This report has been prepared to address a specific area of concern for the Missouri Department of Transportation (DOT)—the most effective methods for rehabilitating portland cement concrete (PCC) pavements. The analyses were performed using performance data from the Long Term Pavement Performance (LTPP) database. These data are from Missouri sites that are still being actively monitored, so the findings and conclusions presented are limited to the age and traffic levels on these pavements. Additional data collected in the future will help to confirm, alter, or negate the findings and conclusions in this report.

LTPP PROGRAM BACKGROUND

In 1989, the Strategic Highway Research Program (SHRP) established the LTPP program and began collecting pavement performance data on in-service pavement sections throughout North America. The LTPP effort was roughly one-third of the entire 5-year SHRP effort, with the remainder of SHRP devoted to hot-mix asphalt concrete (HMAC) pavement materials and maintenance and operation issues. In 1992, the responsibility of running LTPP was shifted from SHRP to the Federal Highway Administration (FHWA), which has been responsible for its continued operation since then.

The LTPP program was designed as a 20-year program with the goal of collecting pavement data on existing and newly constructed or rehabilitated pavements to improve design, construction, materials, and maintenance activities. The official objective of the LTPP program was to:

> Increase pavement life by the investigation of the long-term performance of various designs of pavement structures, using different materials and under different loads, environments, subgrade soils, and maintenance practices.

MISSOURI LTPP INVOLVEMENT

The Missouri DOT has participated in the LTPP program since 1989. Currently, the State has 20 sections in the General Pavement Studies (GPS) program and 79 sections in the Specific Pavement Studies (SPS) program at 11 sites, the most recent having been constructed in 1999. Figure 1.1 is a map that shows all Missouri LTPP section locations.

The GPS experiments in which Missouri is participating include:

GPS-1—HMAC on granular base
GPS-2—HMAC on stabilized base
GPS-3—Jointed plain concrete pavement (JPCP)
GPS-4—Jointed reinforced concrete pavement (JRCP)

Missouri (29)

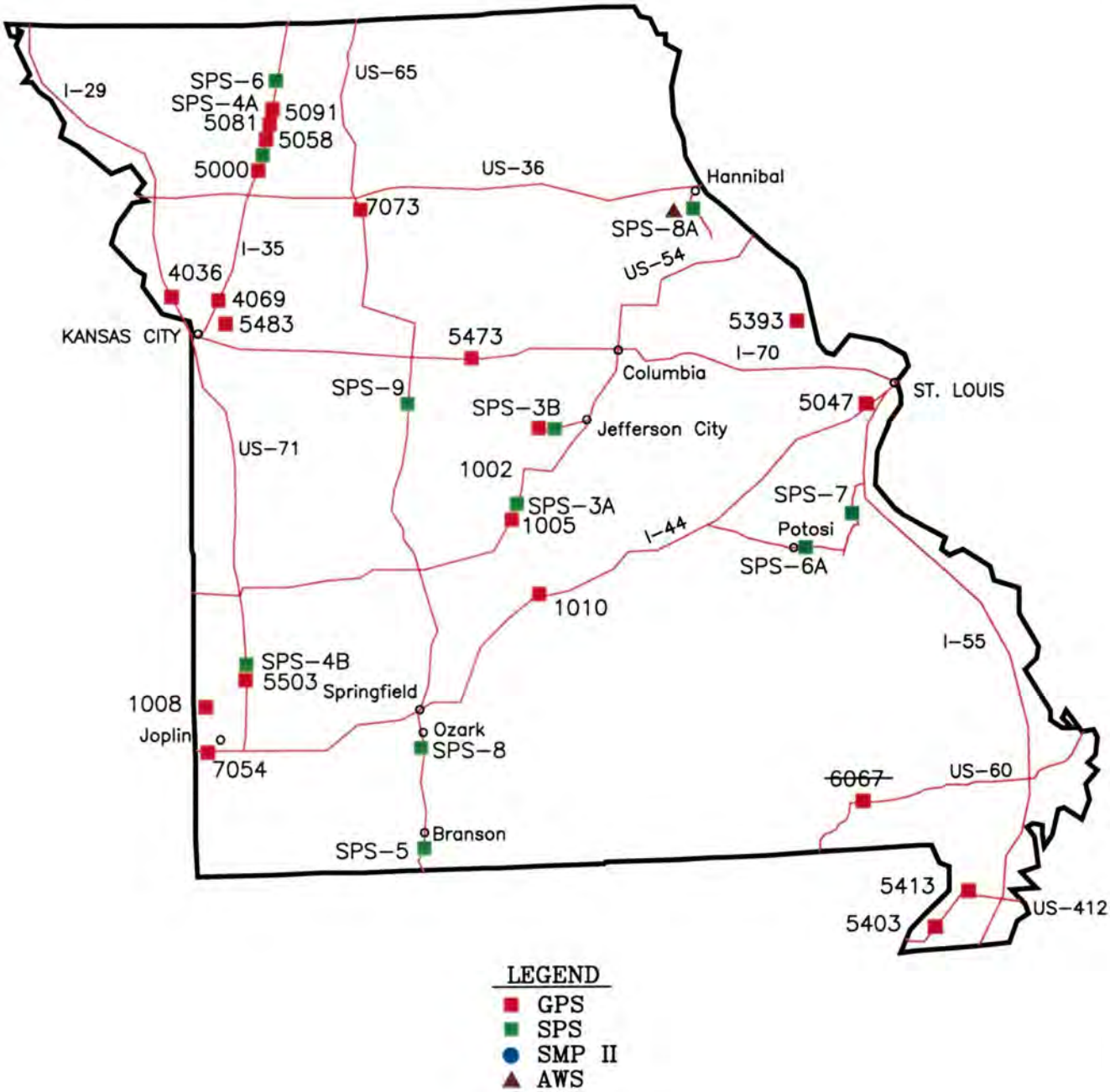


Figure 1.1 Location of all GPS & SPS test sites in Missouri

GPS-5—Continuously reinforced concrete pavement (CRCP)
GPS-6—HMAC overlay of HMAC pavement
GPS-7—HMAC overlay of PCC pavement

GPS sections consist of 500-ft monitoring segments of pavement on in-service routes that reflect standard agency design and construction practices.

The SPS experiments in which Missouri is participating include:

SPS-3—HMAC preventive maintenance effectiveness
SPS-4—PCC preventive maintenance effectiveness
SPS-5—Rehabilitation of HMAC pavements
SPS-6—Rehabilitation of jointed PCC pavements
SPS-7—Bonded PCC overlays of PCC pavements
SPS-8—Environmental effects in the absence of heavy loads
SPS-9A—Validation of SUPERPAVE binder specifications

SPS sections are groups of 500-ft monitoring segments (some SPS-6 sections are 1000 ft long) of newly constructed or rehabilitated pavements that were prepared specifically according to LTPP guidelines. Core SPS projects were built to a single set of standards to allow for more meaningful comparison of performance and analyses of results for projects built by different agencies in different climatic regions, with different levels of traffic. In addition to the core sections, agencies had the option of constructing supplemental SPS test sections to include rehabilitation of construction alternatives that were of interest to themselves.

LTPP test sections included in this study for the Missouri DOT consisted of those projects where rehabilitation was performed on an original PCC pavement, as listed below:

SPS-6—Rehabilitation of jointed PCC pavements
SPS-7—Bonded PCC overlays of PCC pavements
SPS-9A—Validation of SUPERPAVE binder specifications; built as an overlay of jointed PCC pavement
GPS-7A—Existing HMAC overlay of PCC pavement
GPS-7B—Planned HMAC overlay of PCC pavement

The LTPP test sections included in this report are summarized in table 1.1. Appendix A lists the dates of the performance data used in this report.

Table 1.1. Summary of LTPP sites included in this research effort.

SPS-6 Bethany	SPS-7 Festus	SPS-9A Sedalia	SPS-6 Potosi	GPS Sections
290601	290701	290901	29A601	294069 (7B)
290602	290702	290902	29A602	295393 (7B)
290603	290703	290903	29A603	295483 (7B)
290604	290704	290959*	29A604	297054 (7A)
290605	290705	290960*	29A605	297073 (7A)
290606	290706	290961*	29A606	
290607	290707	290962*	29A607	
290608	290708	290963*	29A608	
290659*	290709	290964*		
290660*	290759*			
290661*	290760*			
290662*				
290663*				
290664*				
290665*				
290666*				

* Agency supplemental test sections

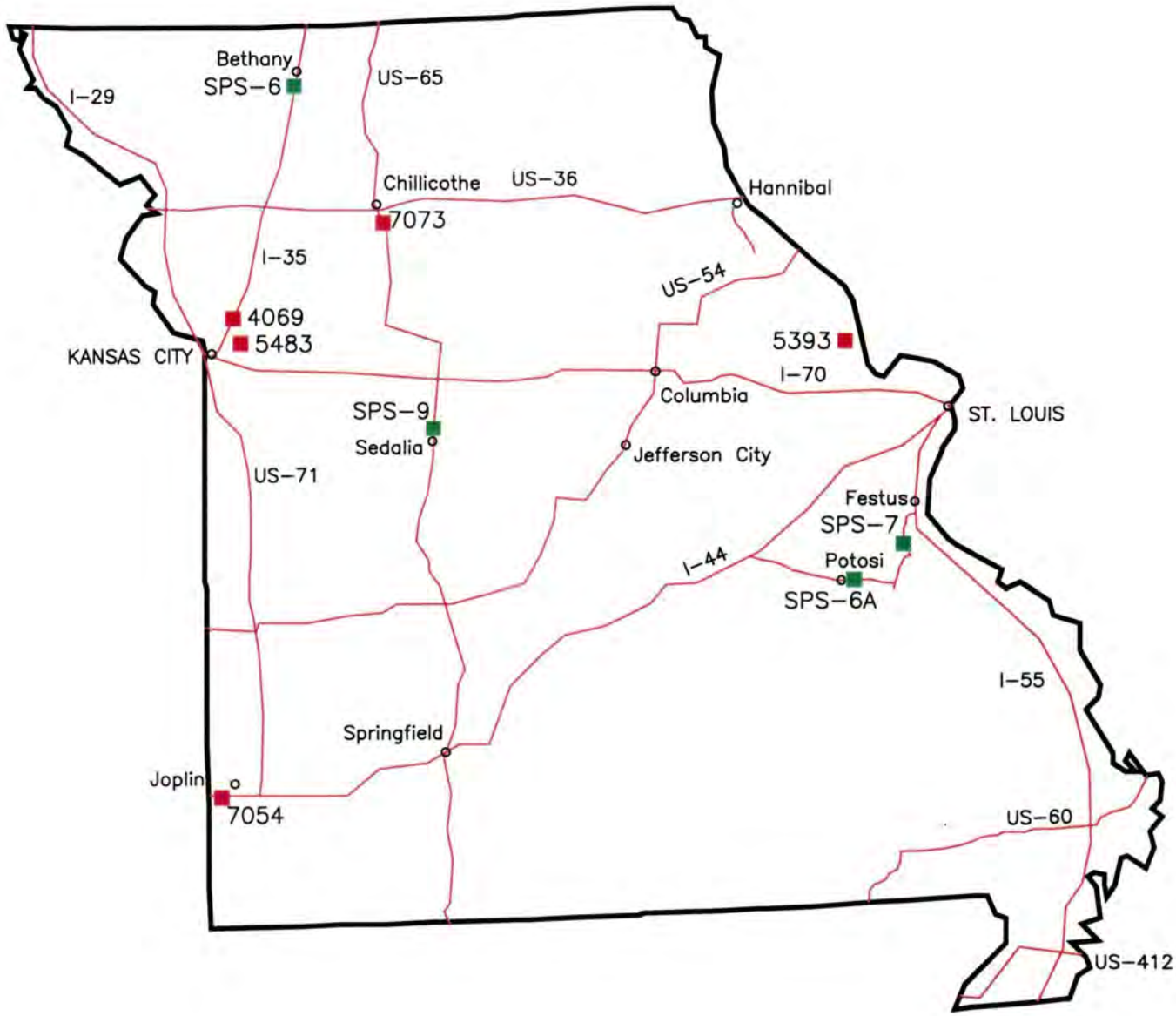
2.0 INVENTORY

The general location information for each Missouri rehabilitated PCC section is described in table 2.1 and illustrated in figure 2.1. Throughout this report, sections will typically be referred to according to the nearest town listed in table 2.1 (e.g., "the Bethany site"). The section identification numbers will be used to distinguish the different rehabilitation techniques from each other within an experiment.

Table 2.1. Section locations in Missouri.

Nearby Town	Sections	Experiment	Highway	Direction
Bethany	290601-290608, 290659-290666	SPS-6	I-35	SB
Potosi	29A601-29A608	SPS-6	Rt. 8	EB
Festus	290701-290709, 290759-290760	SPS-7	US 67	NB
Sedalia	290901-290903, 290959-290964	SPS-9A	US 65	SB
Kansas City	294069	GPS-7B	I-635	SB
St. Louis	295393	GPS-7B	Rt. 79	NB
Kansas City	295483	GPS-7B	Rt. 210	WB
Joplin	297054	GPS-7A	I-44	EB
Chillicothe	297073	GPS-7A	US 65	NB

The dates of initial construction and rehabilitation for each site are listed in table 2.2. This table shows that the original PCC construction occurred between 1955 and 1975 and that the various rehabilitation activities were performed between 1973 and 1998. Only two Missouri sections have formally been de-assigned from the program—sections 290607 and 290659 at the Bethany site. They were both placed out-of-study on September 2, 1995. Sections which are de-assigned from the LTPP program are viewed as no longer existing as a valid test section from the point in time when they are de-assigned. All data collected prior to the de-assign date will be maintained as valid data in the database for the remainder of the program.



LEGEND

- General Pavement Studies (GPS)
- Specific Pavement Studies (SPS)

Figure 2.1 Location of PCC rehabilitated GPS and SPS test sites in Missouri

Table 2.2. Initial construction and rehabilitation dates.

Nearby Town	Sections	Experiment	Highway
Bethany	290601-290608, 290659-290666	1975	1992**
Potosi	29A601-29A608	1969*	1998
Festus	290701-290709, 290759-290760	1955	1990
Sedalia	290901-290903, 290959-290964	1966	1996
Kansas City	294069	1974	1991
St. Louis	295393	1957	1990
Kansas City	295483	1973	1989
Joplin	297054	1957	1973
Chillicothe	297073	1964	1981

* Obtained from construction reports of the LTPP coordination office.
** Based on NCRCO data sheets.

3.0 CONSTRUCTION DATA

This chapter includes a detailed description of the construction and rehabilitation procedures performed within each section for each site. Following these descriptions is a summary of key structural data and rehabilitation techniques.

SECTION DESCRIPTIONS

Bethany (SPS-6 1992)

The Bethany SPS-6 site is located on Interstate 35 in the outer lane in the southbound direction, as shown in figure 3.1. The site consists of 16 sections (8 standard and 8 supplemental) of bare and overlaid jointed reinforced concrete pavement (JRCP). The individual test sections are 500 or 1000 ft long and are separated by transition distances ranging from 150 to 1850 ft.

The original pavement was constructed in 1975 and consists of a 9-in JRCP over polyethylene vapor barrier and 4 in of aggregate base and a silty clay subgrade. The test sections are located on a rolling terrain. The original JRCP has transverse doweled joints with a 61.4-ft joint spacing. The design features of this pavement include a 9.8-ft asphalt concrete (AC) outside shoulder.

When this project was rehabilitated in 1992, the JRCP had carried 14 million equivalent single axle loads (ESAL's) in the design lane. The rehabilitation consisted of placing 4- to 12-in HMAC overlays and the SPS-6 treatments. At the time of rehabilitation, D-cracking was the predominant distress. However, preconstruction distress surveys also indicated joint faulting, joint seal damage, transverse cracking, and pumping.

The rehabilitation techniques used at the Bethany SPS-6 test sections are described below.

Section 290601: Control Section (Do Nothing)
This section of JRCP did not receive any rehabilitation. The existing distresses, joints, and patches were left intact.

Sections 290602 and 290666: Minimum Preparation of Original PCC
According to the LTPP Construction Guidelines for SPS-6 projects, minimum surface preparation sections were to have joint and crack sealing (if warranted), partial- and full-depth patching (if warranted), and full surface diamond grinding (if warranted)[SHRP 1990]

Section 290602 received 10 full-depth repairs (with a total area of 807 ft2) of the slab and 4 full-depth repairs (with a total area of 409 ft2) of the slab and base. Joints and cracks were sealed, and diamond grinding was performed to improve the surface profile.

A slab in supplemental section 290666 received one full-depth repair (with a total area of 75 ft2). Joints and cracks in this section were sealed, and after patching a cement-pozzolan slurry was used for undersealing. The lack of surface grinding and the presence of undersealing make this section a hybrid of the original SHRP definitions of minimum and maximum surface preparation.

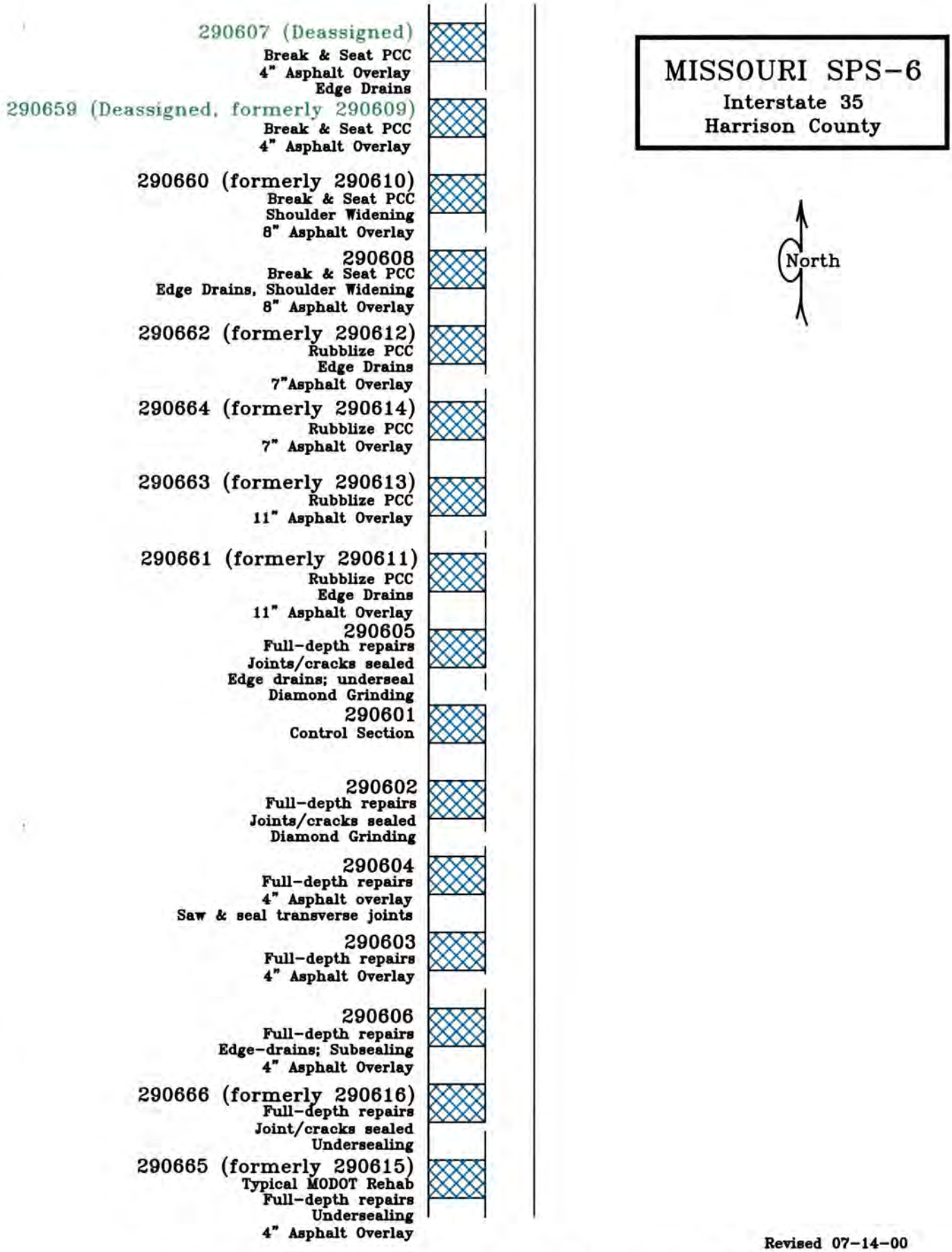


Figure 3.1 Test site layout for SPS-6 at Bethany, Missouri

Section 290605: Maximum Preparation of Original PCC

According to the LTPP Construction Guidelines for SPS-6 projects, maximum surface preparation sections were to have the following activities performed[SHRP, 1990]:

- Remove and replace existing joint and crack sealing (and perform additional sealing if warranted).
- Remove and replace existing partial- and full-depth patches (and perform additional patching if warranted).
- Correct poor load transfer at joints and/or working cracks.
- Perform full surface diamond grinding.
- Retrofit subsurface edge drainage systems.
- Perform undersealing, if warranted.

This section received two full-depth repairs (with a total area of 678 ft2) of the slab and one full-depth repair (with a total area of 657 ft2) of the slab and base. The slab repairs consisted of doweled concrete with epoxy-coated No. 12 bars. After repair, joints and cracks were sealed, edge drains were installed, and diamond grinding was performed. This section also received undersealing.

Sections 290603, 290606, and 290665: 4- and 5-in AC Overlay with Minimum, Maximum, and Typical Preparation

Cores taken from sections 290603 and 290606 showed that the average AC overlay thicknesses were 4 and 3.6 in, respectively. The average AC overlay thickness for supplemental section 290665 was 4.6 in. All of these sections received an asphalt tack coat prior to the placement of the overlay, and the rehabilitation of section 290606 also included placing edge drains and subsealing. Section 290665 received some undersealing. Table 3.1 presents the quantities of pre-overlay repair in each section. The repairs consist of doweled concrete with epoxy-coated No. 12 bars. No diamond grinding was performed on these sections prior to the placement of the AC overlay.

Table 3.1. Full-depth repair quantities in sections 290603, 290606 and 290665.

Section	**Total area (number of repairs)**	
	Slab only	**Slab and base**
290603	355 ft^2 (5)	388 ft^2 (3)
290606	355 ft^2 (6)	549 ft^2 (2)
290665	452 ft^2 (5)	0 ft^2

Section 290604: 4-in AC Overlay with Saw and Seal and Minimum Preparation of PCC

This section received an AC overlay with an average thickness of 3.8 in. Prior to the overlay, the section received seven full-depth repairs (with a total area of 527 ft2) and a tack coat. The full-depth repairs consisted of doweled concrete with epoxy-coated No. 12 bars. The AC overlay was sawed directly above the transverse joints in the original concrete pavement and then

immediately cleaned and sealed. The average depth and width of saw cut in the asphalt overlay are 2 and 0.63 in, respectively. The saw and seal operation is designed to anticipate the location of future reflective cracking and provide a clean, straight joint in the asphalt surface that can be maintained properly. No diamond grinding was performed on this section prior to the placement of the AC overlay.

Sections 290607, 290608, 290659, 290660: AC Overlays of Cracked and Seated PCC

Table 3.2 summarizes the LTPP and State supplemental sections that were rehabilitated by cracking/breaking and seating the JRCP slab and placing an AC overlay, and shows the average AC overlay thickness based on the cores obtained from the sections . The objective of the cracking operation is to crack the concrete through its full depth into large pieces (approximately 2 ft on a side). A guillotine-type hammer capable of delivering dynamic blows sufficient to produce hairline cracks through the full depth of the pavement was used. Cracking was followed by rolling to seat the pieces securely on the subgrade. A 50-ton seating roller was used to seat the broken pavement. In November 1993, a 1-in AC leveling course was placed on sections 290607, 290608, and 290659 to improve safety and rideability of the pavement surface.

Table 3.2. Summary of SPS-6 cracked and seated sections in Missouri.

Section	Surface preparation	AC OL thickness, in.
290607	Geocomposite edge drains, asphalt tack coat	4.3*
290608	Geocomposite edge drains, shoulder widening, asphalt tack coat	7.9*
290659	Asphalt tack coat	4.3*
290660	Shoulder widening, asphalt tack coat	7.9

* Additional 1-in AC leveling course was placed in November 1993.

Sections 290661 through 290664: AC Overlays of Rubblized PCC

Table 3.3 summarizes the Missouri sections that were rehabilitated by rubblizing the JRCP slab and placing an AC overlay. The average overlay thickness was determined from cores.

Table 3.3. Summary of SPS-6 rubblized sections in Missouri.

Section	Subdrainage retrofit	AC OL thickness, in
290661	Geocomposite edge drains	11.4
290662	Geocomposite edge drains	7.3
290663	None	11.5
290664	None	6.9

Potosi (SPS-6 1998)

The Potosi SPS-6 test site includes the eight standard SPS-6 test sections of bare and overlaid jointed plain concrete pavement (JPCP). The individual test sections are 500 or 1000 ft long and are separated by transition distances ranging from 200 to 15,250 ft. The test site is located on State Route 8 and is located in the eastbound lane, as show in figure 3.2.

The original pavement was constructed in 1969 and consists of 7-in JPCP over 4 in of crushed stone Type III aggregate base and a silt subgrade. The test sections are located in an area of cuts and fills, with all sections located completely within either a cut or a fill location. The original JPCP has doweled transverse joints every 30 ft, with 1-in diameter round dowels. The design features of this pavement include an 8-ft shoulder (2 ft are paved) and transverse joints 1.75-in deep and 0.38-in wide with a hot-poured elastic asphalt used as the sealant.

When this project was rehabilitated in 1998, the pavement had carried approximately 2 million ESAL's in the design lane. The rehabilitation consisted of placing 4- to 8-in AC overlays and the SPS-6 standard treatments. At the time of rehabilitation, transverse cracking was the predominant distress, although longitudinal cracking, spalling, and polished aggregate were also observed.

The rehabilitation techniques used in the test sections are described below.

Section 29A601: Control Section (Do Nothing)
This section of JPCP received some joint and crack sealing. Other distresses, joints, and patches were left intact.

Sections 29A602: Minimum Preparation of Original PCC
According to the LTPP Construction Guidelines for SPS-6 projects, minimum surface preparation sections were to have joint and crack sealing (if warranted), partial- and full-depth patching (if warranted), and full surface diamond grinding (if warranted)[SHRP 1990]

Section 29A602 received full-depth repairs (with a total area of 1335 ft2) of the slab. The other preparations included joint and crack sealing and diamond grinding.

Section 29A605: Maximum Preparation of Original PCC
According to the LTPP Construction Guidelines for SPS-6 projects, maximum surface preration sections were to have the following activities performed[SHRP, 1990]:

- Remove and replace existing joint and crack sealing (and perform additional sealing if warranted).
- Remove and replace existing partial- and full-depth patches (and perform additional patching if warranted).
- Correct poor load transfer at joints and/or working cracks.
- Perform full surface diamond grinding.
- Retrofit subsurface edge drainage systems.
- Perform undersealing, if warranted.

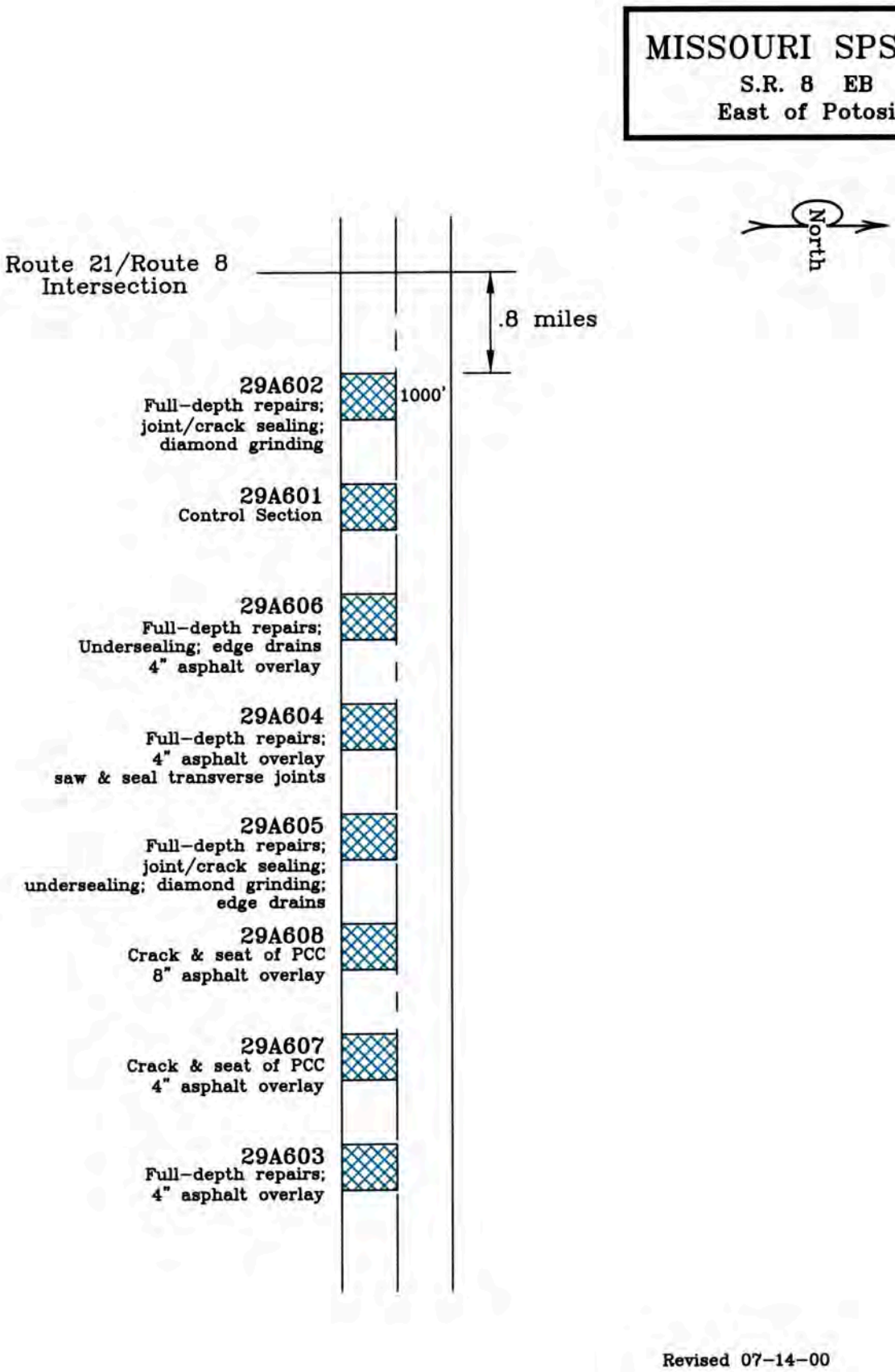


Figure 3.2 Test site layout for SPS-6 at Potosi, Missouri

This section received 11 full-depth repairs (with a total area of 721 ft^2) of the slab. The "maximum preparation" also included joint and crack sealing, slab undersealing, and diamond grinding. A geocomposite edge drain was installed.

Sections 29A603 and 29A606: 4-in AC Overlay with Minimum and Maximum Preparation
Both sections received full-depth repairs. Cores taken from sections 29A603 and 29A606 showed that the average AC overlay thicknesses were 4.3 and 4.4 in, respectively. Both sections received an asphalt tack coat prior to the placement of the overlay. The rehabilitation of section 29A606 also included undersealing and placing edge drains. Shoulders were restored with a 4-in aggregate layer on both sections

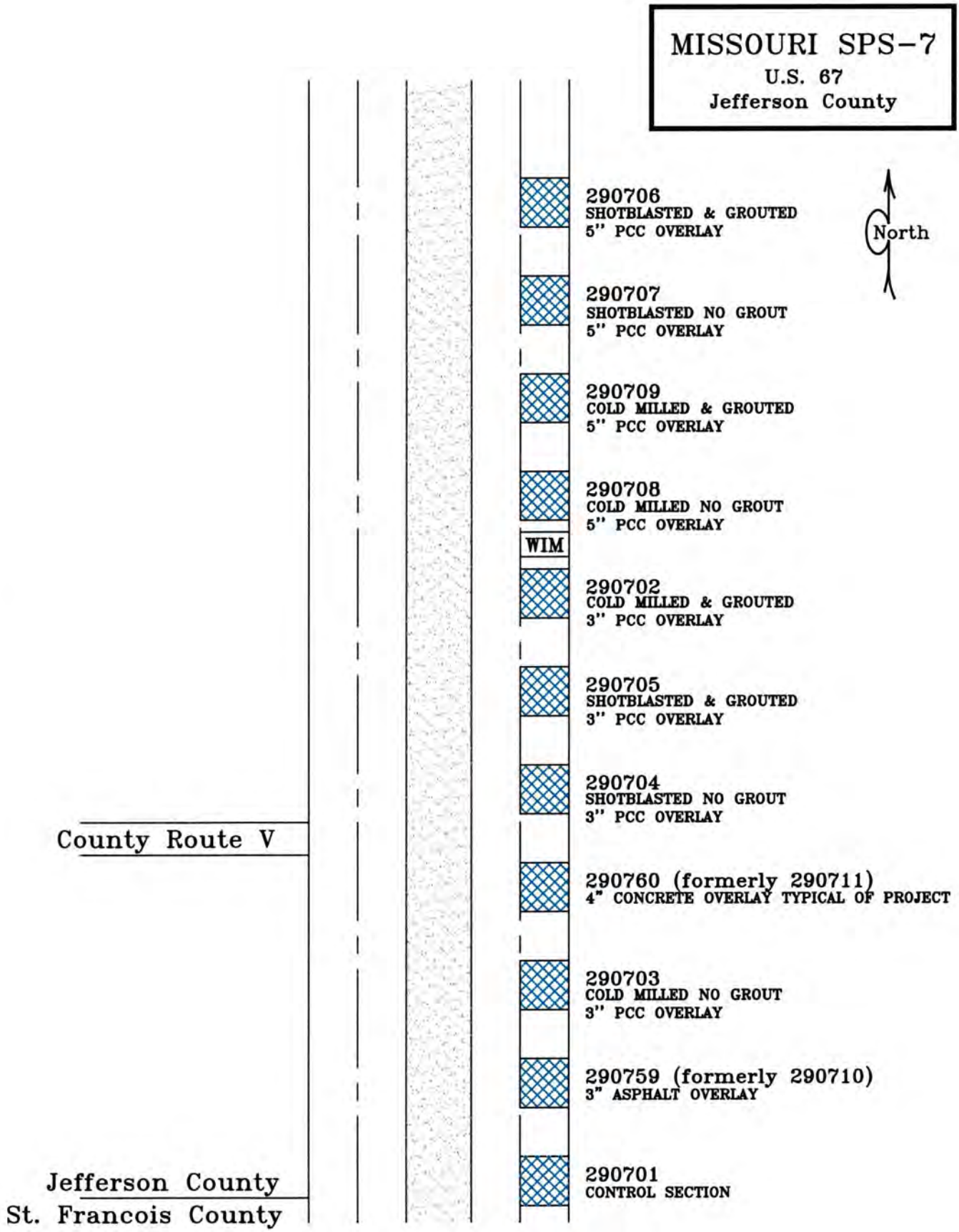
Section 29A604: 4-in AC Overlay with Saw and Seal and Minimum Preparation of JPCP
This section received an AC overlay with an average thickness of 4.1 in. Prior to overlay, the section received seven full-depth patches (with a total area of 441 ft2) and a tack coat. The AC overlay was sawed directly above the transverse joints in the original concrete pavement and then immediately cleaned and sealed. The average depth and width of saw cut in the asphalt overlay are 4 and 0.24 in, respectively. The saw and seal operation is designed to anticipate the location of future reflective cracking and provide a clean, straight joint in the asphalt surface that can be maintained properly. The outside shoulder was also restored with a 4-in aggregate layer.

Sections 29A607 and 29A608: AC Overlays of Cracked and Seated PCC
These sections were rehabilitated by cracking/breaking and seating the JPCP slabs and placing an AC overlay. The objective of the cracking operation is to crack the concrete through its full depth into large pieces. A guillotine-type hammer capable of delivering dynamic blows sufficient to produce hairline cracks through the full depth of the pavement was used. Cracking was followed by rolling to seat the pieces securely on the subgrade. A 50-ton seating roller was used to seat the broken pavement. Section 29A607 received an average 4.2-in thick overlay, and section 29A608 received an average 8-in thick overlay. A geocomposite edge drain was installed on section 29A608. The shoulders of both sections received a 4-in aggregate layer.

Festus (SPS-7)

The Missouri SPS-7 test site is located in the outer lane in the northbound direction of U.S. Highway 67, as shown in figure 3.3. This site includes 9 standard SPS-7 test sections, as well as 2 supplemental test sections, for a total of 11 test sections of bare and overlaid JPCP. The individual test sections are 500 ft long and are separated by transition distances ranging from 150 to 7862 ft.

The original pavement was constructed in 1955 as a two-lane road. In 1971, southbound lanes were constructed and the old pavement then carried the northbound traffic only. The test sections are located on a very hilly terrain with numerous cuts and fills. The SPS-7 site was constructed on 4 in of granular limestone base and a variable subgrade consisting of fine-grained residual clay soils, rock fills (mixed residual clay soil and excavated rock), or rock. The original 8-in PCC pavement has transverse undoweled joints with a 20-ft joint spacing. This pavement includes a 9.5-ft AC outside shoulder but does not have subsurface drainage. No partial-depth patching or any other pre-treatment operation was noted for the Potosi test sections, prior to the



Revised 06-01-00

Figure 3.3 Test site layout for SPS-7 at Festus, Missouri

cold milling or shot blasting.[MO DOT MR91-2] Another interesting aspect of this project was that the overlay material was designed as a high-early strength, fast-track project, which called for careful monitoring of the PCC temperatures. The fast-track mix design may have also been one of the contributing factors to the early crack development observed for the test sections.

When this project was rehabilitated in 1990, the pavement had carried an average of 246,000 ESAL's in the design lane per year. The rehabilitation consisted of placing 3- and 5-in bonded concrete overlays with a combination of various surface preparation efforts and grouting. At the time of rehabilitation, the pavement was in fair condition; the predominant distress was joint faulting with some longitudinal and transverse cracking.

The rehabilitation techniques used in the test sections are described below.

Section 290701: Control Section (Do Nothing)
No rehabilitation was applied to the control section.

Section 290702: 3-in Cold Milled and Grouted
The as-built thickness of the bonded concrete overlay was 4.25 in. The primary surface preparation was cold milling, and the secondary surface preparation was sand blasting. Bonding grout was a mixture of Type I portland cement and water that was prepared and applied in accordance with the requirements of the specifications. The temperature of the air and concrete were 99 °F and 100 °F, respectively, with the concrete temperatures measured at the mid-point of the overlay layer. The concrete was blanketed soon after being placed.

Section 290703: 3-in Cold Milled and Not Grouted
The as-built thickness of the bonded concrete overlay for this section was 3.5 in, with air and mid-slab concrete temperatures of 73 °F and 83 °F, respectively. The primary surface preparation was cold milling, the secondary surface preparation was sand blasting, and the final surface preparation was air blasting. The concrete was not blanketed with wet burlap until 7.75 hours after placement.

Section 290704: 3-in Shotblasted and Not Grouted
The as-built thickness of the bonded concrete overlay of this section was 3.38 in. During the paving operations, the air temperature was 91 °F while the mid-slab concrete temperature was 90 °F. The primary surface preparation was shot blasting, and the final surface preparation was air blasting. The concrete was blanketed 6 hours after being placed.

Section 290705: 3-in Shotblasted and Grouted
The as-built thickness of the bonded concrete overlay was 3.19 in. The primary surface preparation was shot blasting. The bonding grout was a mixture of Type I portland cement and water that was prepared and applied in accordance with the requirements of the specifications. The temperature of the air and mid-slab concrete were 90 °F and 86 °F. The concrete was blanketed within 4 hours of placement.

Section 290706: 5-in Shotblasted and Grouted
The as-built thickness of the bonded concrete overlay was 5.31 in. The primary surface preparation was shotblasting, and air blasting was used as the final surface preparation. The bonding grout was a mixture of Type I portland cement and water that was prepared and applied in accordance with the requirements of the specifications. The mid-slab temperature of the concrete was 89 °F. The concrete was blanketed within 4 hours of placement.

Section 290707: 5-in Shotblasted and Not Grouted
The as-built thickness of the bonded concrete overlay for this section was 5.25 in. The primary surface preparation was shotblasting, with a secondary surface preparation of air blasting. During the paving operations, the air temperature was 94 °F while the mid-slab concrete temperature was 100 °F. The concrete was blanketed soon after placement.

Section 290708: 5-in Cold Milled and Not Grouted
The as-built bonded concrete overlay thickness of this section was 5.38 in. The primary surface preparation was cold milling, secondary surface preparation was sand blasting, and the final surface preparation was air blasting, though the effective completion of the sand blasting is questionable. The concrete was blanketed within 4 hours of placement.

Section 290709: 5-in Cold Milled and Grouted
The as-built bonded concrete overlay thickness of this section was 5.3125 in. During the paving operations, the air temperature was 88 °F while the mid-slab concrete temperature was 96 °F. The primary surface preparation was sand blasting. The bonding grout was a mixture of Type I portland cement and water that was prepared and applied in accordance with the requirements of the specifications. The concrete was blanketed soon after being placed.

Section 290759: 3-in Asphalt Overlay
Standard paving practices were used during placement of an asphalt concrete overlay. The material for the leveling course was IB mix placed at a thickness of 1.75 in while the IC mix was used for the surface at a thickness of 1.25 in.

Section 290760: 4-in Concrete Overlay Typical of Project
The primary surface preparation for this section included milling and shot blasting. During the paving operations, the air temperature was 77 °F while the mid-slab concrete temperature was 86 °F. The bonding grout was a mixture of Type I portland cement and water that was prepared and applied in accordance with the requirements of the specifications. The concrete was blanketed with wet burlap about 4 hours after placement.

Sedalia (SPS-9A)

The Missouri SPS-9A test site is located on U.S. Highway 65, in the outer lane in the southbound direction, as shown in figure 3.4. The site includes three test sections that were constructed for the standard SPS-9A experiment, as well as six sections that were added by the State. The SPS-9A experiment concerns performance-based specifications for asphalt binder and asphalt-aggregate mixtures. In Missouri, these materials were used as overlays of the existing JRCP.

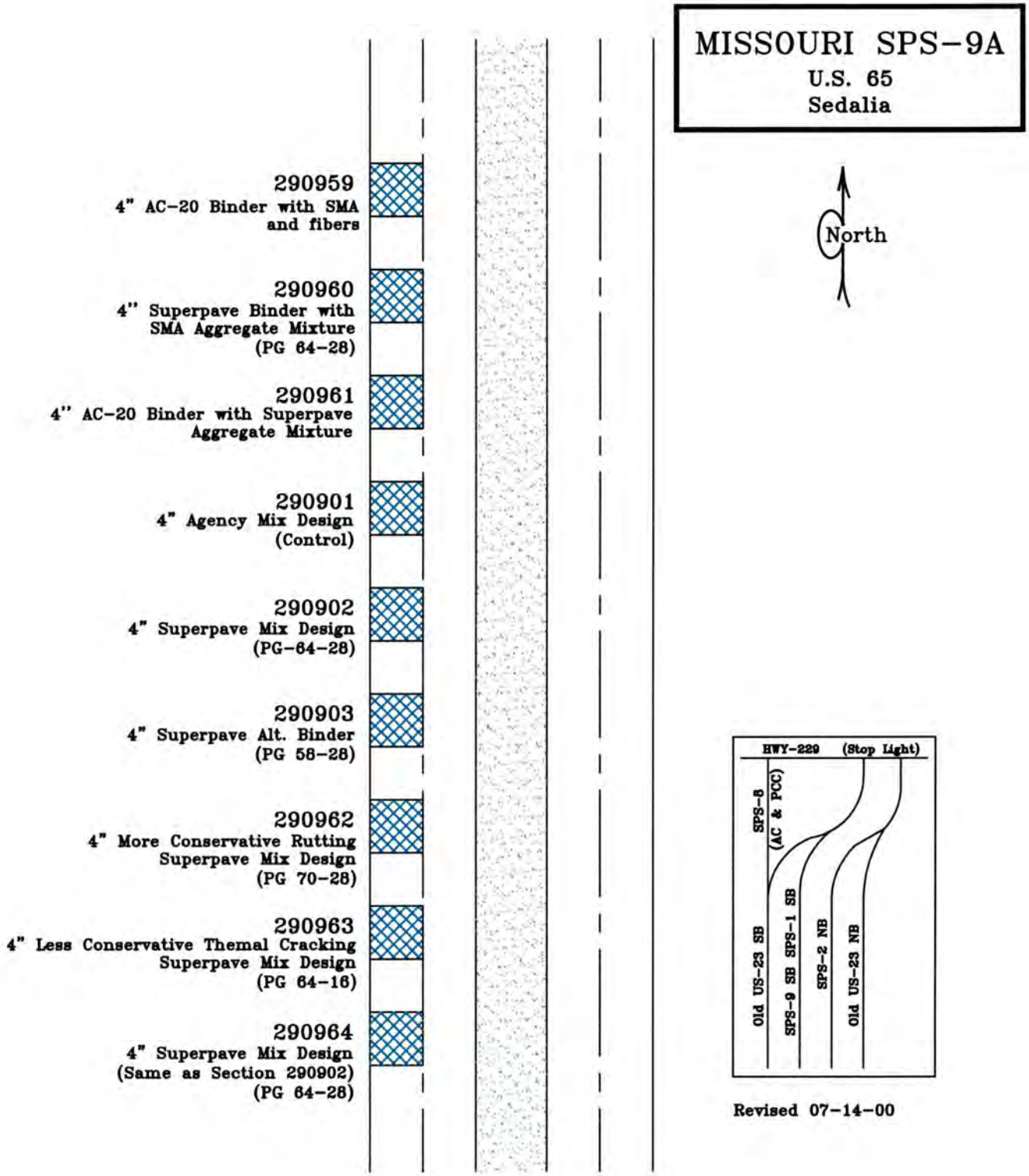


Figure 3.4 Test site layout for SPS-9A at Sedalia, Missouri

The original JRCP was constructed between 1966 and 1968. It consists of an 8-in JRCP over 4 in of crushed stone Type III aggregate base and a clay subgrade. The original JRCP has doweled transverse joints every 61.5 ft, with 1-in diameter round dowels, which were noted to have a dowel coating of paint or grease, and were placed using baskets. The design features of this pavement also included 4- and 10-ft wide paved shoulders along the inside and outside lanes, and transverse joints 2 in deep and 0.38 in wide with a hot-poured asphalt cement used as the sealant.

When this project was rehabilitated in 1996, the pavement had carried approximately 33 million ESAL's in the design lane. The rehabilitation consisted of placing various HMAC materials as 4-in overlays to investigate the effects of the SUPERPAVE design process on the performance of AC overlays of PCC. At the time of rehabilitation, polished aggregate and pumping were the predominant distresses, though transverse cracking, spalling, and patching were also observed. Pre-rehabilitation repairs made to the PCC surface included joint and crack sealing, joint load restoration, and varying amounts of partial- and full-depth repairs. Table 3.4 contains a summary of the repairs placed at each of the Sedalia test section prior to rehabilitation.

Table 3.4 Partial- and full-depth repair quantities at Sedalia SPS-9A.

Test section	Partial-depth		Full-depth (slab only)	
	Number	Area	Number	Area
290901			8	696 ft^2
290902			4	288 ft^2
290903			9	648 ft^2
290959	2	9 ft^2	3	216 ft^2
290960	2	15 ft^2	6	304 ft^2
290961	2	7 ft^2	4	288 ft^2
290962			8	648 ft^2
290963			6	364 ft^2
290964			11	936 ft^2

The rehabilitation techniques used in the test sections are described below.

Section 290901: Agency Mix Design (Control)

The control section was a typical AC overlay that is used and selected by Missouri for this experiment. This overlay included an AC-20 grade of asphalt. It was placed in two lifts, which included a 2-in IC top layer and a 2-in IB bottom layer.

Section 290902: SUPERPAVE Mix Design
This section is a SUPERPAVE mix design. The AC grade was a PG 64-28. The PG grade was based on temperature conditions at the project location. The overlay consists of a 2-in surface course and a 2-in binder course.

Section 290903: SUPERPAVE Alternative Binder
This section is a SUPERPAVE mix design with an alternative binder. The AC grade was a PG 58-28. The PG grade was reduced one level to study the effect of selecting a less conservative mix and its effect on rutting. The overlay consists of a 2-in surface course and a 2-in binder course.

Section 290959: AC Binder with Stone Matrix Asphalt Mix
The section is constructed using a 2-in AC-20 asphalt binder (IB) and a 2-in stone mastic asphalt (SMA) with fiber mixture.

Section 290960: SUPERPAVE Binder with SMA Mix
This section is a SUPERPAVE mix design using a SMA with fiber mixture. The AC grade was a PG 64-28. The PG grade was based on temperature conditions at the project location. The overlay consists of a 2-in surface course and a 2-in binder course.

Section 290961: AC Binder with SUPERPAVE Design Mix Aggregate
This section uses a 2-in AC-20 asphalt binder (IB) with the mix design requirements for a 2-in SUPERPAVE SP-125 aggregate gradation.

Section 290962: More Conservative Rutting SUPERPAVE Mix Design
This section is a more conservative SUPERPAVE mix design with an alternative binder. The AC grade was a PG 70-28. The PG grade was increased one level to study the effect of selecting a more conservative mix and its effect on rutting. The overlay consists of a 2-in surface course and a 2-in binder course.

Section 290963: Less Conservative Thermal Cracking SUPERPAVE Mix Design
This section is a SUPERPAVE mix design with an alternative binder. The AC grade was a PG 64-16. The PG grade was reduced one level to study the effect of selecting a less conservative mix and its effect on thermal cracking. The overlay consists of a 2-in surface course and a 2-in binder course.

Section 290964: Performance Variation (Replica of 290902)
This section is a replicate of section 290902 and is a SUPERPAVE mix design. The AC grade was a PG 64-28. The PG grade was based on temperature conditions at the project location. The overlay consists of a 2-in surface course and a 2-in binder course. The purpose of this section is to study the variations in performance.

GPS-7 Experimental Sections

The Missouri GPS-7A sections (297054 and 297073) and GPS-7B sections (294069, 295393, and 295483) represent AC-overlaid jointed concrete pavements. GPS-7A sections were overlaid

before joining the LTPP program, while GPS-7B sections were overlaid as part of the program. The locations of these sections were described in table 2.1.

The cross section data for the test sections are summarized in table 3.5. In the original pavement, the average joint spacing in section 294069 is 61 ft, the spacing in section 295483 is 61.4 ft, and the spacing in sections 297054, 297073, and 295393 is 30 ft. The joints in all sections are doweled.

Table 3.5. Summary of cross section and construction data for GPS-7 sections in Missouri.

Nearby town	Section	Length, miles	AC OL thick, in.	Original surface		Base		Subgrade type
				Type	Thick, in.	Type	Thick, in.	
Joplin	297054	8.7	3.5	JPCP	10	CS, G, or S	4	Sandy clay
Chillicothe	297073	0.7	3	JPCP	8	CS, G, or S LTSB	4 6	Silty clay
Kansas City	294069	1.3	4	JRCP	10	Aggregate	6	Sand
St. Louis	295393	8.2	3	JPCP	8	CS, G, or S	4	Silt
Kansas City	295483	6.2	3	JRCP	9	CS, G, or S	4	Silty clay

Base = Crushed stone, Gravel, or Slag
Subbase = Lime-Treated Subgrade Soil

CONSTRUCTION SUMMARIES

This portion of the report summarizes the constructed thicknesses and rehabilitation techniques employed at each Missouri SPS-6, SPS-7, SPS-9A, and GPS-7 site. Table 3.6 summarizes the existing pavement structures prior to rehabilitation. JPCP and JRCP were rehabilitated as part of the LTPP program in Missouri. On average, the rehabilitated PCC pavements were 8 to 10 in thick, depending on the experiment. In general, most of these sections were constructed on silty to sandy clays, with the exception of the Festus site, which was partially constructed on rock fill and rock. Tables 3.7 through 3.11 summarize the overlay type, overlay thickness, and the rehabilitation techniques applied to each pavement section included in this report.

Table 3.6. Pavement structures prior to rehabilitation.

Nearby town	Section	Original surface		Base		Subgrade type
		Type	Thick, in.	Type	Thick, in.	
Bethany	SPS-6	JRCP	9	Aggregate	4	Silty clay
Potosi	SPS-6	JPCP	7	Aggregate	4	Silt
Festus	SPS-7	JPCP	8	Granular limestone	4	• Residual clay • Rock fill • Rock
Sedalia	SPS-9A	JRCP	8	Aggregate	4	Clay
Joplin	297054	JPCP	10	CS, G, or S*	4	Sandy clay
Chillicothe	297073	JPCP	8	CS, G, or S* LTSB**	4 6	Silty clay
Kansas City	294069	JRCP	10	Aggregate	6	Sand
St. Louis	295393	JPCP	8	CS, G, or S*	4	Silt
Kansas City	295483	JRCP	9	CS, G, or S*	4	Silty clay

* Base = Crushed stone, Gravel, or Slag
** Subbase = Lime-Treated Subgrade Soil

Table 3.7. Rehabilitation techniques used for the SPS-6 sections near Bethany.

Section	Overlay type	Planned overlay thickness, in.	Rehabilitation technique
290601	None	0	• Control
290602	None	0	• Minimum restoration (Includes ...)
290603	AC	4	• Minimum restoration
290604	AC	4	• Minimum restoration • Sawed and sealed AC joints
290605	None	0	• Maximum restoration (Includes...
290606	AC	4	• Maximum restoration
290607	AC	4	• Break and seat • With edge drains
290608	AC	8	• Break and seat • With edge drains
290659	AC	4	• Break and seat • Without edge drains
290660	AC	8	• Break and seat • Without edge drains • Shoulder widening
290661	AC	11	• Rubblized • With edge drains
290662	AC	7	• Rubblized • With edge drains
290663	AC	11	• Rubblized • Without edge drains
290664	AC	7	• Rubblized • Without edge drains
290665	AC	4	• Typical Missouri AC overlay
290666	None	0	• Minimum restoration • Undersealing

Table 3.8. Rehabilitation techniques used for the SPS-6 sections near Potosi.

Section	Overlay type	Planned overlay thickness, in.	Rehabilitation technique
29A601	None	0	• Control
29A602	None	0	• Minimum restoration (Includes ...)
29A603	AC	4	• Minimum restoration
29A604	AC	4	• Minimum restoration • Sawed and sealed AC joints
29A605	None	0	• Maximum restoration (Includes...
29A606	AC	4	• Maximum restoration
29A607	AC	4	• Crack and seat • With edge drains
29A608	AC	8	• Crack and seat • With edge drains

Table 3.9. Rehabilitation techniques used for the SPS-7 sections near Festus.

Section	Overlay type	Planned overlay thickness, in.	Rehabilitation technique
290701	None	0	• Control
290702	Bonded PCC	3	• Cold milled • Grouted
290703	Bonded PCC	3	• Cold milled • Not grouted
290704	Bonded PCC	3	• Shotblasted • Not grouted
290705	Bonded PCC	3	• Shotblasted • Grouted
290706	Bonded PCC	5	• Shotblasted • Grouted
290707	Bonded PCC	5	• Shotblasted • Not grouted
290708	Bonded PCC	5	• Cold milled • Not grouted
290709	Bonded PCC	5	• Cold milled • Grouted
290759	AC	3	• Standard Missouri overlay
290760	Bonded PCC	4	• Standard Missouri overlay

Table 3.10. Rehabilitation techniques used for the SPS-9A sections near Sedalia.

Section	Overlay type	Planned overlay thickness, in.	Rehabilitation technique
290901	AC	4	Standard Missouri overlay
290902	AC	4	SUPERPAVE mix design
290903	AC	4	SUPERPAVE alternate binder
290959	AC	4	AC Binder with SMA aggregate mixture
290960	AC	4	SUPERPAVE binder with SMA aggregate mixture
290961	AC	4	AC Binder with SUPERPAVE aggregate mixture
290962	AC	4	More conservative rutting SUPERPAVE mix design
290963	AC	4	Less conservative thermal cracking SUPERPAVE mix design
290964	AC	4	Performance variation (same as 290902)

Table 3.11. Rehabilitation techniques used for the GPS-7 sections.

Section	Overlay type	Planned overlay thickness, in.	Rehabilitation technique
297054	AC	3.5	Missouri AC overlay
297073	AC	3	Missouri AC overlay
294069	AC	4	Missouri AC overlay
295393	AC	3	Missouri AC overlay
295483	AC	3	Missouri AC overlay

4.0 TRAFFIC, CLIMATE, AND MATERIALS

Traffic, climate, and material properties must be considered in the analysis of each section because they can significantly influence the performance of each rehabilitation alternative.

TRAFFIC

Traffic loading level is particularly important when comparing the performance of pavements at different locations. The amount of traffic that any given rehabilitation technique has received will directly affect its performance and design life.

Various traffic components have been reviewed for each site included in this report. Appendix B contains the single axle distribution, tandem axle distribution, and the vehicle classification information for each site. In general, all of the sections within a site should have the same traffic loadings.

Some of the information presented in appendix B is summarized in table 4.1. The annual ESAL estimates for PCC rehabilitation sections are provided in table 4.2. Vehicle types 5 and 9 are highlighted because there are relatively many of them on these pavement sections, in comparison to other vehicle types (see table 4.3 for a list of all vehicle types). As these data show, sites 2906** and 297054 carry the highest volumes of traffic, while sites 297073 and 295393 carry much smaller traffic volumes. At the time of this report, no traffic information was available for the SPS-6A site in Potosi.

Table 4.1. Annual single and tandem axle counts and peak vehicle classification.

Site	Experiment type	Number of 9,000 lb single axles		Number of 36,000 lb tandem axles		Peak vehicle classifications	
		Low	High	Low	High	Class 5	Class 9
Bethany	SPS-6	101,000	151,000	62,000	100,000	50,000	400,000
Potosi	SPS-6	n/a	n/a	n/a	n/a	n/a	n/a
Festus	SPS-7	35,000	57,000	15,000	18,000	70,000	120,000
Sedalia	SPS-9A	46,000	50,000	15,000	16,000	48,000	120,000
297054	GPS-7A	110,000	350,000	10,000	220,000	300,000	1,000,000
297073	GPS-7A	6,000	17,000	3,900	9,500	30,000	40,000
294069	GPS-7B	25,000	70,000	10,000	21,000	170,000	180,000
295393	GPS-7B	8,000	29,000	2,000	8,000	80,000	60,000
295483	GPS-7B	10,000	58,000	1,000	7,000	110,000	70,000

Table 4.2. Annual ESAL estimates for PCC rehabilitation sections.

Year	Bethany (290600)	Festus (290700)	Sedalia (290900)	Kansas City I-635 (294069)	St. Louis (295393)	Kansas City Rt. 210 (295483)	Joplin (297054)	Chillicothe (297073)
1965		185,000			20,000			
1966		191,000			21,000			
1967		177,000			23,000			
1968		180,000			24,000			
1969		183,000			31,000			
1970		228,000			34,000			
1971		238,000			35,000			
1972		246,000			40,000			
1973		194,000			30,000	168,000	666,000	
1974		183,000			25,000	168,000	616,000	
1975	513,000	204,000		82,000	26,000	169,000	640,000	
1976	513,000	214,000		115,000	23,000	170,000	749,000	
1977	633,000	163,000		120,000	19,000	176,000	684,000	
1978	598,000	173,000		300,000	20,000	199,000	711,000	
1979	583,000	173,000		298,000	27,000	192,000	1,103,000	
1980	595,000	241,000		286,000	27,000	202,000	980,000	
1981	614,000	238,000		286,000	30,000	209,000	1,307,000	99,000
1982	639,000	225,000		260,000	27,000	192,000	1,115,000	97,000
1983	656,000	188,000		336,000	28,000	198,000	1,248,000	101,000
1984	698,000	232,000		342,000	29,000	165,000	1,127,000	97,000
1985	693,000	223,000		346,000	26,000	172,000	1,206,000	97,000
1986	720,000	311,000		353,000	26,000	180,000	1,117,000	102,000
1987	723,000	315,000		330,000	31,000	304,000	1,357,000	108,000
1988	741,000	322,000		341,000	32,000	308,000	1,402,000	109,000
1989	839,000	368,000		347,000	55,000	327,000	1,691,000	112,000
1990	852,000	374,000		**276,000**		**134,000**		**61,000**
1991	873,000	378,000		356,000	**23,000**		**1,577,000**	**83,000**
1992		**280,000**				**124,000**		81,000
1993	**827,000**	**311,000**		**414,000**	**27,000**	**139,000**	**945,000**	
1994	**686,000**	**406,000**		**496,000**	**47,000**	**70,000**	**908,000**	**46,000**
1995	**537,000**	**262,000**		**312,000**	**49,000**	**78,000**	**1,308,000**	**53,000**
1996	**591,000**	**216,000**	198,000	**212,000**	**95,000**	**43,000**	**3,552,000**	**66,000**
1997	**769,000**	**267,000**	**249,000**	**345,000**	**150,000**	**36,000**	**1,732,000**	85,000
1998	**499,000**	**168,000**	**312,000**	**650,000**	**105,000**	**36,000**	**1,595,000**	**85,000**

Plain text represents sheet estimates provide by Missouri DOT
Bold text represents estimates based on monitored WIM data.

Table 4.3. Summary of vehicle classification types.

Class	Type
1	Motorcycles
2	Passenger cars
3	Other two-axle, four-tire, single unit vehicles
4	Buses
5	Two-axle, six-tire, single unit trucks
6	Three-axle, single unit trucks
7	Four or more axle single unit trucks
8	Four or less axle single trailer trucks
9	Five-axle single trailer trucks
10	Six or more axle single trailer trucks
11	Five or less axle multi-trailer trucks
12	Six-axle multi-trailer trucks
13	Seven or more axle multi-trailer trucks

CLIMATIC DATA

All of the LTPP sites in Missouri are classified as wet-freeze test sites within the context of the LTPP program. However, some differences in the climatic factors affecting each of the sites do exist. To further define the climatic conditions at each site, "virtual" weather data from the LTPP database was obtained to quantify temperature and precipitation conditions over time. This information is generated using an algorithm that uses data from National Oceanic and Atmospheric Administration (NOAA) weather stations to calculate the weighted average of various climatic elements. The algorithm uses five nearby NOAA weather stations and weights the data, giving more weight to the sources of data closer to the test sites. Table 4.4 shows some of the annual virtual climatic values for each of the test sites in this study.

Data for the SPS-9A site at Sedalia and the SPS-6 site at Potosi are not available from the LTPP database at this time, but it is expected that values at Sedalia will be similar to those at Chillicothe and Kansas City, while Potosi will experience very similar conditions to Festus.

In general, the freezing index values reflect the temperature trends that would be expected in Missouri, with colder temperatures in the northern portion of the state and progressively warmer temperatures as you proceed south. The range of average annual precipitation is fairly constant for the sites in this study, ranging from 36.6 to 46.2 in per year.

Table 4.4. Climatic values for Missouri PCC rehabilitation sites.

Test site	Location	Years of data	Annual Freezing Index, °F-days	Annual Days below 32 °F	Annual Days above 90 °F	Average Annual Precipitation, in.
290600	Bethany	1980-96	797	127	26	38.7
290700	Festus	1980-96	402	105	29	43.7
290900	Sedalia	n/a	n/a	n/a	n/a	n/a
29A600	Potosi	n/a	n/a	n/a	n/a	n/a
294069	Kansas City	1974-96	508	99	41	36.6
295393	St. Louis	1957-96	512	111	33	38.5
295483	Kansas City	1972-96	548	105	31	39.0
297054	Joplin	1973-96	299	91	45	46.2
297073	Chillicothe	1980-96	758	138	31	38.6

Detailed plots of the precipitation and temperature data from the LTPP database can be found in appendix C. For the precipitation data, monthly values for each year of available data are shown for each site, along with the mean monthly precipitation amounts for each month based on the years of data available. For the temperature data, monthly average values for each year of available data are shown, along with the mean monthly average temperature for each month based on the years of available data.

MATERIALS TESTING DATA

Materials test data from the LTPP database were evaluated for each site in the study. In general, LTPP materials testing data are organized by layer for each individual test section. However, in some instances, samples will be taken from only a representative portion of the test sections at an SPS site with the intent that the results will be applied to that layer through all of the test sections. This is particularly relevant to the SPS-6, -7, and -9A projects, where material properties for the subgrade, base, and original PCC layers were assumed to be fairly consistent throughout all of the test sections at an SPS location. The materials testing tables evaluated for this study included:

- Natural moisture content of subgrade soils and granular base layers (Table TST_UG10_SS09).
- Optimum moisture-density for subgrade soils and granular base layers (Table TST_UG05_SS05).
- Atterberg limits for subgrade soils and granular base layers (Table TST_UG04_SS03).
- Particle size gradation for subgrade soils and granular base layers (Table TST_SS01_UG01_UG02).
- Flexural strength of PCC layers (Table TST_PC09).
- Density and percent voids for PCC layers (Table TST_PC05).

- Elastic modulus and Poisson's ratio for PCC layers (Table TST_PC04).
- Split tensile strength for PCC layers (Table TST_PC02).
- Compressive strength for PCC layers (Table TST_PC01).
- Slump and air content of fresh PCC (Table TST_FRESH_PCC).
- Aggregate gradation for HMAC layers (TST_AG04).
- Asphalt binder content for HMAC layers (TST_AC04).
- Maximum specific gravity for HMAC layers (TST_AC03).
- Bulk specific gravity for HMAC layers (TST_AC02).

One of the other materials testing tables which was reviewed for this project was TST_L05B. This table contains the best estimates of layer material classifications and thicknesses for a particular LTPP test section. Data from core thickness measurements, boring operations, test pit investigations, and other sources were used to determine the values that are included in the L05B table. Tables 4.5 through 4.8 show the layer types and thicknesses for the test sections included in this study.

Table 4.5. Test section layer summaries for Bethany (SPS-6) sections.

Test section	Subgrade type	Bottom >>>> Top			
290601	Sandy clay	4.2-in granular base	9.1-in PCC		
290602	Sandy clay	3.4-in granular base	9.2-in PCC		
290603	Sandy clay	4.9-in granular base	9.1-in PCC	2.1-in AC binder	1.7-in AC surface
290604	Sandy clay	4.5-in granular base	9.1-in PCC	2.3-in AC binder	1.5-in AC surface
290605	Sandy clay	3.8-in granular base	9.1-in PCC		
290606	Sandy clay	3.5-in granular base	8.9-in PCC	2.1-in AC binder	1.5-in AC surface
290607	Sandy clay	4.2-in granular base	9.3-in B&S PCC	2.5-in AC binder	1.8-in AC surface
290608	Sandy clay	5.3-in granular base	9.4-in B&S PCC	5.6-in AC binder	2.3-in AC surface
290659	Sandy clay	6.0-in granular base	9.3-in B&S PCC	2.6-in AC binder	1.7-in AC surface
290660	Sandy clay	4.2-in granular base	9.7-in B&S PCC	5.4-in AC binder	2.4-in AC surface
290661	Sandy clay	4.2-in granular base	9.4-in rub. PCC	9.5-in AC binder	1.9-in AC surface
290662	Sandy clay	5.5-in granular base	9.4-in rub. PCC	5.4-in AC binder	1.9-in AC surface
290663	Sandy clay	4.5-in granular base	9.5-in rub. PCC	8.9-in AC binder	1.8-in AC surface
290664	Sandy clay	5.1-in granular base	9.7-in rub. PCC	5.4-in AC binder	1.5-in AC surface
290665	Sandy clay	4.6-in granular base	9.0-in PCC	2.9-in AC binder	1.7-in AC surface
290666	Sandy clay	4.6-in granular base	9.1-in PCC		

Table 4.6. Test section layer summaries for Festus (SPS-7) sections.

Test section	Subgrade type	Bottom >>>> Top			
290701	Sandy clay	4.0-in granular base	8.0-in original PCC		
290702	Sandy clay	6.2-in granular base	7.6-in original PCC	4.4-in PCC overlay	
290703	Sandy clay	4.0-in granular base	7.9-in original PCC	3.2-in PCC overlay	
290704	Sandy clay	4.0-in granular base	8.1-in original PCC	3.4-in PCC overlay	
290705	Sandy clay	6.0-in granular base	8.1-in original PCC	3.1-in PCC overlay	
290706	Crushed rock and stone	4.0-in granular base	8.1-in original PCC	5.6-in PCC overlay	
290707	Crushed rock and stone	4.0-in granular base	8.2-in original PCC	4.9-in PCC overlay	
290708	Sandy clay	6.0-in granular base	8.0-in original PCC	5.1-in PCC overlay	
290709	Sandy clay	4.5-in granular base	7.9-in original PCC	5.0-in PCC overlay	
290759	Sandy clay	5.0-in granular base	8.1-in original PCC	1.8-in AC binder	1.2-in AC surface
290760	Crushed rock and stone	16-in granular base	7.7-in original PCC	4.1-in PCC overlay	

Table 4.7. Test section layer summaries for Sedalia (SPS-9A) sections.

Test section	Subgrade type	Bottom >>>> Top			
290901	Clayey sand	4.0-in granular base	8.0-in original PCC	2.1-in AC binder	2.3-in AC surface
290902	Clayey sand	5.8-in granular base	8.0-in original PCC	2.0-in AC binder	2.6-in AC surface
290903	Poorly graded gravel	4.9-in granular base	8.0-in original PCC	2.3-in AC binder	1.8-in AC surface
290959	Clay	4.5-in granular base	8.1-in original PCC	1.7-in AC binder	1.9-in AC surface
290960	Clay	4.3-in granular base	8.1-in original PCC	2.0-in AC binder	1.9-in AC surface
290961	Clay	4.3-in granular base	7.8-in original PCC	1.6-in AC binder	1.9-in AC surface
290962	Clay	4.5-in granular base	8.1-in original PCC	2.2-in AC binder	2.3-in AC surface
290963	Clay	4.4-in granular base	8.1-in original PCC	2.5-in AC binder	2.7-in AC surface
290964	Clay	4.3-in granular base	8.0-in original PCC	1.9-in AC binder	2.6-in AC surface

Table 4.8. Test section layer summaries for GPS sections.

Test section	Subgrade type	Bottom >>>> Top				
294069	Poorly graded sand	4.0-in granular base	9.9-in PCC	2.3-in AC binder	1.5-in AC surface	
295393	Gravelly lean clay	3.3-in granular base	7.7-in PCC	1.8-in AC binder	1.2-in AC surface	
295483	Lean inorganic clay	4.7-in granular base	9.0-in PCC	1.8-in AC binder	1.2-in AC surface	
297054	Clayey gravel with sand	4.0-in granular base	10.1-in PCC	4.2-in old AC layers	2.4-in new AC surface	
297073	Lean inorganic clay	5.5-in treated base	4.0-in granular base	8.2-in PCC	1.4-in AC binder	1.0-in AC surface

In general, materials test data for SPS test sections was obtained by Missouri DOT using their facilities, with data submitted to the regional contractor for entry into the LTPP database system. Test data for GPS test sections was obtained by LTPP contract laboratories and then submitted to the regional contractor for entry into the LTPP database.

Following are some observations regarding the materials testing data reviewed for this project:

Subgrade and Granular Base Layers

- The natural moisture contents of the subgrade soils were between 17 and 28 percent for all GPS sites except 4069 (less than 3 percent), while the granular bases were between 6 and 9 percent for all GPS sites except 4069 (12 percent).
- The natural moisture contents of the subgrade soils for the three SPS projects ranged from 6 to 33 percent. Sedalia had higher values than Bethany, and Festus only had results from one section (17 percent).
- The natural moisture contents of the SPS section granular bases were 6 to 7 percent, with the exception of 0603 (12 percent).
- Optimum density for the GPS section subgrade layers ranged from 103 to 115 pcf, while the optimum moisture content was between 13 and 20 percent. Optimum density for the GPS granular base layers ranged from 134 to 140 pcf, and the optimum moisture content was between 6 and 7 percent.
- Optimum density for the SPS section subgrade layers ranged from 109 to 126 pcf, while the optimum moisture content was between 11 and 15 percent. Optimum density for the granular base layers ranged from 138 to 143 pcf, while the optimum moisture content was between 6 and 7 percent.
- Gradation data for the SPS-6 at Bethany showed between 40 and 70 percent passing the #200 sieve. For the SPS-7 at Festus, the silty clay soil identified for section 0709 had 32 percent passing the #200 sieve, while the sandy clay identified for section 0701 had 86 percent passing the #200 sieve.
- For the GPS subgrade layers, the amount of material passing the #200 sieve ranged from 2 percent (4069) to 98 percent (5473).

PCC Pavement Layers

- Flexural strength values for the PCC overlay at the SPS-7 near Festus ranged from 634 to 745 psi at 28 days.
- Density of the original PCC at the SPS-6 near Bethany ranged from 137 to 141 pcf, while the densities of the PCC overlay layers at the SPS-7 near Festus were between 136 and 139 pcf.
- Elastic modulus of the PCC layer at Bethany was between 4.1 and 6.1 million psi; for the PCC overlay layer at Festus, the elastic modulus value was between 4.5 and 4.9 million psi. Values of the elastic modulus for the GPS section PCC layers were between 3.2 and 5.1 million psi.
- Split tensile strengths for the original PCC at SPS-6 ranged from 621 to 899 psi, and the split tensile strengths for the PCC overlay layer at SPS-7 were between 649 and 685 psi. Split tensile strengths for the GPS section PCC layers ranged from 475 to 607 psi.

HMAC Pavement Layers

- Mean asphalt contents for the SPS overlay HMAC binder layers ranged from 4.1 to 4.5 percent, and for the surface layers it ranged from 4.3 to 5.6 percent. GPS overlay surface layers ranged from 4.0 to 4.7 percent, and only one binder layer had data reported (7073) with a mean asphalt content of 3.4 percent.
- Bulk specific gravities for the SPS overlay binder layers ranged from 2.451 to 2.464, while the only GPS binder layer with data had a bulk specific gravity of 2.371. SPS surface layers were between 2.439 and 2.718 (0960), while the GPS surface layers were between 2.341 and 2.399.
- Maximum specific gravities for the SPS overlay binder layers ranged from 2.463 to 2.510, while the only GPS binder layer with data had a maximum specific gravity of 2.498. SPS surface layers were between 2.442 and 2.780 (0960), while the GPS surface layers were between 2.431 and 2.493.

Appendix D contains plots of the materials testing data for the various tests for the study sections. The values shown in the plots represent the average values for a specific section, for comparison.

5.0 PAVEMENT PERFORMANCE INDICATORS

The Missouri sections have been surveyed periodically under the LTPP monitoring program to collect time-series performance data. These data were used to evaluate the performance of the rehabilitated PCC pavement sections in Missouri, which include pavement surface characteristics (roughness and distress) and structural capacity. The observed performance trends were then used to compare the effectiveness of the various rehabilitation techniques. This evaluation includes all of the data collected up to January 2000 that had been uploaded into the North Central Region Coordination Office (NCRCO) regional information management system (RIMS) database.

The Missouri sites included in this report were designed to provide information on the effectiveness of various methods of rehabilitation for jointed concrete pavements. As such, the most important question to address in this evaluation is the relative performance of the different rehabilitation techniques. Because each experiment encompasses a range of traffic levels and rehabilitation techniques with widely varying levels of corrective effort, a comprehensive and fair comparison of the effectiveness of these techniques is difficult. For example, if one rehabilitation technique exhibits less cracking but more rutting than another, it would be difficult to say which one provided "better" performance. However, one measure of performance common to all techniques is roughness. Therefore, the overall performance comparison of all sections included in this report is based on roughness using the International Roughness Index (IRI). Once the performance trends were firmly established, an economic analysis was conducted to determine the cost-effectiveness of various rehabilitation alternatives.

SURFACE DISTRESS

The Missouri experimental sections are separated into four pavement categories: bare PCC, bonded PCC overlay of PCC, AC overlay of PCC, and AC overlay of fractured PCC. Within each pavement category, direct comparisons of performance based on distress are also possible, as described below:

- Bare PCC–The rehabilitation techniques in this category may include some or all of the concrete pavement restoration (CPR) techniques other than overlay, including full-depth repair, diamond grinding, joint sealing, and addition of retrofitted edge drains. For jointed concrete pavements, the performance measures of interest for this group of pavement sections include the following:
  - IRI.
  - Transverse cracking.
  - Faulting of joints and cracks.
  - Longitudinal cracking.

- Bonded PCC overlay–This technique involves various surface preparation techniques and placing a bonded PCC overlay on the existing PCC pavement. The performance measures of interest for this group of pavement sections are similar to the bare PCC pavement and include the following:

- IRI.
- Transverse cracking.
- Longitudinal cracking.
- Total (transverse and longitudinal) cracking.
- Faulting of joints and cracks.

- AC overlay on PCC–This technique involves applying varying degrees of preoverlay repairs and placing an AC overlay. The performance measures of interest for this group of pavement sections include the following:
  - IRI.
  - Transverse and reflection cracking.
  - Fatigue cracking.
  - Longitudinal non-wheelpath cracking.
  - Rutting.

- AC overlay on fractured PCC – This category includes AC overlays placed on break and seated PCC or rubblized PCC. The performance measures of interest for this group of pavement sections include the following:
  - IRI.
  - Transverse and reflection cracking.
  - Fatigue cracking.
  - Longitudinal non-wheelpath cracking.
  - Rutting.

Some of the distress types overlap different categories of rehabilitation techniques, as defined above. Wherever possible, direct comparisons of performance will be made on the basis of observed distress.

RIDE DATA

The IRI provides a common and consistent quantitative basis on which different measures of roughness can be compared. The IRI utilizes the longitudinal surface profile in the wheelpath and is computed from surface elevation data collected by a mechanical profilometer. It is expressed in units of inches per mile and is independent of the pavement surface type. [Haas, Hudson, and Zaniewski, 1994]

A recent research project developed models to correlate the measured IRI values with the Present Serviceability Rating (PSR). Once the IRI values are associated with the PSR scale, each pavement section can be categorized, based on the user's perception, as a smooth, moderately rough, or rough pavement section. Table 5.1 lists the ranges of IRI for each range of PSR values and their corresponding roughness category. [Al-Omari and Darter, 1992]

Table 5.1. Approximate IRI values and corresponding PSR classifications.

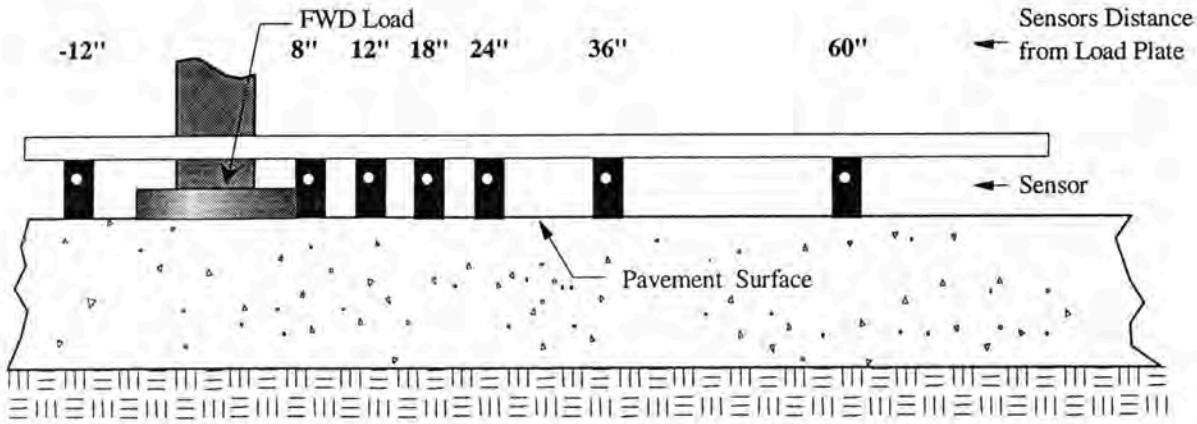
Approximate IRI, in/mile	PSR	PSR classification
0-95	3.5-5.0	Smooth
95-133	2.5-3.5	Moderately rough
> 133	< 2.5	Rough

Because the measure of roughness or ride quality is not dependent on surface type, the roughness for all sections included in this report can be directly compared to each other.

STRUCTURAL RESPONSE

The structural response for each of the pavement sections was also evaluated in this report. Nondestructive deflection testing (NDT) was conducted using a falling weight deflectometer (FWD). An FWD, illustrated in figure 5.1, is an impulse loading device that exerts a force similar in magnitude and duration to that produced by a moving vehicle tire load. To accomplish this, a weight is dropped onto a spring connected to a load plate of known dimensions. By varying the magnitude of the weight and the height from which it is dropped, the applied load can be changed. Because traffic is often given in terms of 18-kip ESAL's, the magnitude and height are typically adjusted to simulate a 9-kip wheel load. The impact of the weight produces a pavement deflection, which is measured by deflection transducers. The spacing and location of each sensor is shown in figure 5.2.

Figure 5.1. The FWD.



Note: Sensor D8 is located 12 inches to the right of the

Figure 5.2. Schematic of the FWD load plate and sensor configurations.

Because the experiment encompasses a whole range of rehabilitation techniques with widely varying levels of corrective effort, fair comparison of the effectiveness of different techniques is difficult. The structural performance of a pavement section can be determined using FWD deflection data. Various inferences regarding PCC pavement performance can be made using deflection data, such as structural comparisons among sections, load transfer efficiency, and the presence of voids. In addition, the deflection data can be used to back calculate the elastic modulus (or stiffness) of pavement layers. This information is useful in determining the structural performance of the pavement and the relative contribution of each layer to load-carrying capacity.

The deflections of the different pavement sections were evaluated using the Outer AREA parameter (Hall, et al. 1997; McPeak and Khazanovich 1997). The Outer AREA is similar to the AREA parameter (Hoffman and Thompson 1981) used in many back calculation procedures and is the normalized area under the deflection profile. The Outer AREA is determined without the deflections from the first two sensors (d0 and d8) to exclude the effects of the direct compression in the AC layer. This enables fair comparison of the structural capacity of bare concrete sections to that of the overlaid sections. The Outer AREA concept was originally used for backcalculation of AC-overlaid concrete pavement parameters and is defined as:

$$OuterAREA = 25.4\times[3 + 6\times(d_{18}/d_{12}) + 9\times(d_{24}/d_{12}) + 18\times(d_{36}/d_{12}) + 12\times(d_{60}/d_{12})]$$

where d_{12}, d_{18}, d_{24}, d_{36}, and d_{60} are sensor deflections 12, 18, 24, 36, and 60 in from the center of the load plate. The Outer AREA term has dimensions of inches.

6.0 PERFORMANCE TRENDS

Each pavement section was evaluated based on ride quality (or roughness), surface distresses, and structural characteristics. This chapter briefly discusses the preliminary findings for each of these categories.

ROUGHNESS TRENDS

Roughness trends are discussed according to each experiment type. Therefore, the IRI for each SPS and GPS site is compared directly with the sections within that experiment type. The SPS-6 sections are further broken down and compared by similar rehabilitation techniques, such as bare PCC-surfaced pavements or AC overlays of non-fractured PCC pavements.

Bethany and Potosi (SPS-6)

Both the Bethany and Potosi sites are part of the SPS-6 experiment. Currently, the Bethany site (rehabilitation of JRCP) has almost 7 years' worth of monitoring data available since rehabilitation was performed. Because the Potosi site (rehabilitation of JPCP) was recently constructed, there were no monitoring data available for analysis at the time that this report was prepared. Therefore, the preliminary trends discussed below are only applicable to the Bethany site.

Bethany Bare PCC Sections (JRCP)

Both the minimum and maximum preparation bare PCC sections showed a large decrease in roughness immediately after rehabilitation. The minimum preparation alternative (section 290602) decreased from 125 to 80 in/mile, as shown in figure 6.1. The maximum preparation alternative (section 290605) decreased from 170 to 80 in/mile. This decrease in IRI is due to the diamond grinding that was performed on each section.

Since rehabilitation, the increase in IRI of both minimum and maximum preparation sections has been approximately the same for both alternatives. The rate of increase in IRI of these sections is higher than the rate of increase of the control section since rehabilitation. Figure 6.1 clearly shows that the minimum and maximum preparation techniques have performed similarly since being rehabilitated even given the fact that the maximum preparation section began with a higher pre-rehab IRI (175 in/mi) than the minimum preparation (125 in/mi). Given this difference in initial condition, it appears that the level of pre-rehabilitation preparation had no effect on the rate of IRI increase. Of course, this may change in the future. This figure also shows that the IRI of both the minimum and maximum rehabilitation sections "catches up" to that of the control section after about 7 years of service.

The rehabilitation on one supplemental section (section 290666) used minimum restoration techniques (undersealing but no diamond grinding). This section demonstrates no initial reduction in roughness, similar to the control section. This is logical, since the existing roughness was not removed (e.g., via diamond grinding). After 5.5 years, both the minimum and

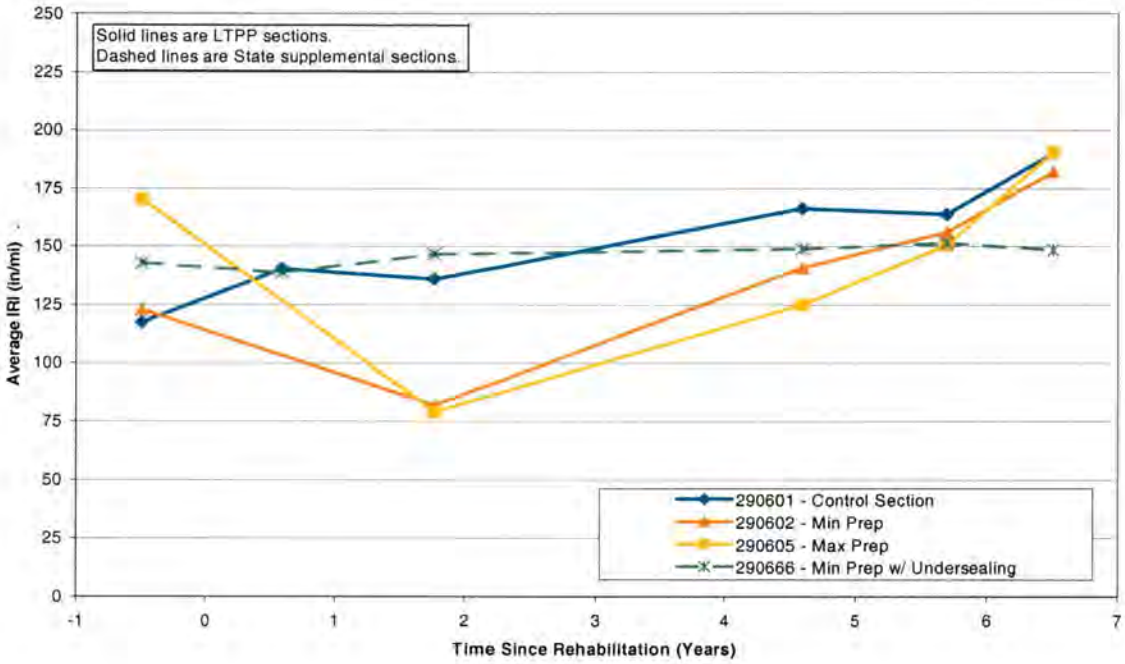


Figure 6.1. Roughness development trends for bare concrete JRCP sections.

maximum preparation techniques became rougher and continued to increase in roughness, while this supplemental section is still not showing any increase in roughness. This finding could become even more significant as each of the rehabilitation techniques continues to age.

Bethany AC Overlays of Non-Fractured PCC

The non-fractured rehabilitation techniques for SPS-6 included a minimum preparation 4-in AC overlay, a minimum preparation with a sawed and sealed 4-in AC overlay, a maximum preparation with a 4-in AC overlay, and a typical Missouri project construction with a 4.5-in overlay. Each section with an AC overlay decreased to the same level of roughness for all rehabilitation techniques, as shown in figure 6.2. This level is an IRI of about 75 in/mile. Currently, all of the non-fractured concrete sections are performing similarly, with very little increase in IRI within the first 6 years after rehabilitation. Additional monitoring data may or may not determine any significant variations in roughness between each rehabilitation alternative. Currently, it appears that there is no difference in the performance of roughness due to the extent of the pre-overlay preparation techniques used. Also, these sections are not increasing in IRI, as did the bare PCC rehabilitation sections.

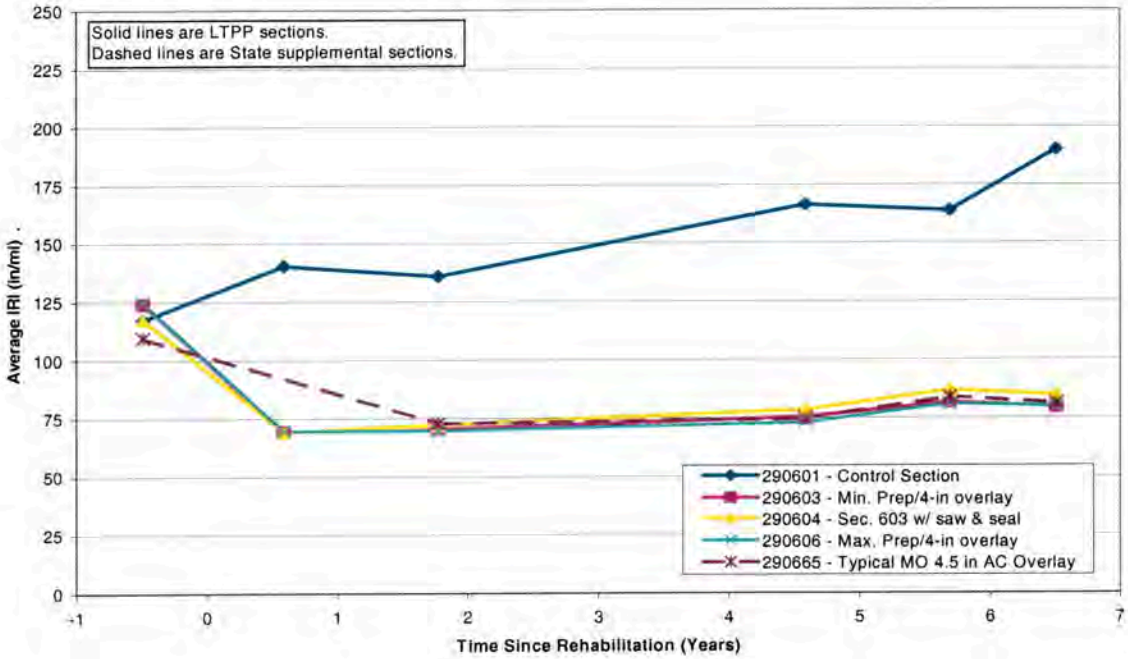


Figure 6.2. Roughness development trends for AC overlays of non-fractured JRCP.

Bethany AC Overlays of Fractured Concrete

This group consists of two types of slab fracturing techniques—crack/break and seat, and rubblizing. These methods were developed to minimize reflective cracking problems in AC overlays of jointed concrete pavements. Break and seat is a method used to reduce the JRCP slab size in order to minimize the movement of the JRCP under the AC overlay at transverse joints and working cracks. In addition, break and seat requires that the steel reinforcing material be ruptured during the fracturing process. The fractured the amount of faulting slabs are seated with a roller to ensure that there are no voids beneath the JRCP that would allow the JRCP to move under the AC overlay. The rubblizing procedure consists of fracturing the JRCP into small pieces (usually less than 9 in) using a resonant pavement breaker and compacting the layer prior to placement of the AC overlay.

Break and Seat

The break and seat rehabilitation alternatives consist of breaking and seating the JRCP and then placing 4- and 8-in asphalt overlays with and without edge drains. After construction, all of the break and seated sections had better IRI values than the control section, as shown in figure 6.3.

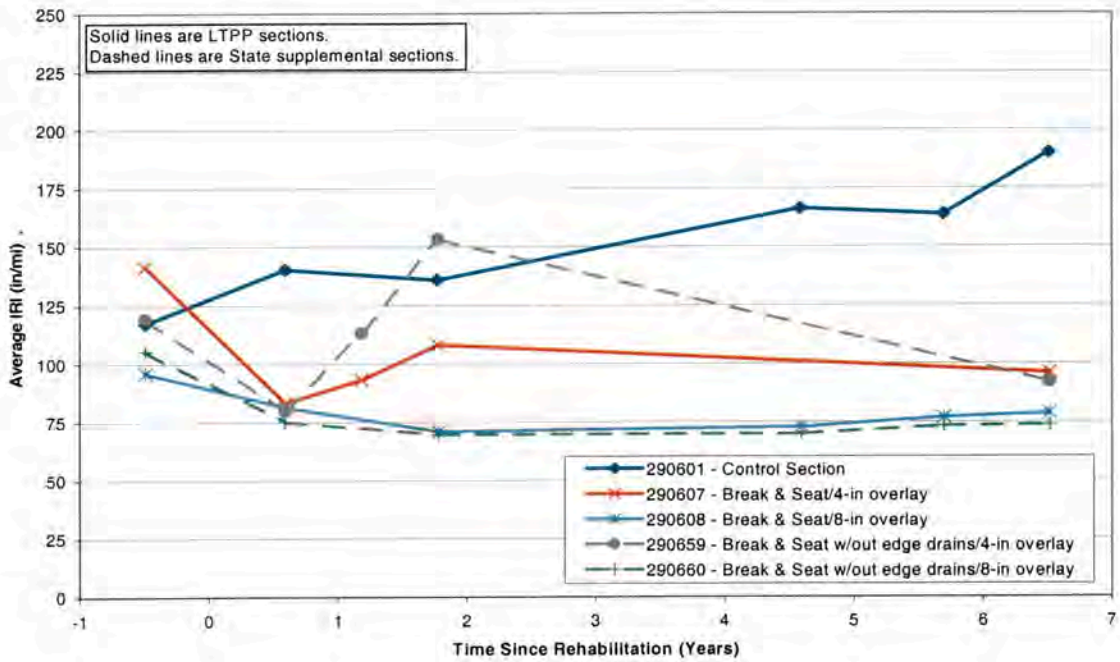


Figure 6.3. Roughness development trends for AC overlays of break and seated PCC.

Within two years of rehabilitation some significant performance differences had occurred:

- The 4-in AC overlays with and without edge drains (sections 290607 and 290659) are deteriorating at much more rapid rates than the control section and the 8-in AC overlays.
- The thinner AC overlay without edge drains had the greatest increase in roughness.
- The 8-in AC overlays with and without edge drains performed similarly.
- The 4-in AC overlays of break and seated JRCP increased in IRI much more than the same 4-in AC overlays of non-fractured JRCP, but the 8-in AC overlays of break and seated JRCP performed similar to the non-fractured 4-in AC overlays.

Based on these observations, it can be concluded that edge drains significantly impact the performance of thinner (4-in) AC overlays, while for thicker (8-in) AC overlays the edge drains did not have any effect. In addition, the 4-in AC overlays of non-fractured PCC pavements had a smoother surface than the same overlay thickness of a break and seated PCC pavement.

It is obvious that 2 years after rehabilitation occurred, additional rehabilitation efforts were applied to the break and seat sections with 4-in AC overlays. Apparently, the break and seat and AC overlay requires a thicker overlay to perform the same as the JRCP with an AC overlay but no break and seat.

Rubblized JRCP

Four JRCP sections were rubblized and overlaid with AC overlays of either 4 or 8 in. The IRI immediately after rehabilitation was better than that of the control section, as shown in figure 6.4. All of the rubblized sections are performing about the same as the 8-in break and seat overlays and the conventional 4-in AC overlays over nonfractured JRCP. Currently there appears to be little performance difference between the 7 and 11.5 in AC overlays and the sections with and without overlays. Therefore, additional time is needed to ascertain significant differences between each rehabilitation alternative.

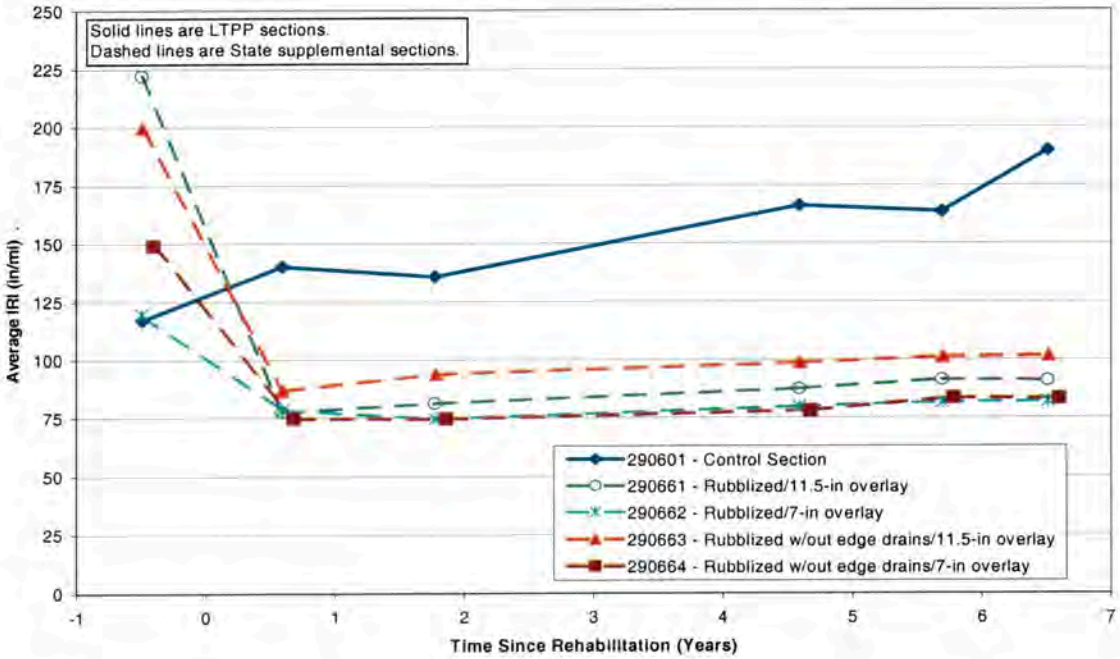


Figure 6.4. Roughness development trends for AC overlays of rubblized JRCP.

Festus (SPS-7)

Immediately after rehabilitation, all of the Festus sections exhibited a large reduction in roughness, as shown in figures 6.5 and 6.6. The initial IRI values after overlay of the different sections range from 60 to 120 in/mile, indicating a wide range of construction smoothness quality. Note that the 3-in AC overlay shown in figure 6.6 ended up with an initial IRI of over 100 in/mile, but this pavement is currently performing similar to the bonded concrete overlays in figure 6.5. All of the sections have similar increases in roughness over time. Additional time is needed to identify the unique performance trends due to the various rehabilitation techniques.

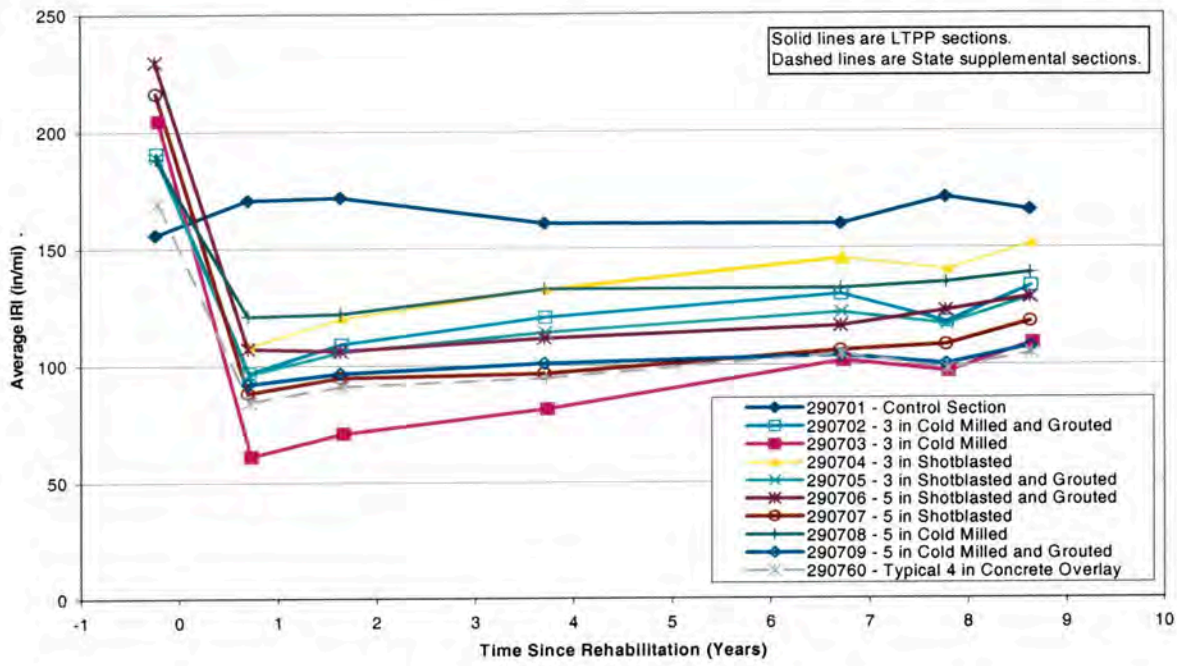


Figure 6.5. Roughness development trends for bonded PCC overlays of PCC.

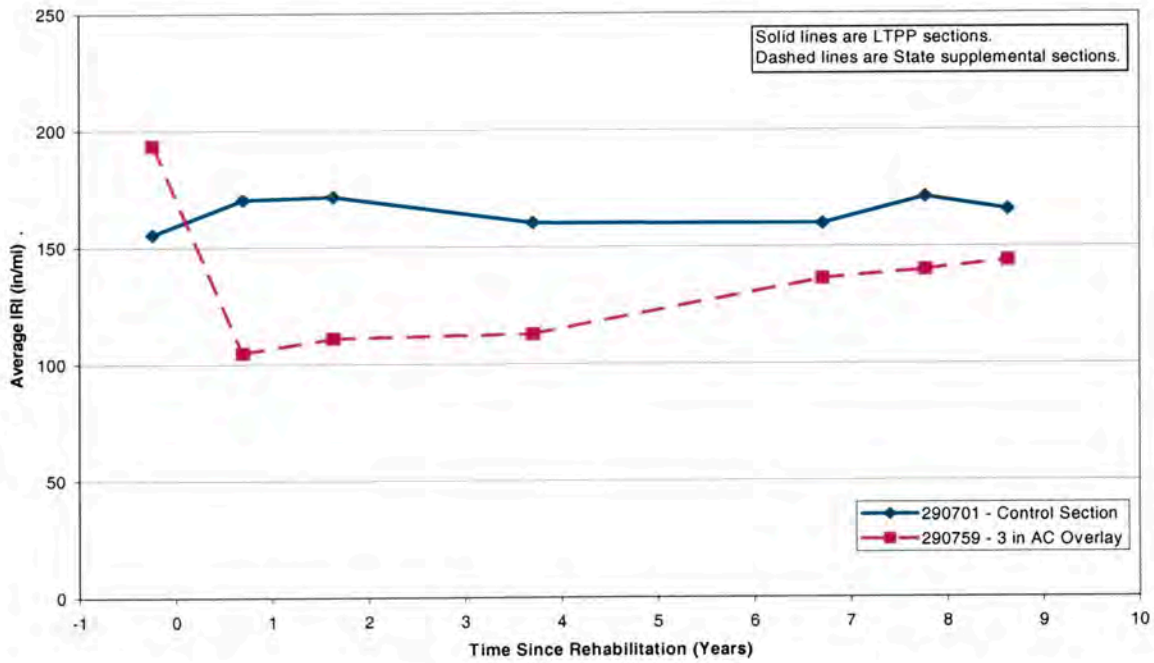


Figure 6.6. Roughness development trends for AC overlay of PCC.

Sedalia (SPS-9A)

Immediately after rehabilitation, roughness was reduced in all of the Sedalia sections, resulting in an initial IRI of 60 to 80 in/mile, as shown in figure 6.7. All of the sections have similar increases in roughness over time, and the plots appear to be generally parallel, indicating the importance of achieving a low initial IRI. Additional time is needed to identify the unique performance trends due to the various rehabilitation techniques.

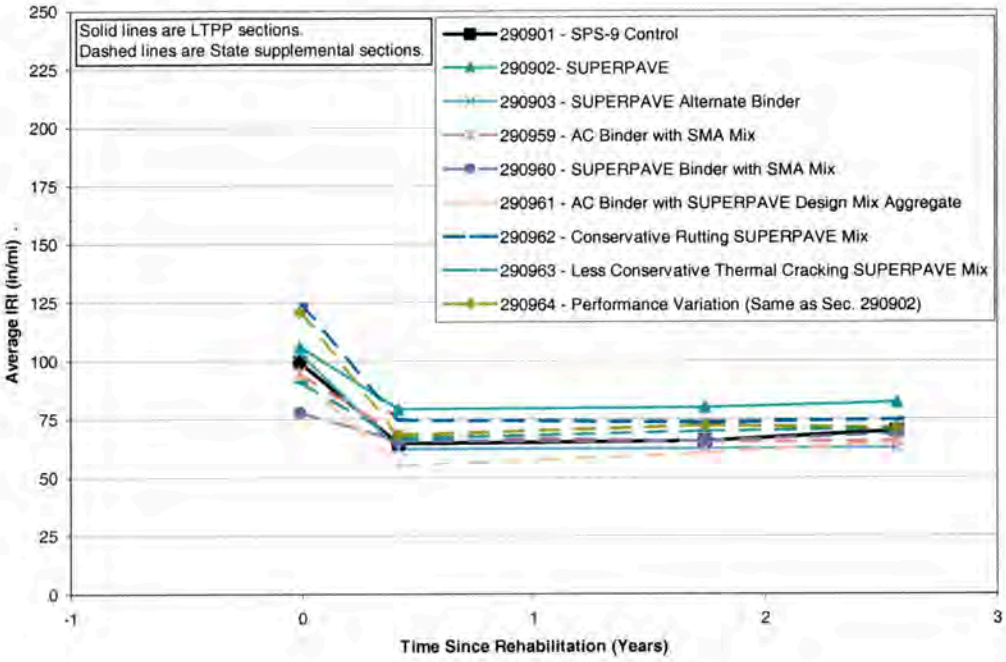


Figure 6.7. Roughness development trends for SUPERPAVE overlays of PCC.

GPS-7

The GPS-7 sections exhibit a reduction in IRI after overlay and then a slow increase in IRI over time, as shown in figure 6.8. The 2.4- and 2.5-in AC overlays are rougher 6.5 years after rehabilitation than the 3- and 4.5-in AC overlays. In general, the thinner AC overlays were slightly rougher than the thicker AC overlays immediately after rehabilitation. In addition, the 3- and 4.5-in AC overlays have a lower rate of increasing roughness.

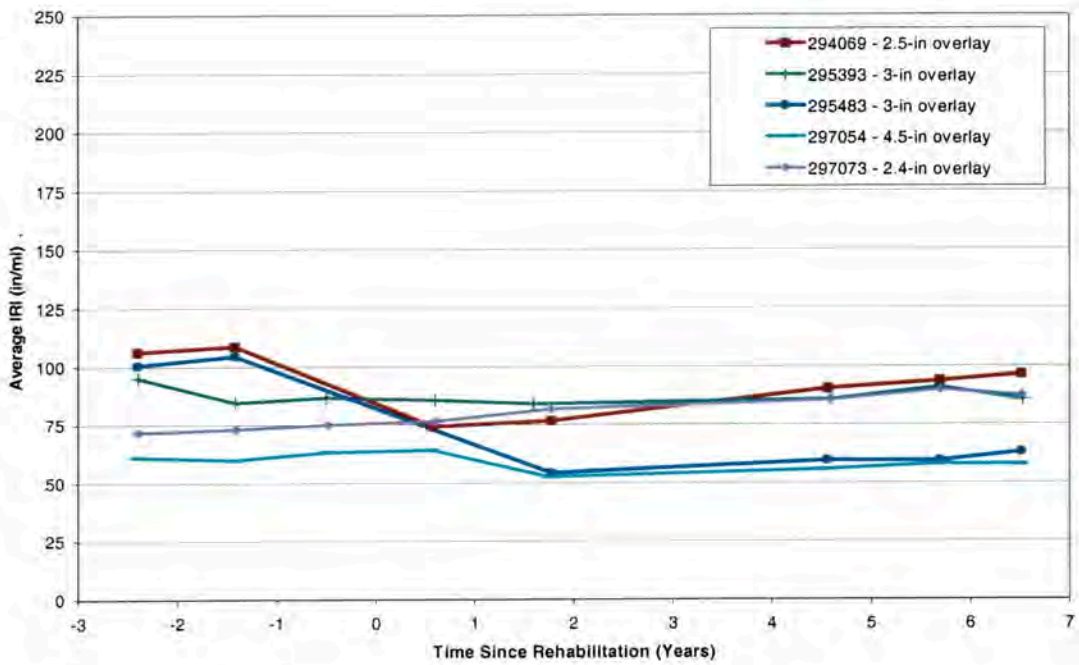


Figure 6.8. Roughness development trends for GPS-7 sites (AC overlay of PCC).

SURFACE DISTRESS

The surface distresses for each rehabilitation alternative depend on the surface type (AC or PCC). As discussed earlier, only certain distresses can be measured for each of these pavement types. This section discusses the existing performance trends that have developed since rehabilitation for the Bethany (SPS-6) and Festus (SPS-7) sites. Currently, there is not enough data available in the database to identify preliminary performance trends for the Potosi (SPS-6) and Sedalia (SPS-9A) sites.

Bethany (SPS-6)

The Bethany site includes bare PCC and AC-surfaced pavements. It is nearly impossible to directly compare the distress performance of all of the SPS-6 rehabilitation alternatives against one another. Therefore, these rehabilitation alternatives can only be directly compared within each basic rehabilitation method, depending on the surface type and if the PCC was fractured. Table 6.1 shows the distresses that were evaluated for each major rehabilitation alternative.

Table 6.1. Distress trends evaluated for various rehabilitation alternatives.

Distress	Bare PCC	AC over PCC	AC over fractured PCC
Faulting	Yes	No	No
Transverse cracking	Yes	No	No
Transverse and reflection cracking	No	Yes	Yes
Longitudinal cracking (wheelpath)	Yes	Yes	Yes
Longitudinal cracking (non-wheelpath)	Yes	Yes	Yes
Rutting	No	Yes	Yes

Faulting

Faulting of joints and cracks has a very significant effect on the ride quality of PCC pavements, so it is important to control its occurrence. Figure 6.9 shows the amount of faulting, before and after rehabilitation, for the control (290601), minimum preparation (290602), maximum preparation (290605), and minimum preparation with undersealing (290666) sections. The faulting values are based on data collected along transverse joints approximately 1-ft from the edge of the slabs, using a Georgia faultmeter. In calculating the average faulting for a section, both positive and negative values were included as absolute values to show the overall magnitude of the faulting present in the section.

The control section shows that, without restoration, the amount of faulting on this PCC pavement is around 0.16 in approximately 1 year after this study began. This amount of faulting would typically trigger pavement rehabilitation due to excessive roughness.

The diamond grinding applied to the maximum preparation section reduced faulting to almost zero immediately after rehabilitation; however, diamond grinding only slightly reduced the amount of faulting in the minimum preparation section (apparently not all joints were ground). Nevertheless, 6 years after rehabilitation these sections have approximately the same amount of faulting. There must be a significant amount of pumping and erosion occurring for these pavements to fault so quickly after rehabilitation. The edge drains installed in the maximum preparation sections obviously did not reduce the rate of faulting.

For the State supplemental section of minimum preparation with undersealing, diamond grinding was not performed, so there was no reduction in the amount of faulting after rehabilitation.

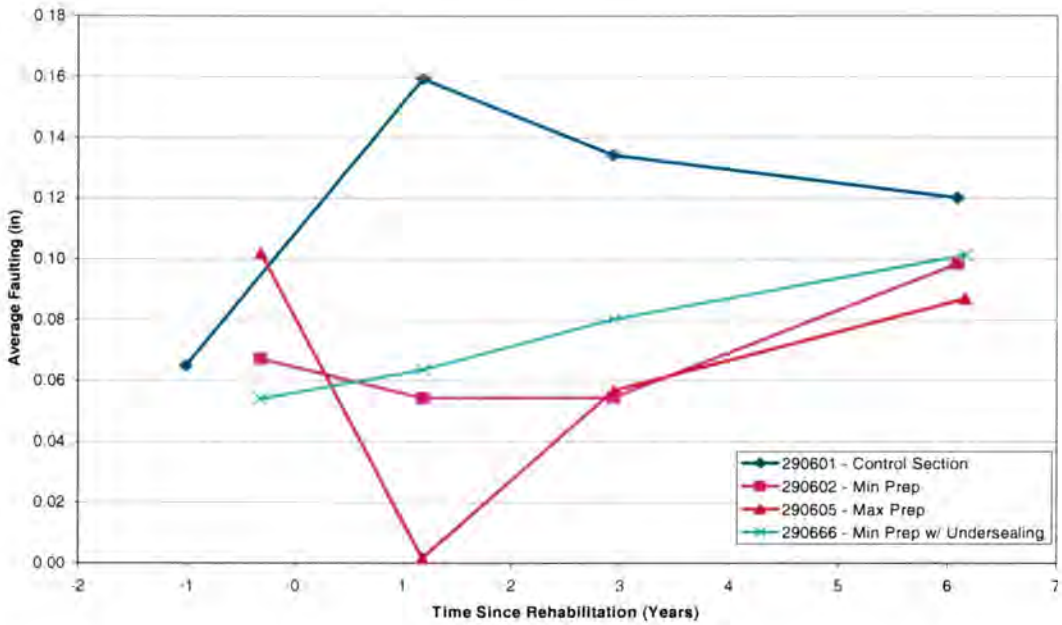


Figure 6.9. Average joint faulting in bare SPS-6 sections.

Transverse and Reflection Cracking

Transverse cracking and reflection cracking are key distresses that affect ride quality. Transverse cracking can be measured on bare concrete pavements, AC overlays of PCC, and AC overlays of fractured PCC. Reflection cracking can only be measured for AC overlays of PCC pavements. Sections that have been fractured and seated should not have reflection cracking; if they do, it is an indication that the PCC was not completely fractured prior to placement of the overlay.

Figures 6.10 through 6.12 show the total transverse and reflection cracking reported for each rehabilitation alternative. Both the minimum preparation (290602) and maximum preparation (290605) have similar amounts of transverse cracking since rehabilitation. Approximately 1.5 years after rehabilitation, the control section (290601) received 1 full-depth patch. Approximately 4 years after rehabilitation, the control (3 repairs), minimum preparation (3 repairs), and maximum preparation (1 repair) received full-depth repairs. It is interesting to note that the transverse cracking for the minimum preparation with undersealing section (290666) has remained fairly stable since rehabilitation. Moreover, all of the rehabilitation alternatives have experienced more transverse cracking than the control section (290601).

Six years after rehabilitation, all of the 4-in AC overlays have approximately the same amount of transverse and reflection cracking. The 4-in AC overlay with sawed and sealed joints has noticeable more transverse and reflection cracks since rehabilitation than the over AC overlays. This can be explained by the LTPP distress survey protocol, which requires that all sealed joints in AC overlays be labeled as reflection cracks. The AC overlay of fractured PCC sections have very little transverse and reflection cracking 6 years after rehabilitation.

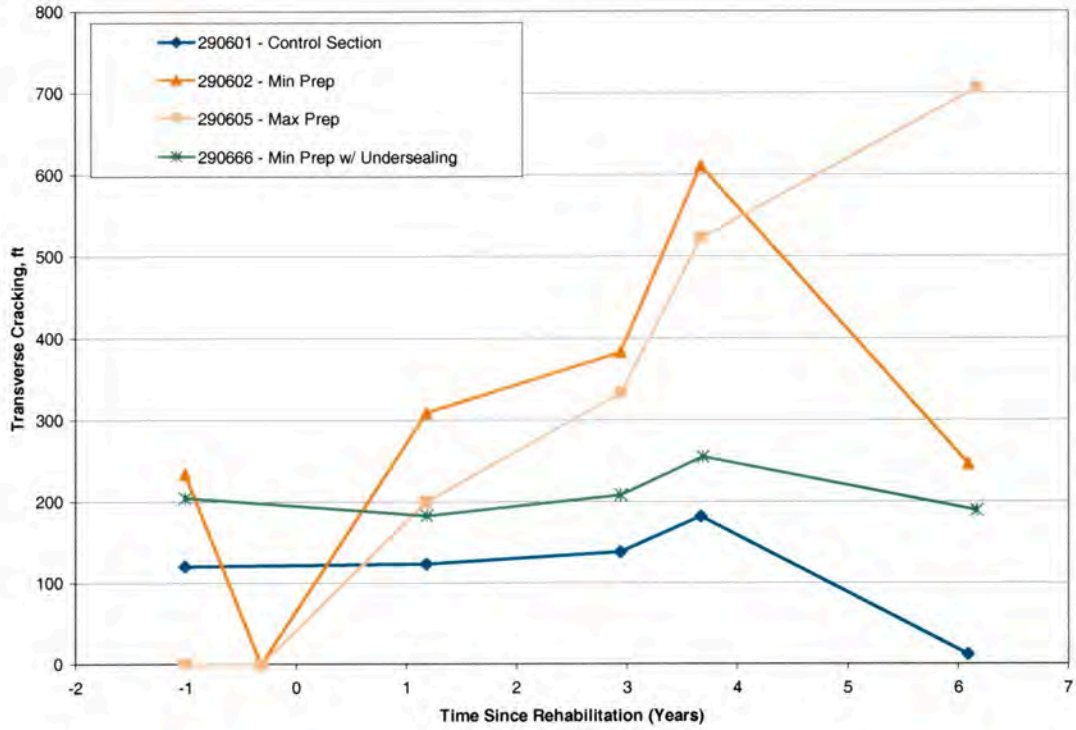


Figure 6.10. Transverse crack deterioration in the bare PCC SPS-6 sections.

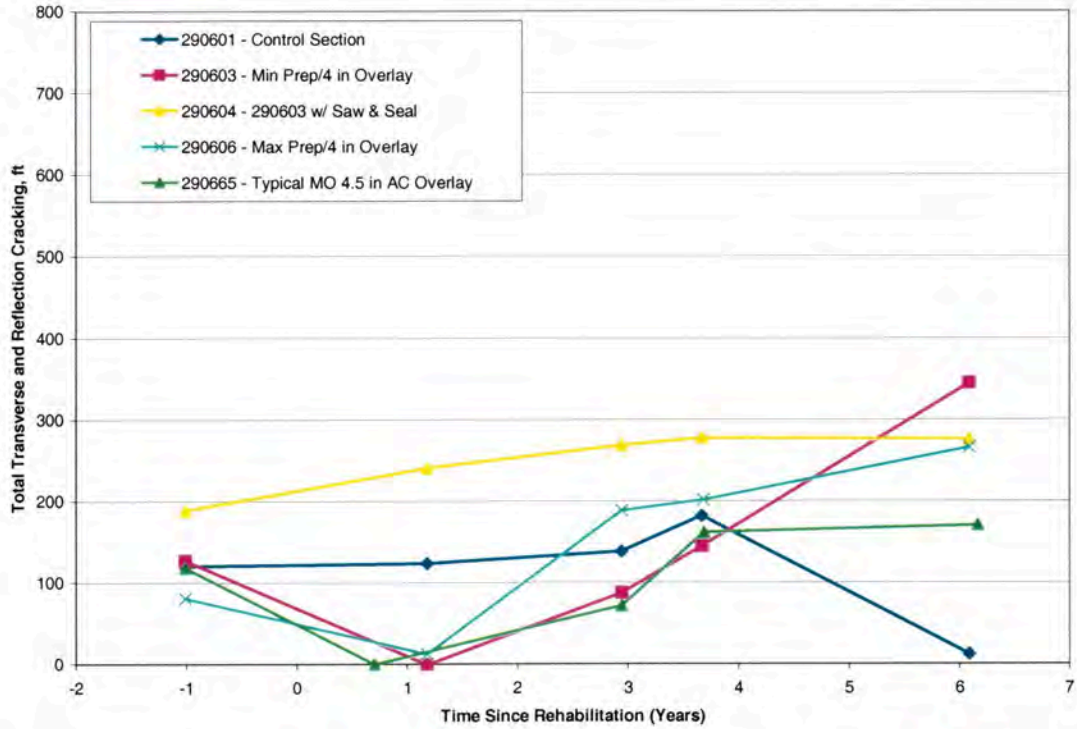


Figure 6.11. Transverse and reflection crack deterioration in the SPS-6 AC overlay of non-fractured PCC.

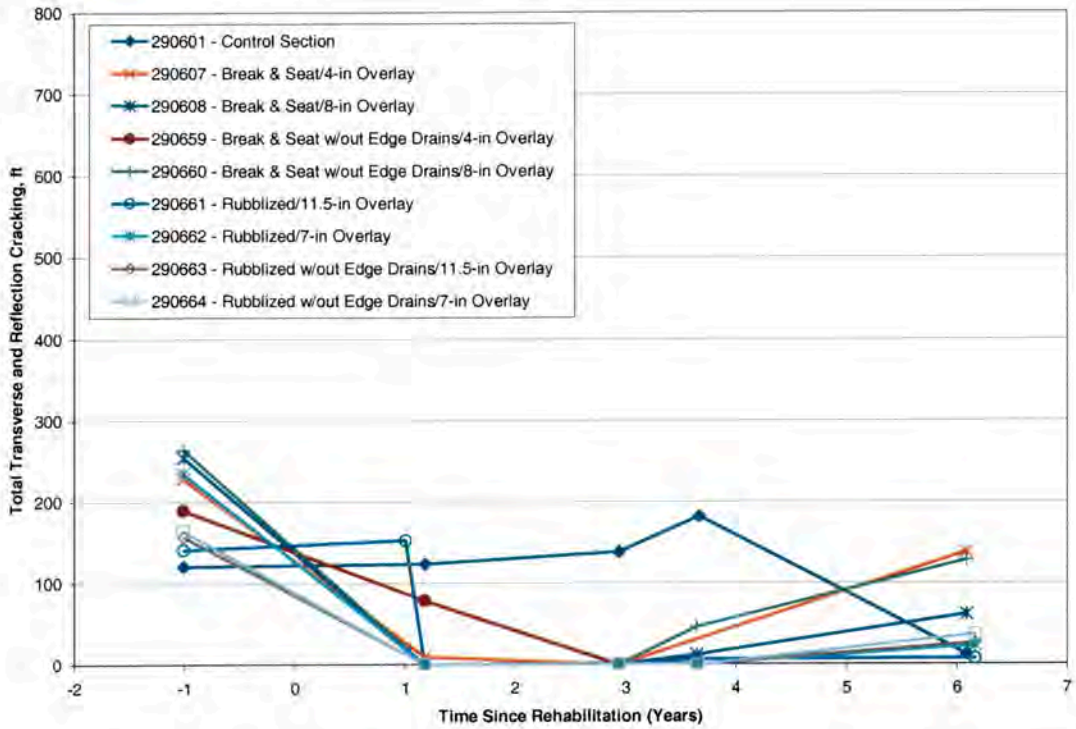


Figure 6.12. Transverse and reflection crack deterioration in the SPS-6 AC overlay of fractured PCC.

In general, the bare concrete sections have more transverse cracking than the AC-overlaid sections. In addition, the break and seated and rubblized pavement sections have less transverse and reflection cracking than the AC over non-fractured PCC pavement sections. This is an indication that the PCC was completely fractured prior to overlay of these sections and that the slab size has been reduced to a sufficient size to reduce reflection cracking.

Fatigue Cracking

Longitudinal cracking in the wheelpath may indicate the initiation of fatigue cracking in AC pavements. None of the bare PCC and AC over non-fractured PCC sections have longitudinal wheelpath cracking, meaning that the original PCC pavement has remained structurally sound and intact since rehabilitation occurred.

In 1998, only sections 290663 and 290664 (11.5- and 7-in AC overlays of rubblized JRCP without edge drains) exhibited a combination of longitudinal and fatigue cracking in the wheelpaths. It is important to note that the two rubblized sections with edge drains did not exhibit fatigue cracking. This observation emphasizes the importance of proper roadway drainage and the impact of moisture in the pavement structure. None of the break and seated sections are showing signs of fatigue at the time of this report.

Longitudinal Cracking Not in the Wheelpath

Both the control (290601) and the minimum preparation bare PCC (290602) had no longitudinal non-wheelpath cracking. The maximum preparation bare PCC (290905) has one non-wheelpath longitudinal crack. This is an isolated crack, and there do not appear to be any non-wheelpath longitudinal cracking trends developing at this time.

All of the AC-overlaid pavement sections at the Bethany SPS-6 site have a considerable amount of longitudinal non-wheelpath cracking. Figure 6.13 shows the increasing amount of this cracking. At this time, no trends were identified based on the rehabilitation technique.

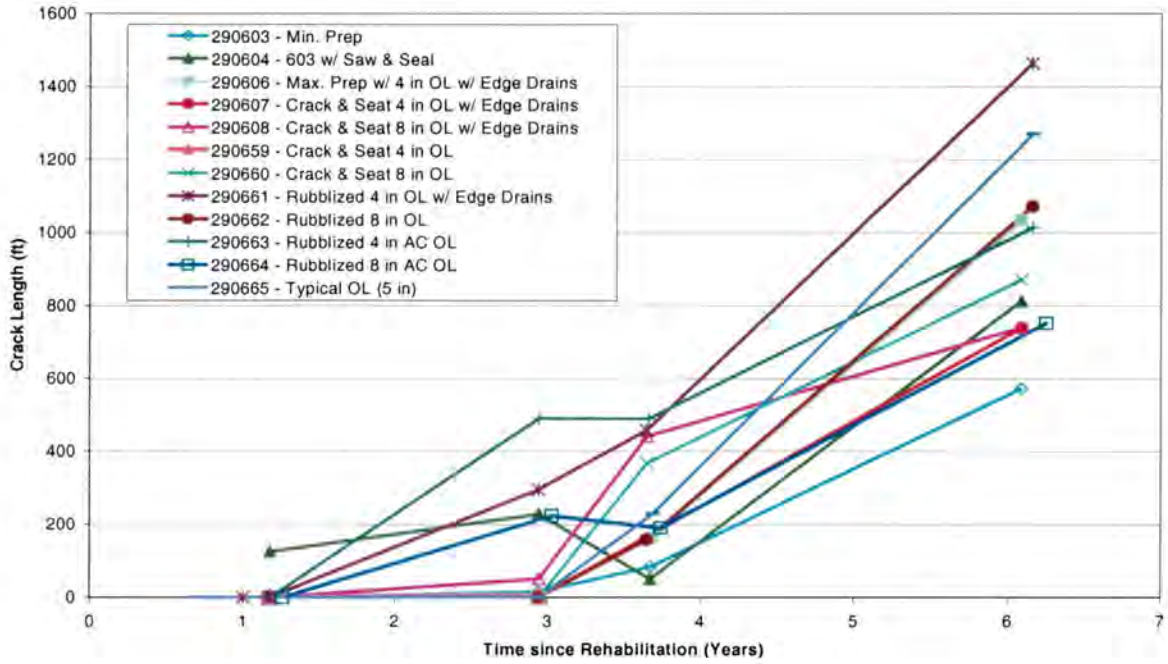


Figure 6.13. The longitudinal non-wheel path cracking of the Bethany SPS-6 site.

Rutting of AC Overlays

Rutting can become a safety hazard as the rut depth increases. Rutting greater than 0.5 in can cause hydroplaning or confine the tires to the wheelpaths, making it difficult to change lanes or avoid foreign objects in the travel lane. Fortunately, at the time of this report, none of the rehabilitated PCC sections in Missouri had rutting greater than 0.2 in; therefore, rutting is not currently a concern.

Festus (SPS-7)

The Festus site consists of PCC surfaced pavements, with the exception of section 290759 (a standard 3-in AC overlay). For this site, the distresses that were evaluated were faulting,

transverse cracking, longitudinal cracking, and total cracking (a combination of transverse and longitudinal cracking).

Faulting

Faulting of joints and cracks has a very significant effect on ride quality, so it is important to control its occurrence. Figure 6.14 shows the faulting, after rehabilitation, for the control section (290701) and all of the bonded PCC overlays. The control section shows a steady rate of increase in faulting. Since rehabilitation, most of the other sections have had minimal faulting of 0 to 0.03 in; therefore, no faulting trends can be identified at this time.

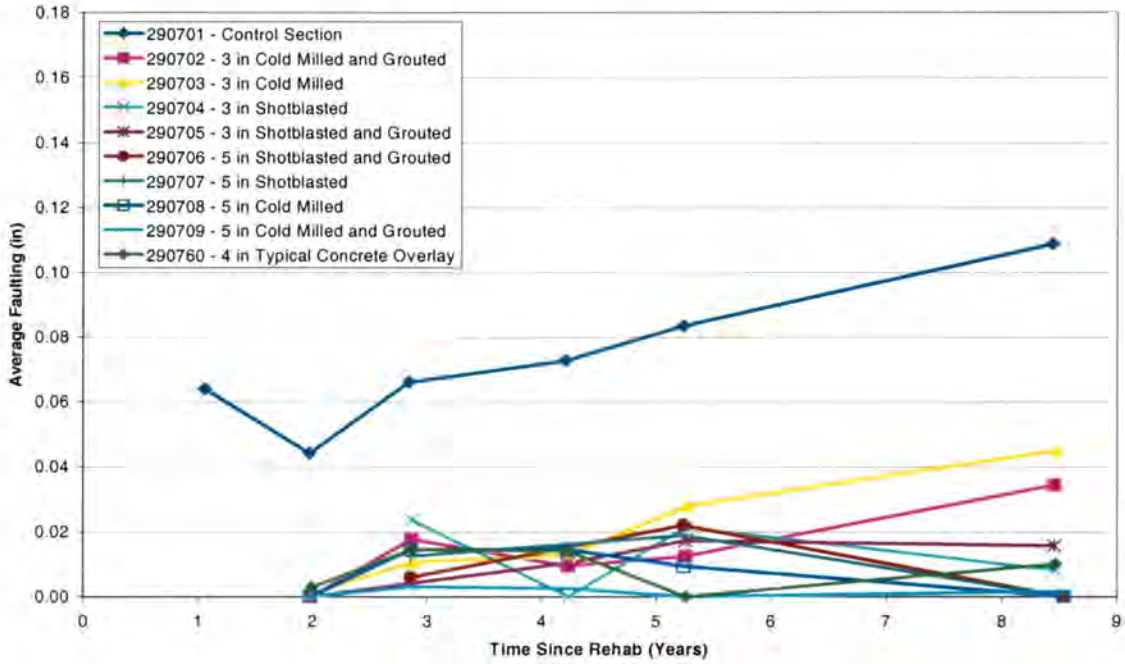


Figure 6.14. Average faulting in the SPS-7 PCC-surfaced sections.

Two sections have exhibited a steady increase in faulting since rehabilitation: the 3-in cold milled and grouted (290702) and the 3-in cold milled (290703) sections. For both of these sections, the faulting after 8 years is approximately 0.04 in. However, the faulting in these sections is still notably less than the 0.13 in faulting that is occurring in the control section (290701).

Overall, these bonded concrete overlays have faulted very little over 8 or 9 years, and it does not appear that they will "catch up" to the control section for many years. The bonded overlaid sections are much thicker and would have somewhat reduced deflections. As these sections continue to age, it is expected that more notable trends will develop.

Transverse Cracking

The transverse cracking for the Festus sections is shown in figure 6.15. A lot of transverse cracking occurred rapidly after construction. This may be attributed to the fact that the overlay material was placed as part of a fast-track project, which called for very high early strength concrete to be used. Since the placement of the PCC overlays, the amount of cracking has been relatively constant. In general, very little new cracking has occurred on each of these sections since the first year after rehabilitation was completed. Based on the information shown in this graph, some preliminary observations can be made:

- As the thickness of the bonded PCC overlay increases, the amount of cracking also increases (this could be a construction-related phenomenon).
- The control section (290701) has little to no cracking.
- The 3-in AC overlay (290759) has the same amount of cracking as the 3-in bonded PCC overlay. As these sections continue to age, the rate of deterioration of the AC overlay may exceed the deterioration of the bonded PCC overlays.
- Even with this extent of transverse cracking, the IRI of these sections with PCC overlays remains lower than the control and AC overlay sections.

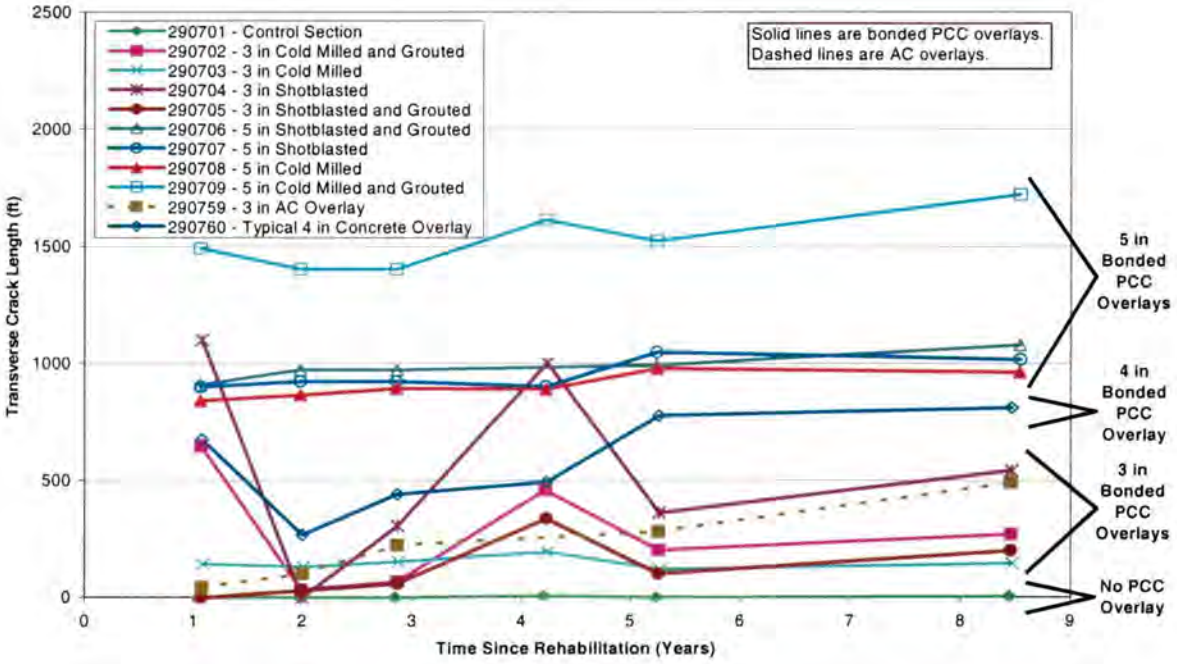


Figure 6.15. The transverse cracking of the Festus SPS-7 site.

Longitudinal Cracking

The longitudinal cracking for the Festus sections is shown in figure 6.16. A lot of longitudinal cracking occurred rapidly after construction, again, most like the result of the high early strength PCC material used for the overlay. The amount of cracking has been relatively constant since the rehabilitation. In general, very little new cracking has occurred on each of these sections since the first year after rehabilitation was completed. Based on the information shown in this graph, some preliminary observations can be made:

- The sections that received shotblasting have the highest amount of cracking (this could be a construction-related phenomenon). This is very noticeable for the 5-in bonded PCC overlays. In addition, the 3-in bonded PCC overlays that were shotblasted instead of being cold milled also have more longitudinal cracking.
- The control section (290701) has little to no cracking.
- For at least the first 5 years after rehabilitation, the 3-in AC overlay (290759) had no longitudinal cracking.
- Eight years after rehabilitation, the 3-in AC overlay (290759) has more longitudinal cracking than the 3-in bonded PCC overlay. This section now has approximately the same amount of longitudinal cracking as the shotblasted 5-in bonded PCC overlays.
- Even with this extent of longitudinal cracking, the IRI of the PCC overlay sections remains lower than the control and AC overlay sections.

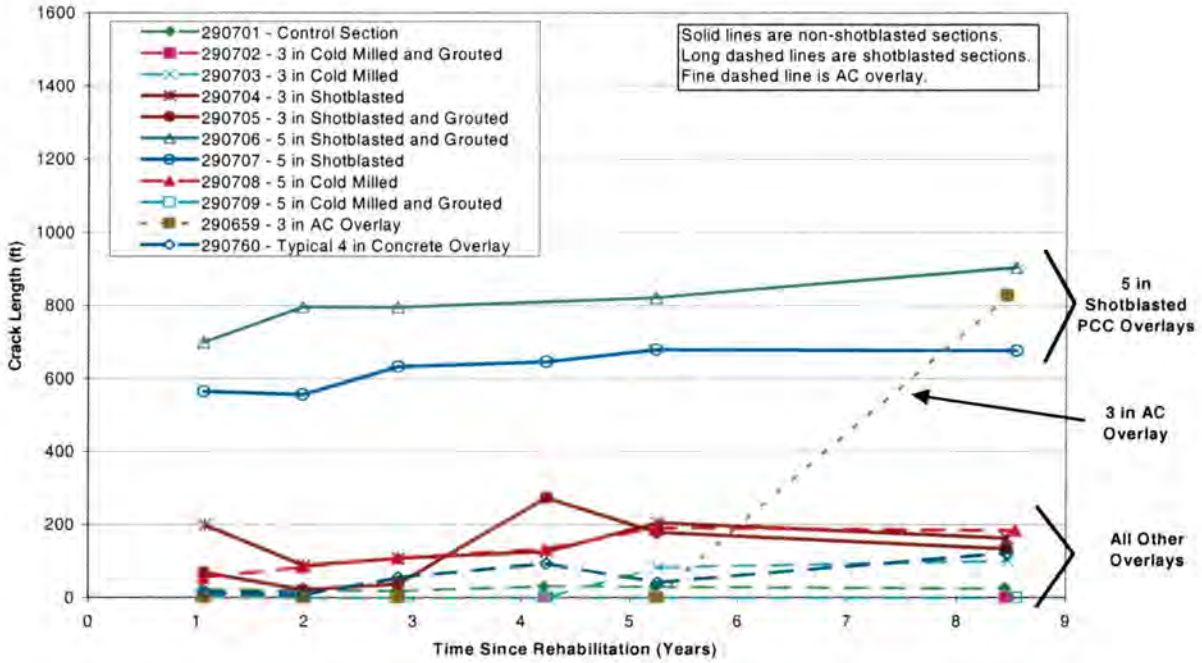


Figure 6.16. The longitudinal cracking of the Festus SPS-7 site.

Total Cracking

The total (transverse plus longitudinal) cracking for the Festus sections is shown in figure 6.17. A lot of cracking occurred rapidly after construction, suggesting that construction problems may have caused debonding of the overlay from the existing slab early on. However, the amount of cracking has been relatively constant since the rehabilitation. In general, very little new cracking has occurred on each of these sections since the first year after rehabilitation was completed. Based on the information shown in this graph, some preliminary observations can be made:

- As the thickness of the bonded PCC overlay increases, the amount of cracking also increases (this could be a construction-related phenomenon).
- The 3- and 5-in bonded PCC sections that were shotblasted have a higher amount of cracking than sections that were cold milled.
- The control section (290701) has little to no cracking.
- For at least the first 5 years after rehabilitation, the 3-in AC overlay (290759) had relatively low amounts of cracking.
- Eight years after rehabilitation, the 3-in AC overlay (290759) has more longitudinal cracking than the 3-in bonded PCC overlay. This section now has approximately the same amount of longitudinal cracking as the shotblasted 5-in bonded PCC overlays.
- Even with this extent of transverse cracking, the IRI of the PCC overlay sections remains lower than the control and AC overlay sections.

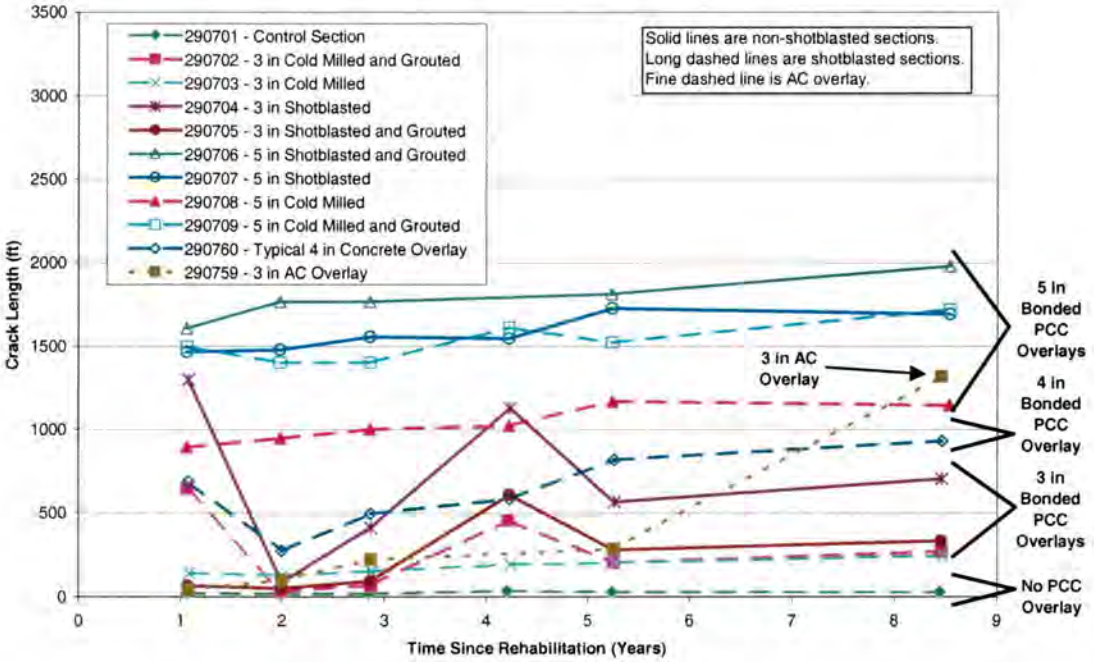


Figure 6.17. The total (transverse and longitudinal) cracking of the Festus SPS-7 site.

STRUCTURAL EVALUATION

The Outer AREA plots created with FWD data for each test section are shown in appendix E. These figures were created for two primary reasons: 1) to allow an evaluation of uniformity of structural support for each of the individual test sections, and 2) to show uniformity of structural support among different test sections. One drawback to this type of evaluation of FWD data is the values cannot be used a predictors of performance from a structural standpoint, as no relations currently exist which relate Outer AREA values to remaining life or other pavement performance indicators.

Bethany (SPS-6)

Figure 6.18 shows the average Outer AREA values for each section included in the Bethany experiment. This figure also shows the average, minimum, and maximum Outer AREA values, including all test dates. The bare PCC and the AC over non-fractured PCC values are very similar and very uniform. This clearly shows that the PCC pavement is providing a significant portion of the structural stiffness for all non-fractured PCC pavement sections, as expected. The maximum preparation with saw and seal has experienced the greatest amount of structural stiffness variability among the non-fractured PCC pavement sections.

The Outer AREA's for the break and seat sections were generally similar to those of the non-fractured overlay sections, indicating that the fractured concrete is still the dominant structural component of the pavement system for those sections. Section 290607, a 4-in AC overlay of break and seat JRCP with edge drains, had several very low Outer AREA values, indicating a possible breakup of the underlying concrete slab.

The Outer AREA's for the rubblized sections are much lower than those for the bare JRCP or the AC overlays of non-fractured JRCP, as would be expected since the primary structural component is in a considerably different state than for the non-rubblized sections. The rubblized sections also showed significant variation along the section. Most sections had several high and several low values for the Outer AREA. This may be due to differences in the level of breakup experienced by each slab during the rubblization effort. Some slabs may have been broken into smaller pieces than others—the smaller the pieces, the lower the Outer AREA value. This higher variation finding is important to overlay design over rubblized sections. A thicker overlay is needed to bridge over weak spots in rubblized pavements.

Potosi (SPS-6)

At this time, no data are available for the structural evaluation of the Potosi JPCP sections. More information will become available as this section continues to age.

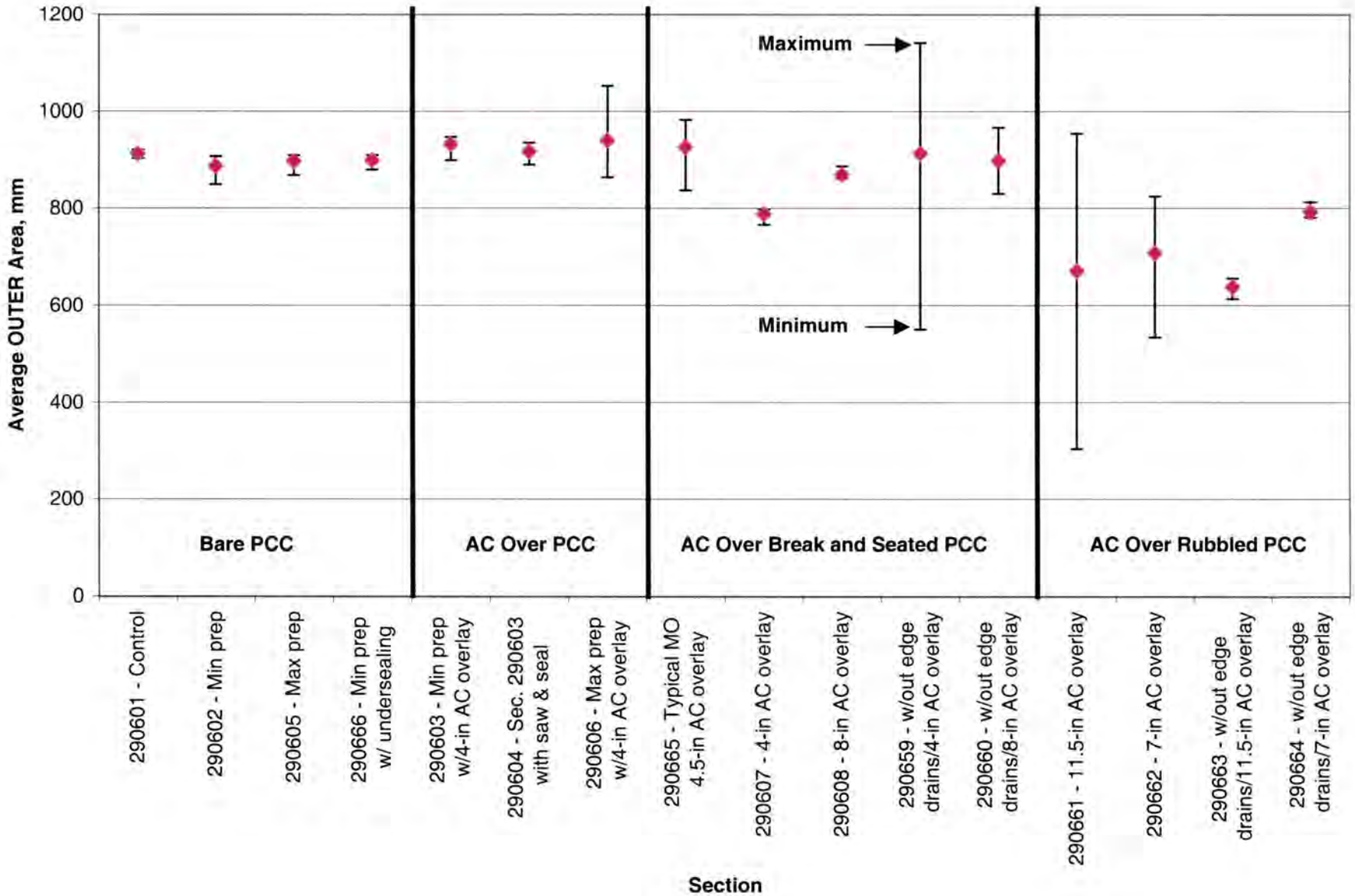


Figure 6.18. Average OUTER Area for the Bethany SPS-6 sections.

Festus (SPS-7)

Figure 6.19 shows the average Outer AREA values for each section included at the Festus site. This figure also shows the average minimum and maximum Outer AREA values, including all test dates. All of the pavement sections at this site have approximately the same average Outer AREA, indicating that all of these pavement sections have similar structural stiffness properties.

Sedalia (SPS-9A)

Figure 6.20 shows the average Outer AREA values for each section included at the Sedalia site. This figure also shows the average minimum and maximum Outer AREA values, including all test dates. All of the pavement sections at this site have approximately the same average Outer AREA, indicating that all of these pavement sections have similar structural stiffness properties.

PERFORMANCE TRENDS SUMMARY

The monitoring data evaluated for each rehabilitation alternative are summarized below. Each rehabilitation technique is summarized according to the experiment type. Note that these performance trends represent initial findings and that these results may change as each rehabilitation alternative continues to age and carry traffic loads.

Bethany (SPS-6)

Roughness

The roughness trends for the Bethany SPS-6 are summarized in table 6.2. Roughness was reduced for all sections immediately after rehabilitation (due to either diamond grinding or AC overlay), except for the control section (290601) and the minimum preparation section with undersealing (290666). Since rehabilitation, the majority of the AC overlay sections have had relatively little change in roughness over time. The two AC overlay sections which experienced large increases in roughness (and which were taken out-of-study) were the break and seat with 4-in AC overlays with and without edge drains (290607 and 290659). After 7 years, the roughness increase has been relatively low for the state supplemental section with undersealing (290666), though its initial roughness was higher than for the other bare PCC sections. The minimum and maximum preparation bare PCC sections (290602 and 290605) experienced higher increases in roughness to the point that the reduction in roughness achieved by the diamond grinding process has been lost when compared to the roughness of the control section.

The changes in roughness since rehabilitation have resulted in some preliminary findings, as listed below.

Bare PCC

- Both the minimum (290602) and maximum (290605) preparation sections had reduced roughness greatly immediately after rehabilitation.

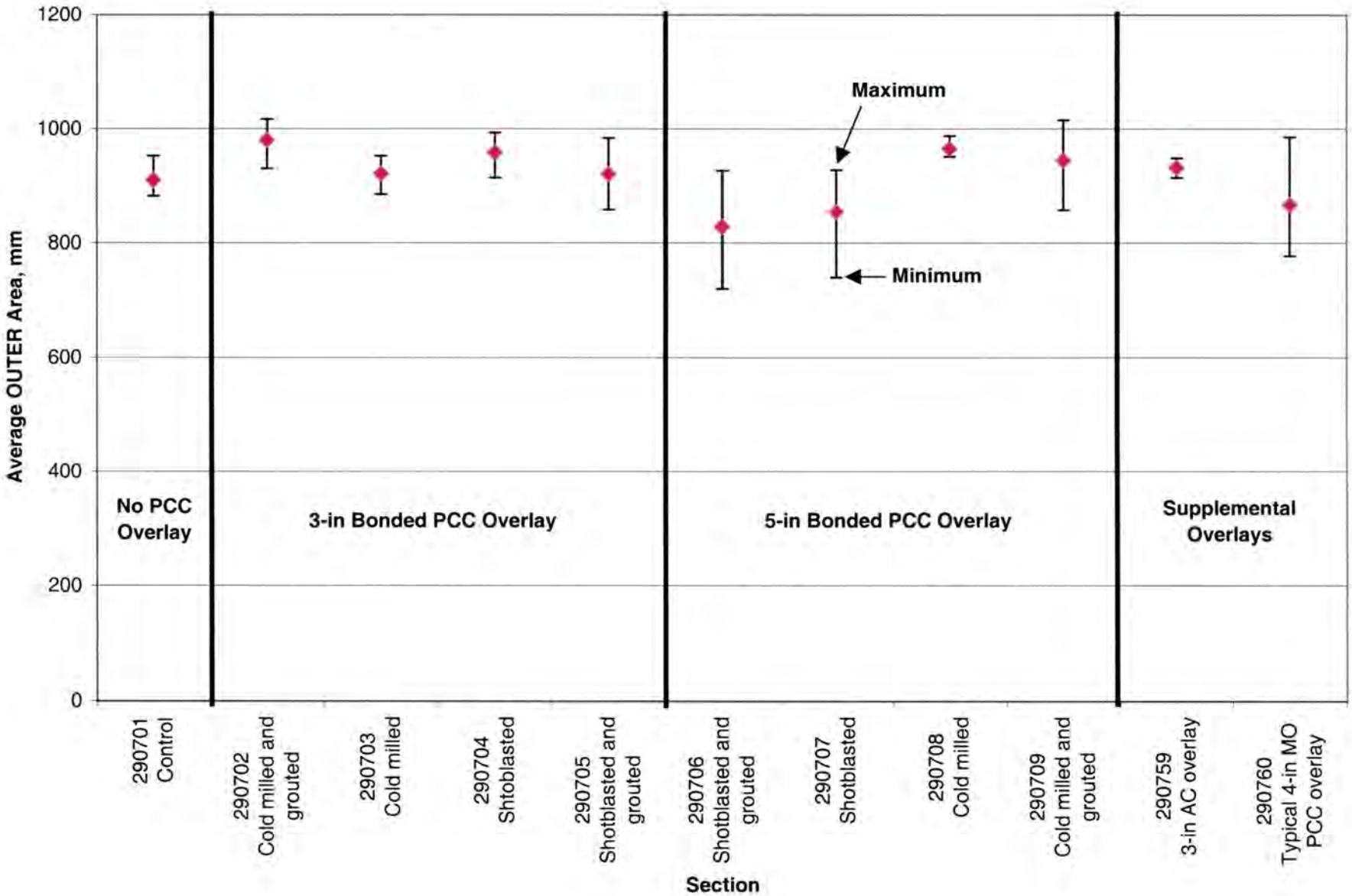


Figure 6.19. Average OUTE Area for the Festus SPS-7 sections.

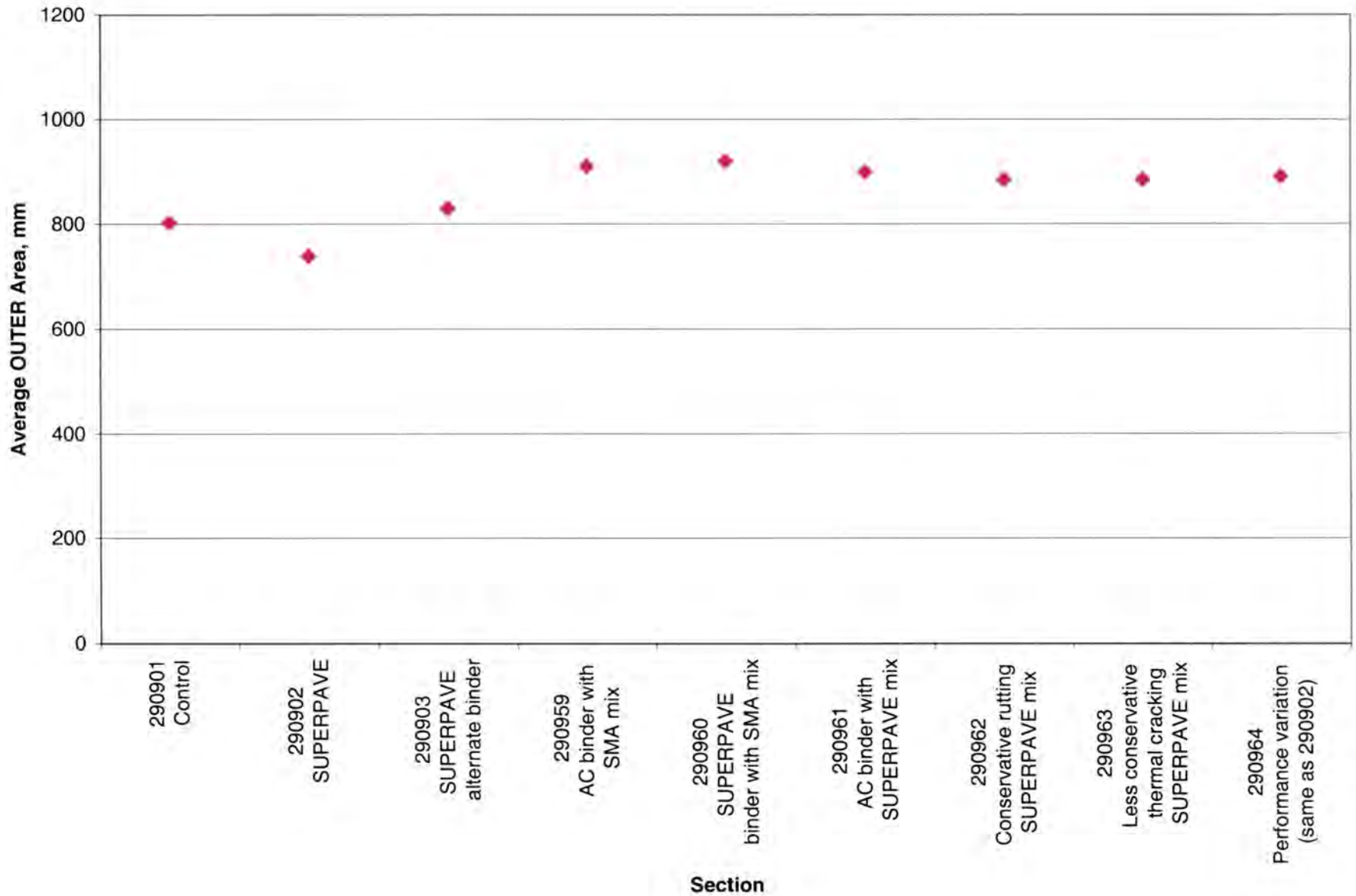


Figure 6.20. Average OUTER Area for Sedalia SPS-9A sections.

- There was no noticeable difference in performance between the minimum and maximum preparation sections for bare or overlaid sections.
- Sections 290602 and 290605 had lower roughness values than the control section for approximately 6 years. However, the faulting of these sections increased greatly, indicating extensive pumping and erosion of the base course. In retrospect, these sections may not have been good candidates for this type of rehabilitation unless the desirable rehabilitation life was about 6 years.
- The minimum preparation with undersealing (290666) exhibited an increase in roughness immediately after rehabilitation; however, there has been very little change in roughness since rehabilitation occurred. Due to the very low change in roughness, this section is notably smoother than the other bare PCC rehabilitation alternatives after 7 years. This may be due to a reduction in the amount of pumping and erosion occurring in the base course as a result of the undersealing.

AC Overlays of Non-Fractured PCC

- During the first 7 years after rehabilitation, there appears to be no significant difference in IRI for the different levels of pre-overlay repairs or overlay thickness.

AC Overlay of Fractured PCC

- The 4-in AC overlay of a break and seat JRCP (with or without edge drains) did not maintain a low IRI over time.
- The break and seat, 4-in AC overlay, without edge drain section (290659) failed at a more rapid rate than the same section with edge drains (290607). This could indicate the need for edge drains for break and seat sections with AC overlays, though there has been no difference observed for the break and seat, 8-in AC overlay sections to this point.
- All of the rubblized sections performed similar to the non-fractured PCC sections for the first 7 years after rehabilitation.

Distress

Faulting

- Diamond grinding applied to the maximum preparation section (290605) reduced faulting to almost zero. Diamond grinding of the minimum preparation section (290902) slightly reduced faulting. Diamond grinding was not applied to the supplemental section of minimum preparation with undersealing (290666) and, therefore, roughness was not reduced immediately after rehabilitation on this section.
- After rehabilitation, faulting increased at the same rate for both the minimum and maximum rehabilitated sections (290602 and 290605).
- Approximately 7 years after rehabilitation, both the minimum and maximum preparation techniques have the same magnitude of faulting.

Table 6.2. Roughness performance summary for Bethany (SPS-6).

Section	Rehabilitation Alternative	Roughness after rehabilitation	Change in roughness over time	Roughness 7 years after rehabilitation
290601	Control	High	Moderate	High
290602	Min prep (diamond grinding)	Low	High	High
290603	Min prep; 4-in AC overlay	Low	Low	Low
290604	Min prep; 4-in AC overlay; saw and seal joints	Low	Low	Low
290605	Max prep (diamond grinding)	Low	High	High
290606	Max prep; 4-in AC overlay	Low	Low	Low
290607	Break & seat; 4-in AC overlay; edge drains	Low	Very high	N/A
290608	Break & seat; 8-in AC overlay; edge drains	Low	Low	Low
290659	Break & seat; 4-in AC overlay; no edge drains	Low	Very high	N/A
290660	Break & seat; 8-in AC overlay; no edge drains	Low	Low	Low
290661	Rubblized; 11-in AC overlay; edge drains	Low	Low	Low
290662	Rubblized; 7-in AC overlay; edge drains	Low	Low	Low
290663	Rubblized; 11in AC overlay; no edge drains	Low	Low	Low
290664	Rubblized; 7-in AC overlay; no edge drains	Low	Low	Low
290665	Typical MO DOT 4-in AC overlay	Low	Low	Low
290666	Min prep; undersealing	High	Low	High

Transverse and Reflection Cracking

- In general, the bare concrete sections have more transverse cracking than the AC-overlaid sections. In addition, the break and seated and rubblized pavement sections have less transverse and reflection cracking than the AC over non-fractured PCC pavement sections. This is an indication that the PCC was adequately fractured prior to overlay of these sections and that the slab size has been reduced to a sufficient size to reduce reflection cracking.

Fatigue Cracking

- Out of all of the fractured (rubblized and break and seated) PCC pavement sections, the only sections that experienced fatigue cracking were the rubblized pavement sections (290663 and 290664) that did not have edge drains. This indicates that proper drainage is important for rubblized PCC pavement sections.

Non-Wheel Path Longitudinal Cracking

- Most of the AC overlays of the fractured and non-fractured PCC exhibited high amounts of longitudinal cracking. Currently, there appears to be no direct correlation between the amount of non-wheelpath longitudinal cracking and the rehabilitation technique selected.

Rutting

- At the present time, no significant rutting trends exist for the AC overlays of non-fractured or fractured PCC pavements. This indicates that the AC overlay materials are not rut-susceptible. In addition, the fractured PCC pavement sections are adequately supporting the current traffic.

Structural

- The bare PCC and the AC over non-fractured PCC sections have approximately the same Outer AREA values. This indicates that for all of the non-fractured PCC sections, both with and without AC overlays, the PCC portion of the pavement is the dominant structural component and is performing similarly for all non-fractured rehabilitation alternatives.
- The Outer AREA's for the break and seat sections were generally similar to those of the non-fractured overlay sections, indicating that the fractured concrete is still the dominant structural component of the pavement system for those sections. Section 290607, a 4-in AC overlay of break and seat JRCP with edge drains, had several very low Outer AREA values, indicating a possible breakup of the underlying concrete slab.
- The Outer AREA's for the rubblized sections are much lower than those for the bare JRCP or the AC overlays of non-fractured JRCP, indicating a significant loss in stiffness of the rubblized JRCP layer. The rubblized sections showed significant variation along the section. Most sections had several high and several low values for the Outer AREA. This may be due to differences in the level of breakup experienced by each slab during the rubblization effort. Some slabs may have been broken more than others—the more broken the JRCP slab, the lower the Outer AREA value. This higher variation finding is important to overlay design over rubblized sections. A thicker overlay is needed to bridge over weak spots in rubblized pavements.

Potosi (SPS-6)

This section is still relatively new. Therefore, no data was available for reviewing the roughness, distress, and structural trends at this time. It is recommended that analysis of these sections be performed in the future.

Festus (SPS-7)

Roughness

- All of the rehabilitation techniques improved roughness levels. There was a considerable range in the improved roughness immediately after rehabilitation. However, at this time, the cause of this variability is not known.
- All of the rehabilitation alternatives appear to have similar increases in roughness regardless of the treatments applied. Now, 9 years after rehabilitation, the magnitude of roughness for each section varies slightly. However, the magnitude of roughness for each section appears to be comparable to the roughness immediately after rehabilitation with only a slight increase in roughness.
- All of the bonded concrete overlays have similar roughness trends to the 3-in AC overlay section that was also included as part of this experiment.

Distress

These sections were evaluated using faulting, transverse cracking, longitudinal cracking, and total (transverse and longitudinal) cracking.

- All of the bonded PCC overlays exhibited similar magnitudes of faulting during the first 8 years after rehabilitation.
- The thinner overlays experienced less transverse cracking and would be perceived as performing best after 9 years, as shown in table 6.3. While the IRI values for these sections have progressed at similar rates—to a point where they range from 100 to 150 in/mile—the larger amounts of cracking for the 5-in overlays provides more opportunity for roughness to develop as time goes on.

Structural

All of the pavement sections at this site have approximately the same average Outer AREA, indicating that they have similar structural stiffness properties.

Sedalia (SPS-9A)

Roughness

This experiment is still very young; therefore, limited performance data is currently available. All of the rehabilitation alternatives have similar roughness values immediately after rehabilitation. In addition, all of the sections have had similar changes in roughness during the first 2.5 years after rehabilitation. Additional time is needed to identify the variations in performance trends for each rehabilitation alternative.

Table 6.3. Ordering of Festus SPS-7 sections based on transverse cracking.

Section	Rehabilitation treatment	Ranking
290702	3-in Bonded PCC overlay; cold milled and grouted	Best
290703	3-in Bonded PCC overlay; cold milled	↓
290704	3-in Bonded PCC overlay; shotblasted	↓
290705	3-in Bonded PCC overlay; shotblased and grouted	↓
290759	3-in AC overlay	↓
290760	4-in Bonded PCC overlay	↓
290708	5-in Bonded PCC overlay; cold milled	↓
290706	5-in Bonded PCC overlay; shotblasted and grouted	↓
290707	5-in Bonded PCC overlay; shotblasted	↓
290709	5-in Bonded PCC overlay; cold milled and grouted	Worst

Distress

No significant data was available for reviewing the distress trends at this time. It is recommended that additional analysis of these sections be performed in the future.

Structural

All of the pavement sections at this site have approximately the same average Outer AREA, indicating that they have similar structural stiffness properties.

GPS-7

Roughness

All of these sections have experienced relatively low levels of roughness during their tenure in the LTPP program. These sections had slightly reduced magnitudes of roughness immediately after rehabilitation and have also had relatively low changes in roughness over time.

7.0 COST DATA

For the calculation of the pavement rehabilitation costs for each test section, it was necessary to identify those activities performed and the unit costs for each. Table 7.1 shows those activities that were performed for the test sections included in this study, along with the unit costs applied to the cost calculations.

Table 7.1. Pavement repair activities and unit costs.

Repair activity	Unit Cost	Source
HMAC overlay	\$1.60/yd^2/in thickness	MO DOT 1998 Unit Bid Prices (major and Interstate)
PCC overlay	\$2.25/yd^2/in thickness	MO DOT 1998 bid book (major and interstate)
PCC crack seal	\$2.00/lin ft	SHRP H-106 Manual of Practice
Tack coat	\$0.06/yd^2	MO DOT 1998 bid book (major and interstate)
Full-depth repair (slab only)	\$81.00/yd^2	MO DOT 1998 bid book (major and interstate)
Full-depth repair (slab and base)	\$83.00/yd^2	MO DOT 1998 bid book (major and interstate)
Underseal	\$8.70/yd^2/0.2 in	MO DOT 1998 bid book (major and interstate)
Diamond grinding	\$5.15/yd^2	MO DOT 1998 bid book (major and interstate)
Edge drains	\$4.62/lin ft	MO DOT 1998 bid book (major and interstate)
Saw and seal	\$4.44/lin ft	MO DOT 1998 bid book (major and interstate) and Potosi SPS-6 bid table
Break and seat	\$1.80/yd^2	Potosi SPS-6 bid table
Rubblize	\$2.00/yd^2	Illinois DOT
Cold milling of PCC	\$1.53/yd^2	MO DOT 1998 bid book (major and interstate)
Sandblasting	\$0.35/yd^2	Engelsman's 1985 Heavy Construction Cost File
Airblasting	\$0.15/yd^2	Engelsman's 1985 Heavy Construction Cost File
Grout placement	\$0.74/yd^2	MO DOT 1998 bid book (major and interstate)
Shotblasting	\$0.35/yd^2	Engelsman's 1985 Heavy Construction Cost File

For the placement of HMAC and PCC overlays, the costs were calculated using dollars per square yard per depth of overlay. For example, a standard 4-in HMAC overlay would be estimated to cost \$6.40/yd^2, and a 4-in PCC overlay would be estimated to cost \$9.00/yd^2. For the HMAC material costs, a premium factor was also applied to note the differences in cost between the standard materials placed for the original SPS-6 and GPS sections and the SUPERPAVE materials placed as part of the SPS-9A project. All unit cost values included in

this study are intended to be representative values for projects in Missouri. Where no direct cost information was available for Missouri DOT project, industry average values were used.

The second part of the repair cost calculation is the summary of repair quantities performed for each test section in this study. Tables 7.2 through 7.6 show the quantities for each test section used for calculating total costs.

Using the unit costs and quantities of repair activities from the test sites, repair costs were calculated for each section on a per mile basis, with the results shown in tables 7.7 to 7.10.

Table 7.2. Repair quantities for SPS-6 at Bethany.

Activity, units	Test section															
	0601	**0602**	**0603**	**0604**	**0605**	**0606**	**0607**	**0608**	**0659**	**0660**	**0661**	**0662**	**0663**	**0664**	**0665**	**0666**
Full-depth repair (slab only), yd^2		90	40	59	75	40									50	8
Full-depth repair (slab and base), yd^2		45	43		73	61										
Joint and crack sealing, lin ft		263			1909											60
Undersealing, yd^2					32	16									36	4
Diamond grinding, yd^2		1332			1332											
HMAC overlay, in thickness			3.8	3.8		3.6	4.3	7.9	4.3	7.9	11.4	7.3	11.5	6.9	4.6	
HMAC overlay multiplier			1	1		1	1	1	1	1	1	1	1	1	1	
Tack coat, yd^2			666	666		666	666	666	666	666					666	
Edge drains, lin ft					1000	500	500	500			500	500				
Saw and seal operation, lin ft				252												
Break and seat operation, yd^2							666	666	666	666						
Rubblization operation, yd^2											666	666	666	666		

Table 7.3. Repair quantities for SPS-7 at Festus.

Activity, units	Test section										
	0701	**0702**	**0703**	**0704**	**0705**	**0706**	**0707**	**0708**	**0709**	**0759**	**0760**
HMAC overlay, in thickness										3.0	
HMAC overlay multiplier										1	
PCC overlay, in thickness		4.3	3.6	3.3	3.2	5.3	5.3	5.4	5.3		4.0
Cold milling operation, yd^2		666	666					666			666
Sand blasting operation, yd^2		666	666					666	666		
Air blasting operation, yd^2			666	666		666	666	666			
Grout application, yd^2		666			666	666			666		666
Shot blasting operation, yd^2				666	666	666	666				666

Table 7.4. Repair quantities for SPS-9A at Sedalia.

Activity, units	Test section								
	0901	**0902**	**0903**	**0959**	**0960**	**0961**	**0962**	**0963**	**0964**
HMAC overlay, in thickness	4	4	4	4	4	4	4	4	4
HMAC overlay multiplier	1	1.2	1.2	1.1	1.3	1.1	1.3	1.3	1.2
Full-depth repair (slab only), yd^2									
Full-depth repair (slab and base, yd^2									
Joint and crack sealing, lin ft									
Undersealing, yd^2									
Diamond grinding, yd^2									
Tack coat, yd^2									

Table 7.5. Repair quantities for SPS-6 at Potosi.

Activity, units	Test section							
	0601	**0602**	**0603**	**0604**	**0605**	**0606**	**0607**	**0608**
Full-depth repair (slab only), yd^2		148		49	80			
Full-depth repair (slab and base), yd^2								
Joint and crack sealing, lin ft		72			360			
Undersealing, yd^2					130	100		
Diamond grinding, yd^2		1332			1332			
HMAC overlay, in thickness			4.3	4.1		4.4	4.2	8.0
HMAC overlay multiplier			1.2	1.2		1.2	1.2	1.2
Tack coat, yd^2			666	666		666		
Edge drains, lin ft					1000	500		500
Saw and seal operation, lin ft				84				
Break and seat operation, yd^2							666	666

Table 7.6. Repair quantities for GPS sections.

Activity, units	Test section				
	4069	**5393**	**5483**	**7054**	**7073**
HMAC overlay, in thickness	4.0	3.0	3.0	3.5	3.0
HMAC overlay multiplier	1	1	1	1	1
Full-depth repair (slab only), yd^2					
Full-depth repair (slab and base, yd^2					
Joint and crack sealing, lin ft					
Undersealing, yd^2					
Diamond grinding, yd^2					
Tack coat, yd^2					

Table 7.7. Summary of rehabilitation cost information for SPS-6, Bethany.

Test section	Length, ft	Estimated repair costs, $	Estimated costs/mile, $
290601	500	0	0
290602	1,000	18,411	97,209
290603	500	10,898	115,085
290604	500	9,987	105,464
290605	1,000	27,710	146,310
290606	500	14,628	154,475
290607	500	8,131	85,862
290608	500	11,967	126,372
290659	500	5,821	61,468
290660	500	9,657	101,978
290661	500	15,790	166,741
290662	500	11,421	120,604
290663	500	13,586	143,472
290664	500	8,685	91,710
290665	500	9,305	98,260
290666	500	803	8,478

Table 7.8. Summary of rehabilitation cost information for SPS-7, Festus.

Test section	Length, ft	Estimated repair costs, $	Estimated costs/mile, $
290701	500	0	0
290702	500	8,188	86,470
290703	500	6,747	71,244
290704	500	5,278	55,736
290705	500	5,521	58,303
290706	500	8,768	92,589
290707	500	8,275	87.385
290708	500	9,444	99,727
290709	500	8,668	91,534
290759	500	3,197	33,758
290760	500	6,758	71,364

Table 7.9. Summary of rehabilitation cost information for SPS-9A, Sedalia.

Test section	Length, ft	Estimated repair costs, $	Estimated costs/mile, $
290901	500	4,262	45,011
290902	500	5,115	54,013
290903	500	5,115	54,013
290959	500	4,689	49,512
290960	500	5,541	58,514
290961	500	4,689	49,512
290962	500	5,541	58,514
290963	500	5,541	58,514
290964	500	5,115	54,013

Table 7.10 Summary of rehabilitation cost information for GPS test sections

Test section	Length, ft	Estimated repair costs, $	Estimated costs/mile, $
294069	500	4,262	45,011
295393	500	3,197	33,758
295483	500	3,197	33,758
297054	500	3,730	39,385
297073	500	3,197	33,758

8.0 COST-EFFECTIVENESS FINDINGS

For each of the PCC rehabilitation projects included in this study, a comparison was made to determine which rehabilitation options have been the most cost-effective up to this point in time. The primary performance measure included in the calculation of cost-effectiveness was the IRI value, because it was available for all sections being evaluated and is independent of pavement surface type or cross-section. Specific distress types that affect ride quality, such as cracking, faulting, and rutting, were available for some sections but are difficult to compare across pavement surface types.

The first comparison was done for the SPS-6 sections at Bethany, where the most recent IRI values available were from a point 6.5 years after the initial rehabilitation. The IRI values for each test section at that time are shown in table 8.1.

Table 8.1. IRI values after 7 years at SPS-6 Bethany.

Test section	Rehabilitation summary	IRI at 7 years, in/mile	IRI difference, in/mile
290601	Control	189.8	N/A
290602	Min prep (diamond grinding)	182.0	7.8
290603	Min prep; 4-in AC overlay	79.5	110.3
290604	Min prep; 4-in AC overlay; saw and seal joints	84.4	105.4
290605	Max prep (diamond grinding)	190.4	-0.6
290606	Max prep; 4-in AC overlay	79.6	110.2
290607	Break & seat; 4-in AC overlay; edge drains	N/A	94.0
290608	Break & seat; 8-in AC overlay; edge drains	78.4	111.4
290659	Break & seat; 4-in AC overlay; no edge drains	N/A	97.8
290660	Break & seat; 8-in AC overlay; no edge drains	73.5	116.3
290661	Rubblized; 11-in AC overlay; edge drains	91.0	98.9
290662	Rubblized; 7-in AC overlay; edge drains	82.0	107.8
290663	Rubblized; 11in AC overlay; no edge drains	101.6	88.2
290664	Rubblized; 7-in AC overlay; no edge drains	83.4	106.4
290665	Typical MO DOT 4-in AC overlay	81.2	108.6
290666	Min prep; undersealing	148.1	41.7

As this table shows, after 7 years, the three bare concrete sections (290601, 290602, and 290605 all have IRI values between 180 and 190 in/mile, while the majority of the HMAC overlay sections have IRI values in the 75- to 90-in/mile range.

When the rehabilitation costs and the IRI data are combined, they can be used to calculate the cost of each IRI point by simply dividing the difference in cost between each rehabilitation option and the control by the difference in performance as measured by the IRI. Since the control for the SPS-6 had no repair activities performed, the cost was $0, meaning that the difference in cost was simply the cost of the rehabilitation alternative being compared to the control. The cost-effectiveness calculation can be represented as:

$$(Cost_{option\ 1} - Cost_{control})/(IRI_{control} - IRI_{option\ 1})$$

The values calculated for the SPS-6 are shown in table 8.2.

Table 8.2. Cost-effectiveness values for SPS-6 Bethany.

Test section	Rehabilitation summary	Cost-effectiveness, $/(in/mile)	Rank of section (1=best)
290601	Control	N/A	N/A
290602	Min prep (diamond grinding)	12,373	14
290603	Min prep; 4-in AC overlay	1,043	8
290604	Min prep; 4-in AC overlay; saw and seal joints	1,001	7
290605	Max prep (diamond grinding)	-251,003	15
290606	Max prep; 4-in AC overlay	1,401	11
290607	Break & seat; 4-in AC overlay; edge drains	913	6
290608	Break & seat; 8-in AC overlay; edge drains	1,135	10
290659	Break & seat; 4-in AC overlay; no edge drains	629	2
290660	Break & seat; 8-in AC overlay; no edge drains	877	4
290661	Rubblized; 11-in AC overlay; edge drains	1,687	13
290662	Rubblized; 7-in AC overlay; edge drains	1,119	9
290663	Rubblized; 11in AC overlay; no edge drains	1,627	12
290664	Rubblized; 7-in AC overlay; no edge drains	862	3
290665	Typical MO DOT 4-in AC overlay	904	5
290666	Min prep; undersealing	203	1

For the SPS-6 site at Bethany, section 290666 is the most cost-effective. This section had very low rehabilitation costs associated with it and has maintained a fairly consistent IRI value over time. The next nine best cost-effectiveness options were HMAC overlay options which all had similar costs and similar performance through 7 years. The worst cost-effectiveness was seen for section 290605, where rehabilitation costs were fairly high and the average IRI observed after 7 years was actually slightly higher than the control section.. (It should be noted that the cost-effectiveness numbers presented here are intended to provide a means of relative ranking among the various rehabilitation options, rather than values which could be used for creating cost estimates for future projects.)

The same exercise and calculations were performed for the SPS-7 project at Festus (see tables 8.3 and 8.4).

Table 8.3. IRI values after 9 years at SPS-7 at Festus.

Test section	Rehabilitation summary	IRI at 9 years, in/mile	IRI difference, in/mile
290701	Control	166.0	n/a
290702	Cold-mill and grout; 3-in PCC overlay	133.4	32.6
290703	Cold-mill; 3-in PCC overlay	109.0	57.0
290704	Shotblast; 3-in PCC overlay	151.5	14.5
290705	Shotblast and grout; 3-in PCC overlay	128.6	37.4
290706	Shotblast and grout; 5-in PCC overlay	128.7	37.3
290707	Shotblast; 5-in PCC overlay	118.2	47.8
290708	Cold-mill; 5-in PCC overlay	139.0	27.0
290709	Cold-mill and grout; 5-in PCC overlay	107.5	58.5
290759	3-in AC overlay	144.2	21.8
290760	4-in PCC overlay	104.6	61.4

Table 8.4. Cost-effectiveness values for SPS-7 at Festus.

Test section	Rehabilitation summary	Cost-effectiveness, $/(in/mile)	Rank of section (1=best)
290701	Control	n/a	n/a
290702	Cold-mill and grout; 3-in PCC overlay	2,651	8
290703	Cold-mill; 3-in PCC overlay	1,250	2
290704	Shotblast; 3-in PCC overlay	3,831	10
290705	Shotblast and grout; 3-in PCC overlay	1,557	4
290706	Shotblast and grout; 5-in PCC overlay	2,479	7
290707	Shotblast; 5-in PCC overlay	1,827	6
290708	Cold-mill; 5-in PCC overlay	3,695	9
290709	Cold-mill and grout; 5-in PCC overlay	1,563	5
290759	3-in AC overlay	1,549	3
290760	4-in PCC overlay	1,162	1

The top three options for this project show a mix of low rehabilitation costs (290759 was the lowest) with high differences in the IRI when compared to the control section (290703 and 290760 were two of the three largest differentials). The worst cost-effective number was calculated for the section with the lowest improvement in IRI (290704, 14 in/mile after 9 years).

For the SPS-9A at Sedalia, the procedure for calculating the cost-effectiveness was altered slightly to take into account the lack of a pure control section. For this analysis, the highest IRI value was assumed to be a control section, which allowed all of the other test sections to have better performance at the 3-year point where the evaluation was being performed. Because the SPS-9A control section did have rehabilitation costs associated with it (unlike the control sections on SPS-6 and SPS-7), improved IRI performance could be obtained by spending less money than for the worst-performing "control" section. As with the SPS-6 and SPS-7 sites, tables 8.5 and 8.6 show the differences in IRI after 3 years, and the corresponding cost-effectiveness values for each section. The negative values for cost-effectiveness shown in table 8.6 are a result of the fact that various test sections had lower repair costs than the "control" while exhibiting better performance.

Table 8.5. IRI values after 3 years at SPS-9A at Sedalia.
(All sections were 4-in asphalt overlays)

Test section	Rehabilitation summary	IRI at 3 years, in/mile	IRI difference, in/mile
290901	AC-20	70.0	11.9
290902	PG 64-28; SUPERPAVE	81.9	n/a
290903	PG 58-28; SUPERPAVE	62.6	19.3
290959	AC-20 and fibers; SMA	65.4	16.5
290960	PG 64-28; SMA	68.6	13.3
290961	AC-20; SUPERPAVE	64.9	17.0
290962	PG 70-28; SUPERPAVE (more conservative rutting)	74.7	7.2
290963	PG 61-16; SUPERPAVE (less conservative thermal cracking)	70.8	11.1
290964	PG-64-28; SUPERPAVE (replicate of 290902)	71.1	10.8

Table 8.6. Cost-effectiveness values after 3 years for SPS-9A at Sedalia.
(All sections were 4-in asphalt overlays)

Test section	Rehabilitation summary	Cost-effectiveness, $/(in/mile)	Rank of section (1=best)
290901	AC-20	-753	1
290902	PG 64-28; SUPERPAVE	n/a	n/a
290903	PG 58-28; SUPERPAVE	0	4
290959	AC-20 and fibers; SMA	-272	2
290960	PG 64-28; SMA	338	6
290961	AC-20; SUPERPAVE	-265	3
290962	PG 70-28; SUPERPAVE (more conservative rutting)	619	8
290963	PG 61-16; SUPERPAVE (less conservative thermal cracking)	405	7
290964	PG-64-28; SUPERPAVE (replicate of 290902)	0	5

For this project, three of the rehabilitation options that were performing better than the worst-performing option and had significantly lower costs (290901, 290959, and 290961), resulting in the negative values for cost-effectiveness. The ability to obtain better performance at lesser costs results in these three options being the best value. Two of the sections (290903 and 290964) currently have cost values that are identical to that of the worst-performing section (290902) so that the cost-effectiveness value calculates to be $0, even though those sections did have lower IRI values after 2.6 years.

For the five GPS sections, a similar exercise was performed using the highest IRI value as the control section and comparing the cost-effectiveness values of the other four sections. The results of these analyses are shown in tables 8.7 and 8.8.

Table 8.7. IRI values for Missouri GPS test sites.

Test section	Rehabilitation summary	IRI in 1999, in/mile	IRI difference, in/mile
294069	4-in asphalt overlay of 10-in JRCP	96.2	n/a
295393	3-in asphalt overlay of 8-in JPCP	85.4	10.8
295483	3-in asphalt overlay of 9-in JRCP	62.8	33.4
297054	3.5-in asphalt overlay of 10-in JPCP	57.6	38.6
297073	3-in asphalt overlay of 8-in JPCP	87.0	9.2

Table 8.8. Cost-effectiveness values for Missouri GPS test sites.

Test section	Rehabilitation summary	Cost-effectiveness, $/(in/mile)	Rank of section (1=best)
294069	4-in asphalt overlay of 10-in JRCP	n/a	n/a
295393	3-in asphalt overlay of 8-in JPCP	1,040	3
295483	3-in asphalt overlay of 9-in JRCP	336	2
297054	3.5-in asphalt overlay of 10-in JPCP	145	1
297073	3-in asphalt overlay of 8-in JPCP	1,216	4

9.0 SUMMARY OF FINDINGS AND CONCLUSIONS

A total of 49 pavement test sections from the FHWA LTPP program were reviewed and analyzed for this report. These test sections represent pavement rehabilitation projects which range in age from just over a year to almost 10 years, at 9 different locations throughout the State of Missouri.

The findings and conclusions presented in this report can be organized according to the primary test sites—Bethany, Festus, Sedalia, Potosi, and GPS locations—as listed below.

BETHANY (SPS-6)

The bare concrete sections at this location had better smoothness characteristics than the control section for a period of about 6 years. After that, the sections had increased in roughness to a point where there was no difference from the control section. Due to the high cost of performing spot repairs to the slabs, and in some cases the base materials, and the relatively low gain in pavement smoothness over time, the bare PCC rehabilitation options (sections 290602 and 290605) were judged to be the least cost-effective options.

The HMAC overlays generally provided good improvements in smoothness over the life of the test sections, with significant reductions in roughness obtained by placing the overlays, and very little increase in roughness over the period of observation. It is expected that distress development and roughness increases will begin in the near future for the thinner HMAC overlay layers, which will allow for cost-benefit analyses of various thickness of HMAC overlays under different traffic and climatic conditions. For the break and seat sections, the 4-in HMAC overlay sections had significant increases in roughness within 2 years of rehabilitation, while the 8-in overlays continue to perform well. For the rubblized sections, no difference was observed in performance for the 7- or 11-in overlay thicknesses.

The effects of pre-overlay repair efforts and the installation of edge drainage systems on surface distress development were generally not pronounced for this site. The two HMAC over rubblized sections without edge drains are beginning to show some fatigue cracking, while those with edge drains have not, though it is too early to estimate if the presence of edge drains will result in an increase in service life for these sections. This is one of the areas where future data collection may identify differences in performance which would allow for relative ranking of the various alternatives into those which work well and those which should be avoided.

Analyses of the deflection data for these sections showed the bare PCC and AC over PCC sections showed similar loading capacity and very good uniformity throughout the sections. Overlays of the break and seat PCC showed slightly lower load capacity, with higher variability for the sections without edge drains. For the overlays of rubblized PCC, the load capacity was even lower as would be expected, but the higher variability within the sections was observed for those sections with edge drains.

FESTUS (SPS-7)

All of the rehabilitation sections at this site consisted of some sort of overlay, either bonded PCC or HMAC, and all began with initial roughness measurements greater than the control section. All of the rehabilitation options significantly reduced the roughness, though the gain in roughness since overlay has been greater than for the HMAC overlays at the Bethany SPS-6 location. Over time, the control section has not seen much increase in roughness, while all of the overlay sections have. While no overlay section has reached the level of the control section, the trends indicate that several will within the next few years.

All of the overlay sections have also been able to maintain reduced levels of faulting, with the worst overlaid sections having faulting magnitudes 3 times less than the control. A great deal of cracking occurred immediately after placement of the bonded PCC overlay layers. This may have been due in part to the use of high-early strength PCC materials since the overlays were placed as part of a fast-track rehabilitation. With respect to transverse cracking, there appears to have been a relationship between overlay thickness and amount of transverse cracking, with thicker overlays developing more cracking.

While a lot of cracking occurred early on, very little additional cracking has been noted. It should also be noted that the presence of cracking has not adversely effected the pavement smoothness, as all of the overlay sections have significantly more cracking than the control, yet all are much smoother than the control.

Evaluation of the structural integrity of the various rehabilitation options showed test sections with fairly uniform structural support, which was not much different than the control section, which did not have an overlay. This indicates that the original PCC pavement system is still providing the majority of the loading support, and that the additional layer thickness resulting from the overlays did not need to add to the load carrying capacity.

SEDALIA (SPS-9A)

The arrangement of the Sedalia test site is such that the questions to be answered were more concerned with the properties of the HMAC materials used for overlays than the different rehabilitation alternatives. At this time, there have been very few differences in the performance of the different overlay materials, as indicated by the data collected by the LTPP program. Because of the development of supplemental test sections to look at the ability of the SUPERPAVE process to address rutting and thermal cracking, this experiment has a lot of potential to answer even more specific questions about the placement of HMAC materials over PCC in the future.

POTOSI (SPS-6)

As with Sedalia, this test site is relatively new and has yet to develop differences in performance which can help sort out the order of relative effectiveness for the various rehabilitation alternatives. In the future, this site will allow comparisons with the Bethany site, and help to determine how differences in traffic levels and climatic conditions affect the performance of

different rehabilitation alternatives.

GPS SITES

At this time, all of the GPS test sites with rehabilitated PCC pavements are performing well, and indicate that the placement of HMAC overlays between 2.5- and 4.5-in thick can be expected to have service lives of greater than 6 or 7 years. Continued monitoring of these sites should allow for a more accurate determination of the expected service lives of these types of projects under different traffic levels and climatic conditions.

REFERENCES

Al-Omari, B., and M.I. Darter. 1992. Relationship Between IRI and PSR. Report UILU-ENG-92-2013. Springfield, IL: Illinois Department of Transportation.

Haas, R., W.R. Hudson, and J. Zaniewski. 1994. Modern Pavement Management. Malabar, FL: Krieger.

Hall, K.T., M.I. Darter, T.E. Hoerner, and L. Khazanovich. 1997. LTPP Data Analysis Phase I: Validation of Guidelines for k-Value Selection and Concrete Pavement Performance Prediction, FHWA-RD-96-198. Washington, DC: Federal Highway Administration.

Hoffman, M.S. and M.R. Thompson. 1981. Mechanistic Interpretation of Nondestructive Pavement Testing Deflections. Transportation Engineering Series No. 32, Illinois Cooperative Highway and Transportation Research Series No. 190, University of Illinois at Urbana-Champaign.

McPeak, T.J., and L. Khazanovich. 1997. "Back calculation of Asphalt-Overlaid Concrete Pavements." Proceedings of the ASCE Airfield Pavement Conference. Seattle, WA.

Specific Pavement Studies; Construction Guidelines for Experiment SPS-6, Rehabilitation of Jointed Portland Cement Concrete Pavements, Strategic Highway Research Program, National Research Council, July 1990. Washington, DC.

Bonded Concrete Overlay—Route 67 Jefferson County; Construction and 60-Day Survey Analysis, Missouri Highway and Transportation Department, Division of Materials and Research, Research Section, Report MR91-2.

Appendix A

Summary of performance data collection dates

Table 1. Summary of Missouri LTPP sites and performance data analyzed.

		Date of data collection activity				
Project	Test section	Profile data	FWD data	Manual distress data	PASCO distress data	Friction data
SPS-6 Bethany,MO	290601	2/13/92 3/13/93 5/18/94 3/11/97 4/18/98 2/10/99	6/2/92 11/17/92 4/22/93 5/10/93 10/6/93 7/21/95 **4/9/97** 9/9/88	8/7/91 10/14/93 7/19/95 4/9/96 9/9/98	4/4/93 4/15/96	9/1/94 8/9/96 10/1/97
	290602	2/13/92 5/18/94 3/11/97 4/18/98 2/10/99	3/12/92 4/22/92 5/11/93 10/13/93 7/20/95 **4/9/97** 9/10/98	8/7/91 4/15/92 10/14/93 7/19/95 4/10/96 9/10/98	4/4/93 4/15/96	9/22/93 9/1/94 8/9/96 10/1/97
	290603	2/13/92 3/13/93 5/18/94 3/11/97 4/18/98 2/10/99	3/3/92 5/11/93 10/14/93 10/19/93 7/21/95 **4/14/97** 9/10/98	8/7/91 3/3/92 10/14/93 7/20/95 4/11/96 9/10/98	4/4/93 4/15/96	9/22/93 9/1/94 8/9/96 10/1/97
	290604	2/13/92 3/13/93 5/18/94 3/11/97 4/18/98 2/10/99	3/2/92 10/21/92 4/20/93 10/14/93 7/21/95 **4/14/97** 9/10/98	8/7/91 3/2/92 10/14/93 7/20/95 4/11/96 9/10/98	4/4/93 4/15/96	9/22/93 9/1/94 8/9/96 10/1/97
	290605	2/13/92 5/18/94 3/11/97 4/18/98 2/10/99	3/10/92 3/11/92 4/28/93 10/6/93 7/20/95 **4/8/97** 10/6/98	8/7/91 4/16/92 10/13/93 7/20/95 4/9/96 10/6/98	4/4/93 4/15/96	9/22/93 9/1/94 8/9/96 10/1/97
	290606	2/13/92 3/13/93 5/18/94 3/11/97 4/18/98 2/10/99	3/4/92 12/1/92 5/12/93 10/19/93 7/21/95 **4/15/97** 9/10/98	3/4/92 10/14/93 7/20/95 4/15/96 9/10/98	4/4/93 4/15/96	9/22/93 9/1/94 8/9/96 10/1/97

Table 1. Summary of Missouri LTPP sites and performance data analyzed.

		Date of data collection activity				
Project	Test section	Profile data	FWD data	Manual distress data	PASCO distress data	Friction data
SPS-6 Bethany,MO	290607	2/11/92 3/13/93 10/14/93 5/18/94 2/10/99	4/28/92 7/7/92 7/9/92 7/10/92 7/11/92 10/19/92 4/6/93 10/7/93 7/19/95 **4/1/97** 9/9/98	8/5/91 4/15/92 10/13/93 7/19/95 9/9/98	4/4/93 4/15/96	9/22/93 9/7/94 8/9/96 10/1/97
	290608	2/11/92 3/13/93 5/18/94 3/11/97 4/18/98 2/10/99	4/28/92 7/8/92 7/10/92 11/4/92 4/21/93 9/21/93 7/19/95 **4/7/97** 9/9/98	8/6/91 4/15/92 10/13/93 7/19/95 4/2/96 9/9/98	4/4/93 4/15/96	9/22/93 9/1/94 8/9/96 10/1/97
	290659	2/11/92 3/13/93 10/14/93 5/18/94 2/10/99	5/5/92 7/7/92 7/19/95 **4/1/97** 9/9/98	8/5/91 4/15/92 10/13/93 7/19/95	4/4/93 4/15/96	9/22/93 9/7/94 8/9/96
	290660	2/11/92 3/13/93 5/18/94 3/11/97 4/18/98 2/10/99	5/5/92 7/8/92 7/19/95 **4/3/97** 9/9/98	8/6/91 4/15/92 10/13/93 7/19/95 4/2/96 9/9/98	4/4/93 4/15/96	9/22/93 9/1/94 8/9/96
	290661	2/11/92 3/13/93 5/18/94 3/11/97 4/18/98 2/10/99	6/4/92 7/9/92 7/10/92 7/11/92 7/19/95 **4/15/97** 10/7/98	8/7/91 4/16/92 8/11/93 10/13/93 7/19/95 4/3/96 10/7/98	4/4/93 4/15/96	9/22/93 9/1/94 8/9/96

Table 1. Summary of Missouri LTPP sites and performance data analyzed.

Project	Test section	Date of data collection activity				
		Profile data	FWD data	Manual distress data	PASCO distress data	Friction data
SPS-6 Bethany,MO	290663	2/11/92 3/13/93 5/18/94 3/11/97 4/18/98 2/10/99	6/4/92 7/8/92 7/10/92 7/11/92 7/14/92 7/19/95 **4/15/97** 10/7/98	8/7/91 4/16/92 10/13/93 7/19/95 4/4/96 10/7/98	4/4/93 4/15/96	9/22/93 9/1/94 8/9/96
	290664	2/11/92 3/13/93 5/18/94 3/11/97 4/18/98 2/10/99	6/3/92 7/8/92 7/19/95 **4/7/97** 10/7/98	8/6/91 4/15/92 10/13/93 7/19/95 4/4/96 10/7/98	4/4/93 4/15/96	9/22/93 9/1/94 8/9/96
	290665	2/13/92 5/18/94 3/11/97 4/18/98 2/10/99	4/23/92 7/24/95 **4/15/97** 10/8/98	8/7/91 4/23/93 7/20/95 4/17/96 10/8/98	4/4/93 4/15/96	9/22/93 9/1/94 8/9/96
	290666	2/13/92 3/13/93 5/18/94 3/11/97 4/18/98 2/10/99	4/22/92 12/2/92 5/12/93 7/24/95 **4/15/97** 10/8/98	8/7/91 4/15/92 10/15/93 7/20/95 4/17/96 10/8/98	4/4/93 4/15/96	9/22/93 9/1/94 8/9/96
SPS-7 Festus, MO	290701	4/6/90 3/13/91 2/18/92 3/16/94 3/16/97 4/9/98 2/15/99	5/16/90 5/17/90 11/5/90 8/23/91 6/22/92 5/6/93 9/15/94 12/8/98	7/24/91 6/22/92 5/6/93 9/15/94 9/25/95 12/8/98	4/19/90 3/28/93 3/25/96	7/24/91 8/18/92 10/5/93 8/29/94 7/25/96 9/29/97
	290702	4/6/90 3/13/91 2/18/92 3/16/94 3/16/97 4/9/98 2/15/99	5/14/90 11/6/90 6/24/92 5/10/93 9/20/94 **9/30/97** 12/10/98	7/23/91 6/23/92 5/10/93 9/15/94 9/20/94 9/28/95 12/10/98	4/19/90 3/28/93 3/25/96	7/24/91 8/18/92 10/5/93 8/29/94 7/25/96 9/29/97

Table 1. Summary of Missouri LTPP sites and performance data analyzed.

Project	Test section	Date of data collection activity				
		Profile data	FWD data	Manual distress data	PASCO distress data	Friction data
SPS-7 Festus, MO	290703	4/6/90 3/13/91 2/18/92 3/16/94 3/16/97 4/9/98 2/15/99	5/14/90 11/5/90 8/23/91 6/23/92 5/6/93 9/16/94 **9/29/97** 12/10/98	7/23/91 6/23/92 5/6/93 9/16/94 9/25/95 12/8/98	4/19/90 3/28/93 3/25/96	7/24/91 8/18/92 10/5/93 8/29/94 7/25/96 9/29/97
	290704	3/13/91 2/18/92 3/16/94 3/16/97 4/9/98 2/15/99	5/17/90 11/5/90 8/26/91 6/23/92 5/7/93 9/19/94 **9/30/97** 12/9/98	7/24/91 6/23/92 5/7/93 9/19/94 9/27/95 12/9/98	4/19/90 3/28/93 3/25/96	7/24/91 8/18/92 10/5/93 8/29/94 7/25/96 9/29/97
	290705	4/6/90 3/13/91 2/18/92 3/16/94 3/16/97 4/9/98 2/15/99	5/14/90 11/6/90 8/26/91 6/23/92 5/10/93 9/19/94 **9/30/97** 12/10/98	7/24/91 6/23/92 5/10/93 9/19/94 9/28/95 12/10/98	4/19/90 3/28/93 3/25/96	7/24/91 8/18/92 10/5/93 8/29/94 7/25/96 9/29/97
	290706	4/6/90 3/13/91 2/18/92 3/16/94 3/16/97 4/9/98 2/15/99	5/18/90 11/6/90 6/25/92 5/11/93 9/22/94 **9/30/97** 1/14/99	7/25/91 6/23/92 5/11/93 9/26/95 1/14/99	4/19/90 3/28/93 3/25/96	7/24/91 8/18/92 10/5/93 8/29/94 7/25/96
	290707	4/6/90 3/13/91 2/18/92 3/16/94 3/16/97 4/9/98 2/15/99	5/18/90 11/6/90 8/27/91 6/25/92 5/11/93 9/21/94 **9/30/97** 1/14/99	7/25/91 6/23/92 5/10/93 9/21/94 9/26/95 1/14/99	4/19/90 3/28/93 3/25/96	7/24/91 8/18/92 10/5/93 8/29/94 7/25/96

Table 1. Summary of Missouri LTPP sites and performance data analyzed.

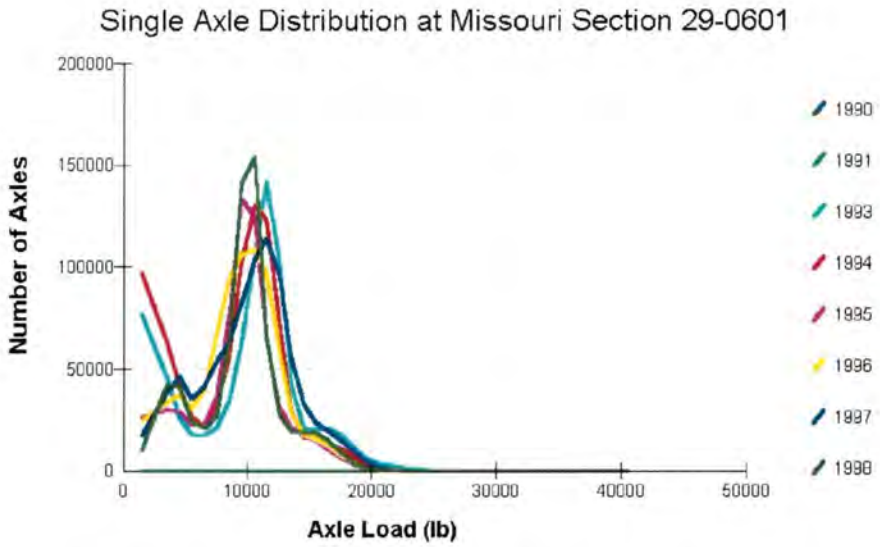
Project	Test section	Date of data collection activity				
		Profile data	FWD data	Manual distress data	PASCO distress data	Friction data
SPS-7 Festus, MO	290708	4/6/90	5/17/90	7/24/91	4/19/90	7/24/91
		3/13/91	11/6/90	6/23/92	3/28/93	8/18/92
		2/18/92	8/27/91	5/10/93	3/25/96	10/5/93
		3/16/94	6/24/92	9/20/94		8/29/94
		3/16/97	5/10/93	9/26/95		7/25/96
		4/9/98	9/20/94	1/11/99		9/29/97
		2/15/99	**9/30/97**			
			1/11/99			
	290709	3/13/91	5/17/90	7/25/91	4/19/90	7/24/91
		2/18/92	11/6/90	6/23/92	3/28/93	8/18/92
		3/16/94	8/27/91	5/10/93	3/25/96	10/5/93
		3/16/97	6/24/92	9/21/94		8/29/94
		4/9/98	5/11/93	9/26/95		7/25/96
		2/15/99	9/21/94	1/12/99		9/29/97
			9/30/97			
			1/12/99			
	290759	4/6/90	5/17/90	7/24/91	3/28/93	8/18/92
		3/13/91	11/5/90	6/23/92	3/25/96	10/5/93
		2/18/92	8/23/91	5/6/93		8/29/94
		3/16/94	6/22/92	9/25/95		7/25/96
		3/16/97	5/6/93	12/7/98		
		4/9/98	12/7/98			
		2/15/99				
	290760	4/6/90	5/17/90	7/24/91	3/28/93	8/18/92
		3/13/91	11/5/90	6/23/92	3/25/96	10/5/93
		2/18/92	8/26/91	5/6/93		8/29/94
		3/16/94	6/23/92	9/16/94		7/25/96
		3/16/97	5/7/93	9/27/95		
		4/9/98	**9/29/97**	12/9/98		
		2/15/99	12/9/98			

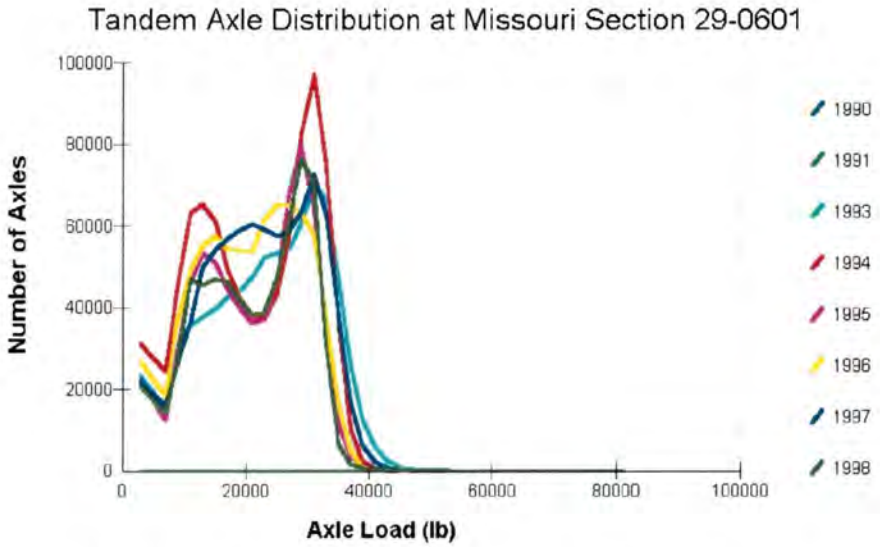
Table 1. Summary of Missouri LTPP sites and performance data analyzed.

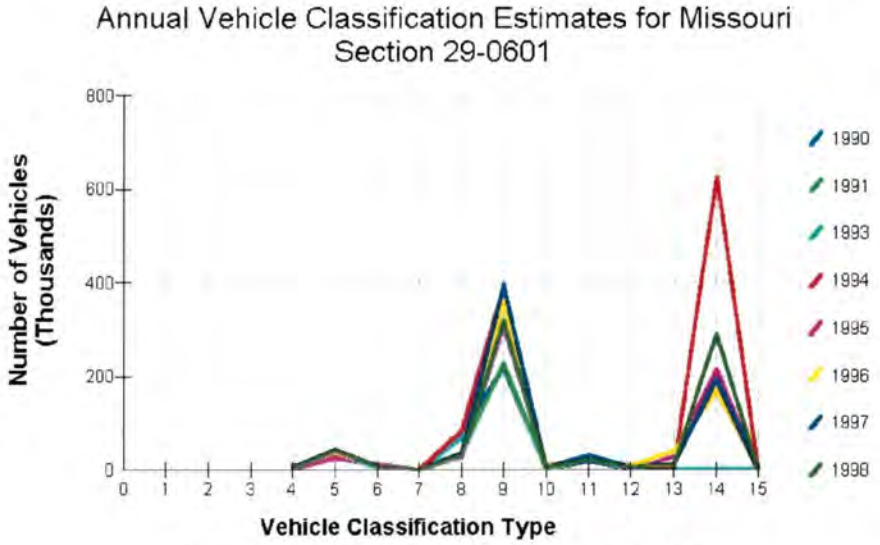
		Date of data collection activity				
Project	Test section	Profile data	FWD data	Manual distress data	PASCO distress data	Friction data
SPS-9A Sedalia, MO	290901	7/16/96 12/18/96 4/16/98 2/12/99	**3/11/97** 3/12/97	7/24/96 3/12/97	4/16/96	9/23/97
	290902	7/16/96 12/18/96 4/16/98 2/12/99	**3/11/97** 3/13/97	7/25/96 3/13/97	4/16/96	9/23/97
	290903	7/16/96 12/18/96 4/16/98 2/12/99	**3/11/97** 3/12/97	7/25/96 3/12/97	4/16/96	9/23/97
	290959	7/16/96 12/18/96 4/16/98 2/12/99	**3/11/97** 3/13/97	7/24/96 3/13/97	4/16/96	9/23/97
	290960	7/16/96 12/18/96 4/16/98 2/12/99	**3/11/97** 3/13/97	7/24/96 3/13/97	4/16/96	9/23/97
	290961	7/16/96 12/18/96 4/16/98 2/12/99	**3/11/97** 3/13/97	7/24/96 3/13/97	4/16/96	9/23/97
	290962	7/17/96 12/18/96 4/16/98 2/12/99	**3/12/97** 3/12/97	7/25/96 3/12/97	4/16/96	9/23/97
	290963	7/17/96 12/18/96 4/16/98 2/12/99	**3/12/97** 3/12/97	7/25/96 3/12/97	4/16/96	9/23/97
	290964	7/16/96 12/18/96 4/16/98 2/12/99	**3/12/97** 3/13/97	7/25/96 3/12/97	4/16/96	9/23/97

Appendix B

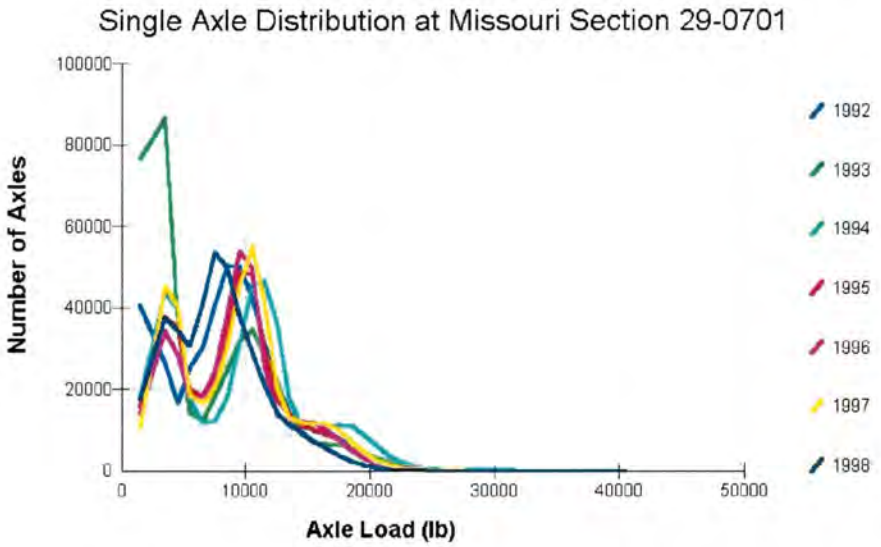
Traffic data plots

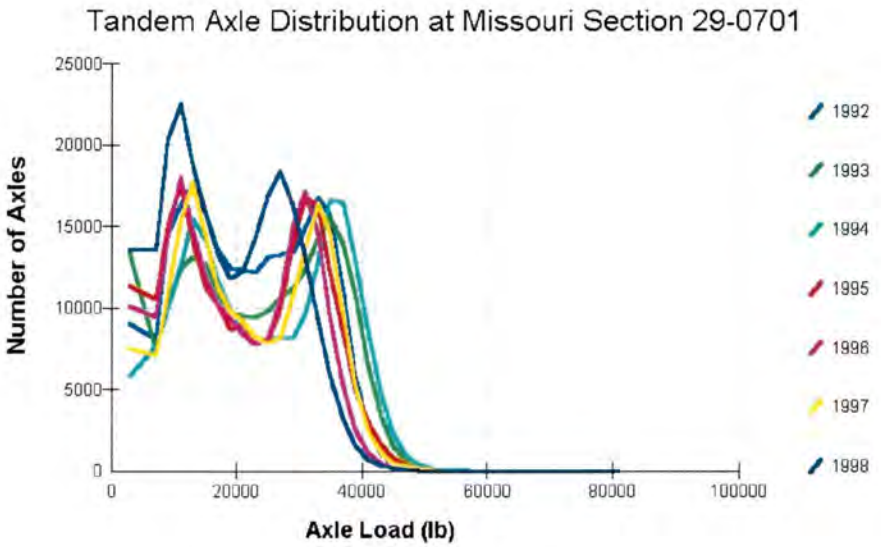


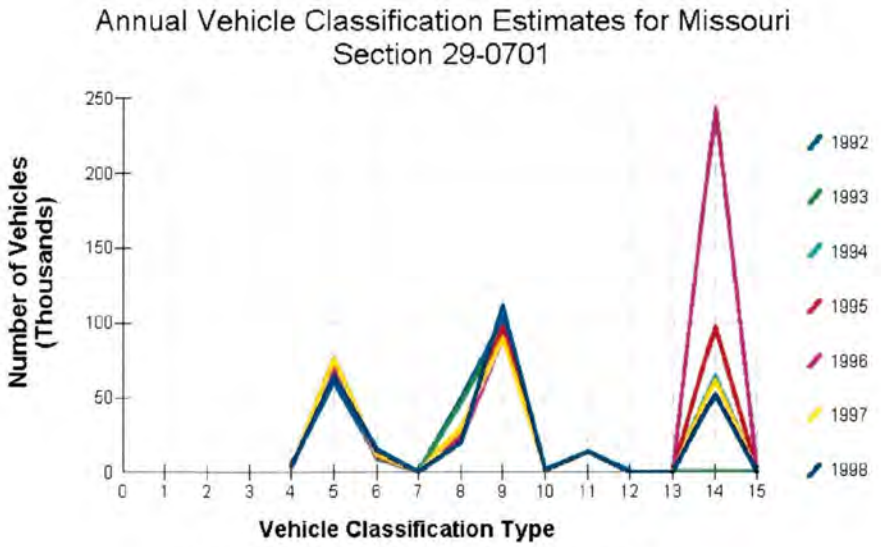




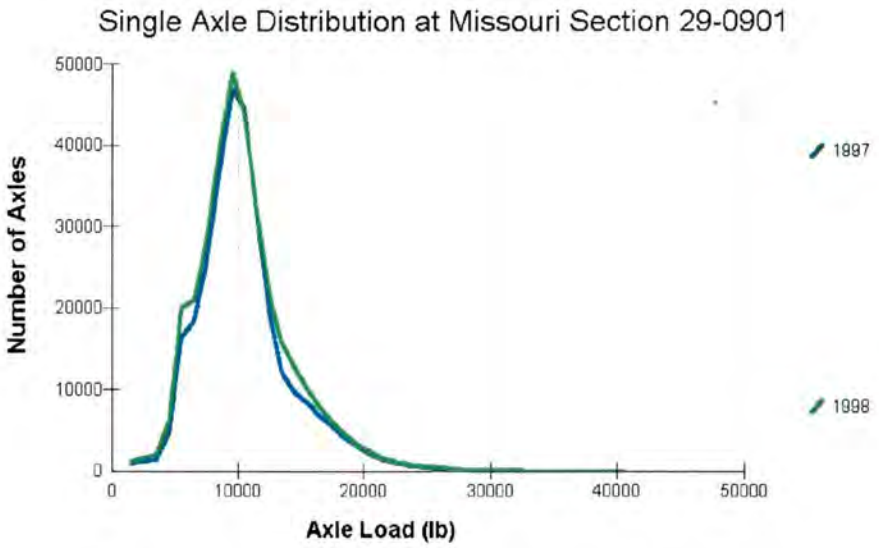
Traffic data for Missouri section 2906**.

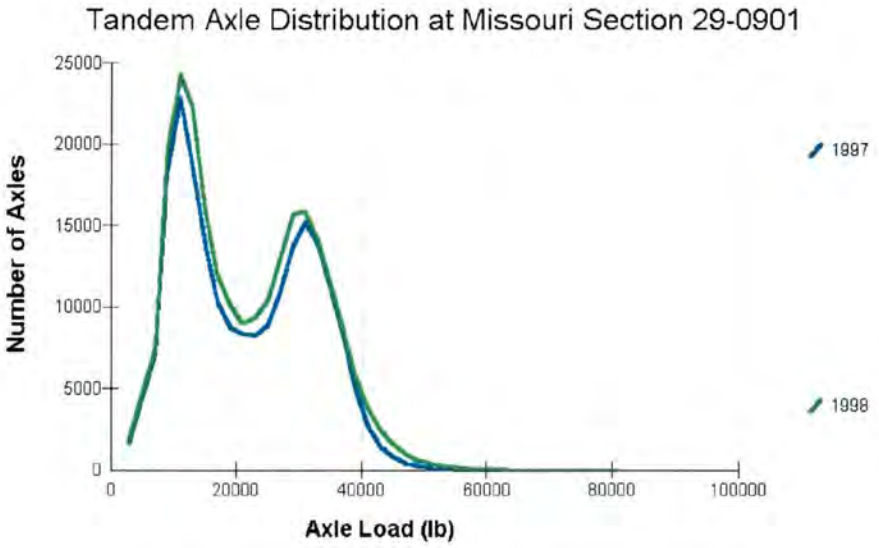


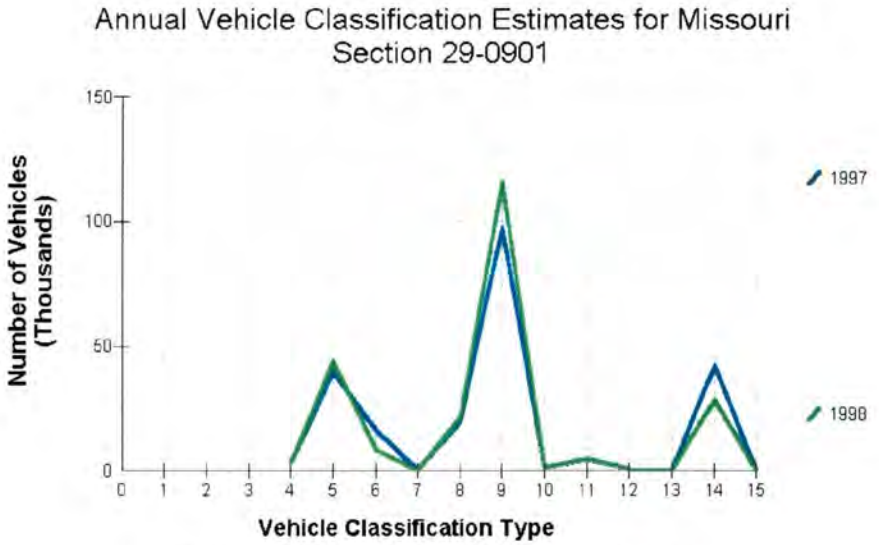




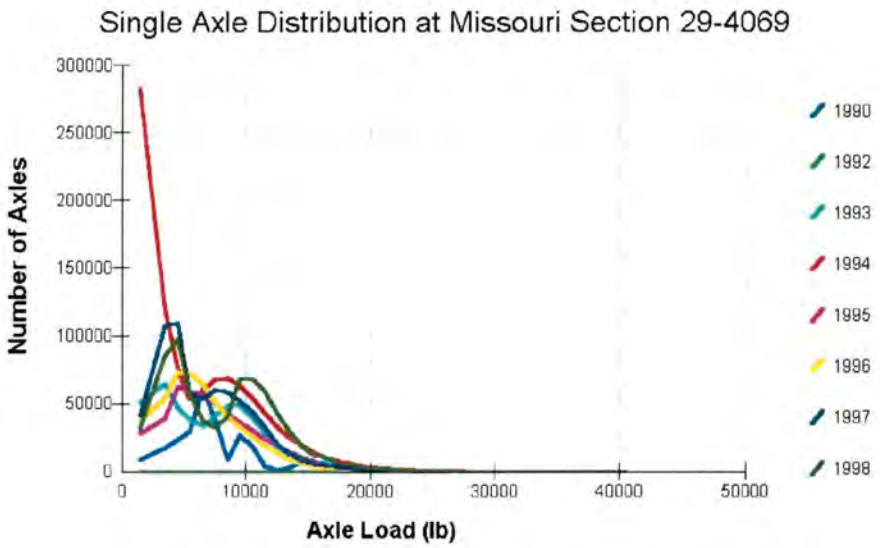
Traffic data for Missouri section 2907**.

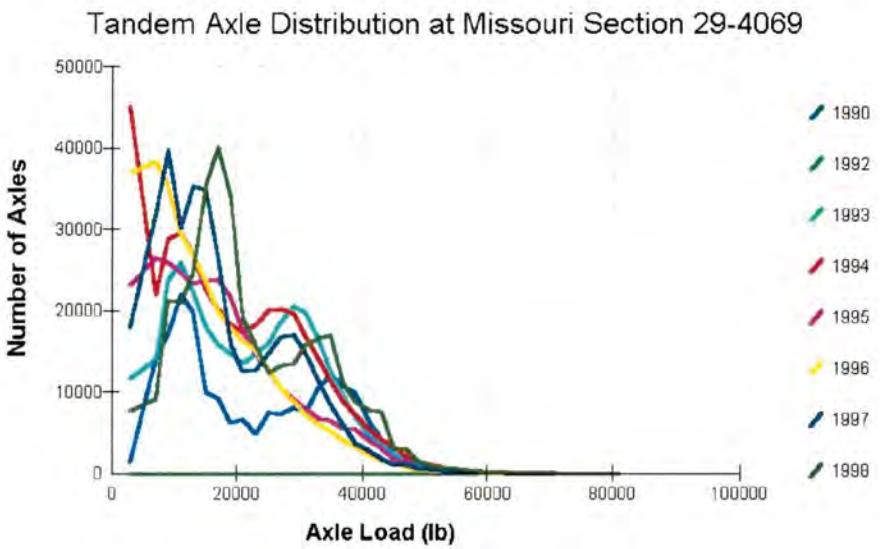


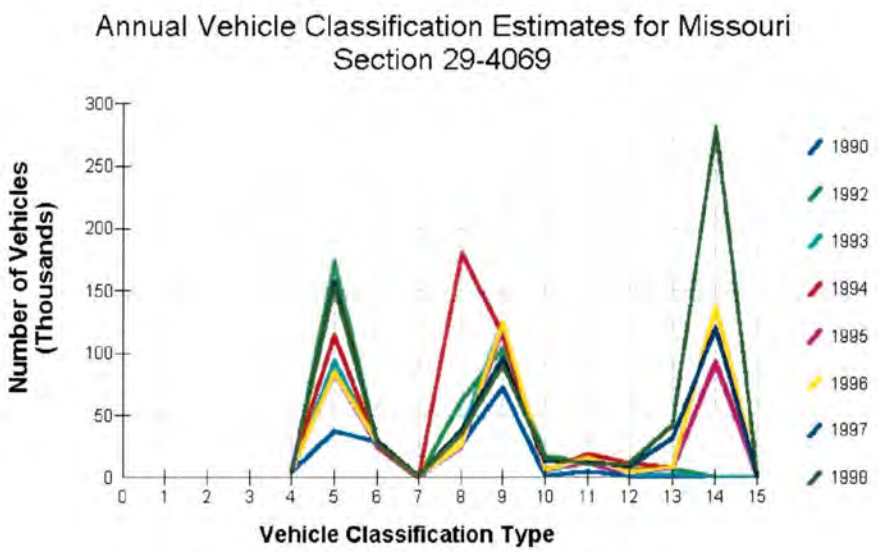




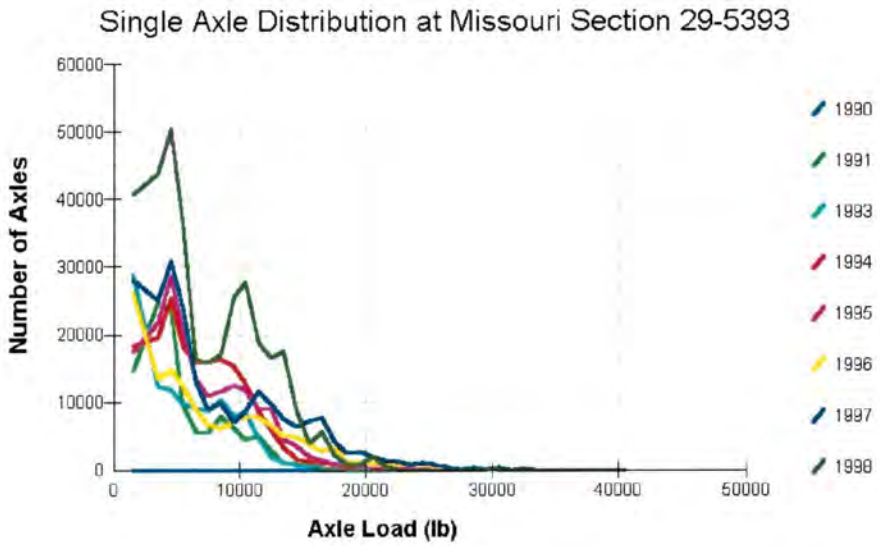
Traffic data for Missouri section 2909**.

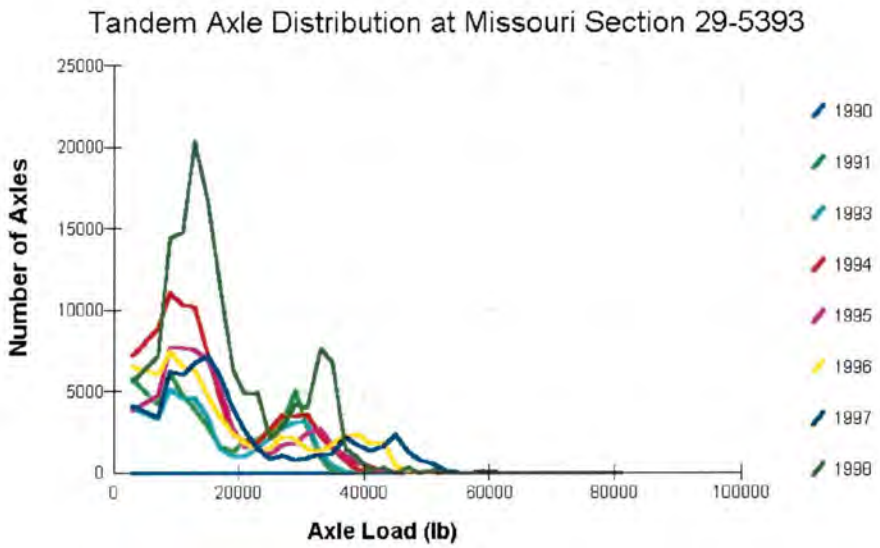


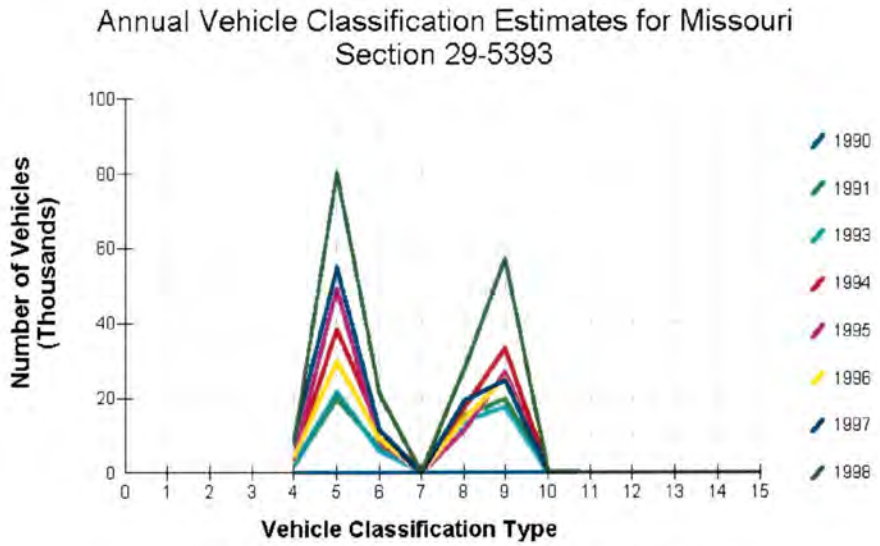




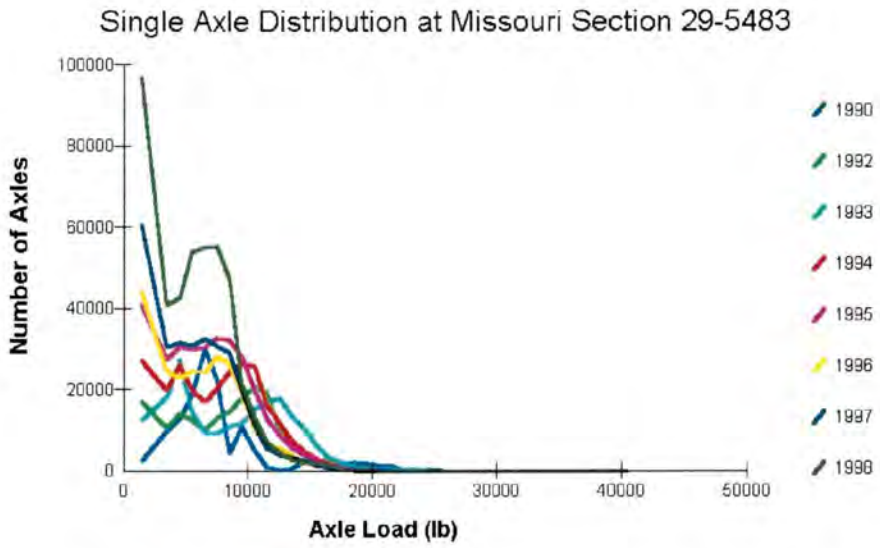
Traffic data for Missouri section 294069.

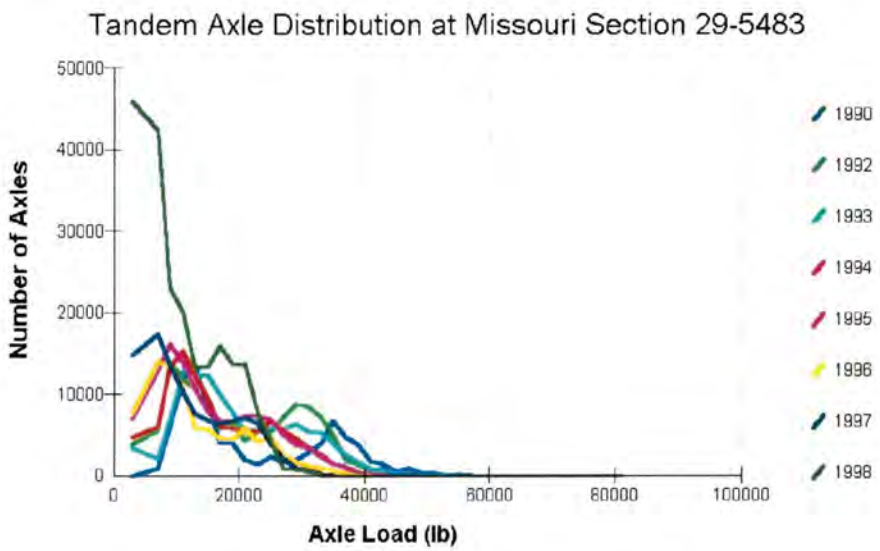


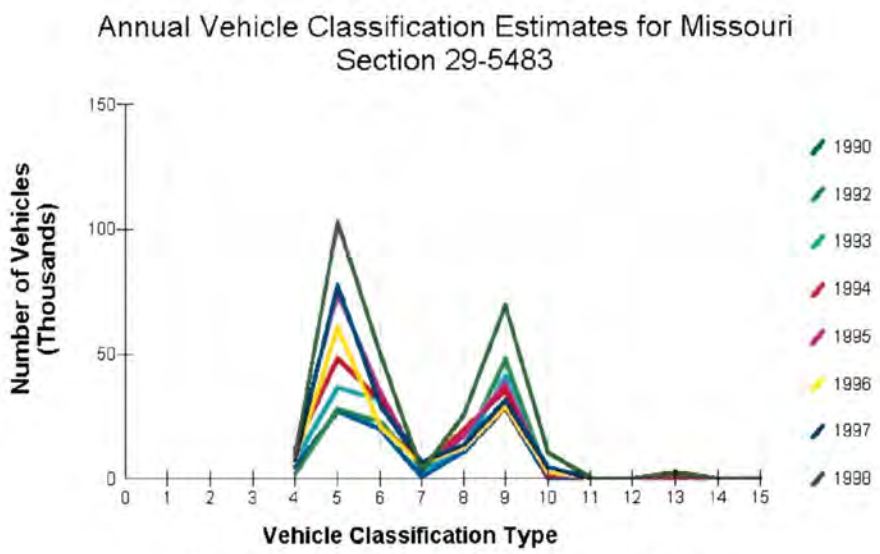




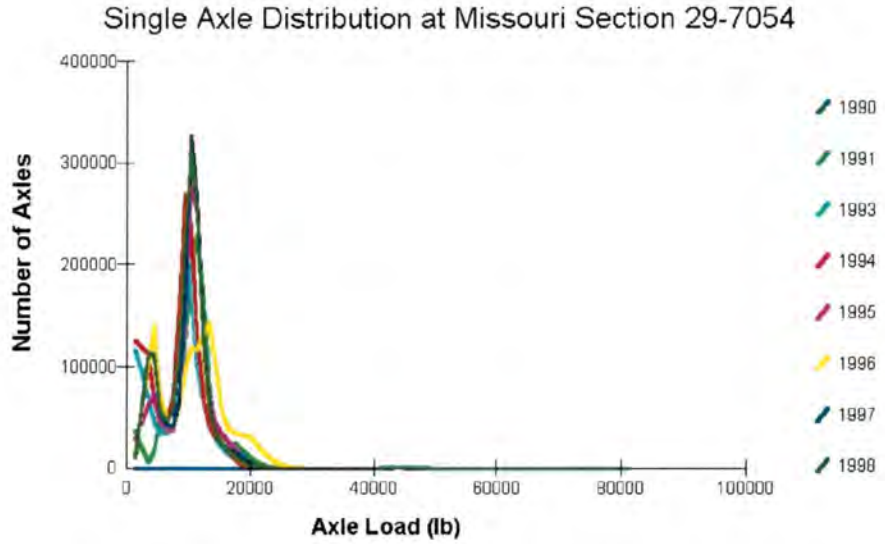
Traffic data for Missouri section 295393.

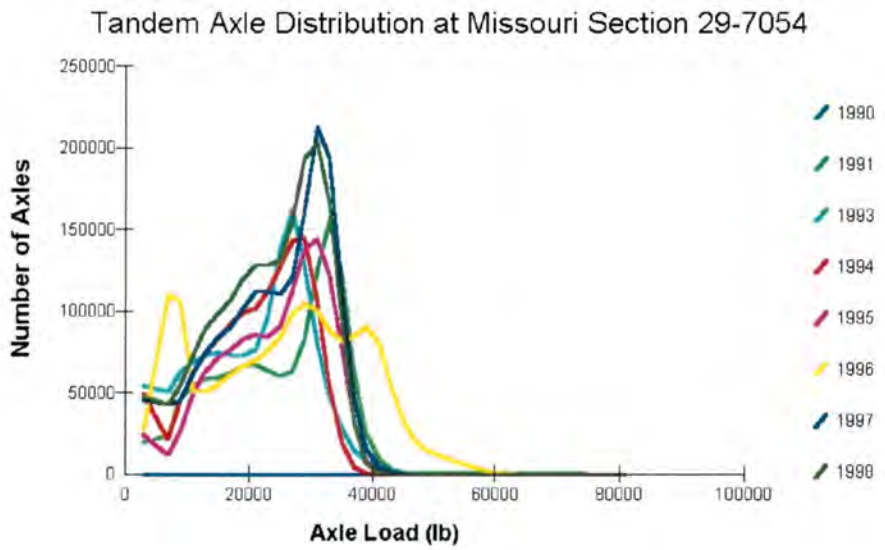


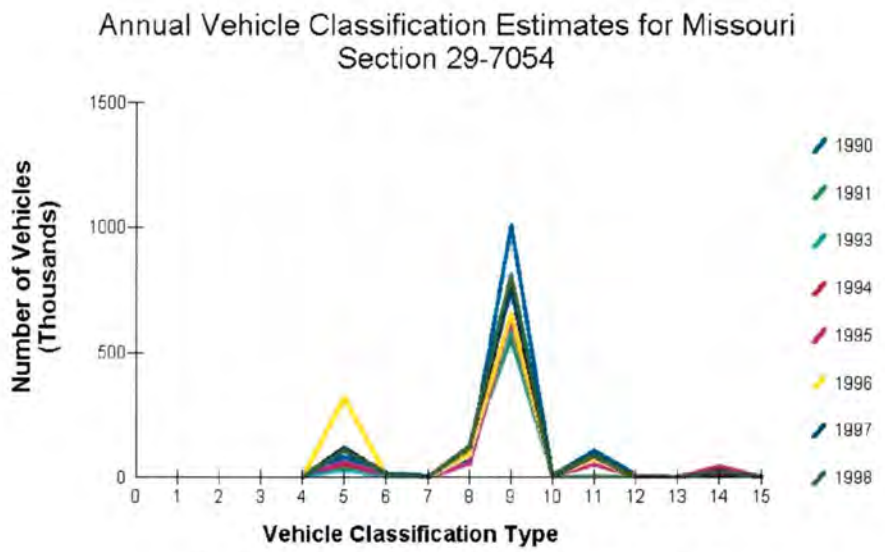




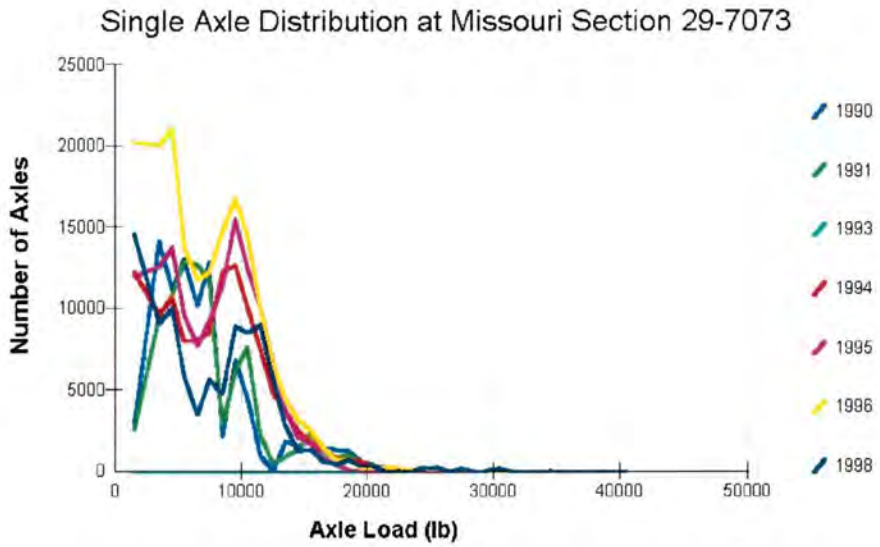
Traffic data for Missouri section 295483.

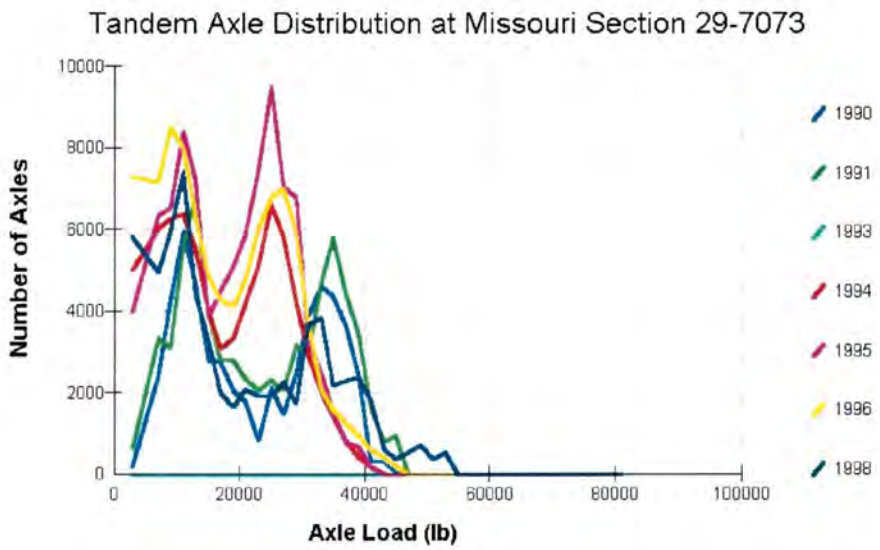


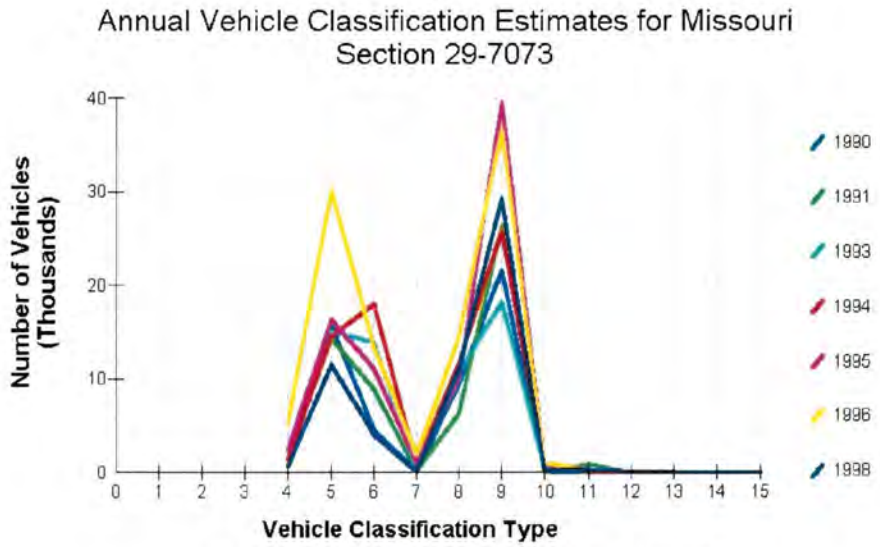




Traffic data for Missouri section 297054.



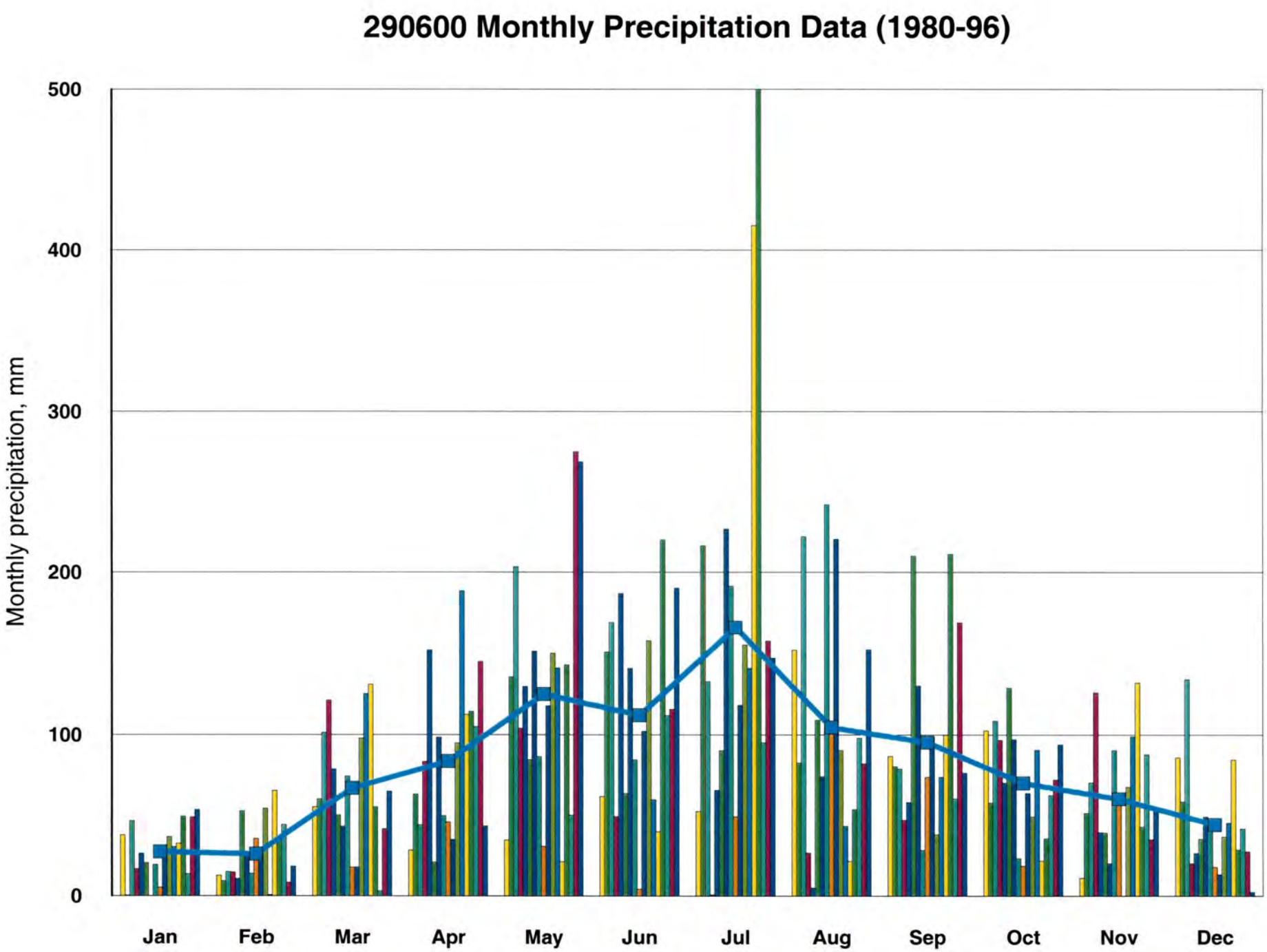




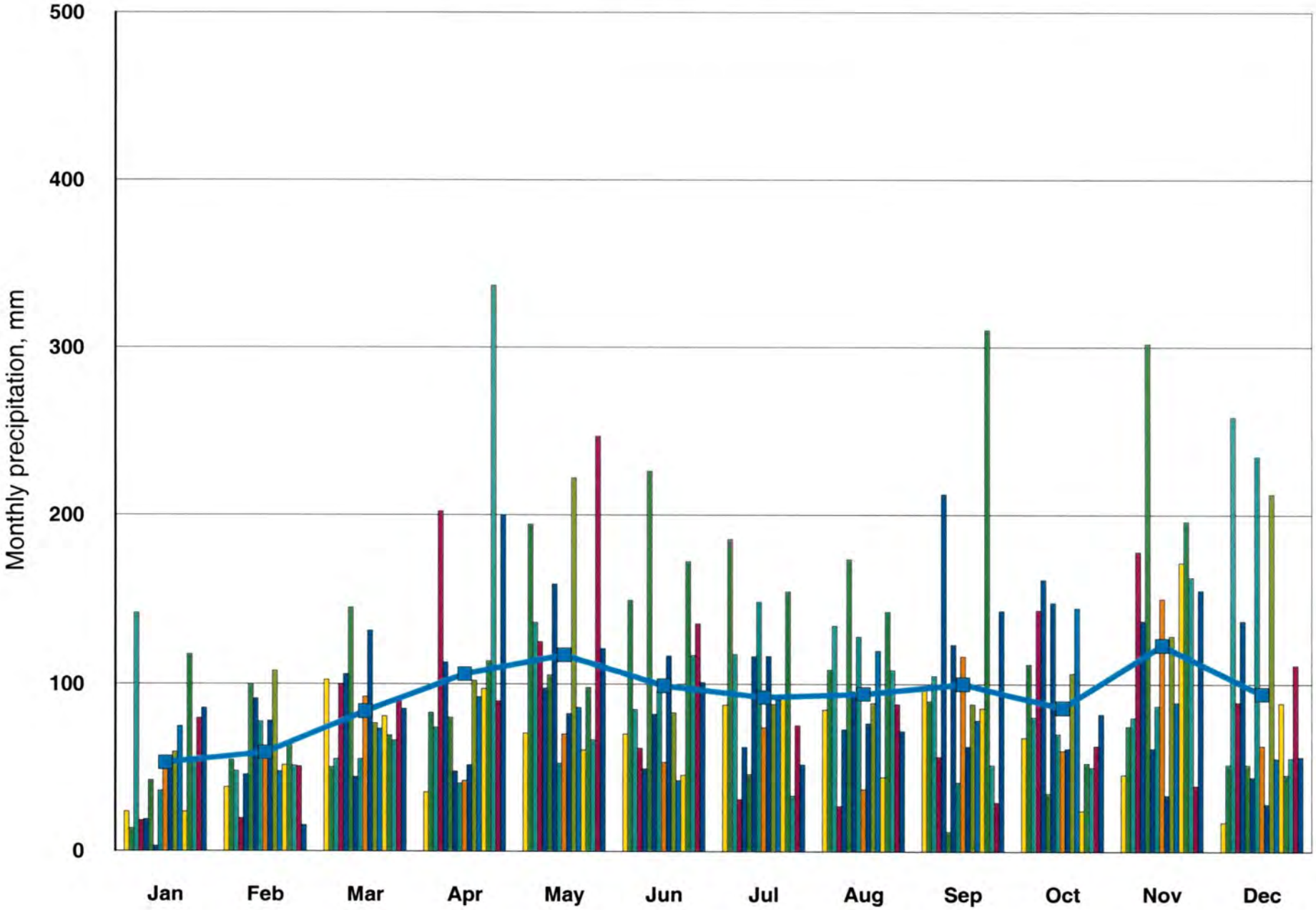
Traffic data for Missouri section 297073.

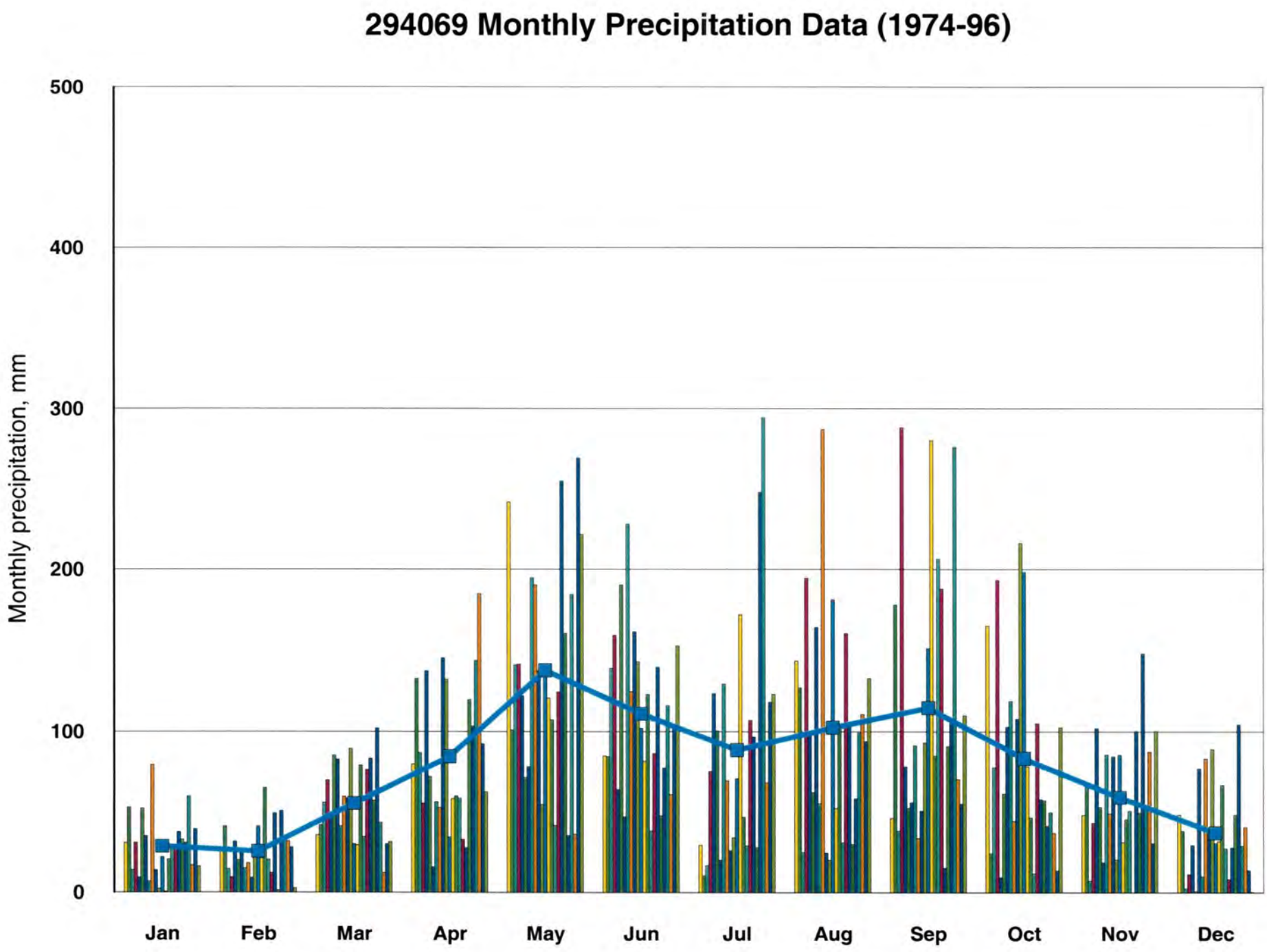
Appendix C

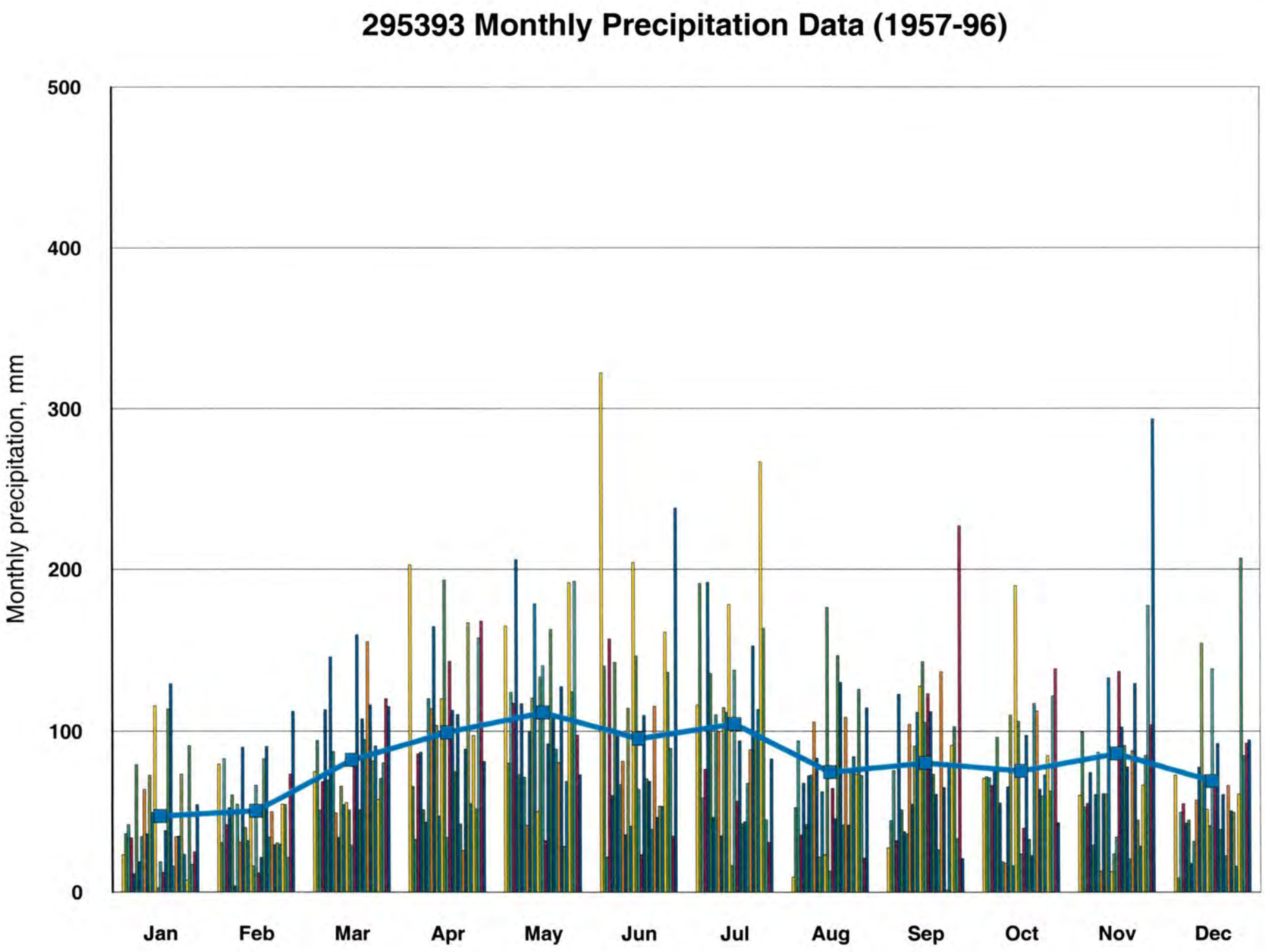
Climatic data plots


290600 Monthly Precipitation Data (1980-96)
Monthly precipitation, mm
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

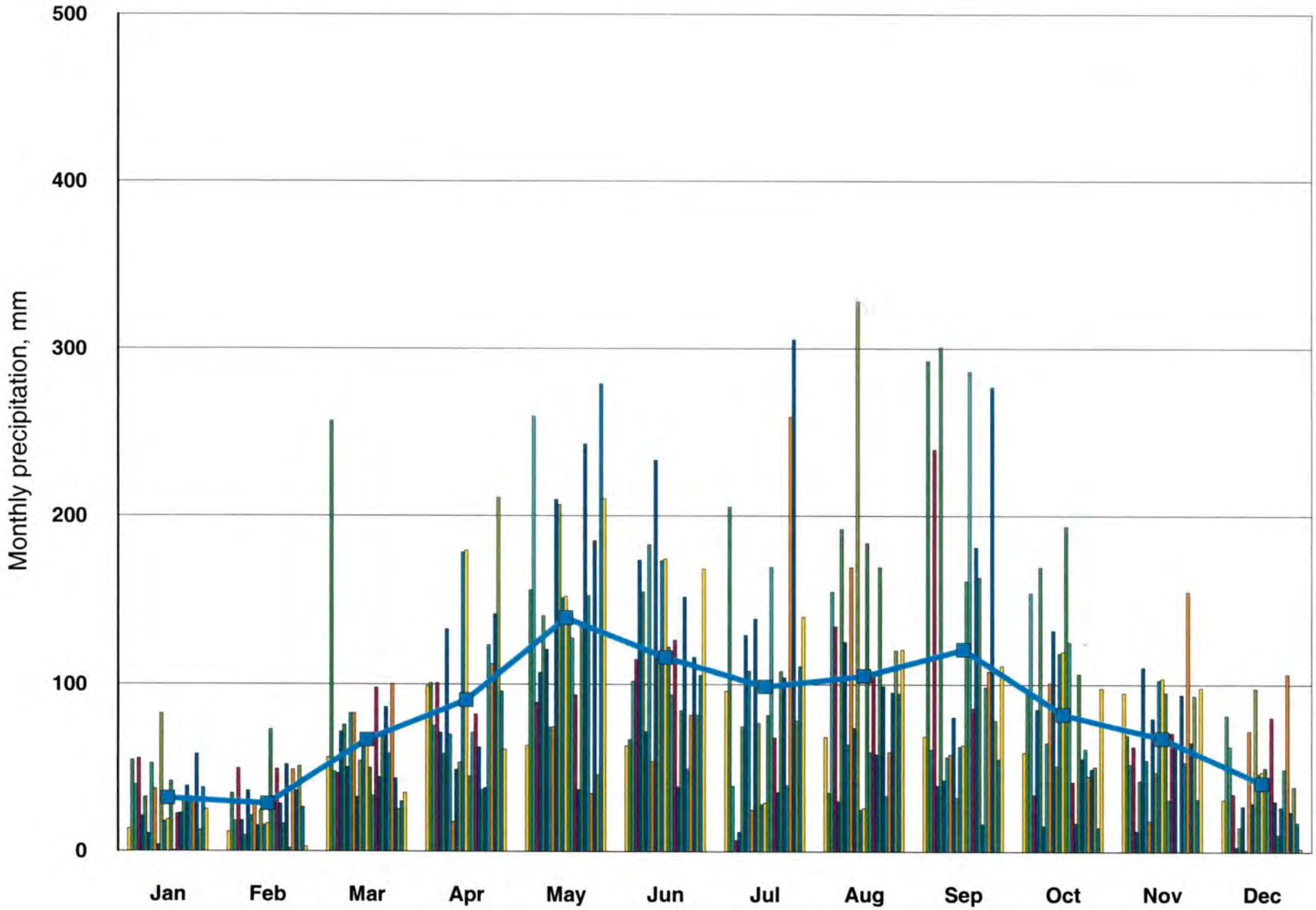
290700 Monthly Precipitation Data (1980-96)



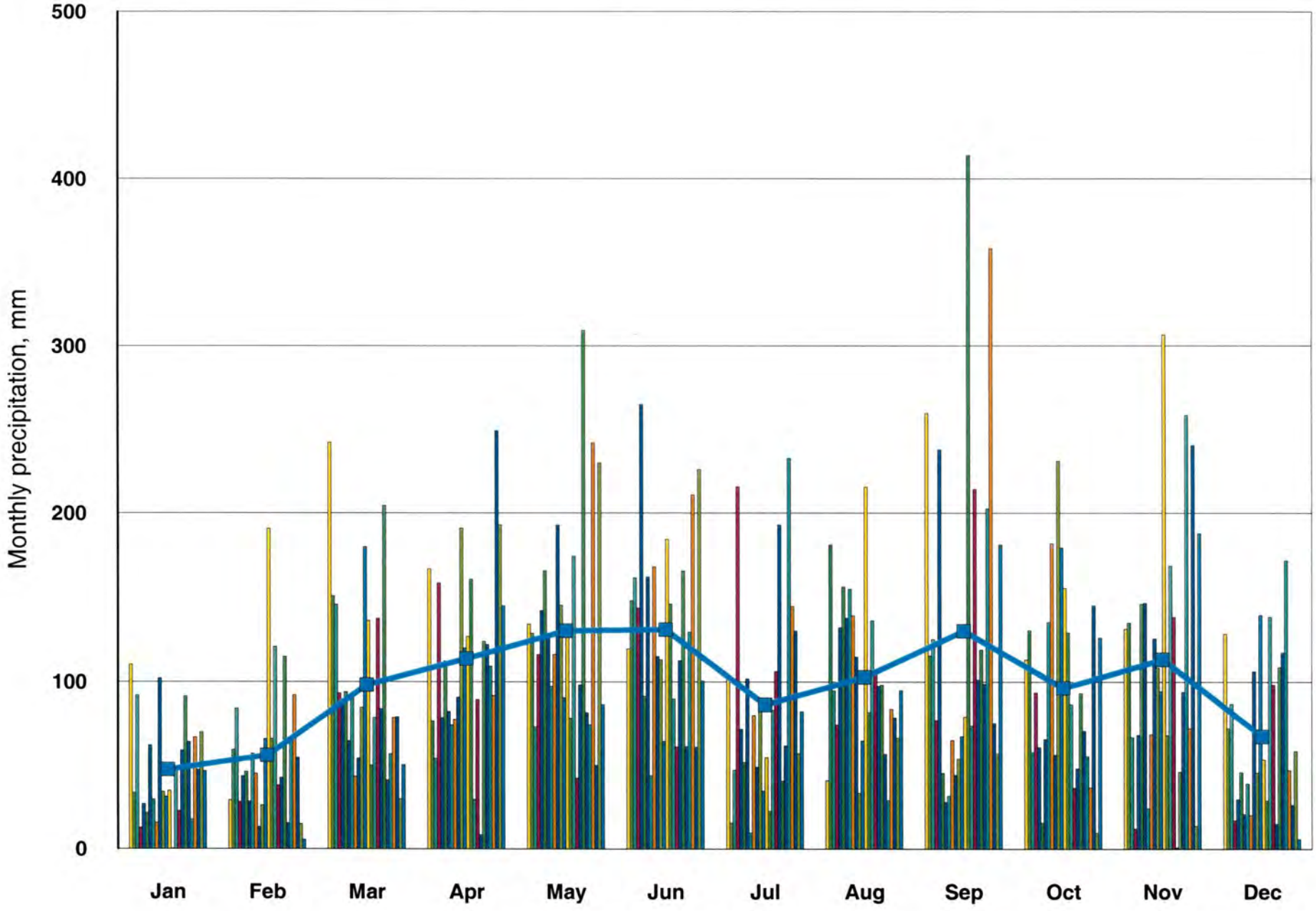

294069 Monthly Precipitation Data (1974-96)
Monthly precipitation, mm
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

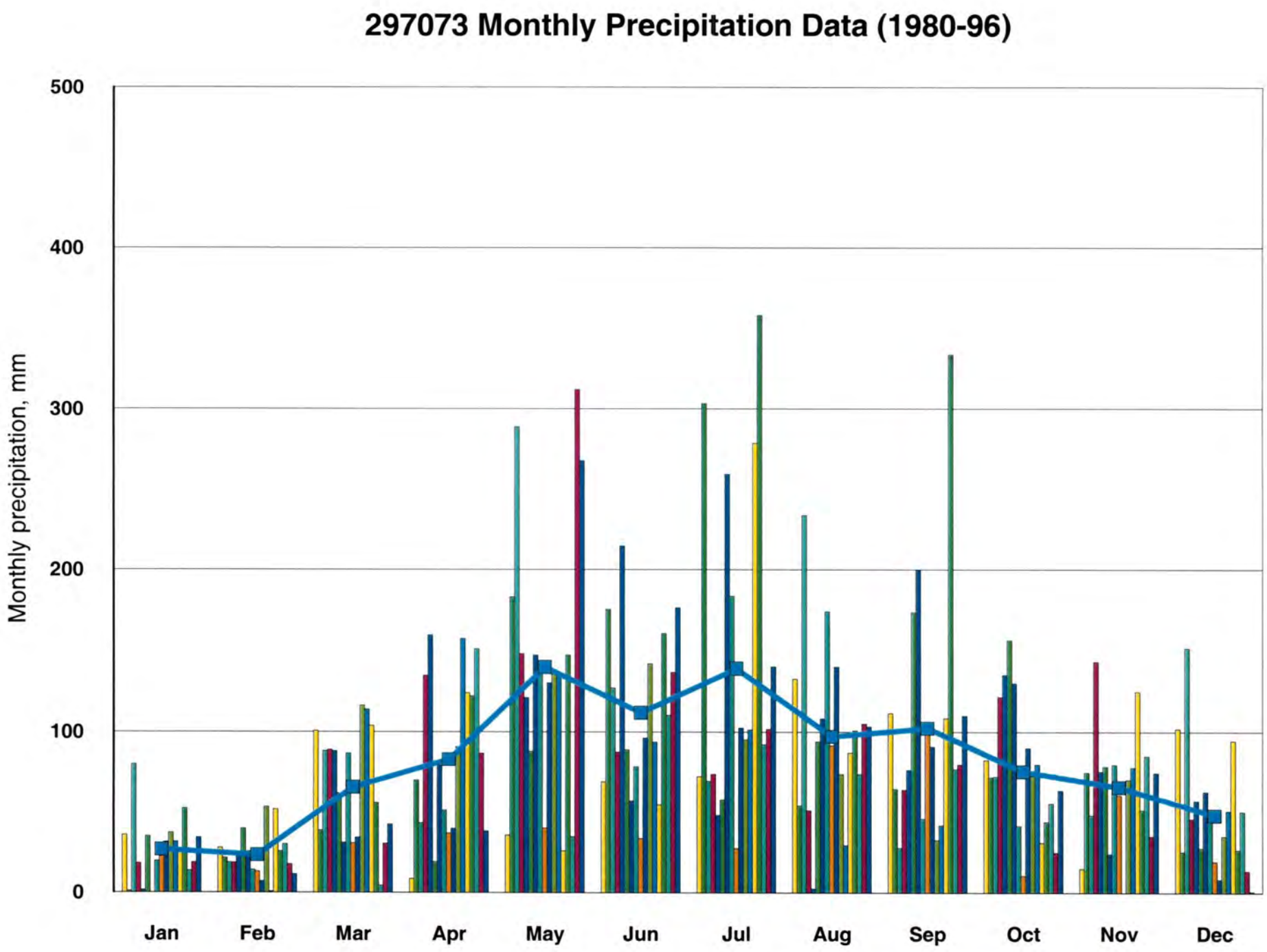

295393 Monthly Precipitation Data (1957-96)
Monthly precipitation, mm
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

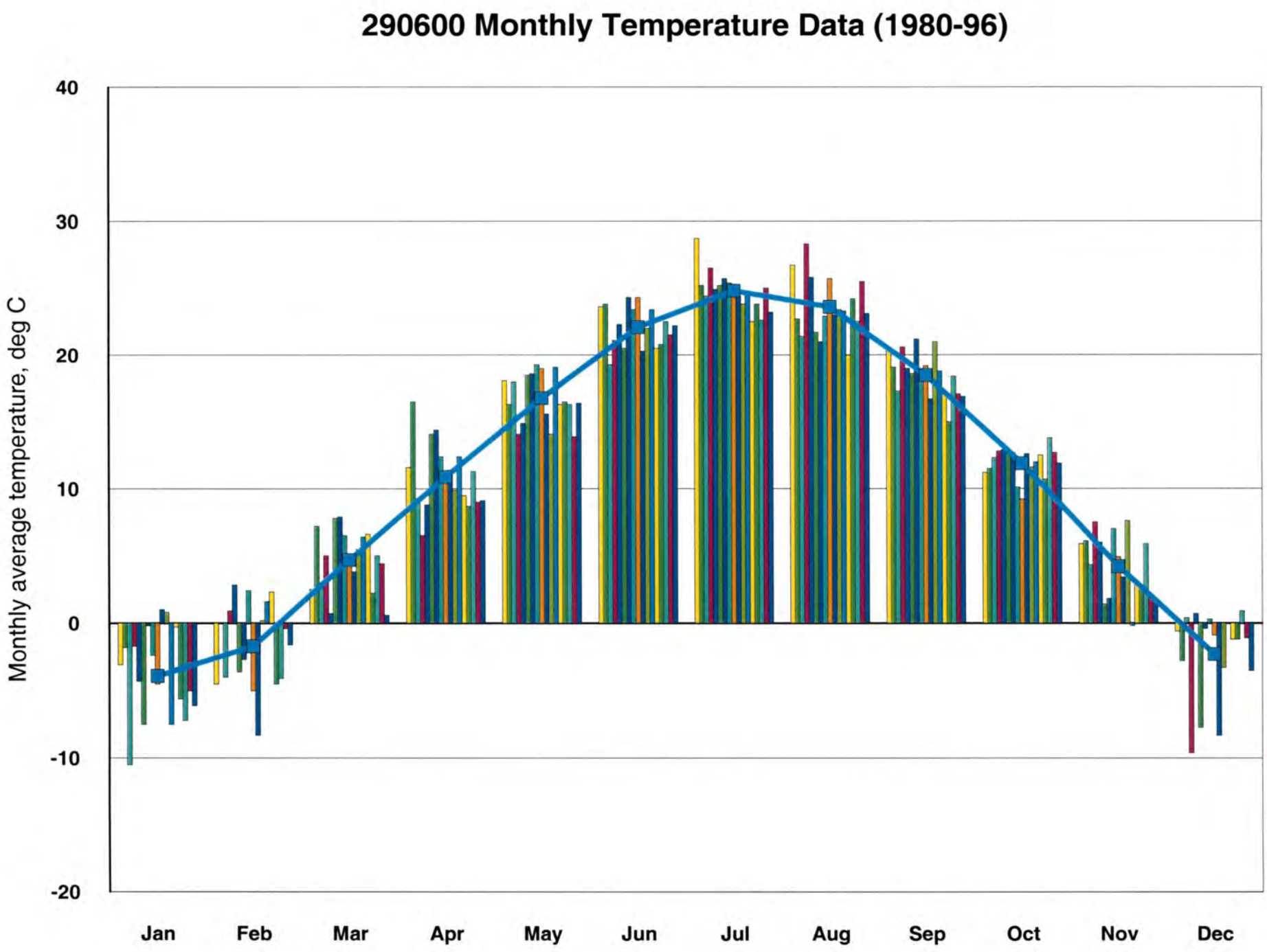
295483 Monthly Precipitation Data (1972-96)

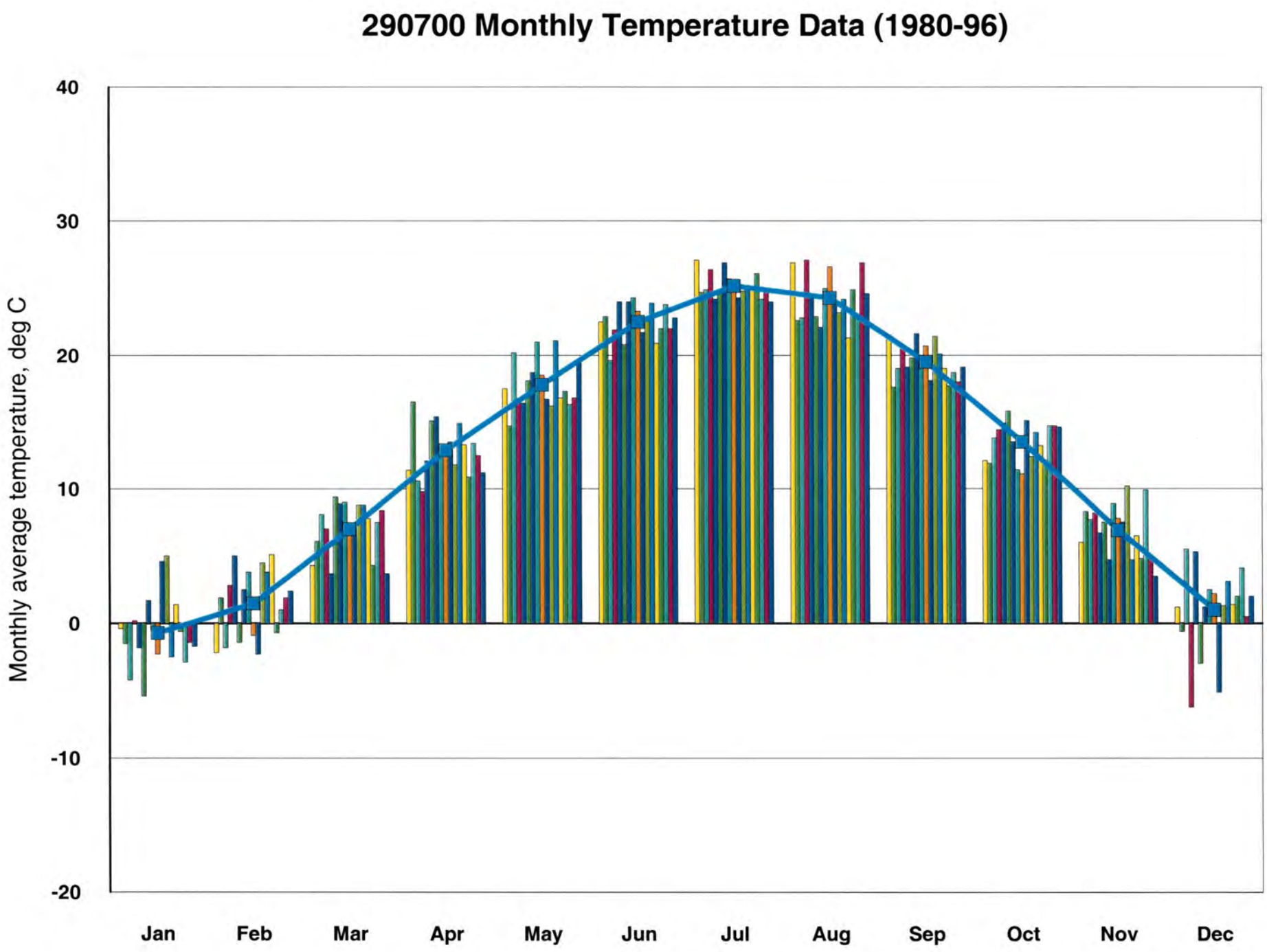


297054 Monthly Precipitation Data (1973-96)

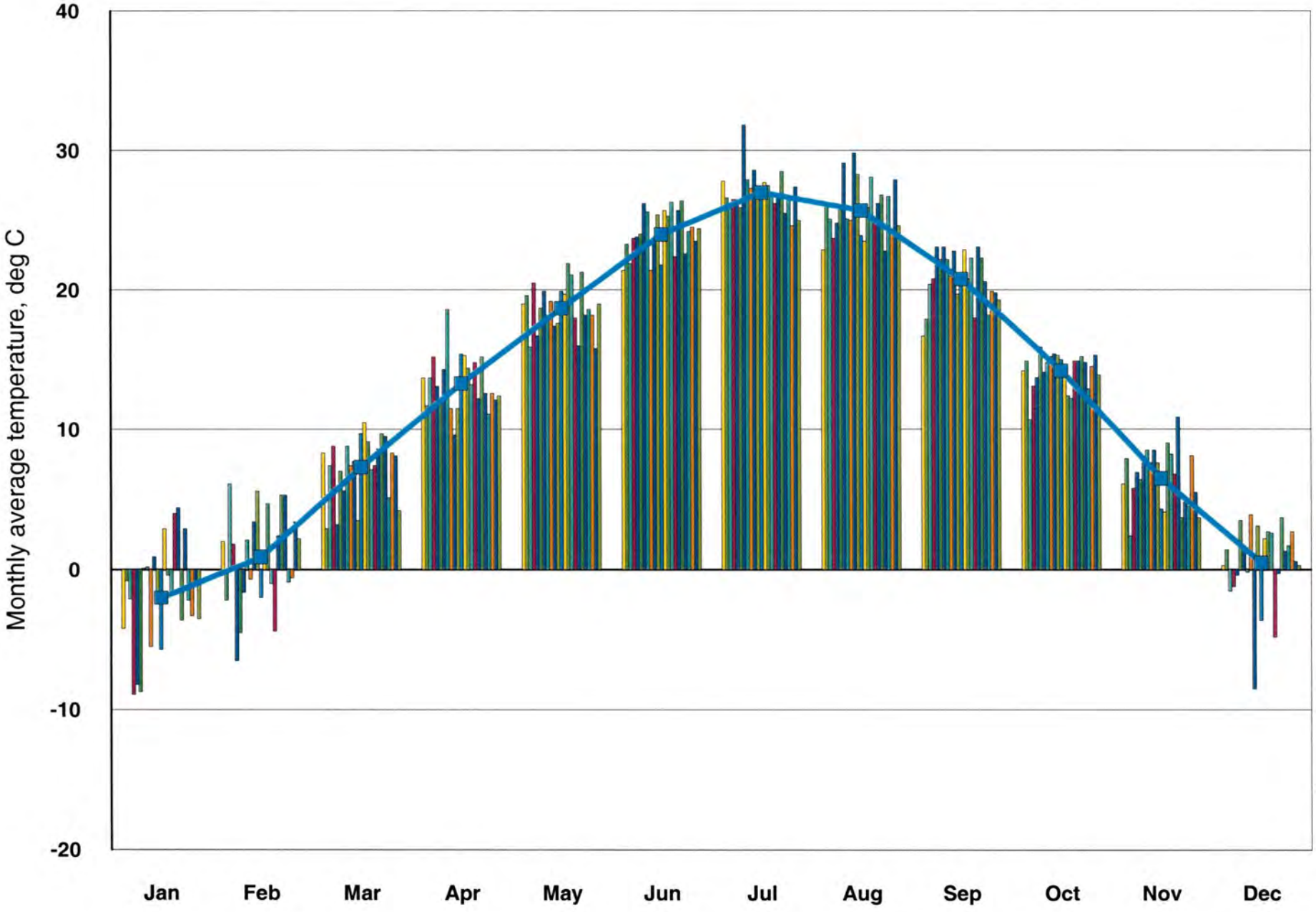


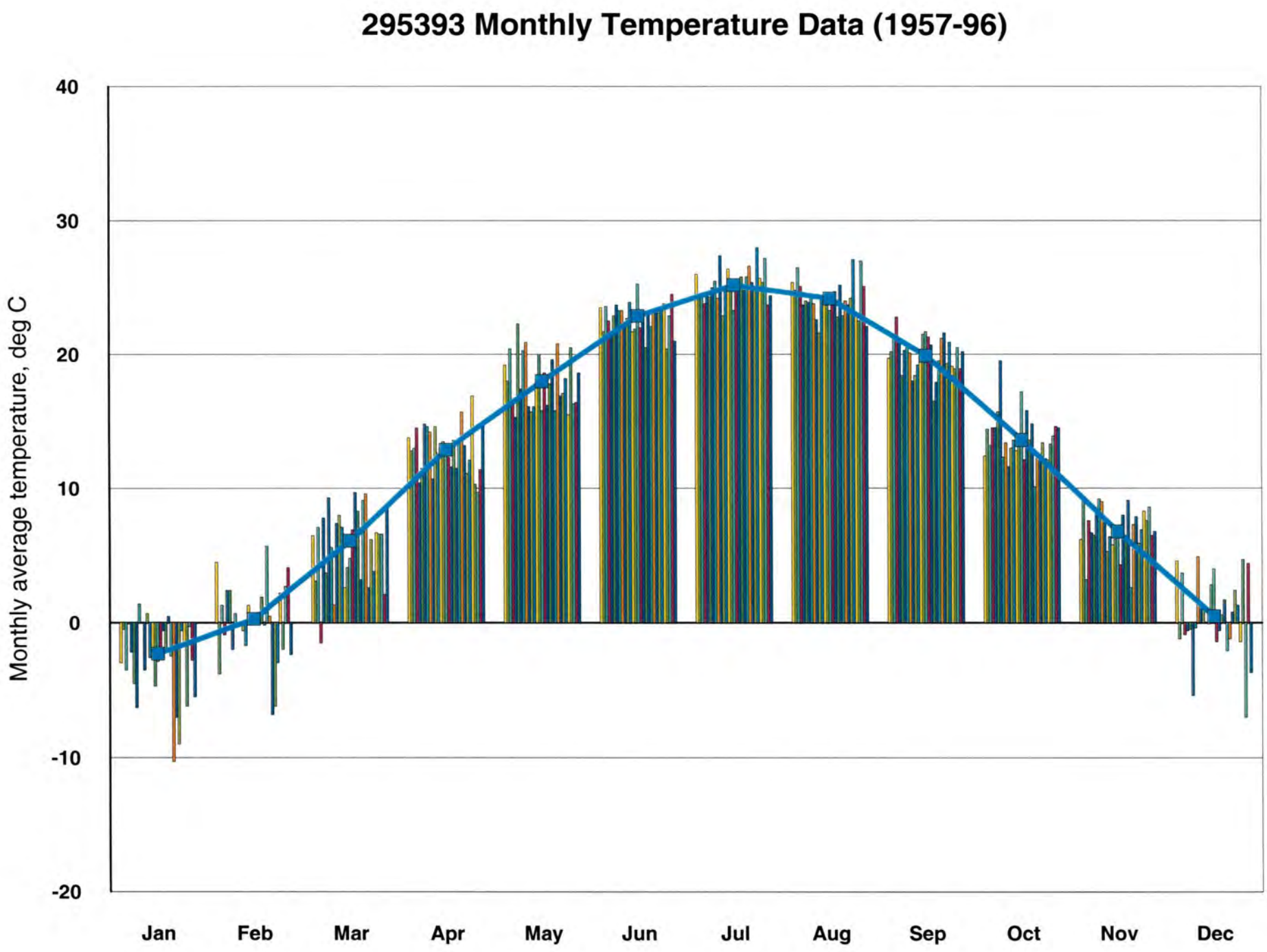

297073 Monthly Precipitation Data (1980-96)
Monthly precipitation, mm
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


290600 Monthly Temperature Data (1980-96)
Monthly average temperature, deg C
40
30
20
10
0
-10
-20
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

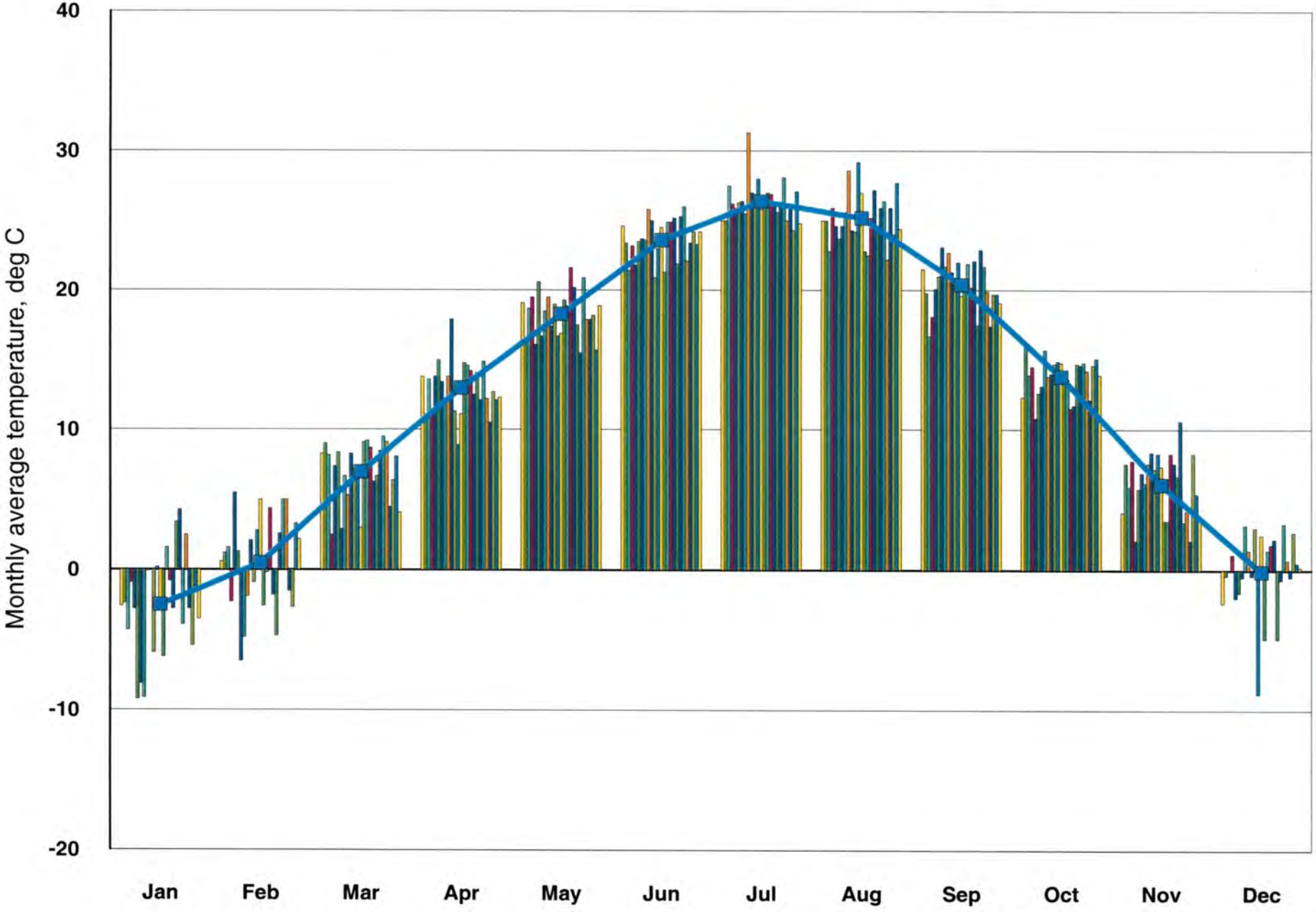

290700 Monthly Temperature Data (1980-96)
Monthly average temperature, deg C
40
30
20
10
0
-10
-20
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

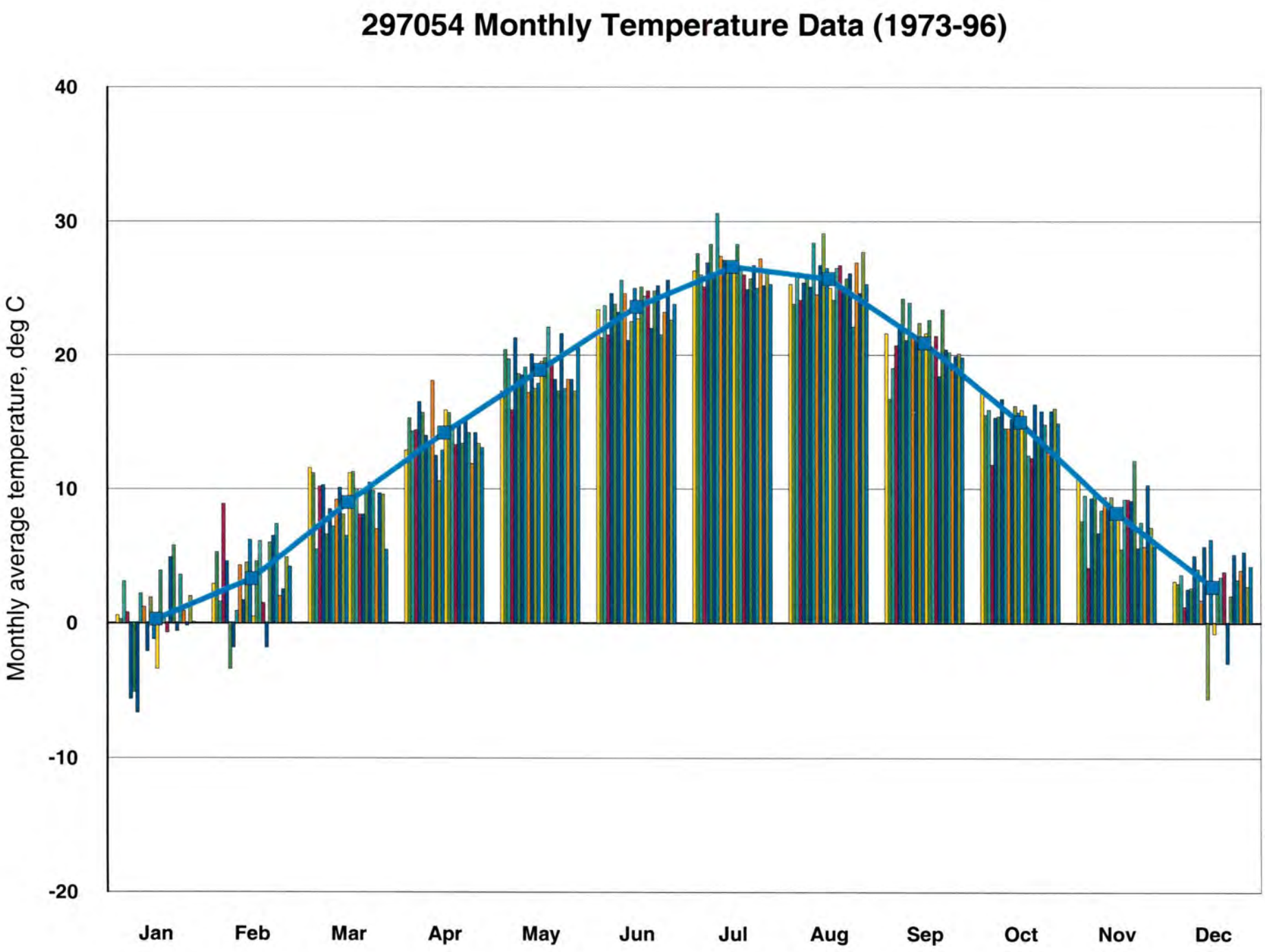
294069 Monthly Temperature Data (1974-96)

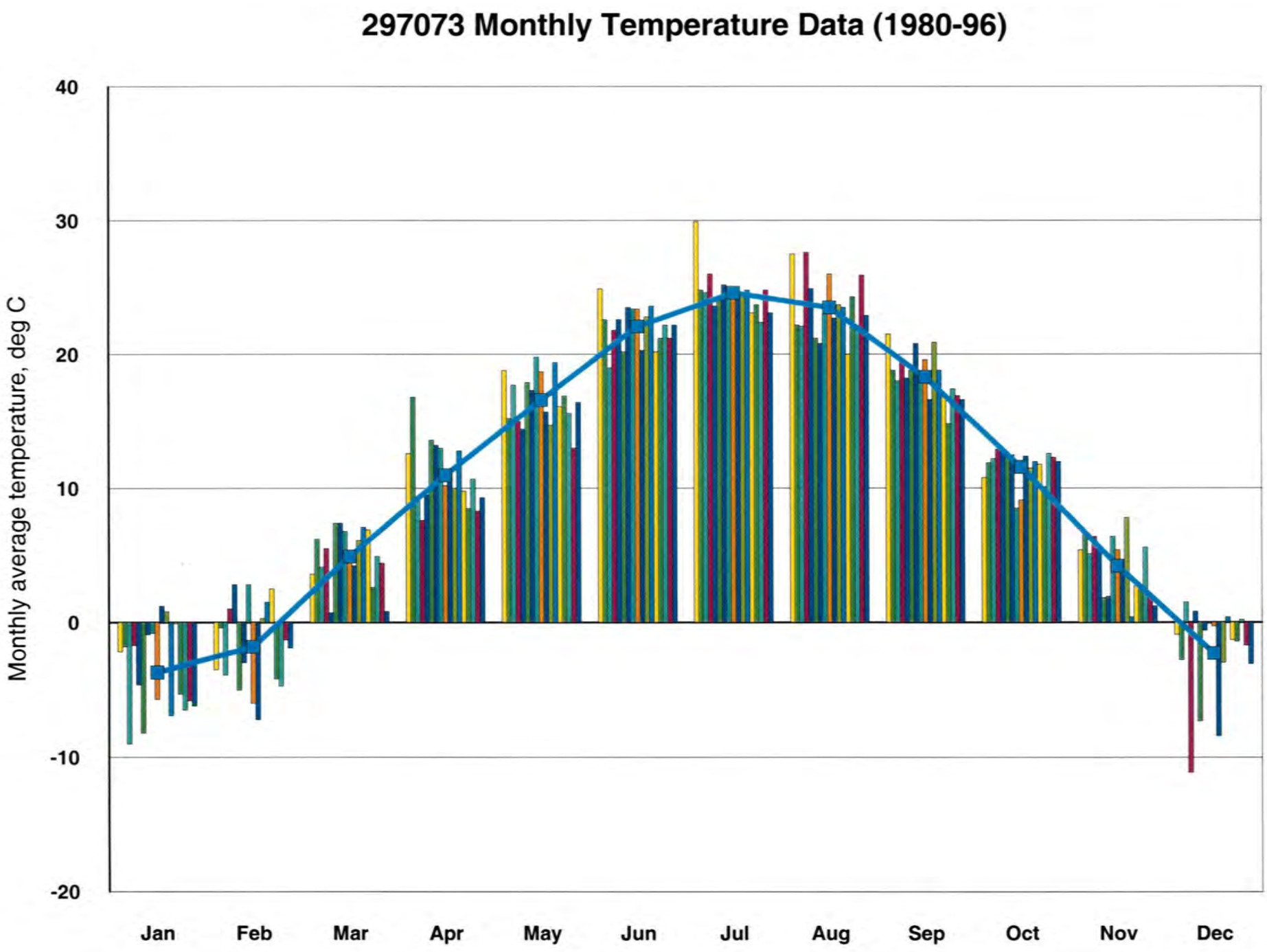



295393 Monthly Temperature Data (1957-96)
Monthly average temperature, deg C
40
30
20
10
0
-10
-20
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

295483 Monthly Temperature Data (1972-96)



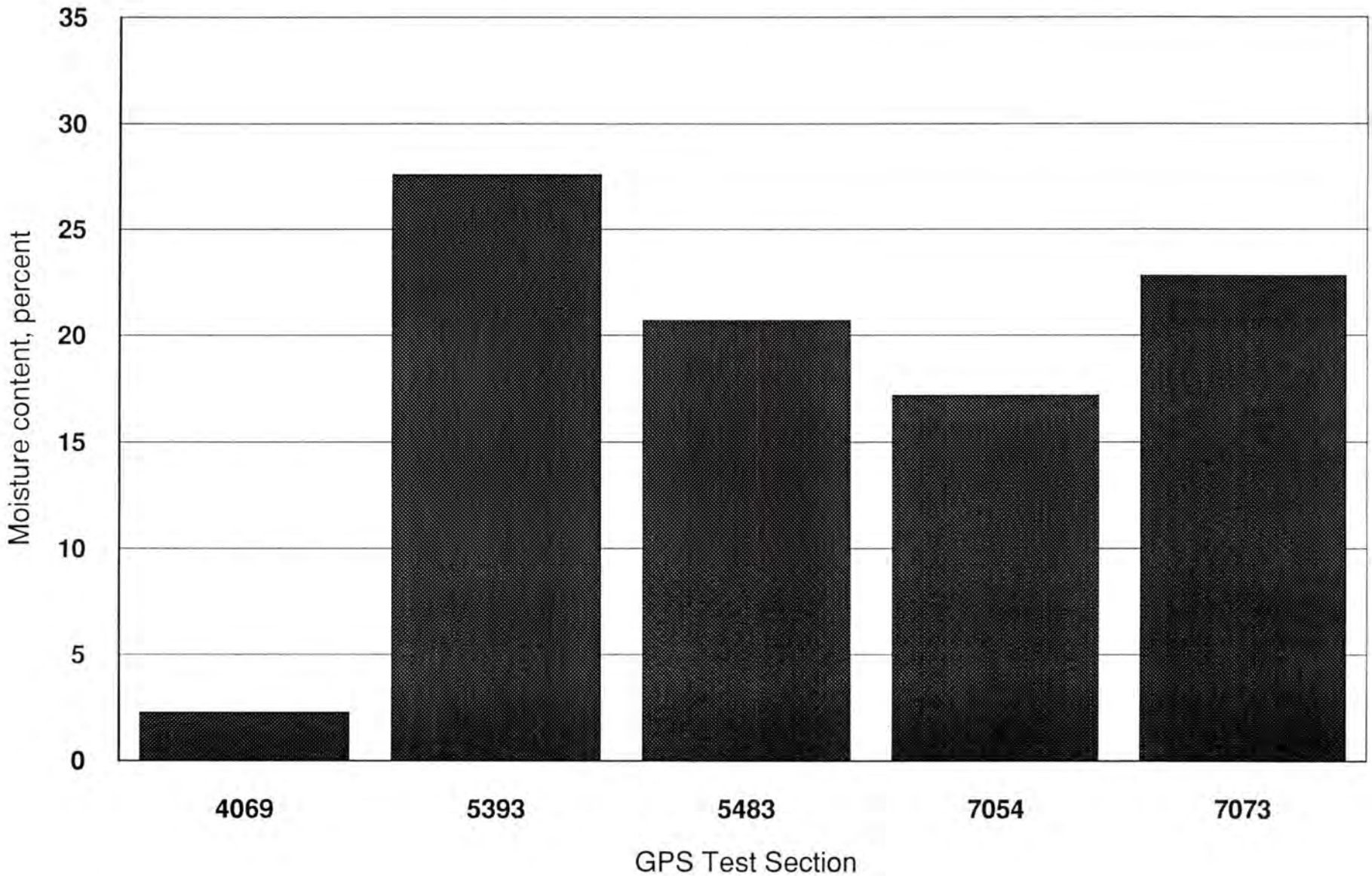

297054 Monthly Temperature Data (1973-96)
Monthly average temperature, deg C
40
30
20
10
0
-10
-20
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


297073 Monthly Temperature Data (1980-96)
Monthly average temperature, deg C
40
30
20
10
0
-10
-20
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

Appendix D

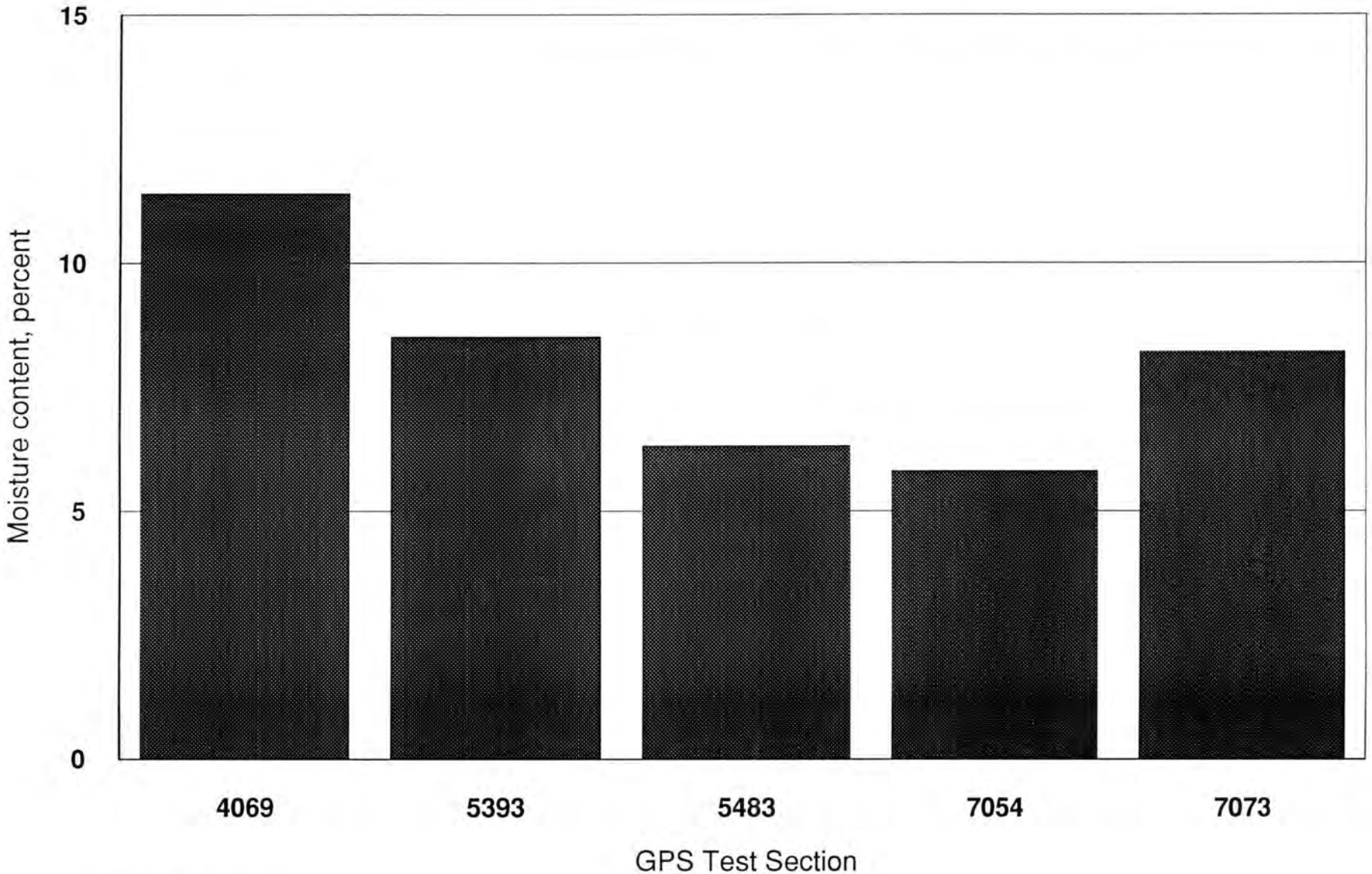
Materials testing data plots

Natural Moisture Content of Subgrade



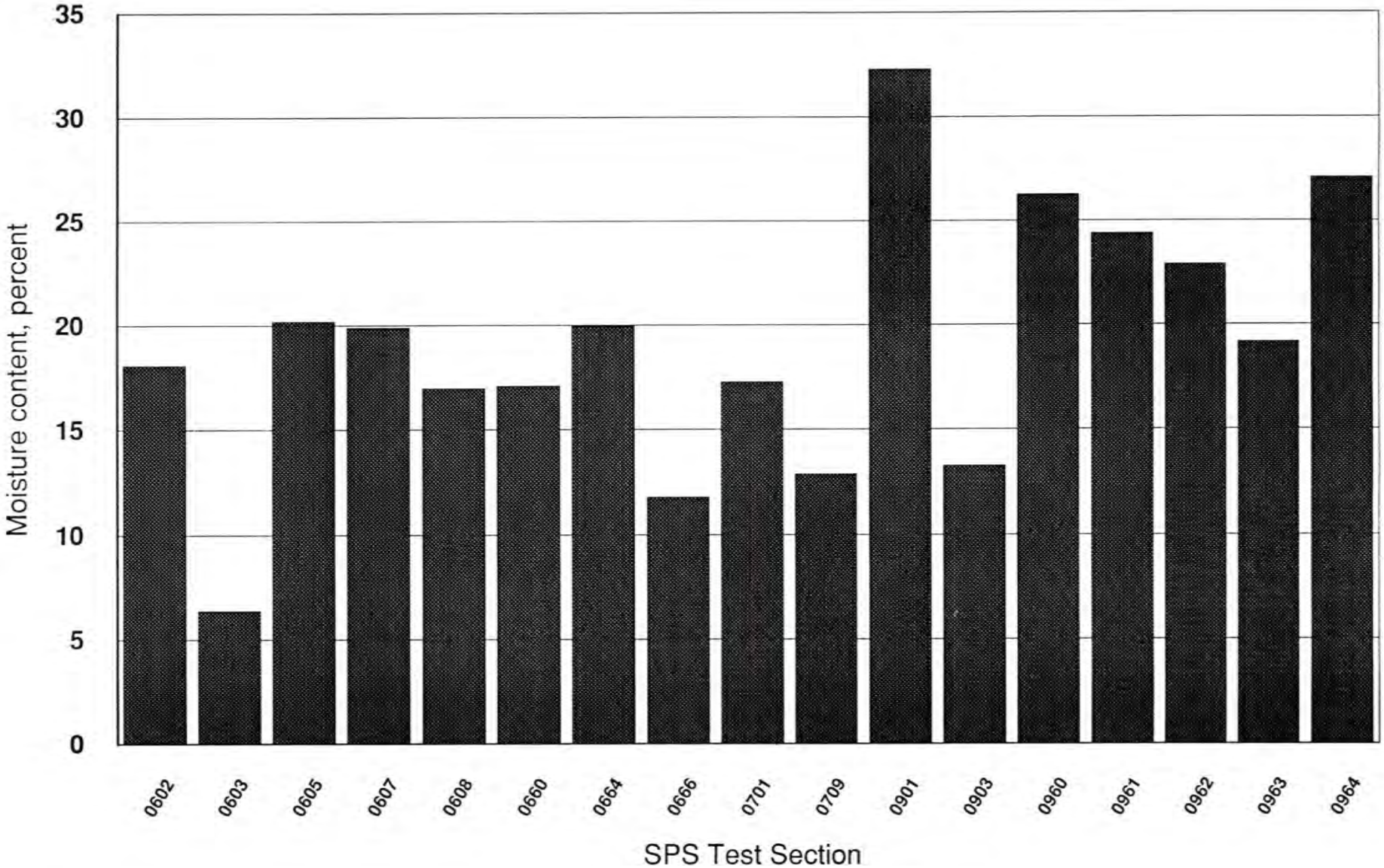
SHRP Test UG10_SS09

Natural Moisture Content of Granular Base



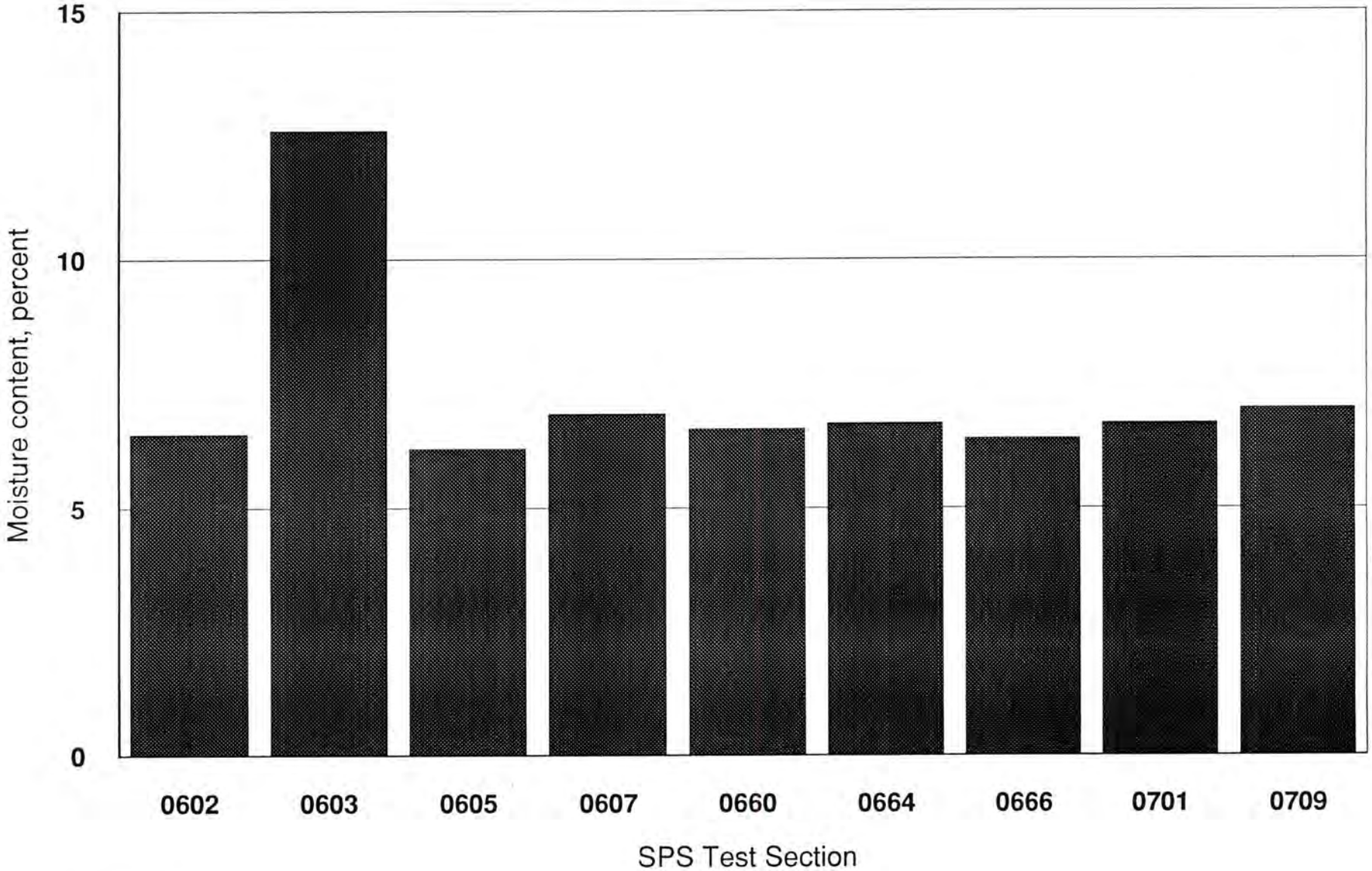
SHRP Test UG10_SS09

Natural Moisture Content of Subgrade



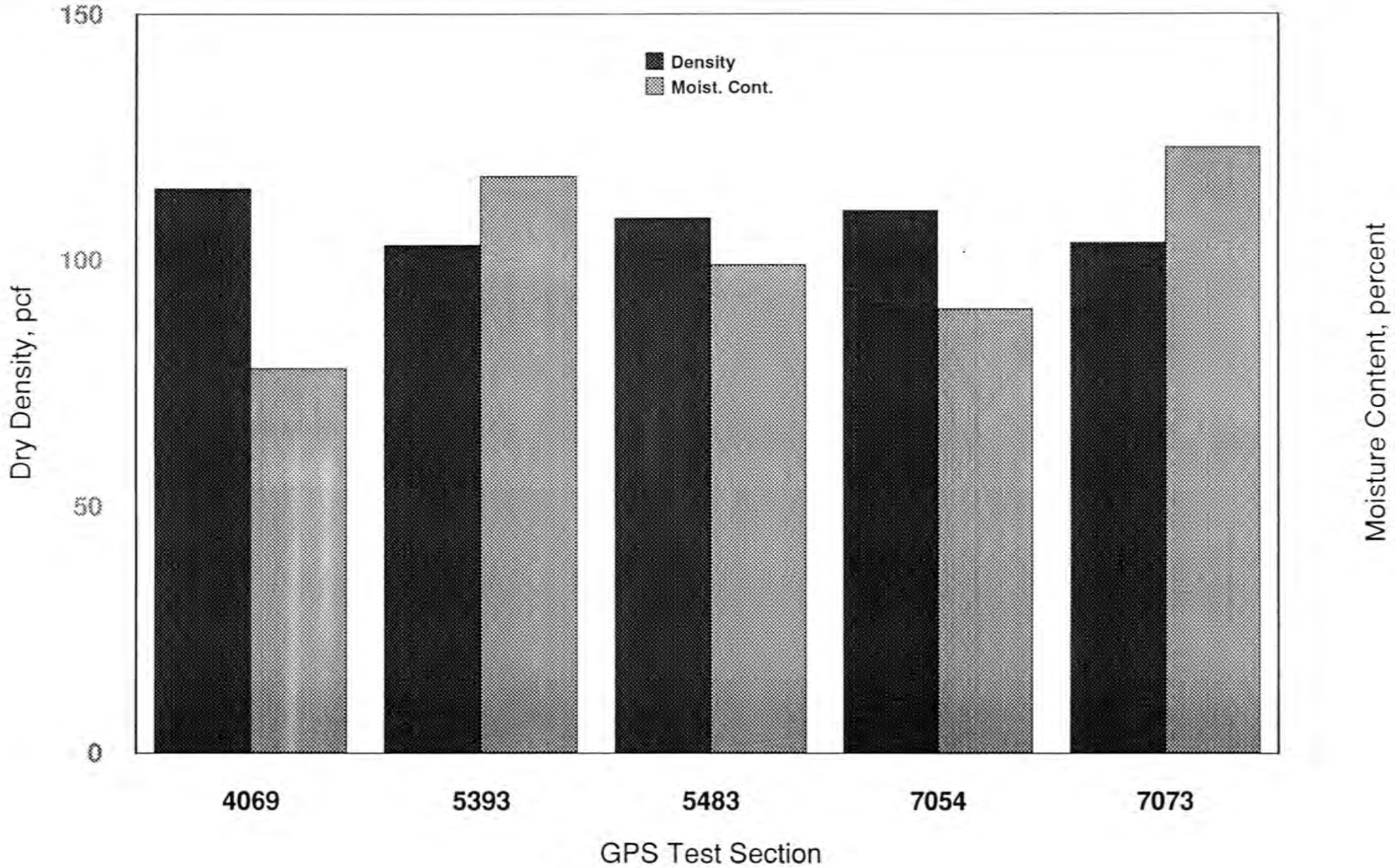
SHRP Test UG10_SS09

Natural Moisture Content of Granular Base



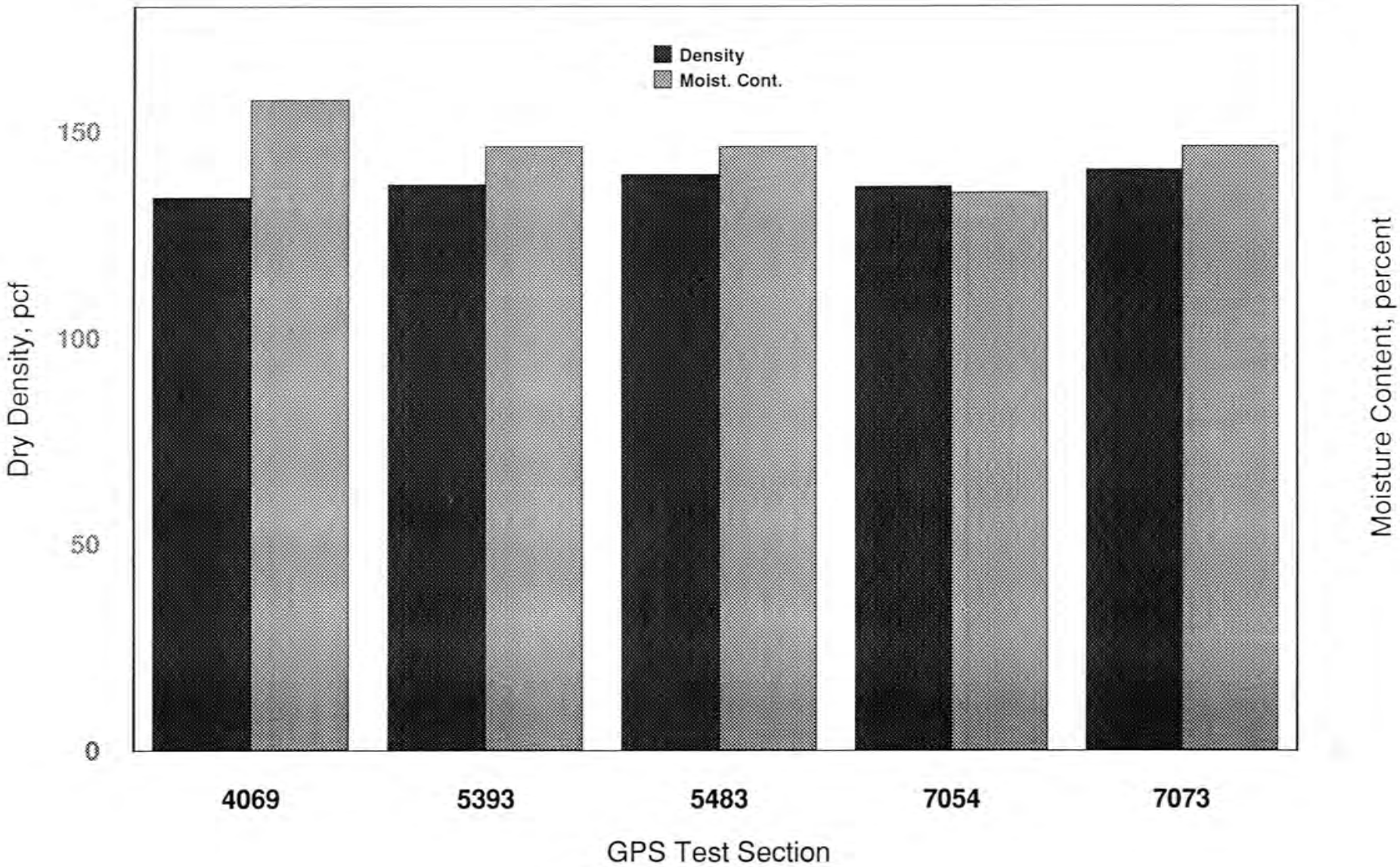
SHRP Test UG10_SS09

Optimum Moisture-Density for Subgrade



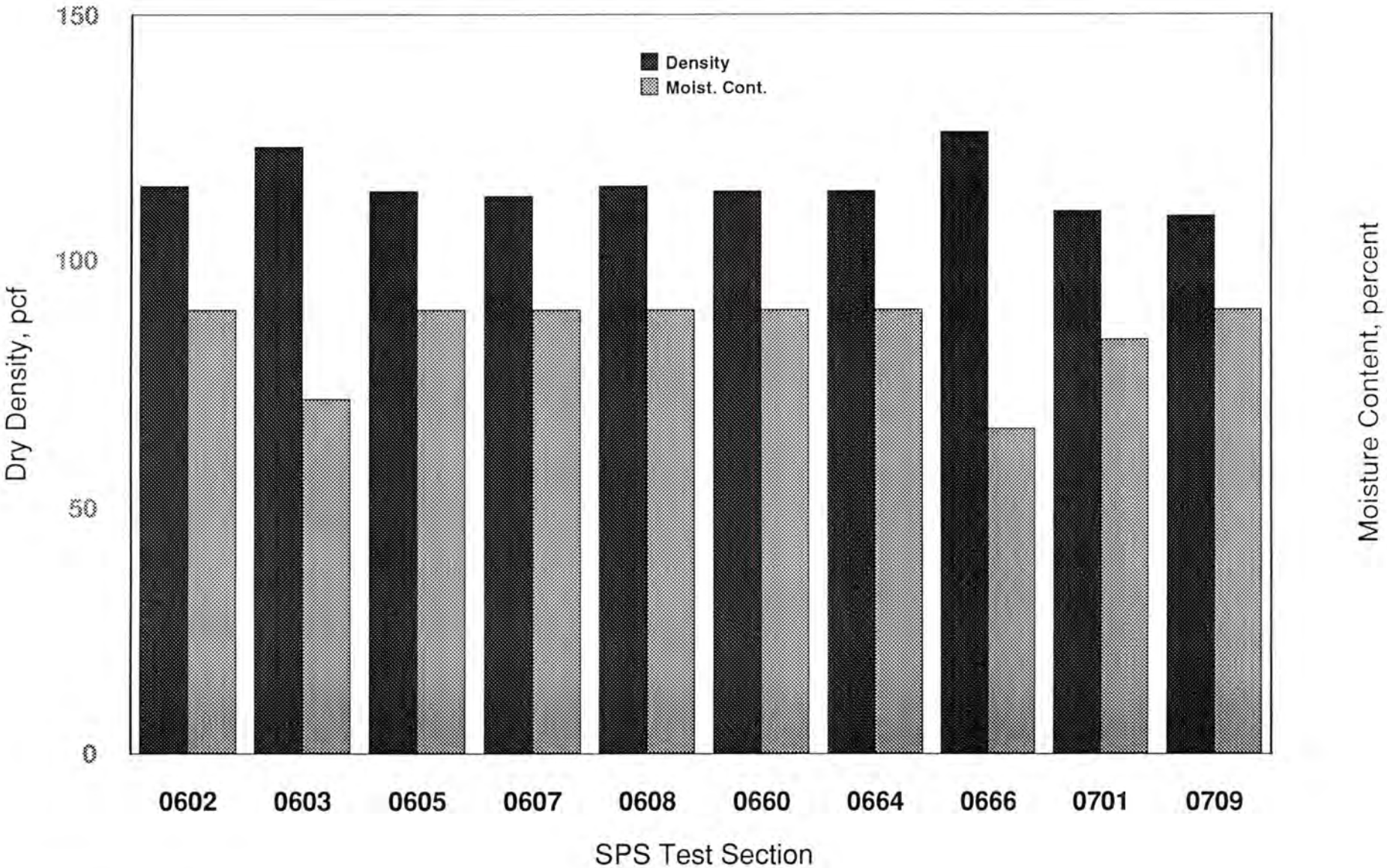
SHRP Test UG05_SS05

Optimum Moisture-Density for Granular Base



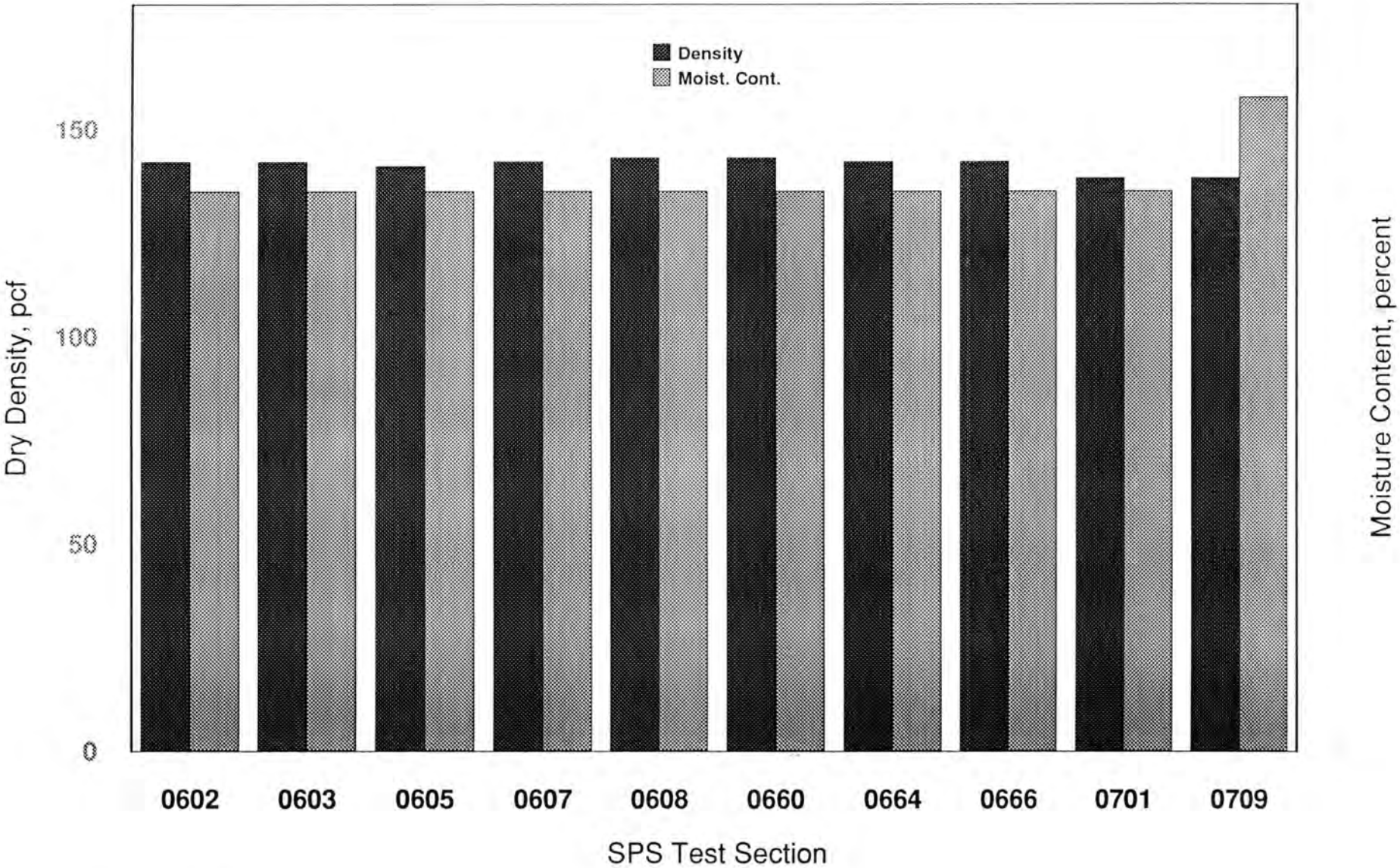
SHRP Test UG05_SS05

Optimum Moisture-Density for Subgrade



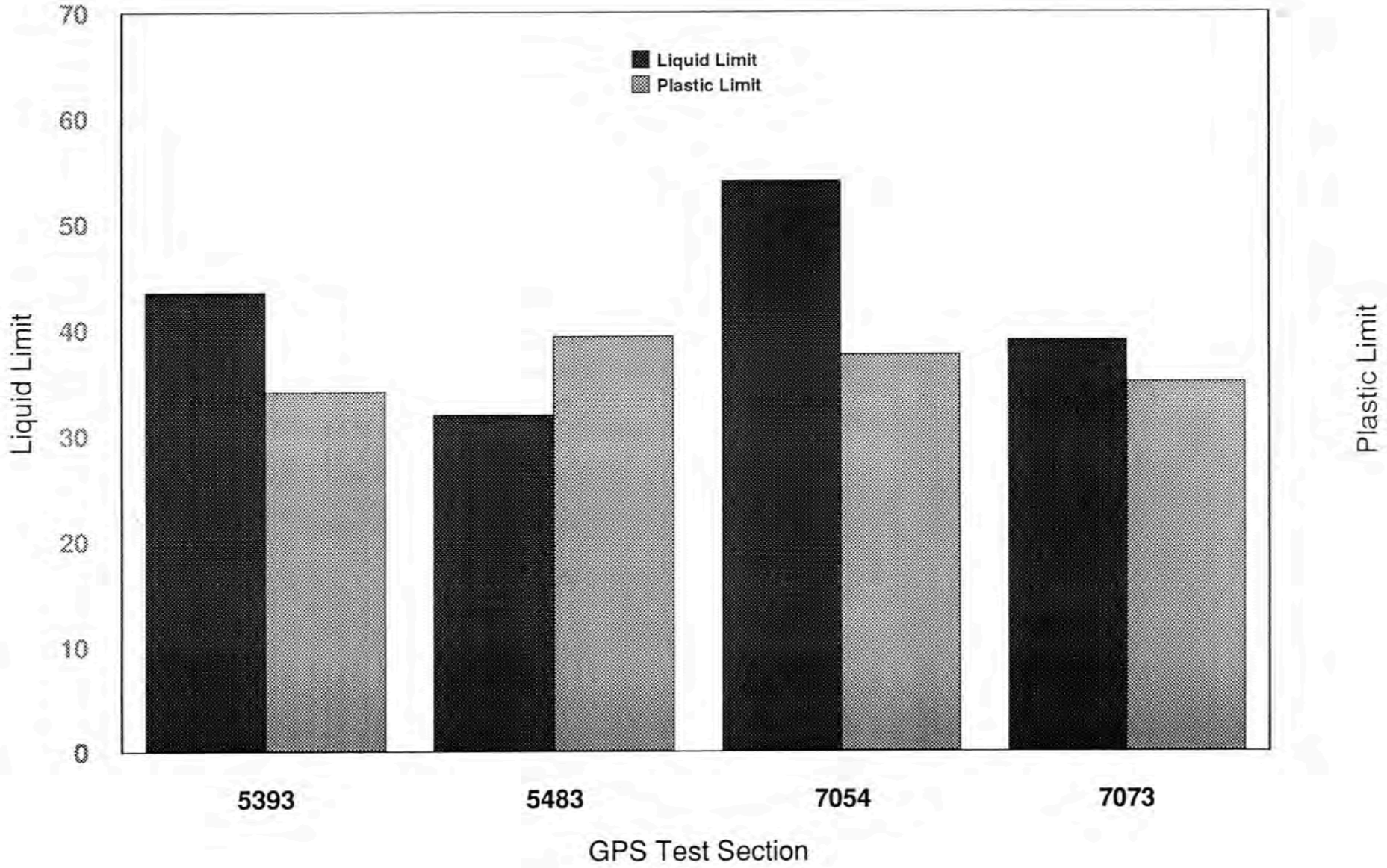
SHRP Test UG05_SS05

Optimum Moisture-Density for Granular Base



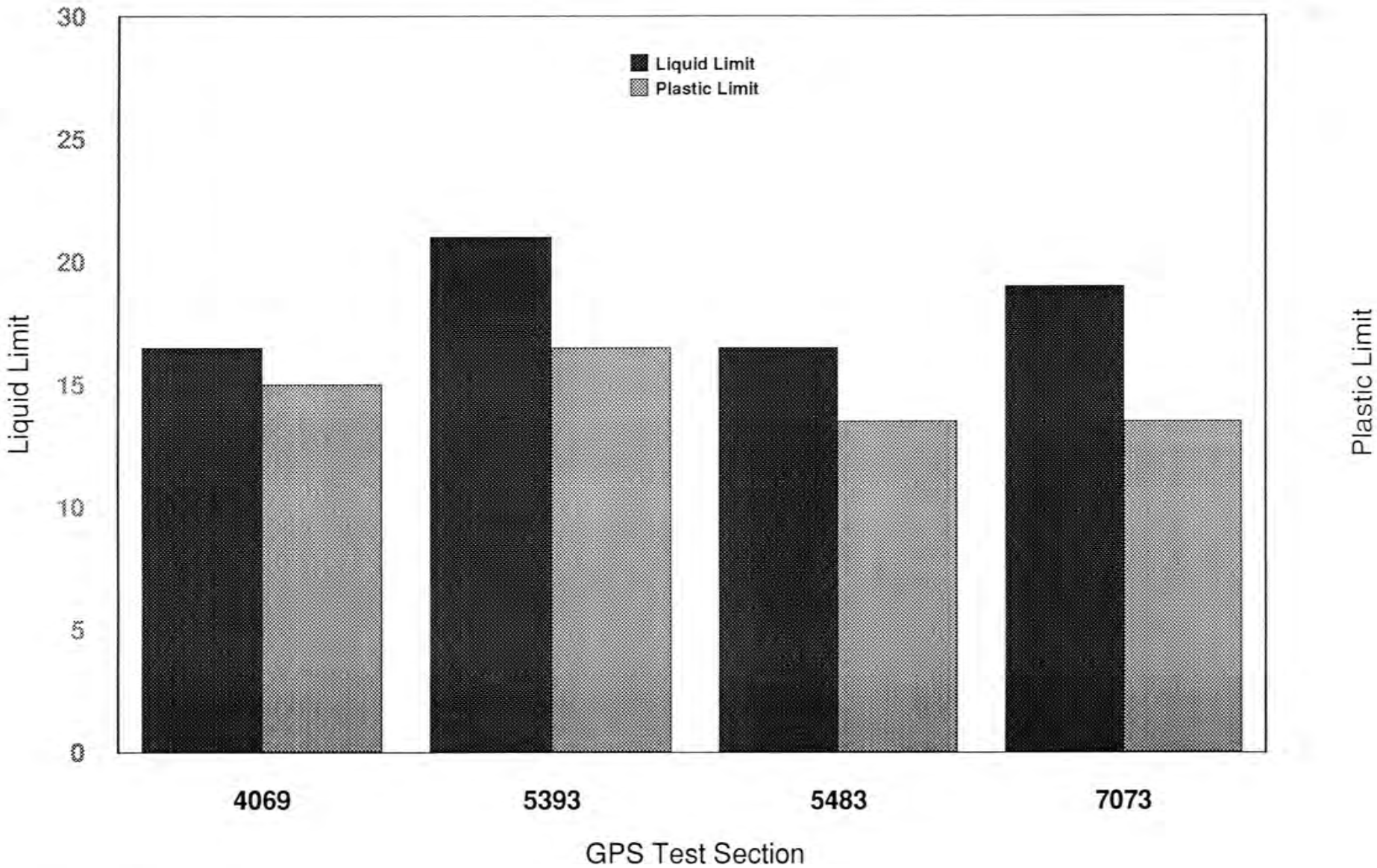
SHRP Test UG05_SS05

Atterberg Limits for Subgrade



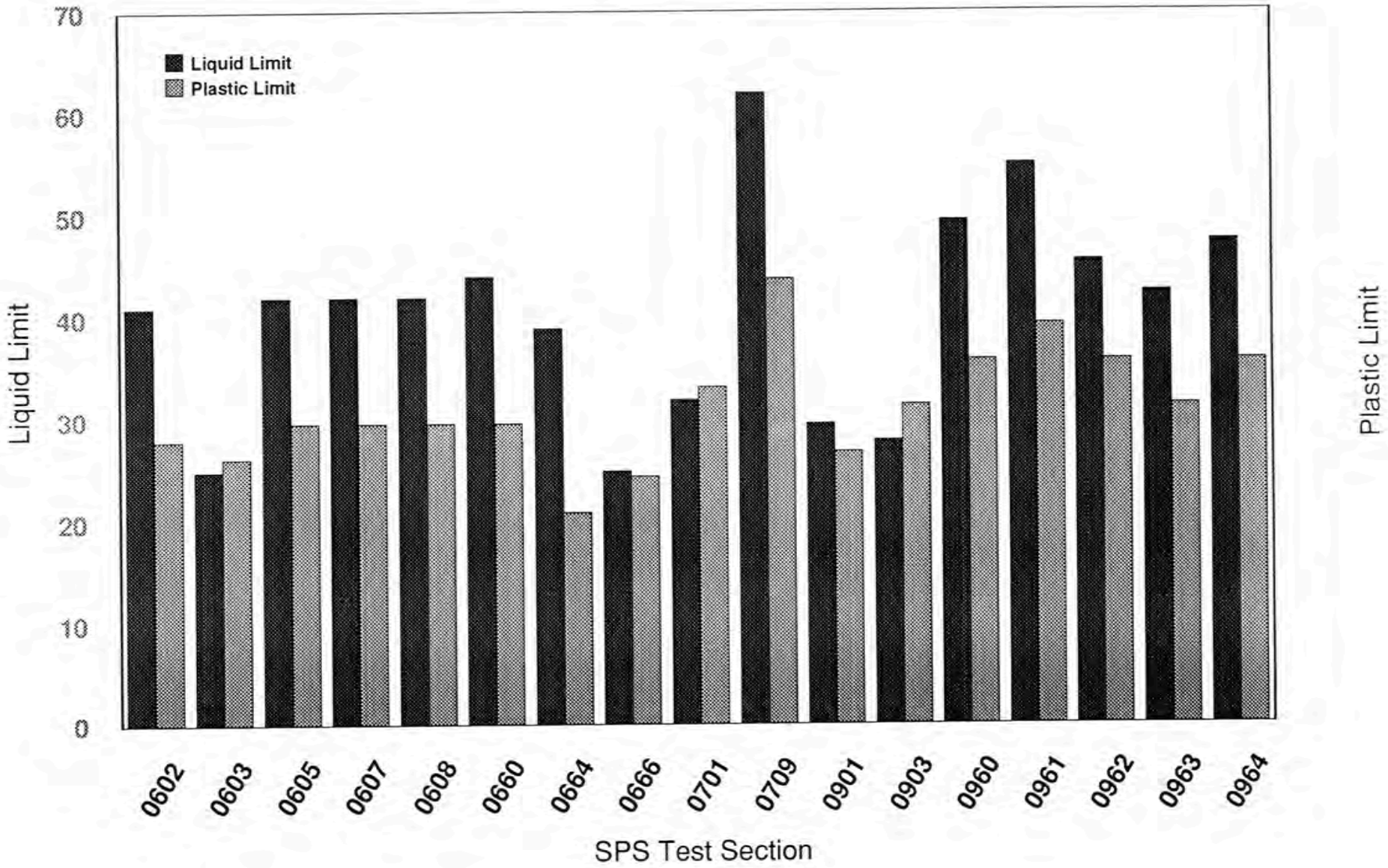
SHRP Test UG04_SS03

Atterberg Limits for Granular Base



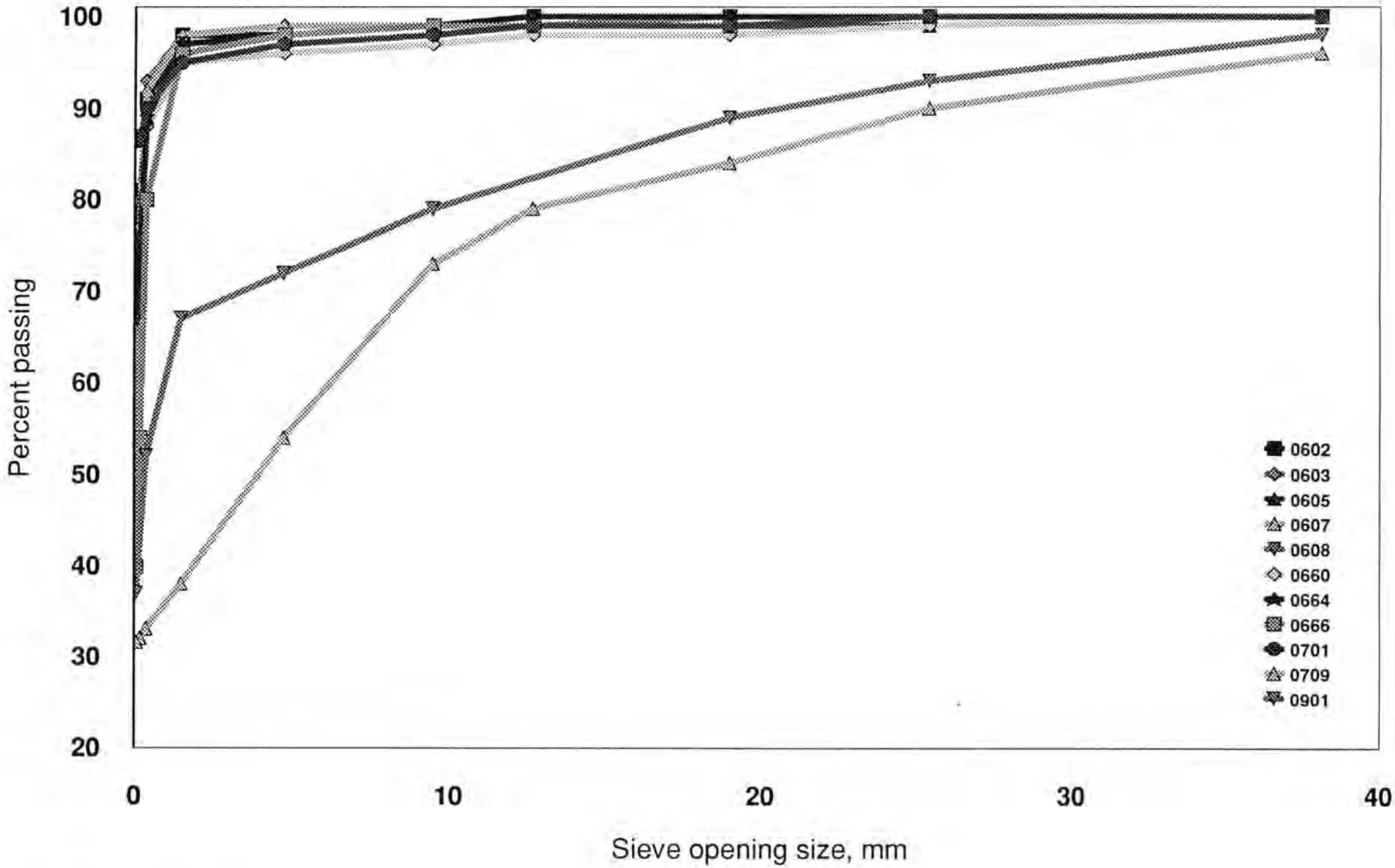
SHRP Test UG04_SS03

Atterberg Limits for Subgrade



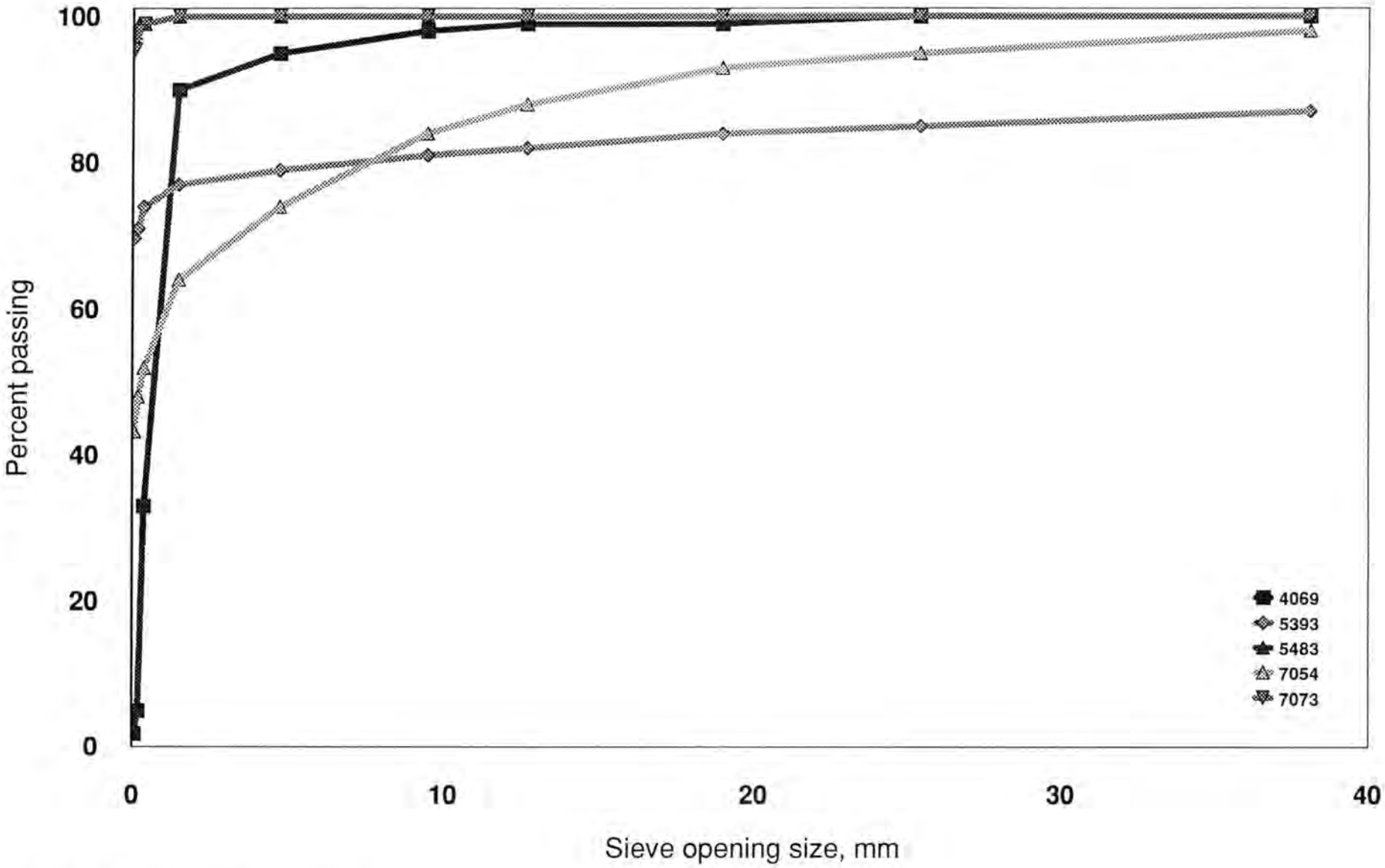
SHRP Test UG04_SS03

Subgrade Gradation for SPS Sites



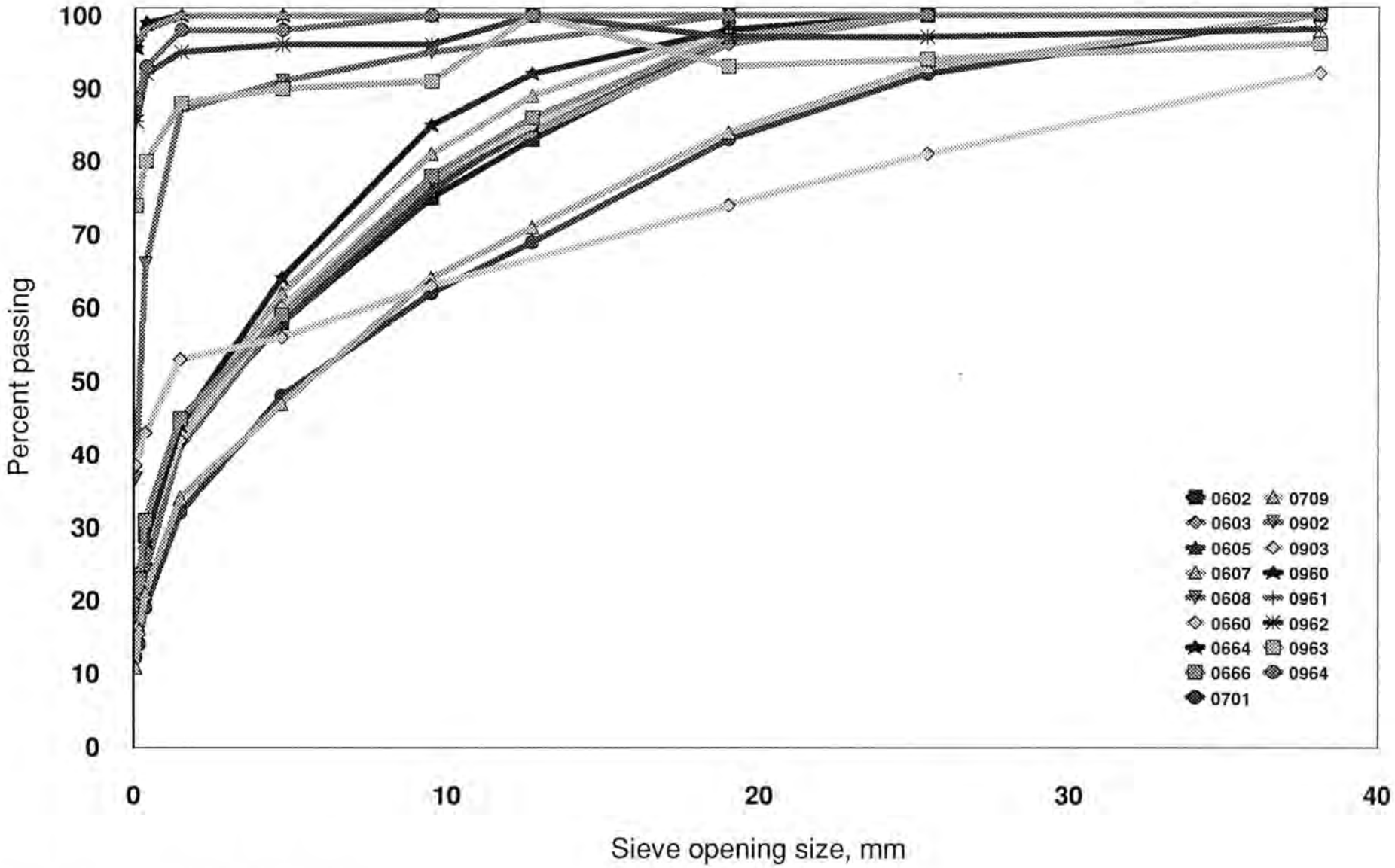
SHRP Test SS01_UG01_UG02

Subgrade Gradation for GPS Sites



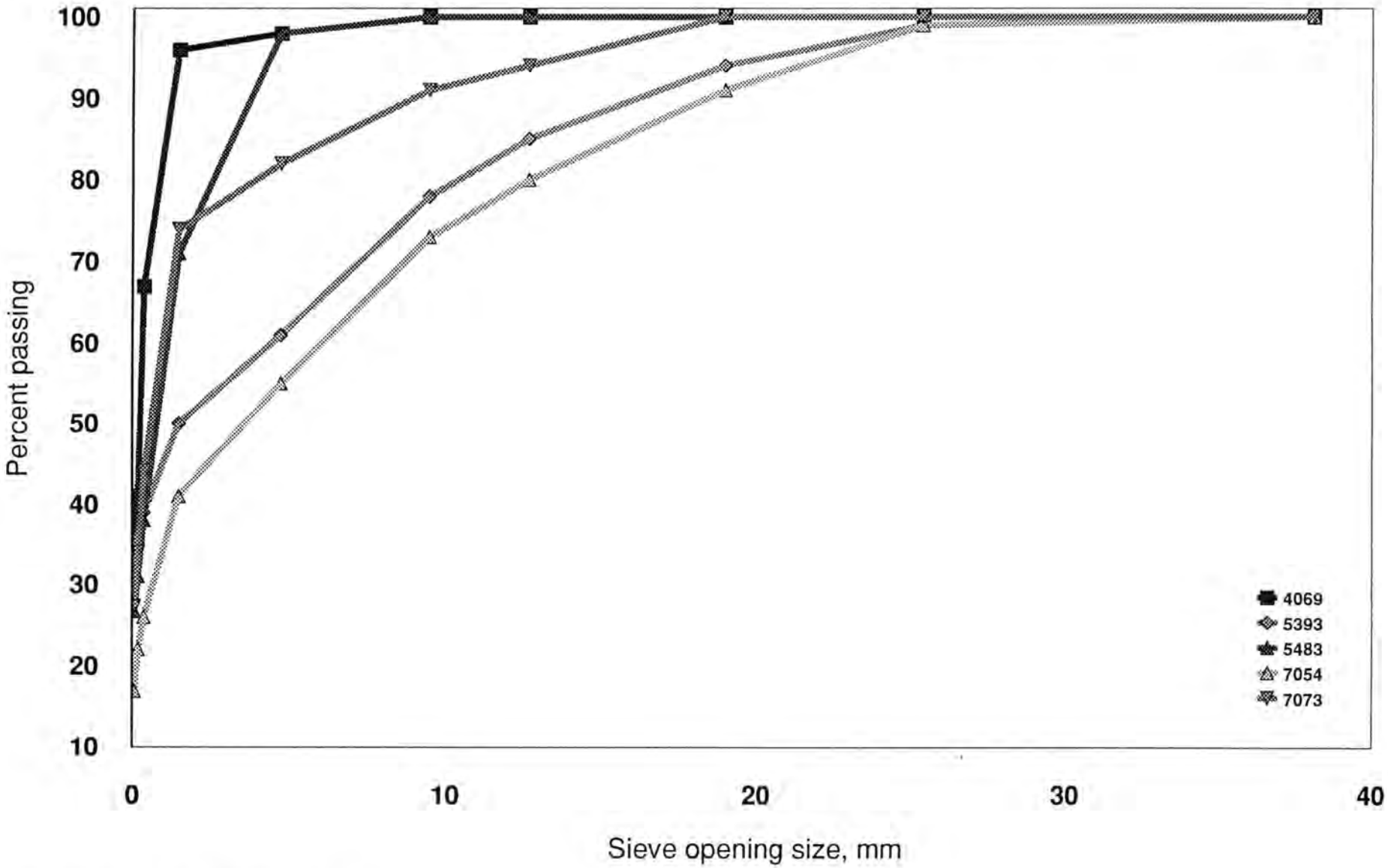
SHRP Test SS01_UG01_UG02

Base Layer Gradation for SPS Sites



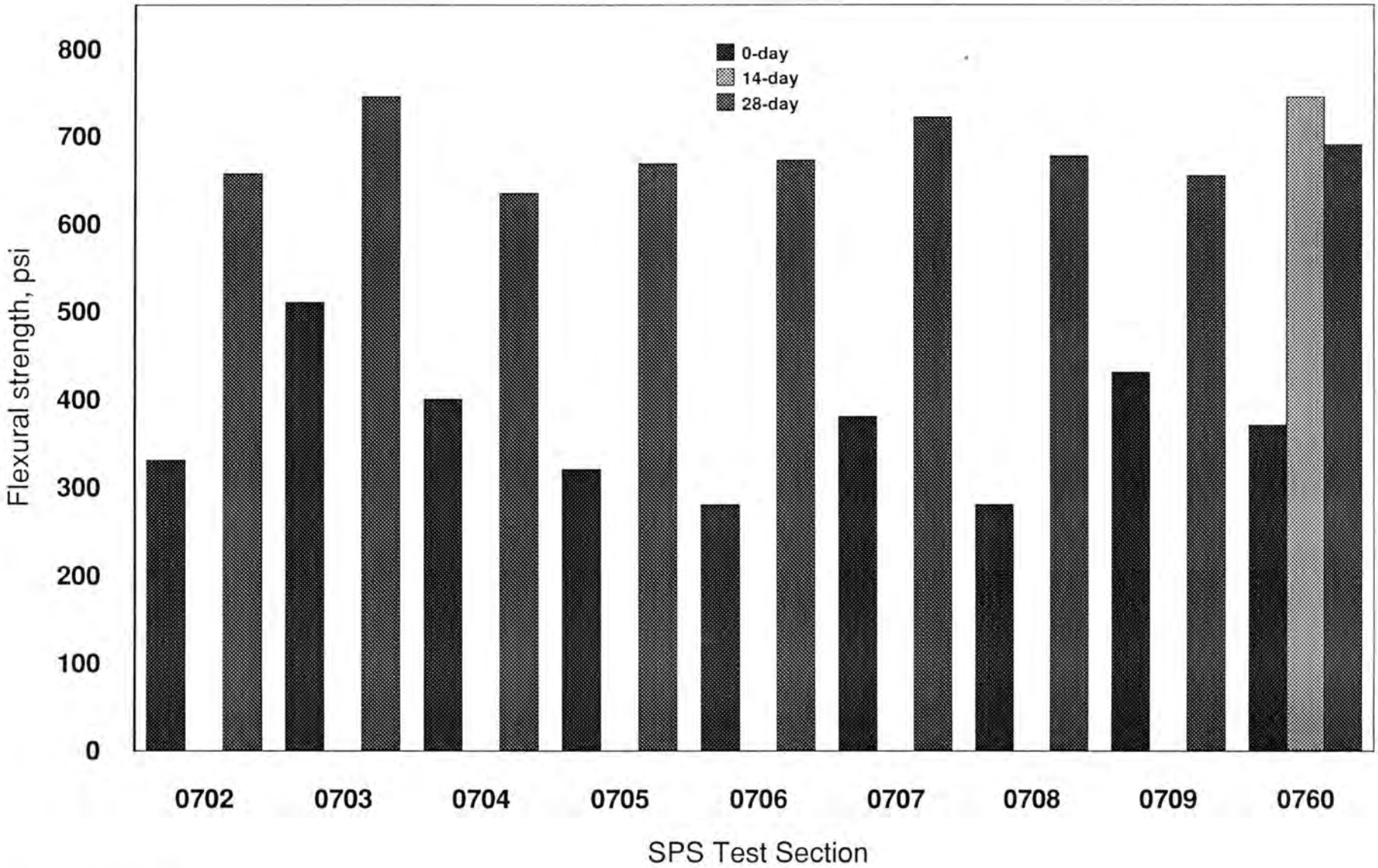
SHRP Test SS01_UG01_UG02

Base Layer Gradation for GPS Sites



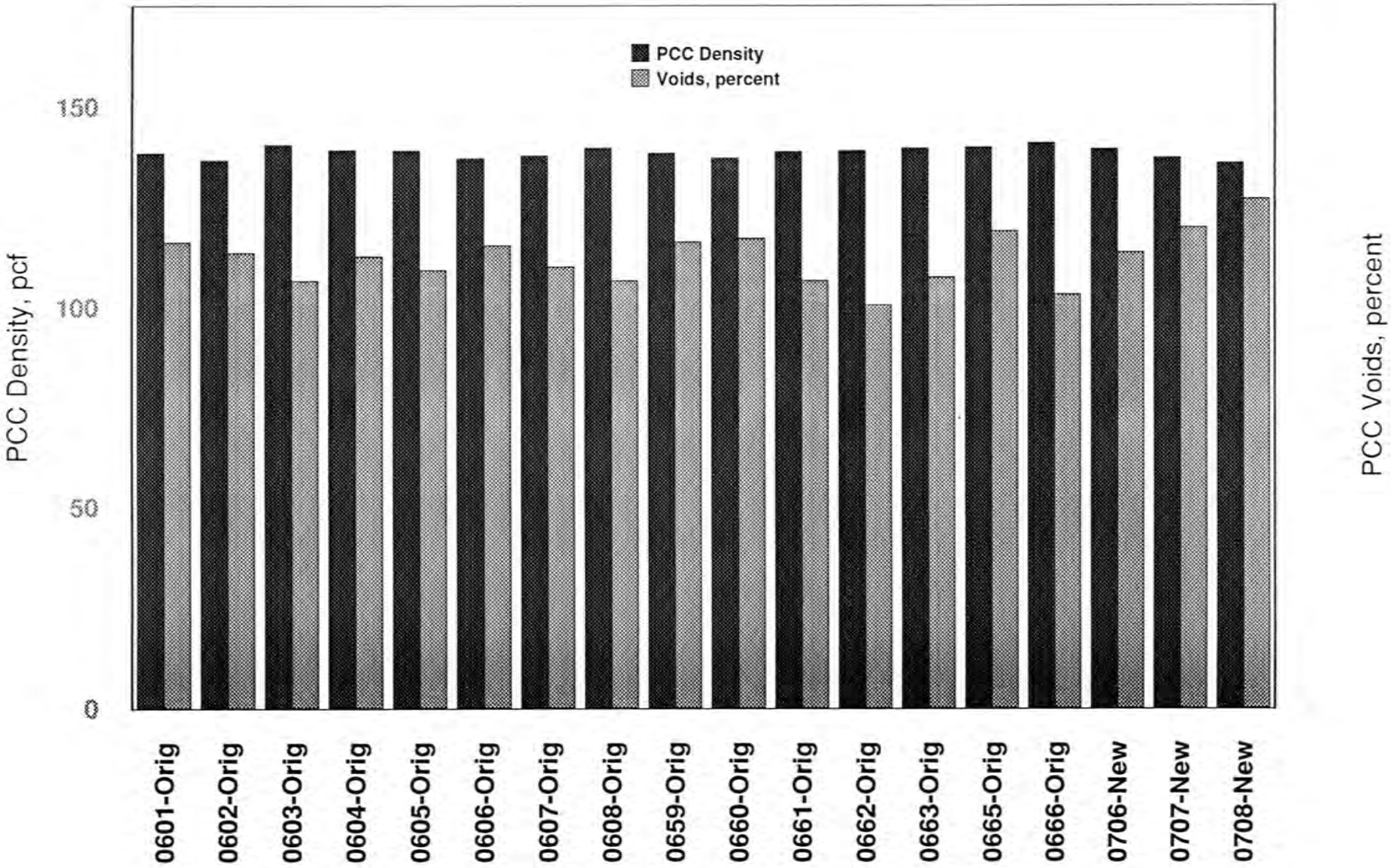
SHRP Test SS01_UG01_UG02

Flexural Strength for PCC Overlay



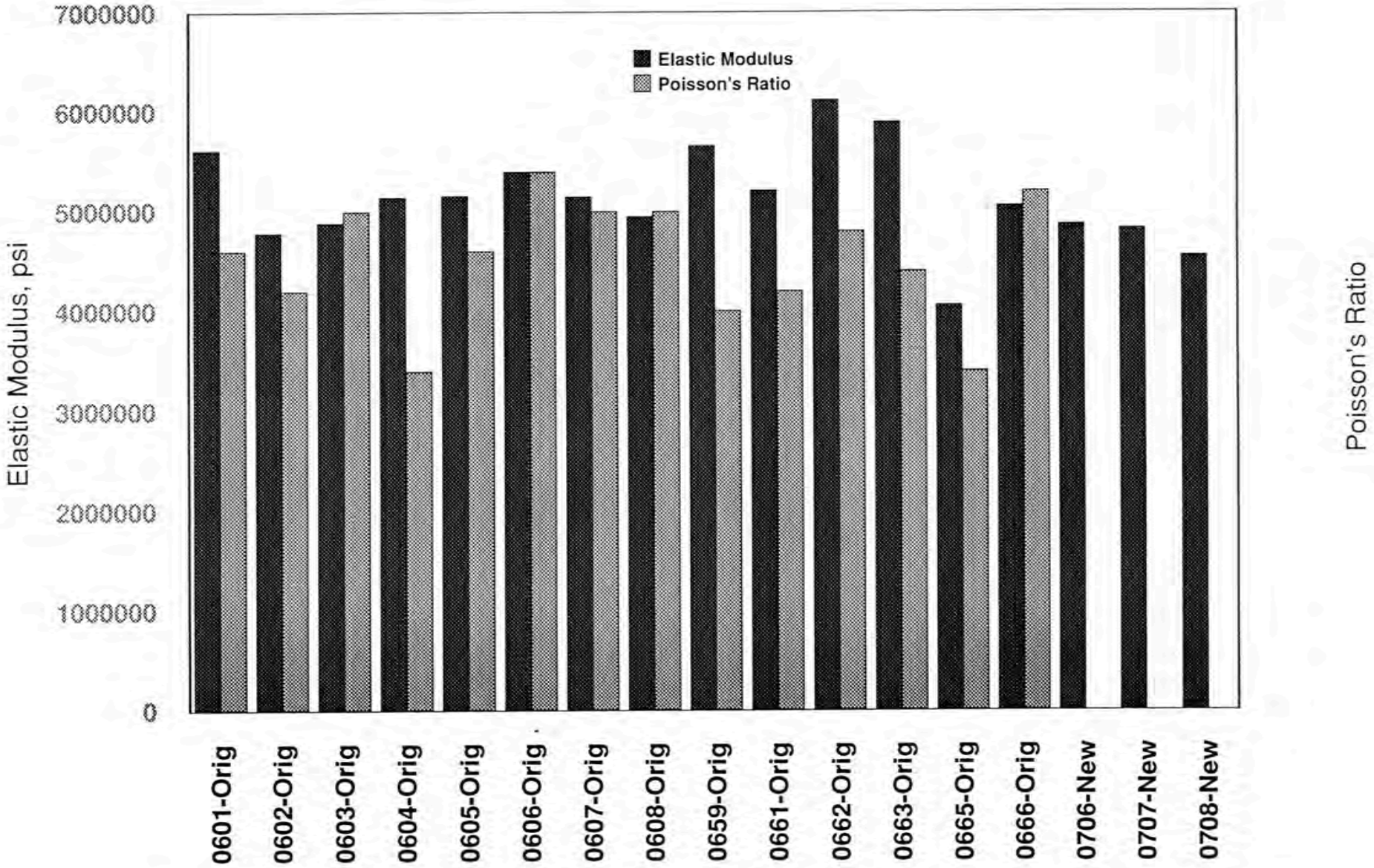
SHRP Test PC09

Density and Percent Voids for PCC Layers



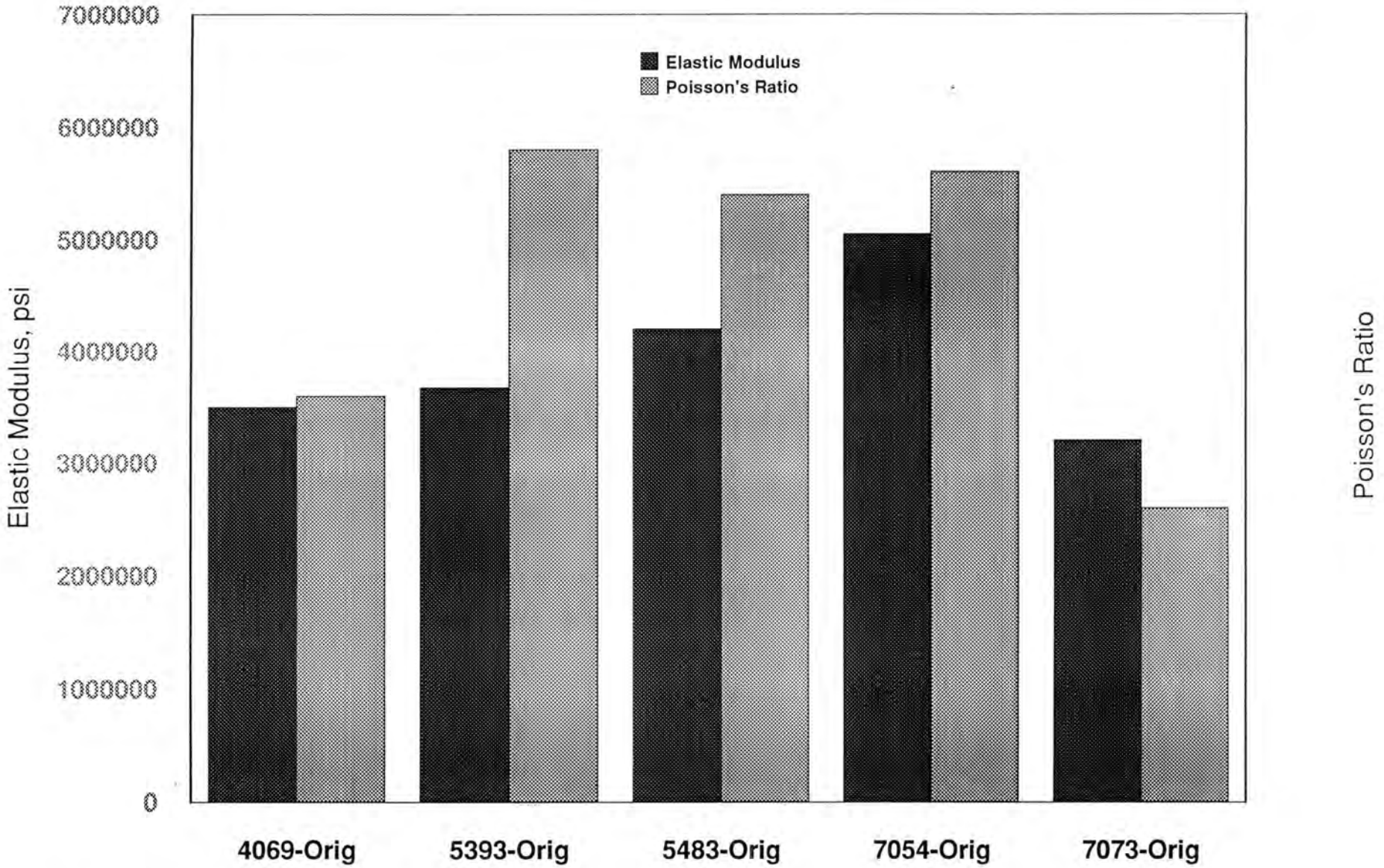
SHRP Test PC05

Elastic Modulus and Poisson's Ration for SPS PCC Layers



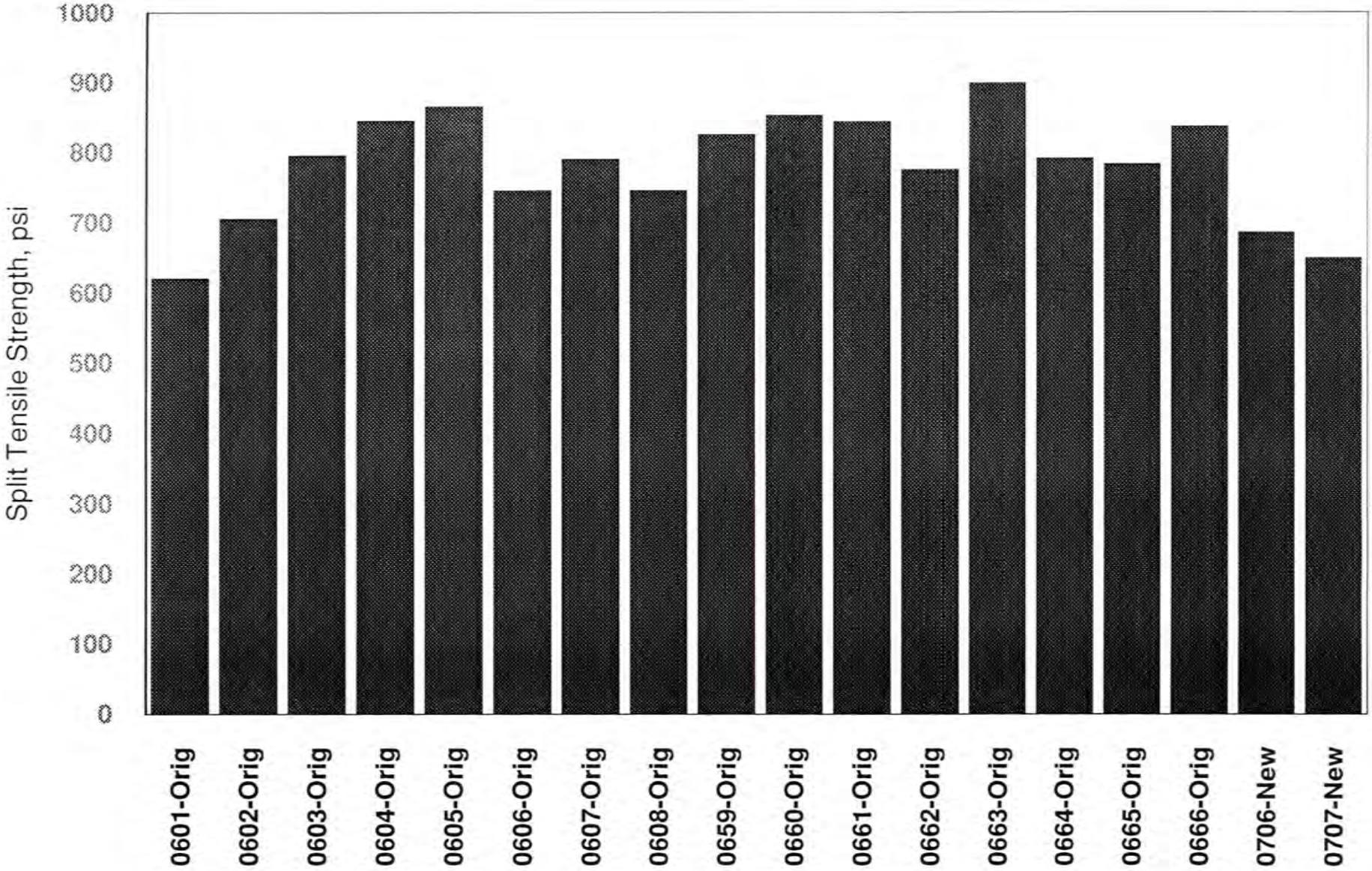
SHRP Test PC04

Elastic Modulus and Poisson's Ration for GPS PCC Layers



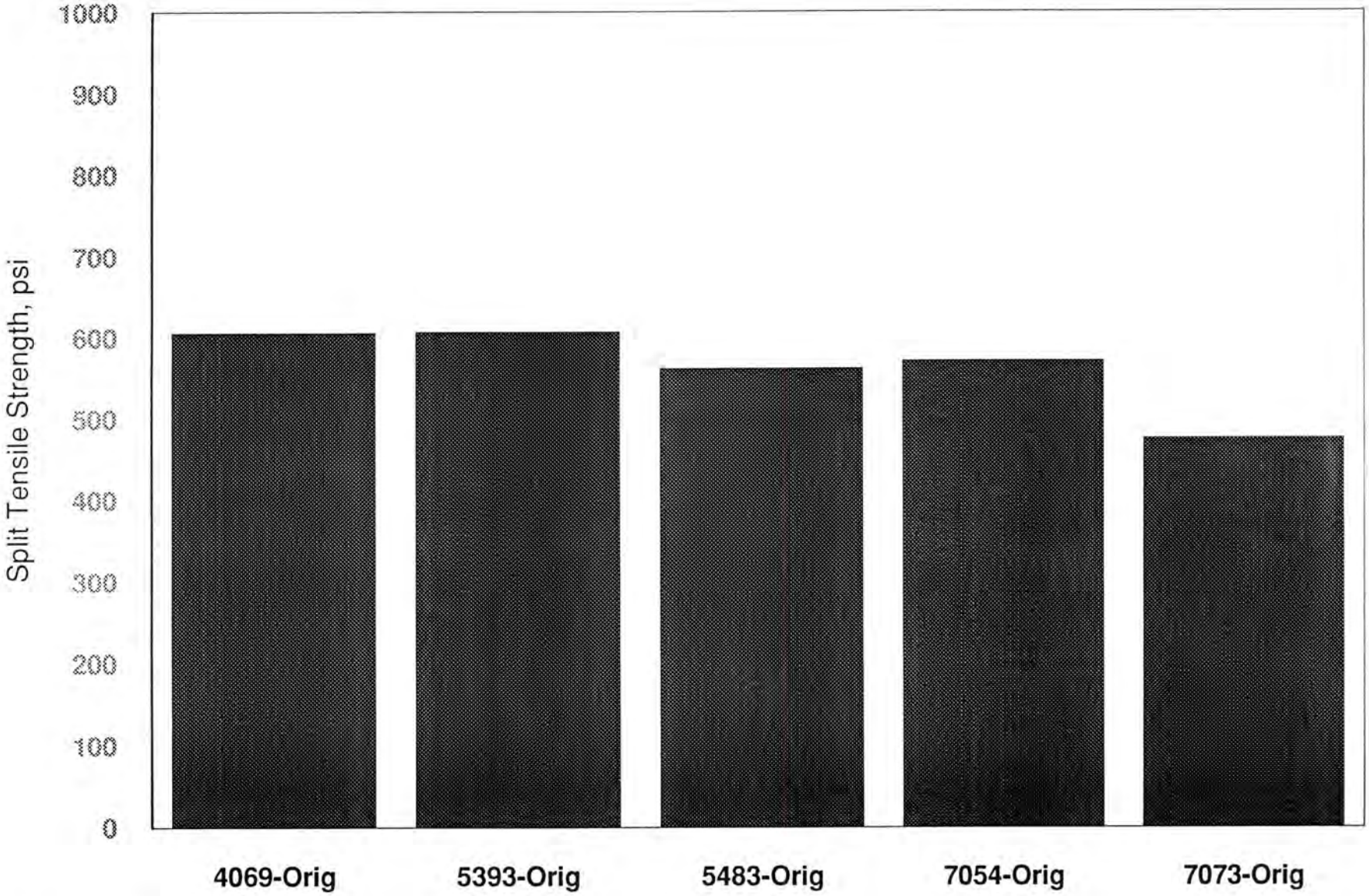
SHRP Test PC04

Split Tensile Strength for SPS PCC Layers



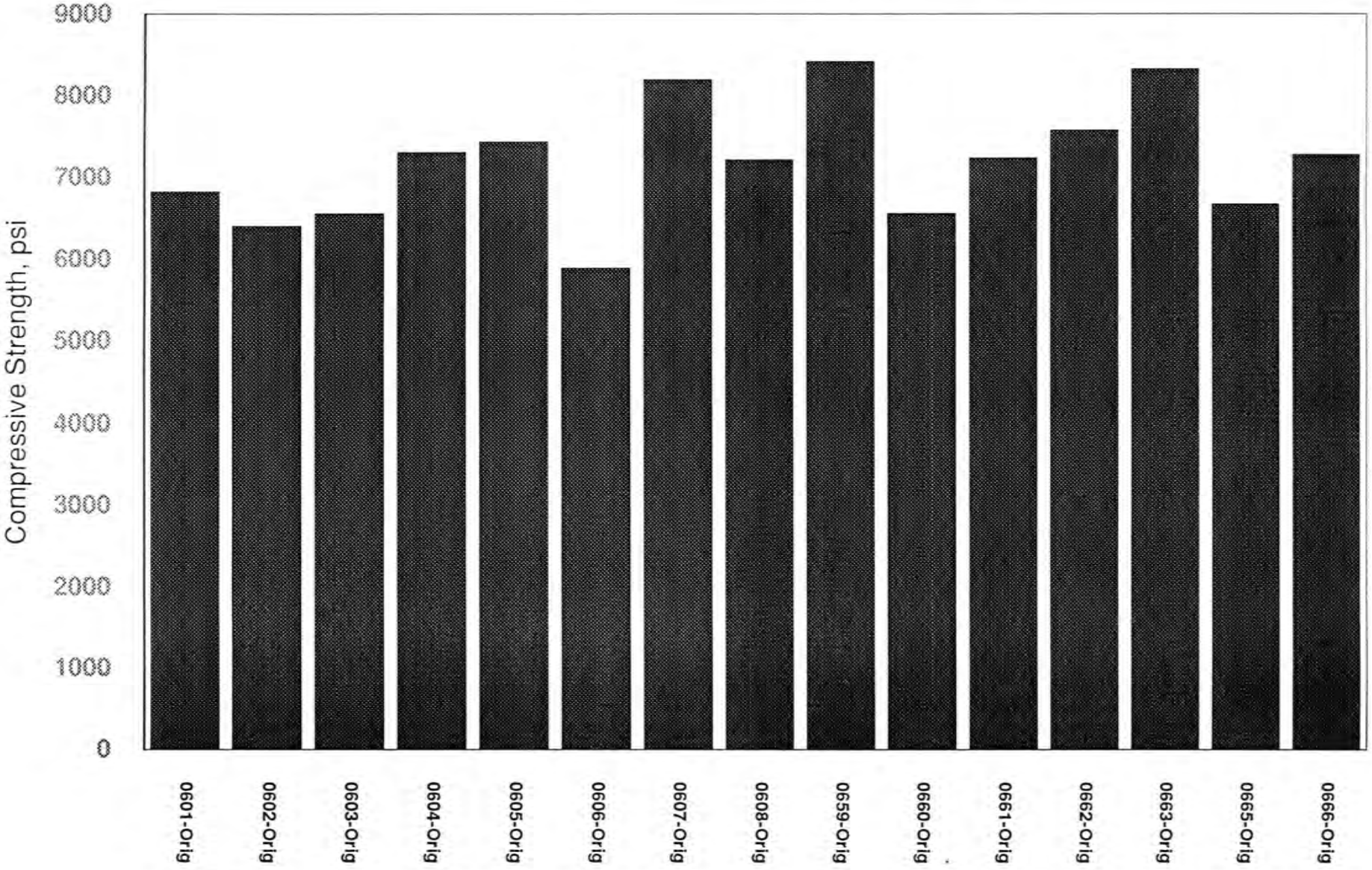
SHRP Test PC02

Split Tensile Strength for GPS PCC Layers



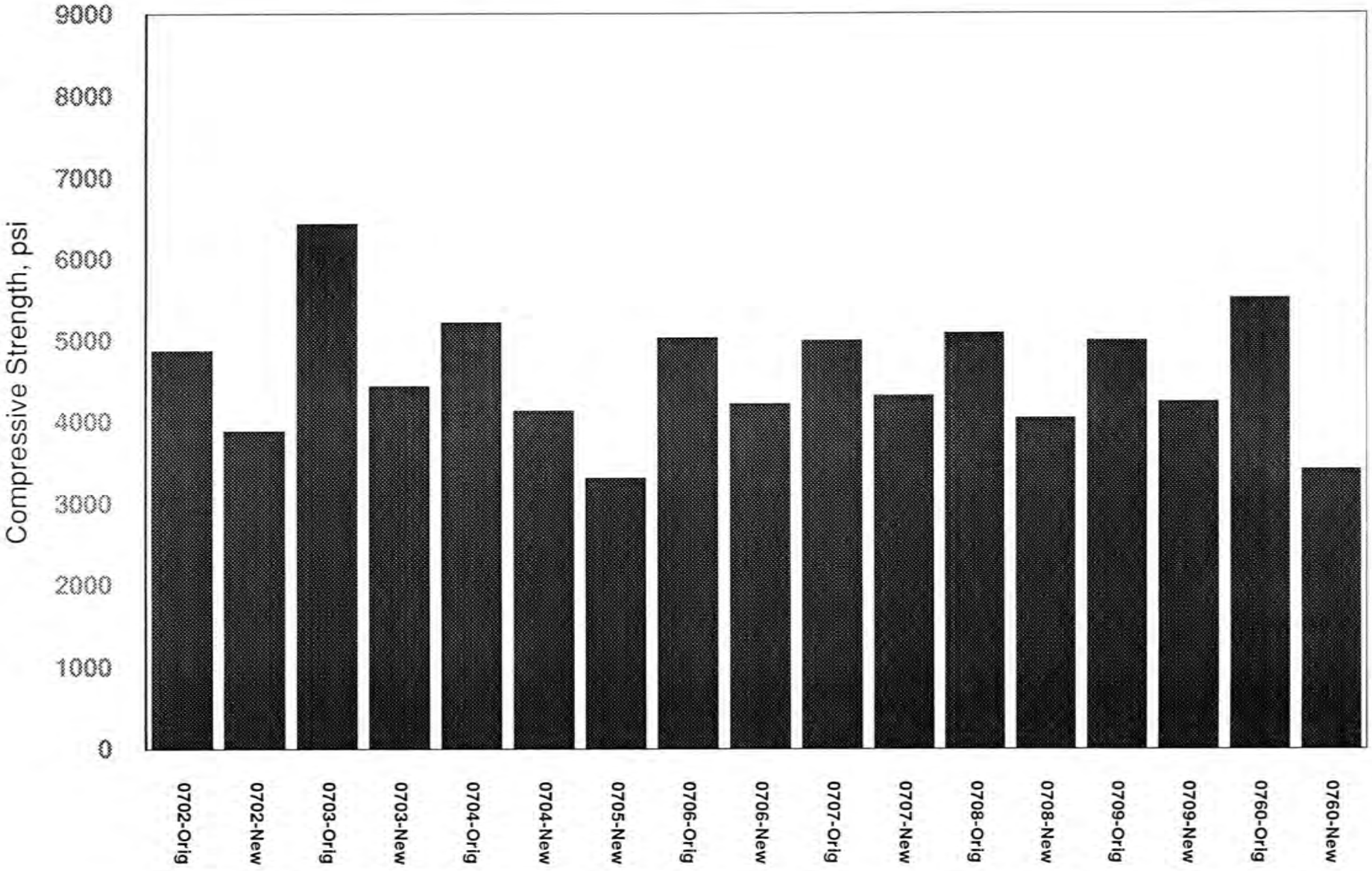
SHRP Test PC02

Compressive Strength for SPS-6 PCC Layers



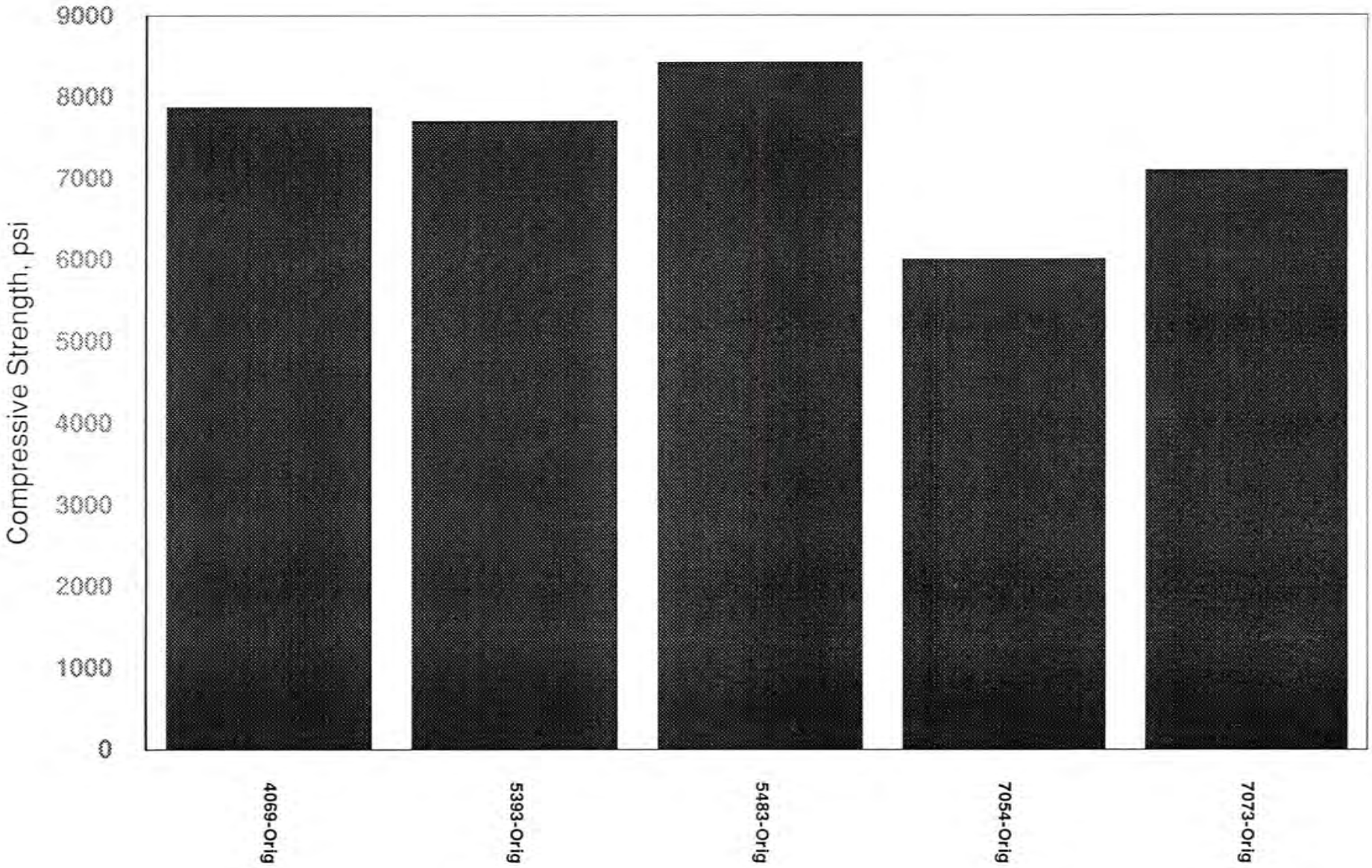
SHRP Test PC01

Compressive Strength for SPS-7 PCC Layers



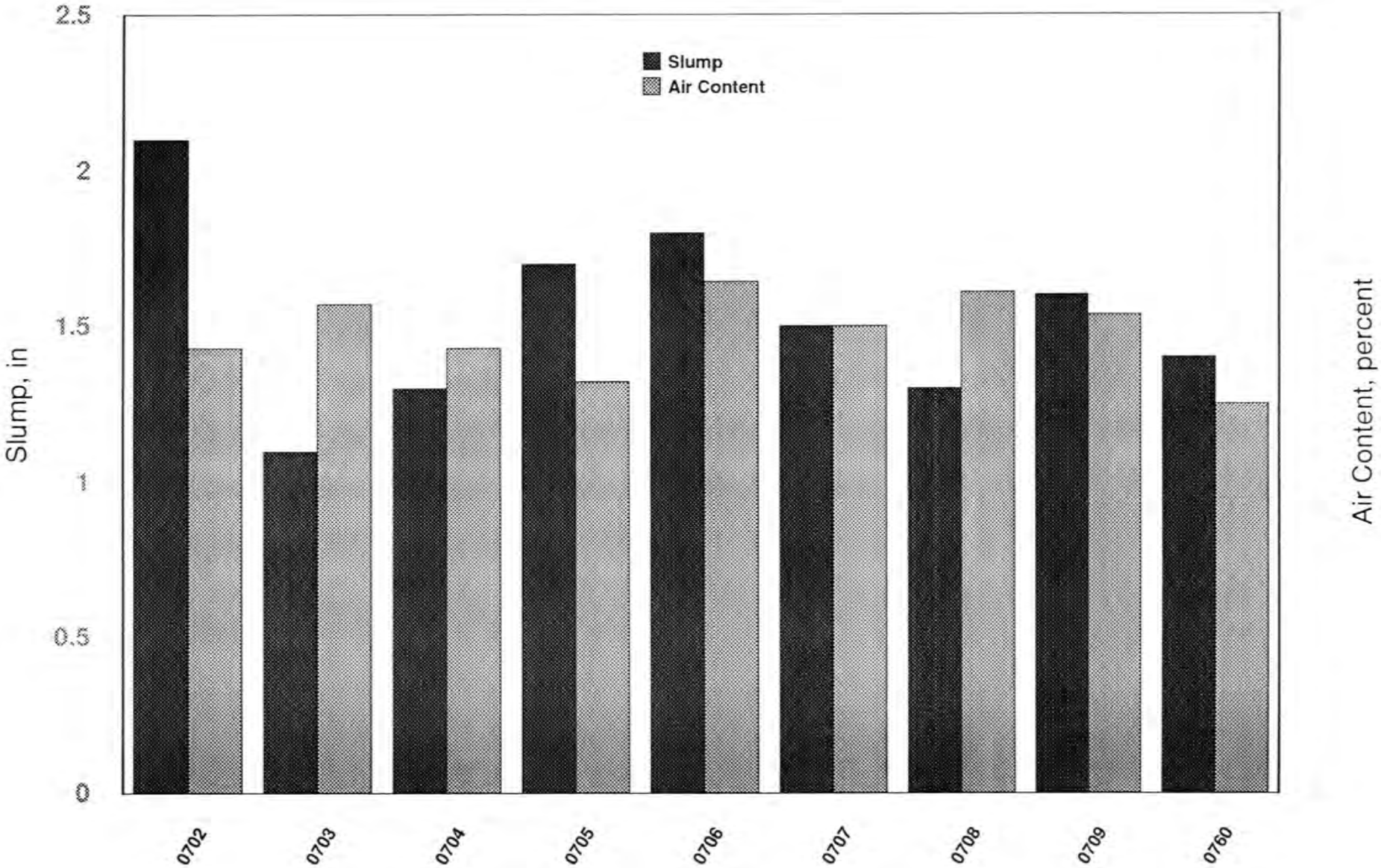
SHRP Test PC01

Compressive Strength for GPS PCC Layers



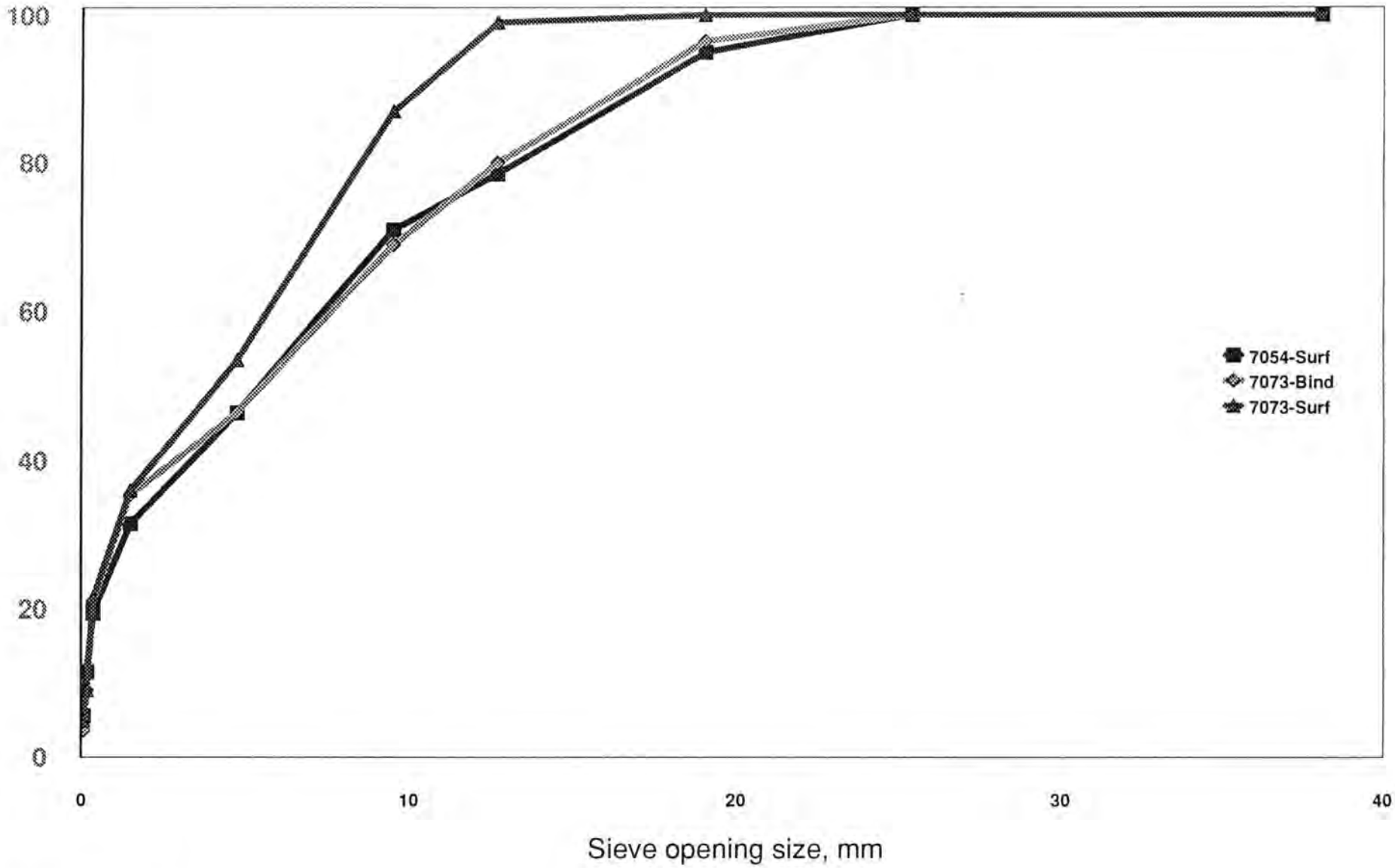
SHRP Test PC01

Slump and Air Content for Fresh PCC Materials



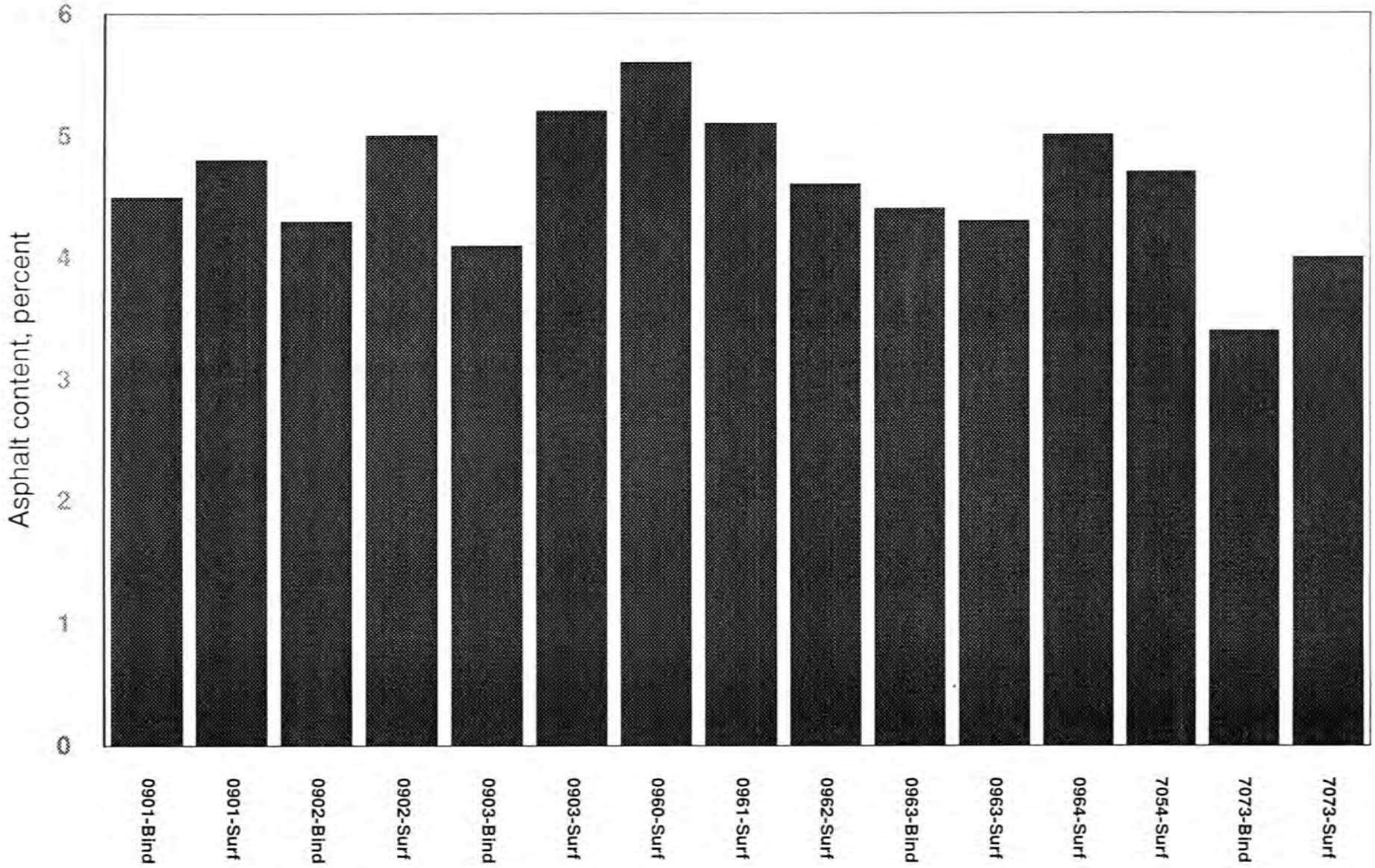
SHRP Table FRESH_PCC

Aggregate Gradation for HMAC layers



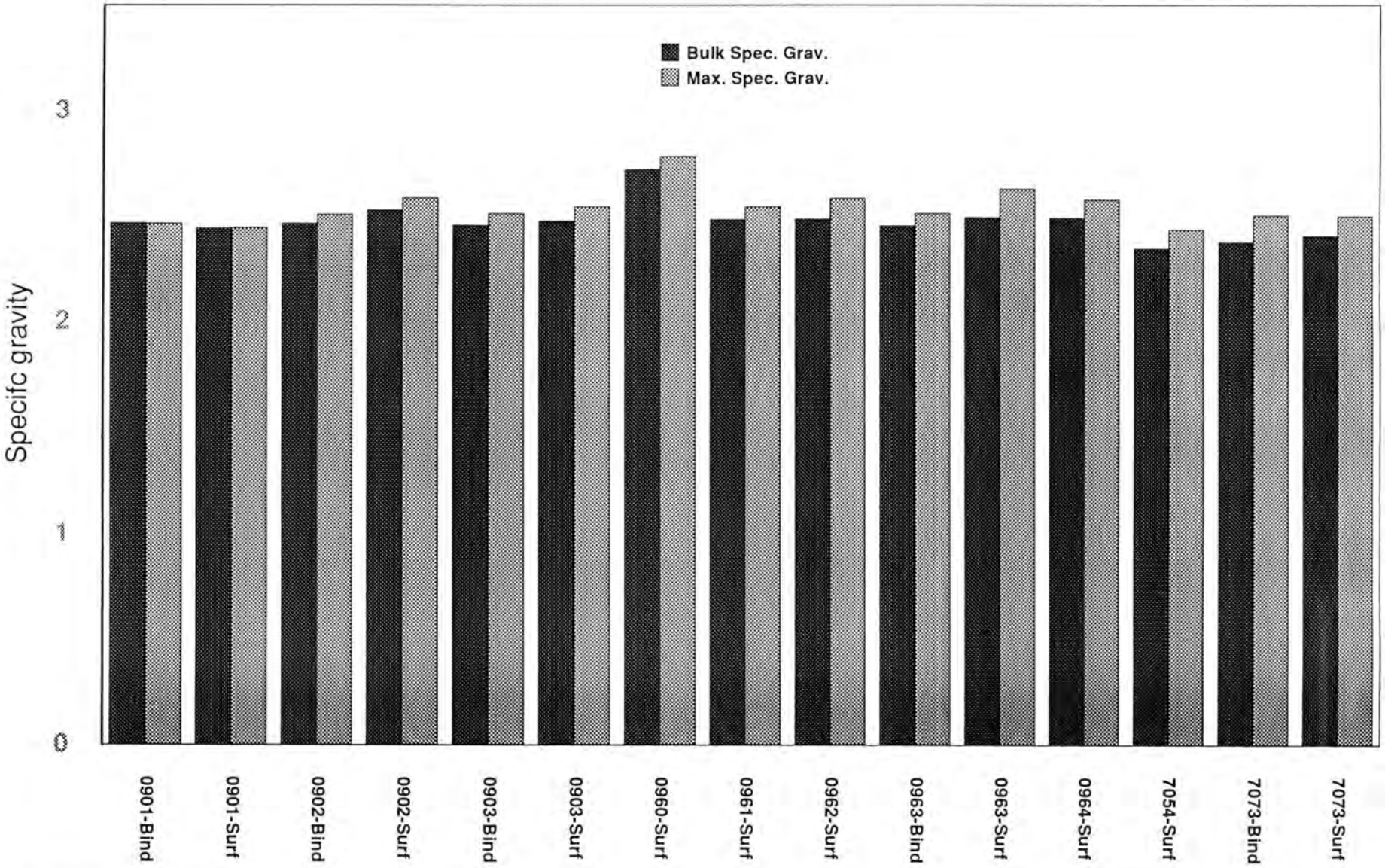
SHRP Table AG04

Mean Asphalt Content



SHRP Test AC04

Bulk and Maximum Specific Gravity

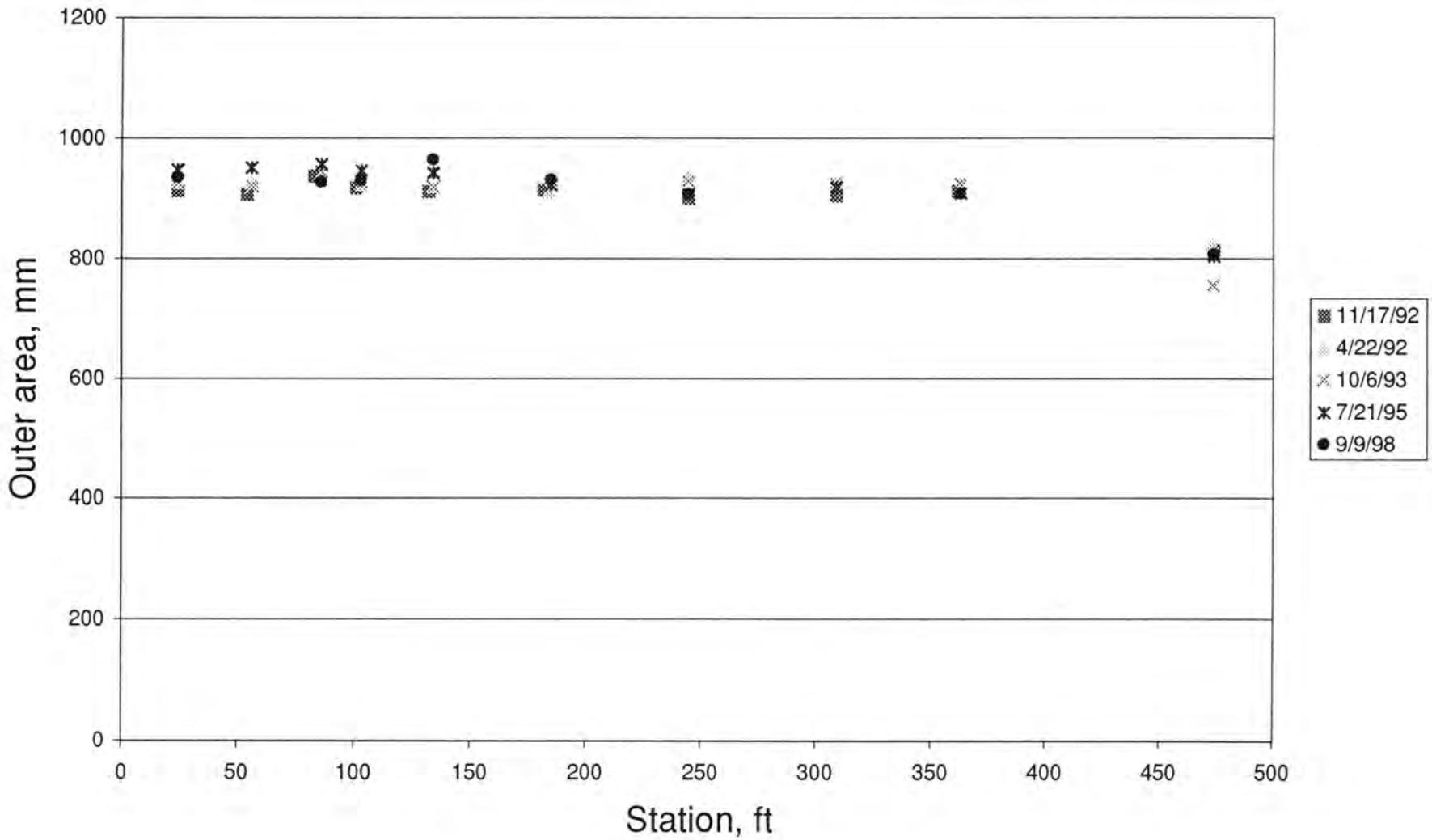


SHRP Tests AC02 and AC03

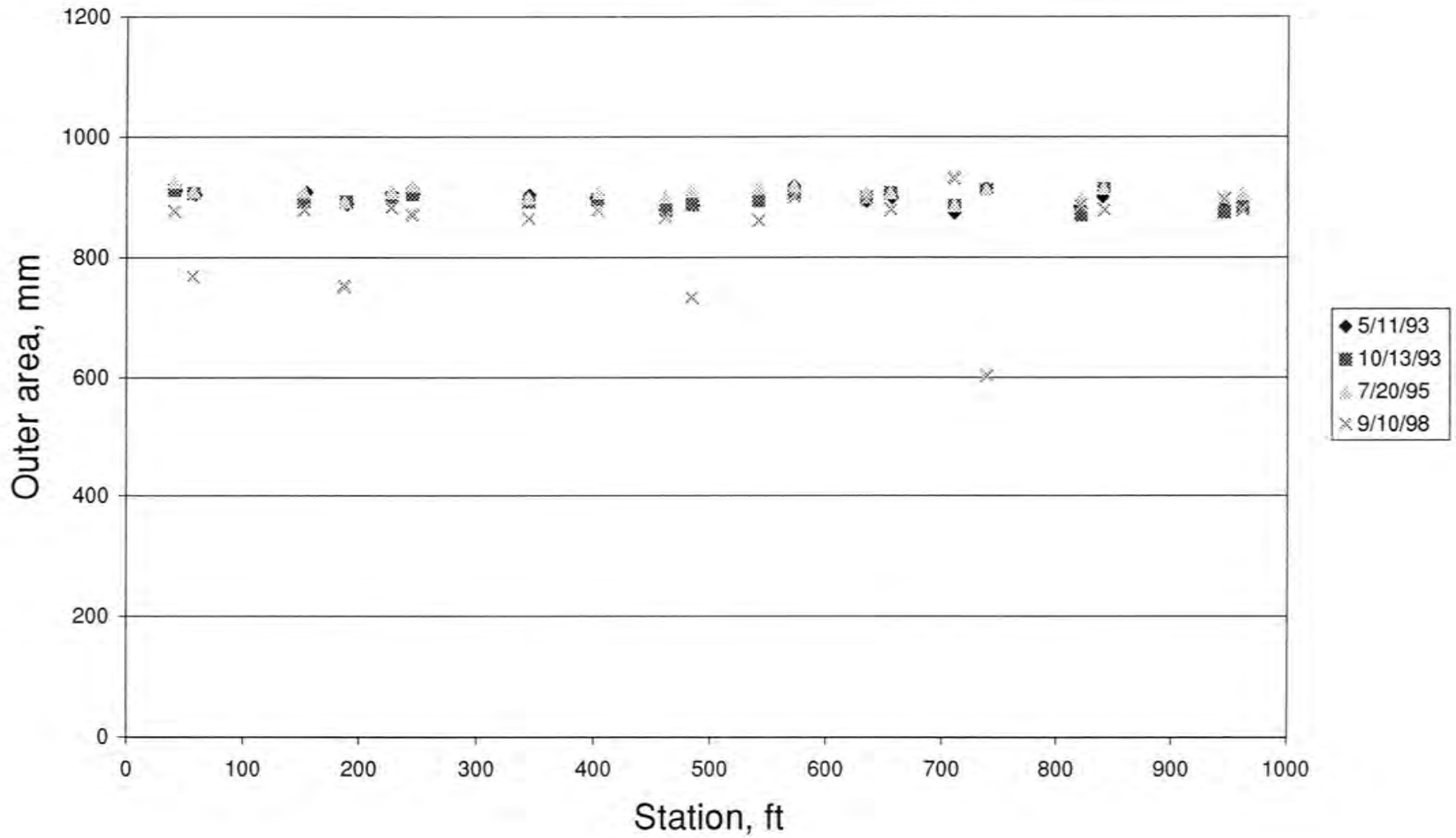
Appendix E

OuterAREA plots

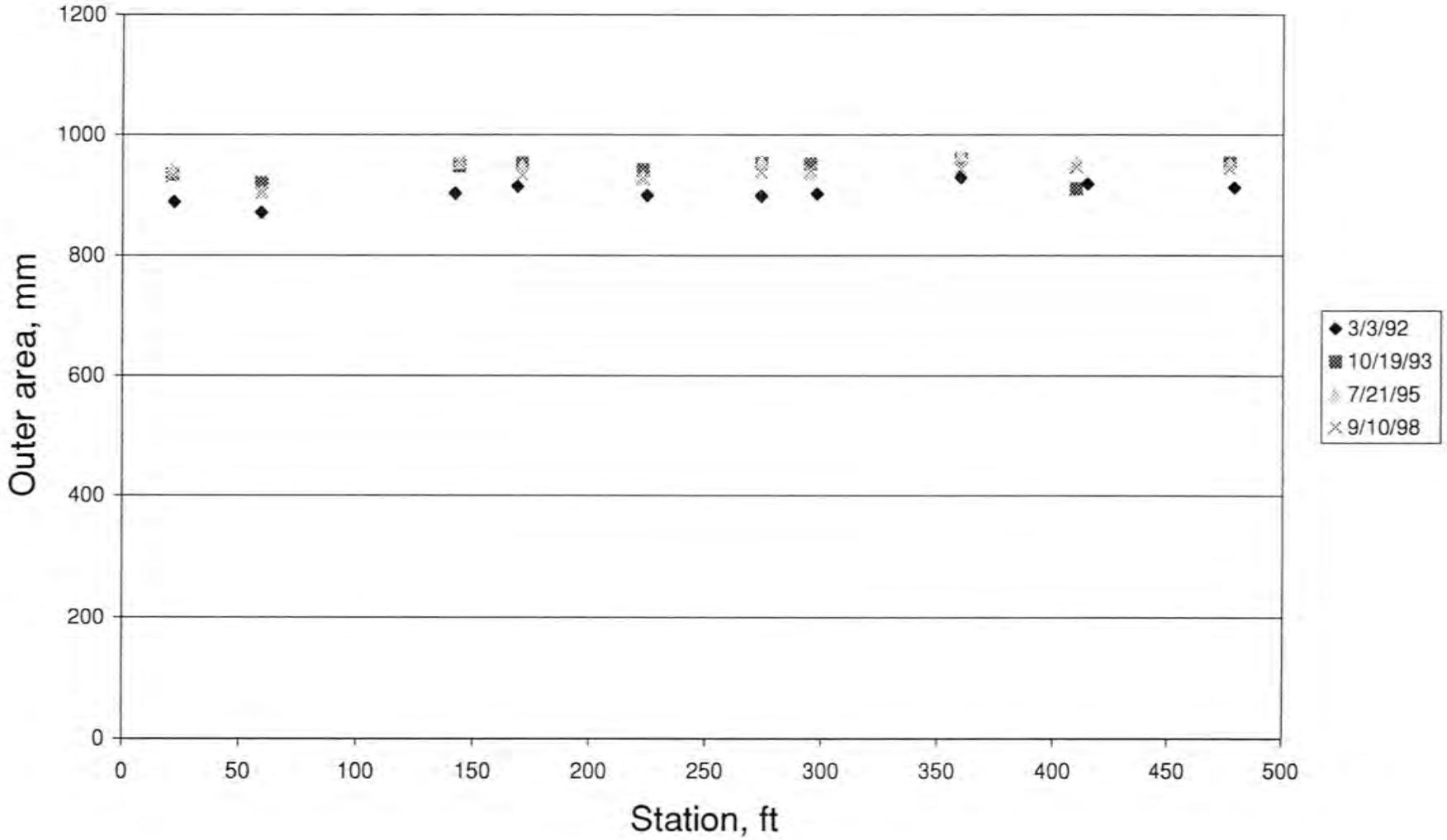
290601


1200
1000
800
600
400
200
0
Outer area, mm
0
50
100
150
200
250
300
350
400
450
500
Station, ft
11/17/92
4/22/92
10/6/93
7/21/95
9/9/98

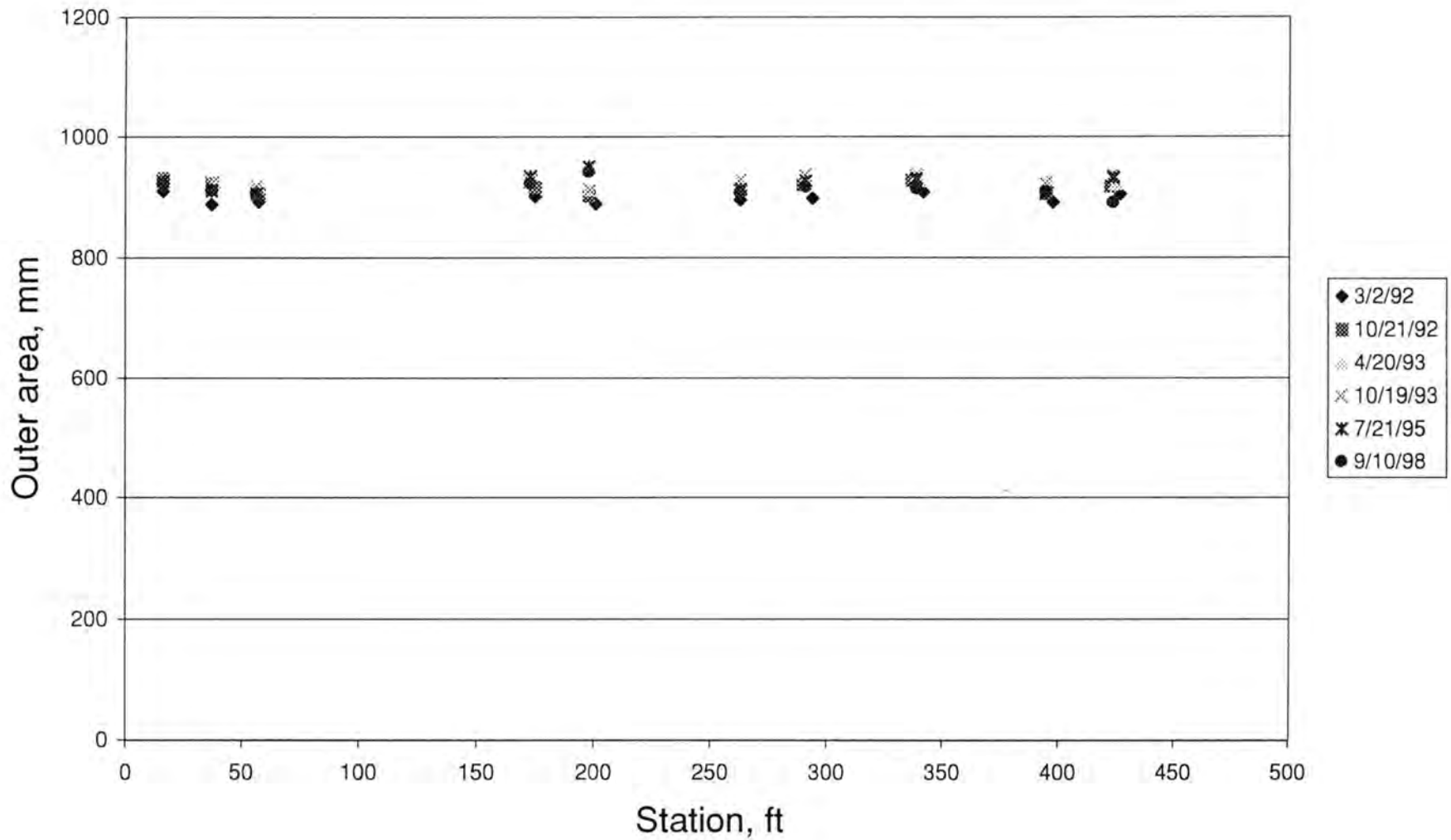
290602


1200
1000
800
600
400
200
0
Outer area, mm
0
100
200
300
400
500
600
700
800
900
1000
Station, ft
5/11/93
10/13/93
7/20/95
9/10/98

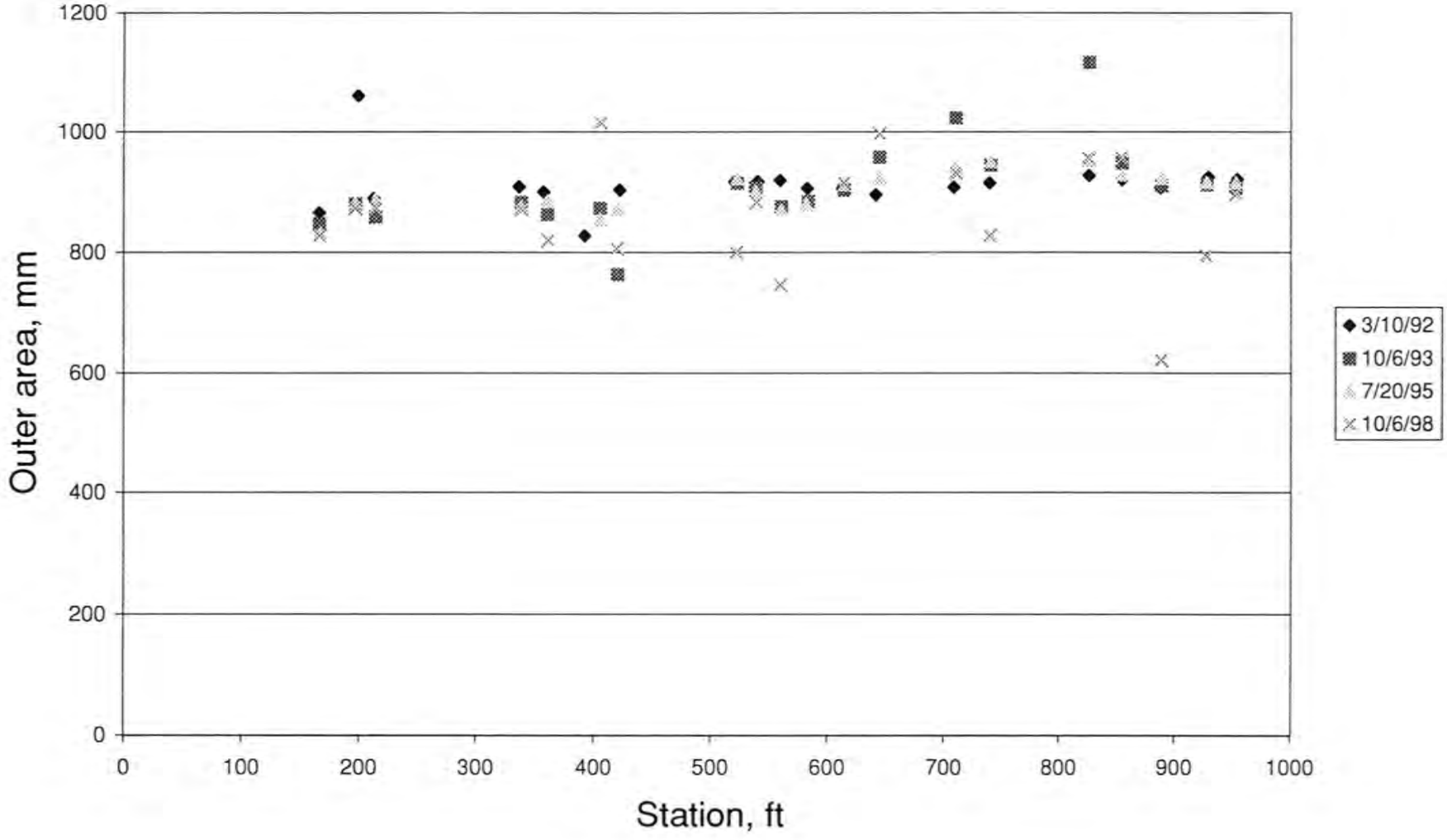
290603


1200
1000
800
600
400
200
0
Outer area, mm
0
50
100
150
200
250
300
350
400
450
500
Station, ft
3/3/92
10/19/93
7/21/95
9/10/98

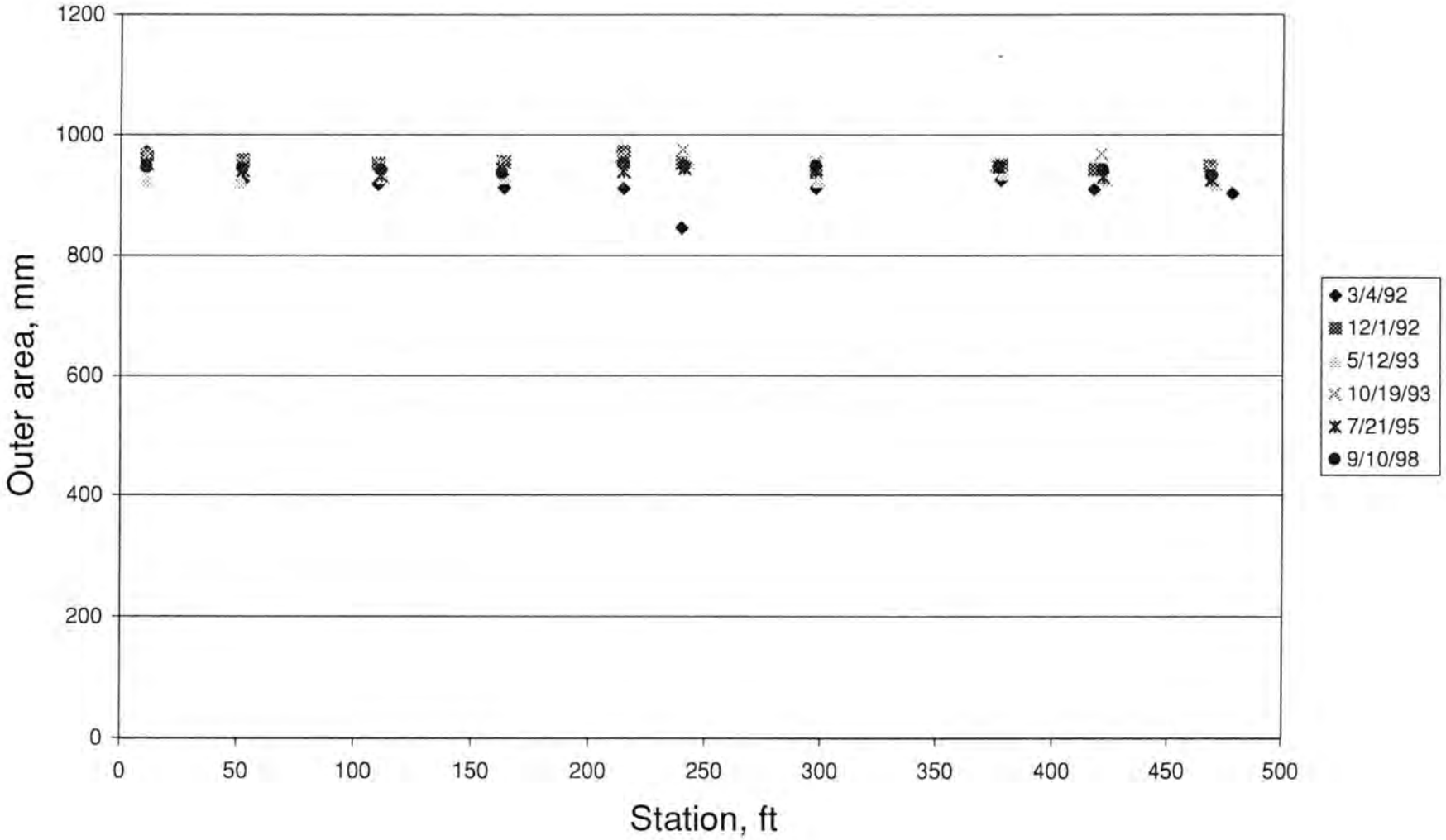
290604


1200
1000
800
600
400
200
0
Outer area, mm
0
50
100
150
200
250
300
350
400
450
500
Station, ft
3/2/92
10/21/92
4/20/93
10/19/93
7/21/95
9/10/98

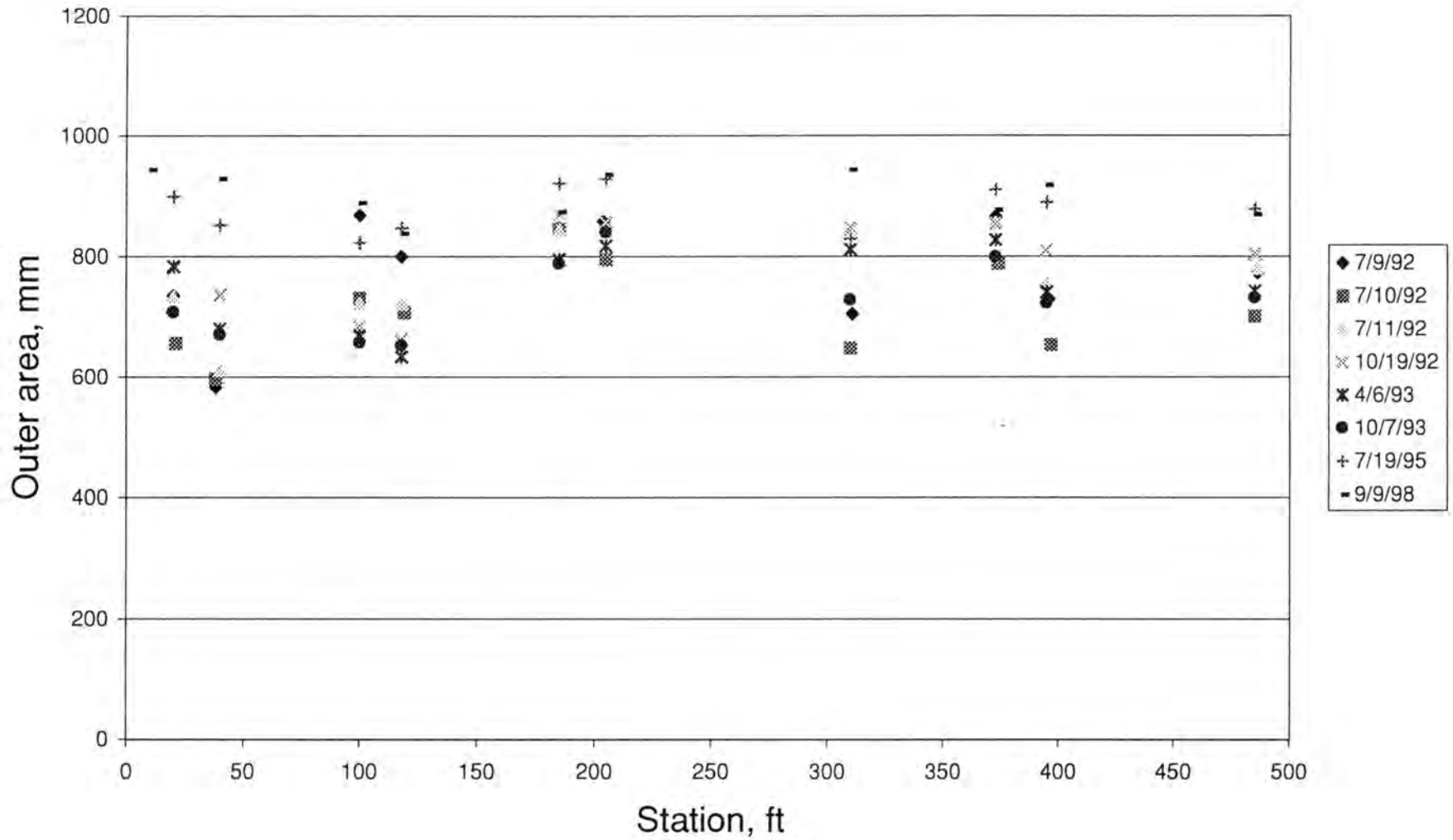
290605


1200
1000
800
600
400
200
0
Outer area, mm
0
100
200
300
400
500
600
700
800
900
1000
Station, ft
3/10/92
10/6/93
7/20/95
10/6/98

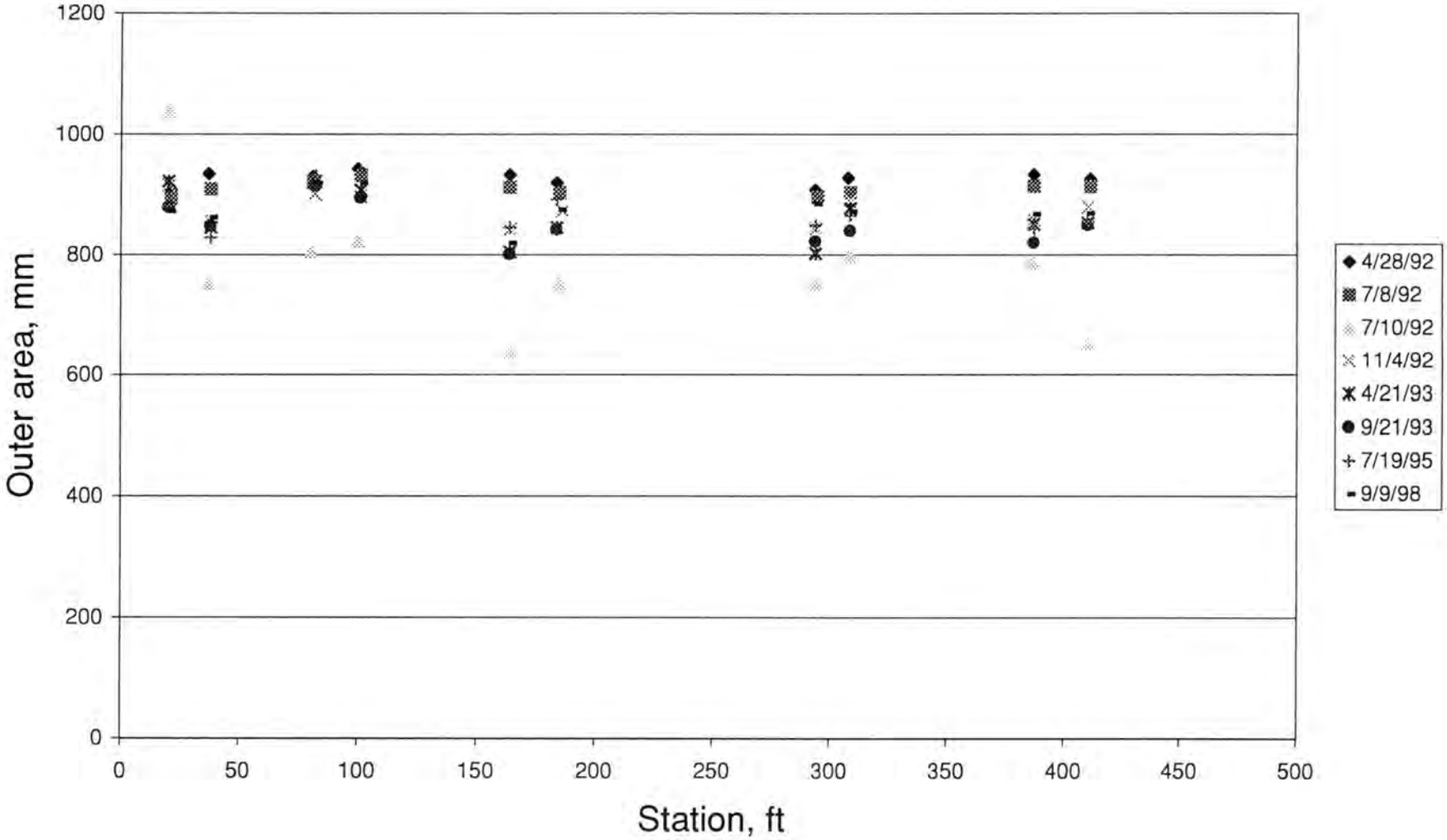
290606


1200
1000
800
600
400
200
0
Outer area, mm
0
50
100
150
200
250
300
350
400
450
500
Station, ft
3/4/92
12/1/92
5/12/93
10/19/93
7/21/95
9/10/98

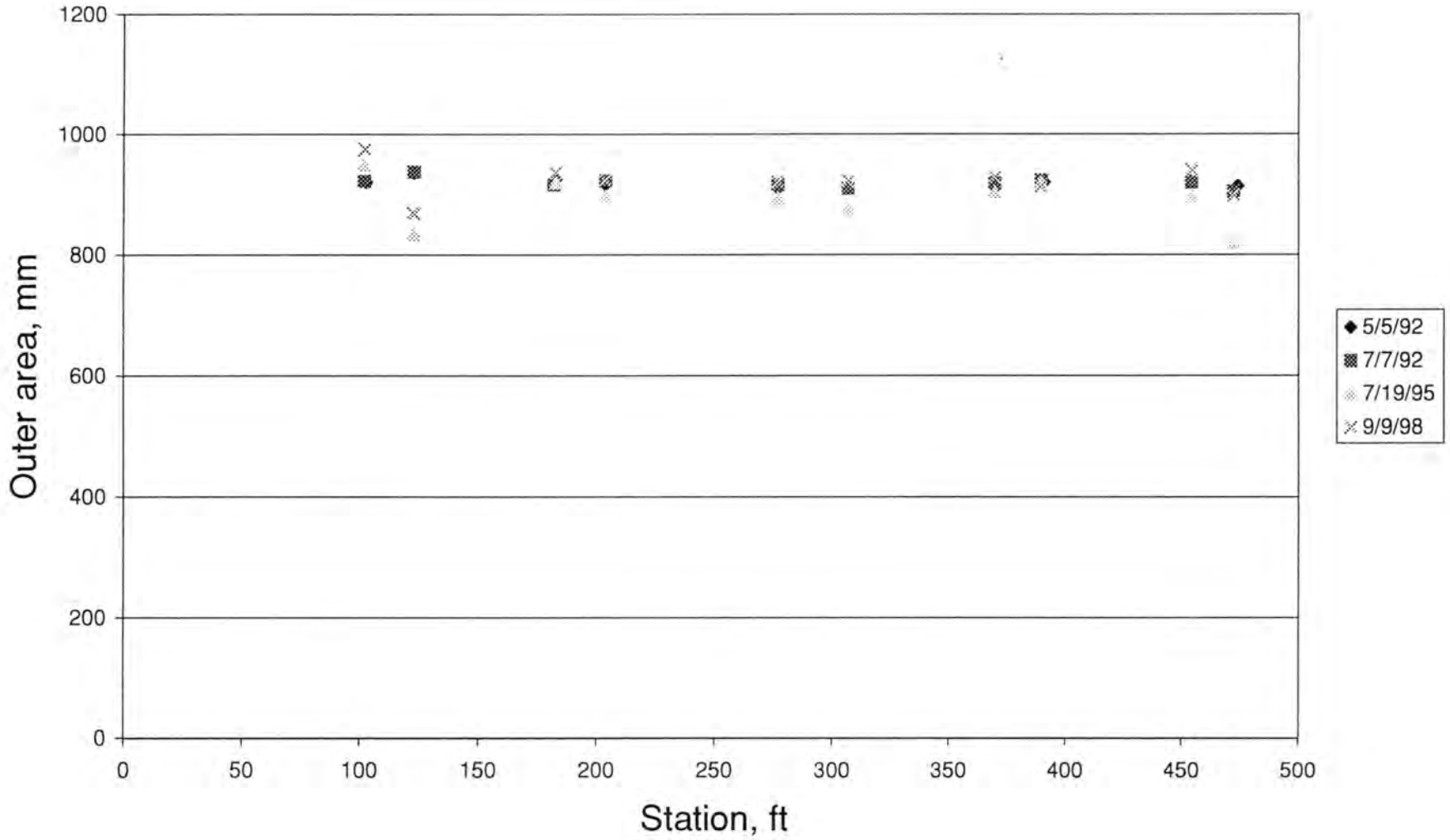
290607


1200
1000
800
600
400
200
0
Outer area, mm
0
50
100
150
200
250
300
350
400
450
500
Station, ft
7/9/92
7/10/92
7/11/92
10/19/92
4/6/93
10/7/93
7/19/95
9/9/98

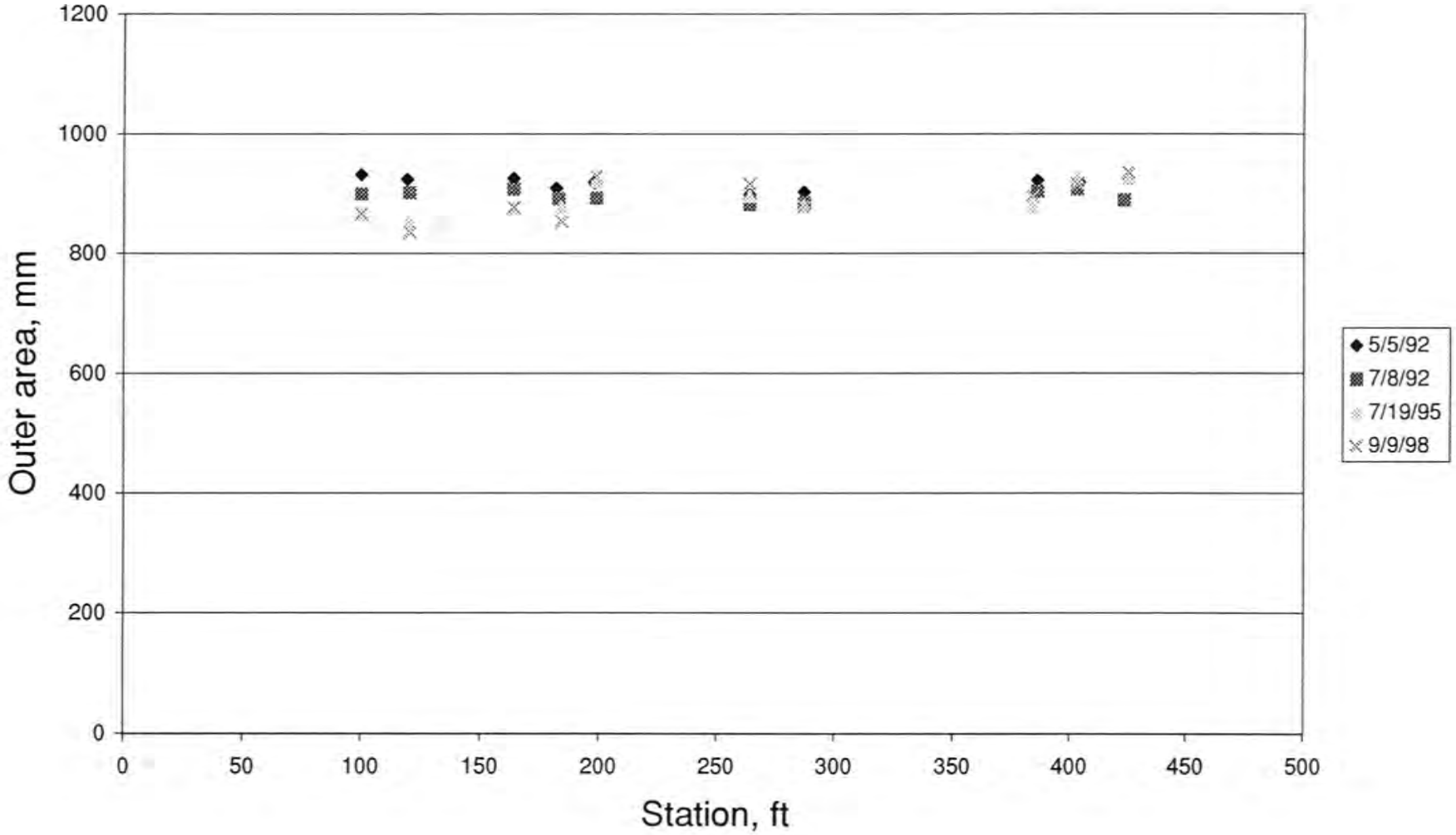
290608


1200
1000
800
600
400
200
0
Outer area, mm
0
50
100
150
200
250
300
350
400
450
500
Station, ft
4/28/92
7/8/92
7/10/92
11/4/92
4/21/93
9/21/93
7/19/95
9/9/98

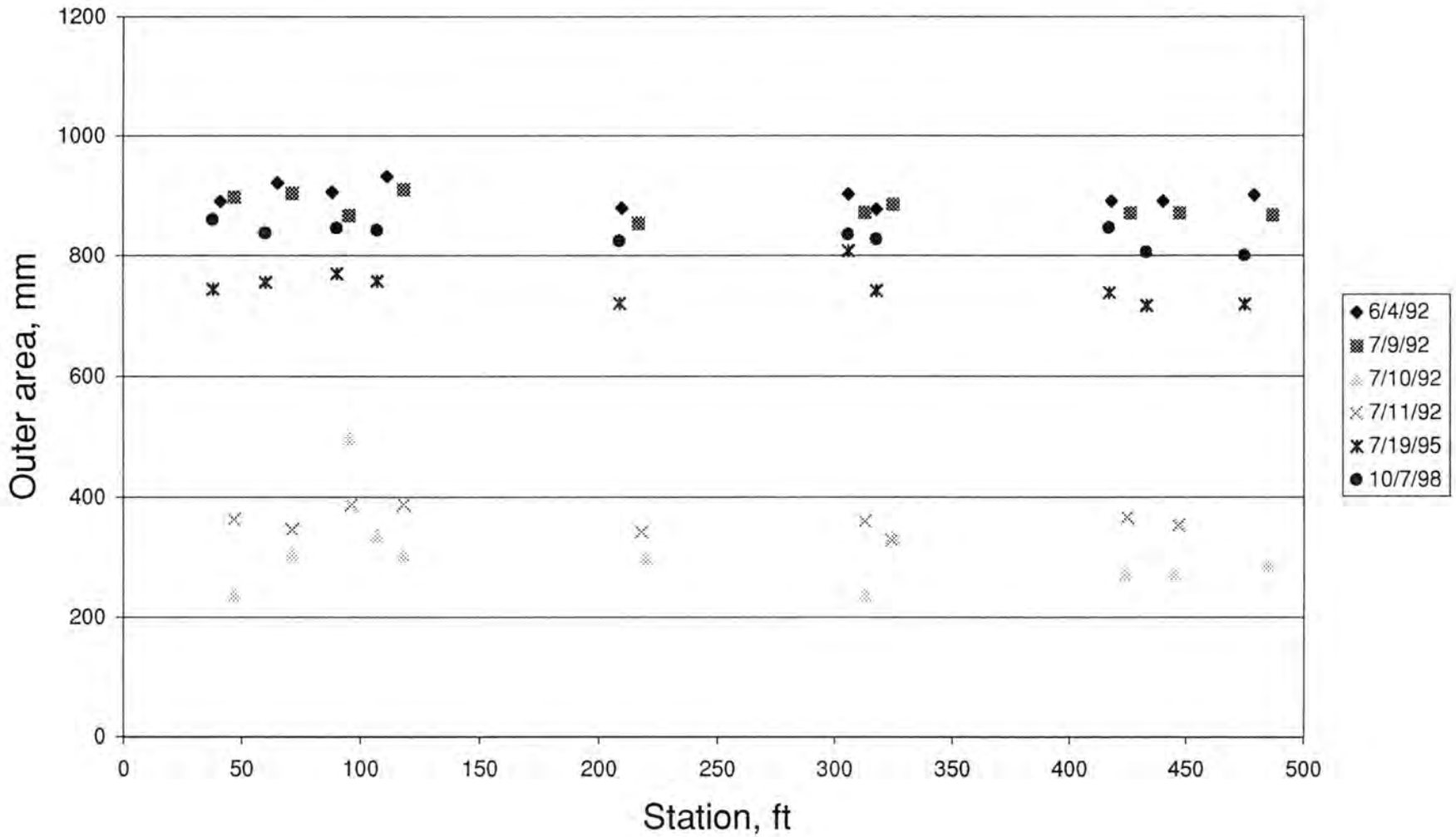
290659


1200
1000
800
600
400
200
0
Outer area, mm
0
50
100
150
200
250
300
350
400
450
500
Station, ft
5/5/92
7/7/92
7/19/95
9/9/98

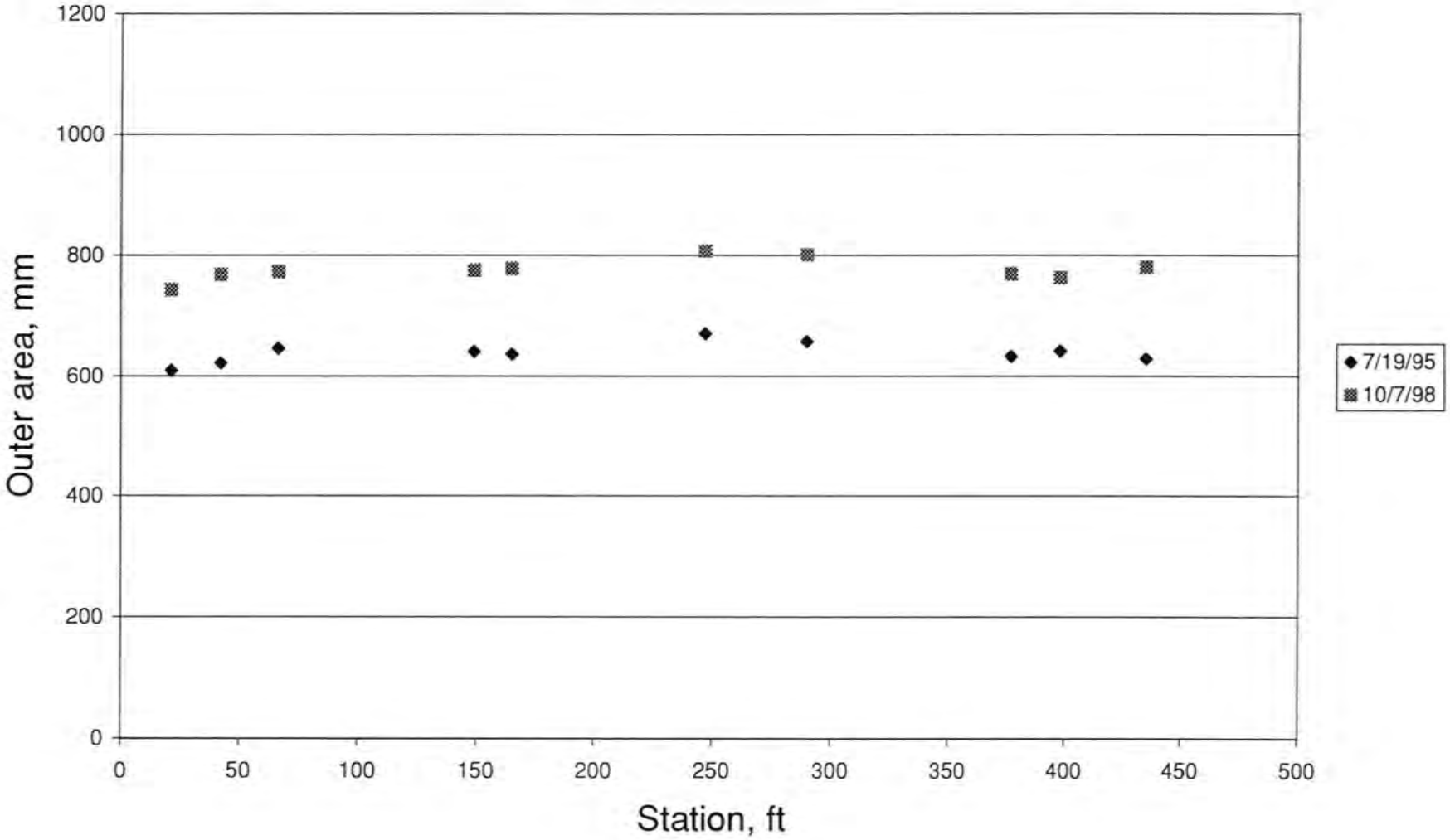
290660


1200
1000
800
600
400
200
0
Outer area, mm
0
50
100
150
200
250
300
350
400
450
500
Station, ft
5/5/92
7/8/92
7/19/95
9/9/98

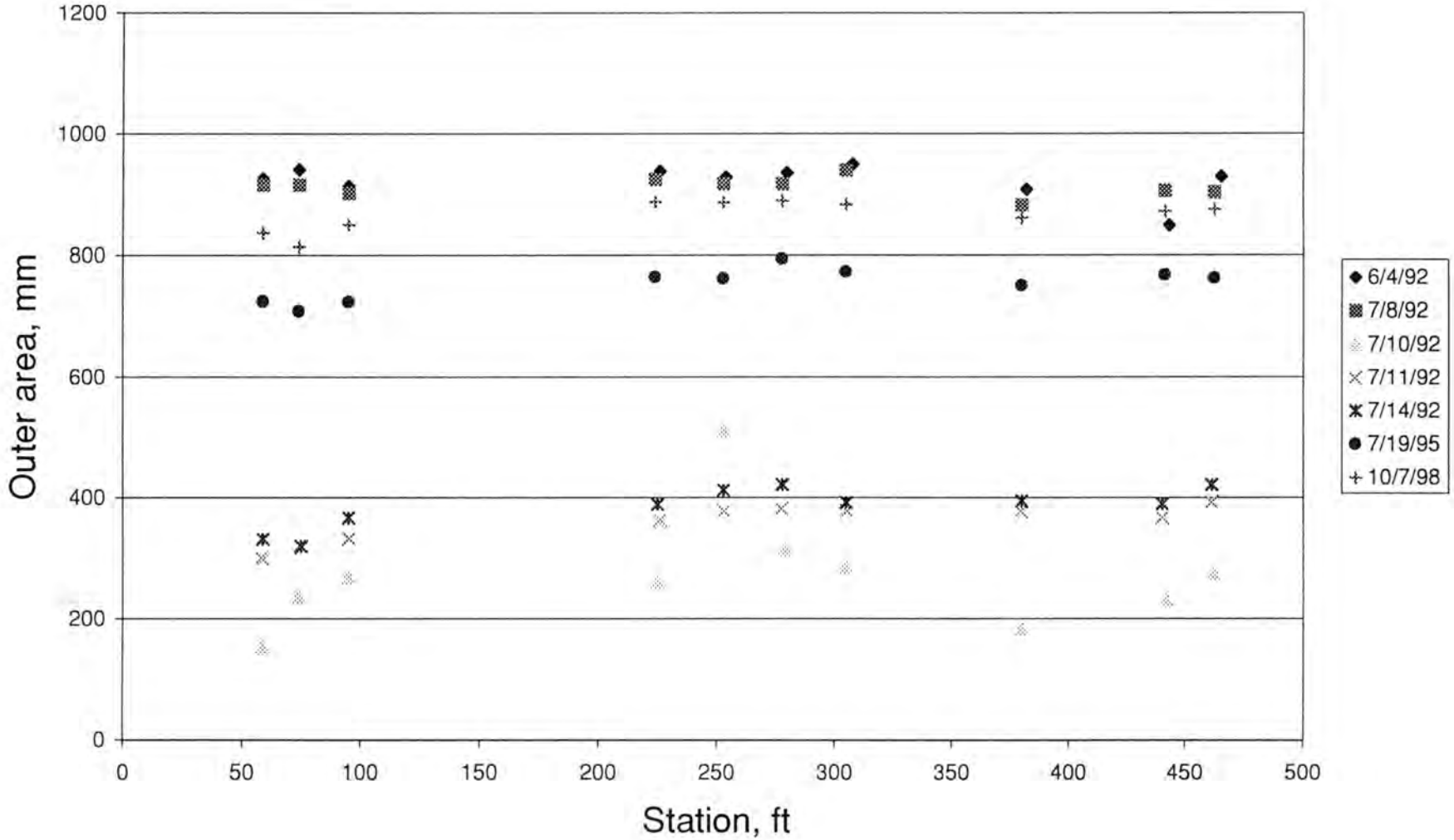
290661


1200
1000
800
600
400
200
0
Outer area, mm
0
50
100
150
200
250
300
350
400
450
500
Station, ft
6/4/92
7/9/92
7/10/92
7/11/92
7/19/95
10/7/98

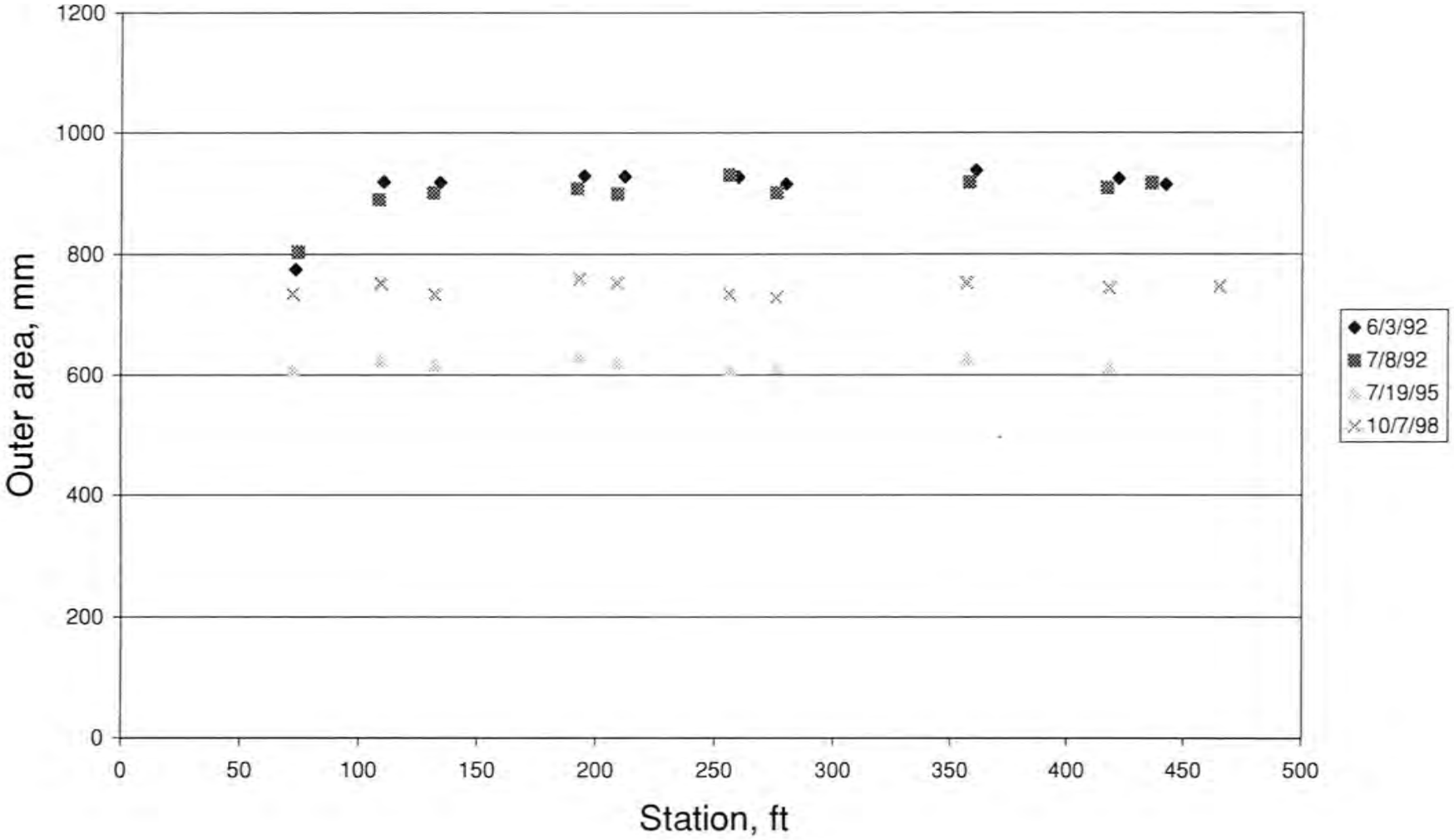
290662


1200
1000
800
600
400
200
0
Outer area, mm
0
50
100
150
200
250
300
350
400
450
500
Station, ft
7/19/95
10/7/98

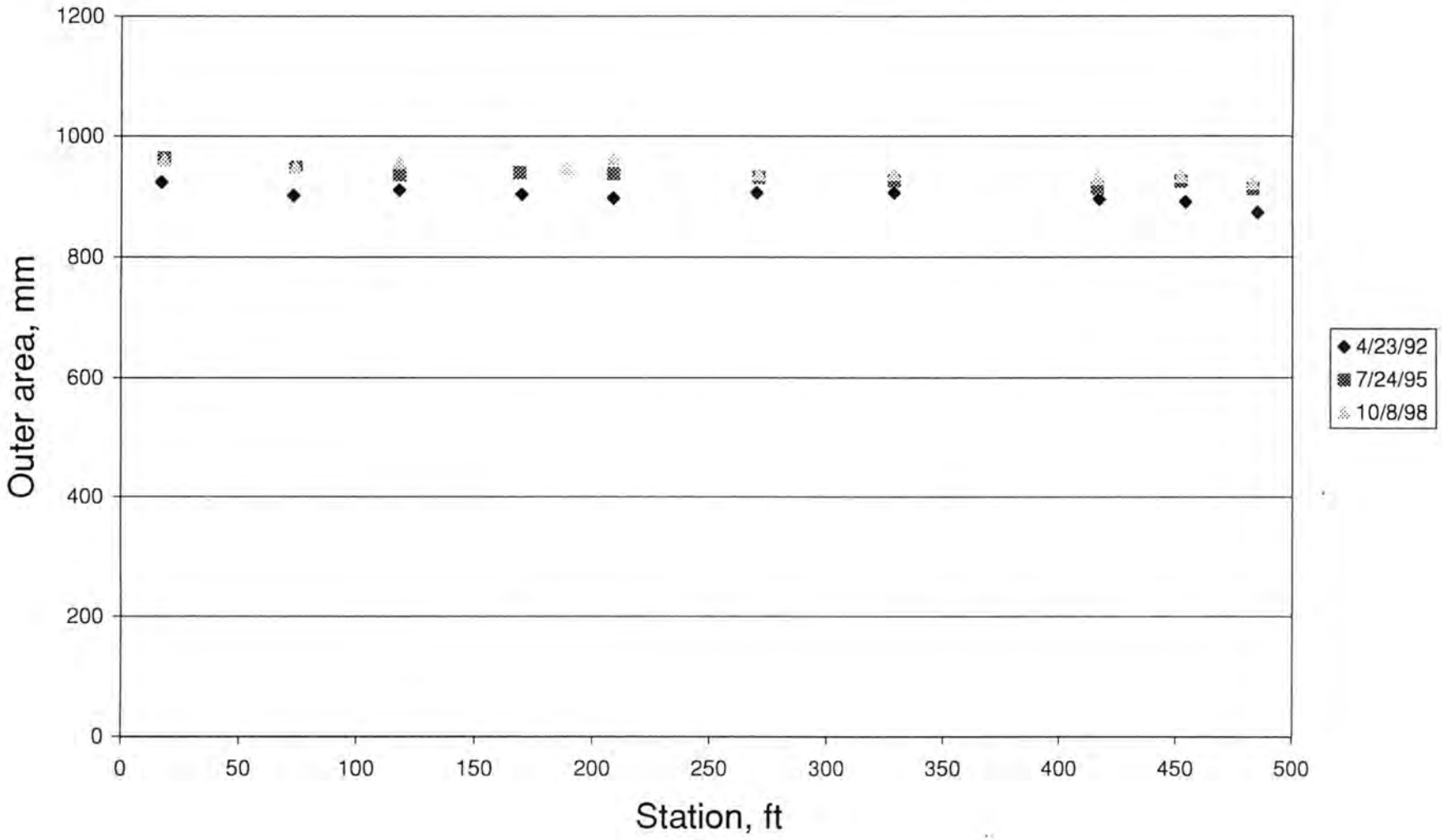
290663


1200
1000
800
600
400
200
0
Outer area, mm
0
50
100
150
200
250
300
350
400
450
500
Station, ft
6/4/92
7/8/92
7/10/92
7/11/92
7/14/92
7/19/95
10/7/98

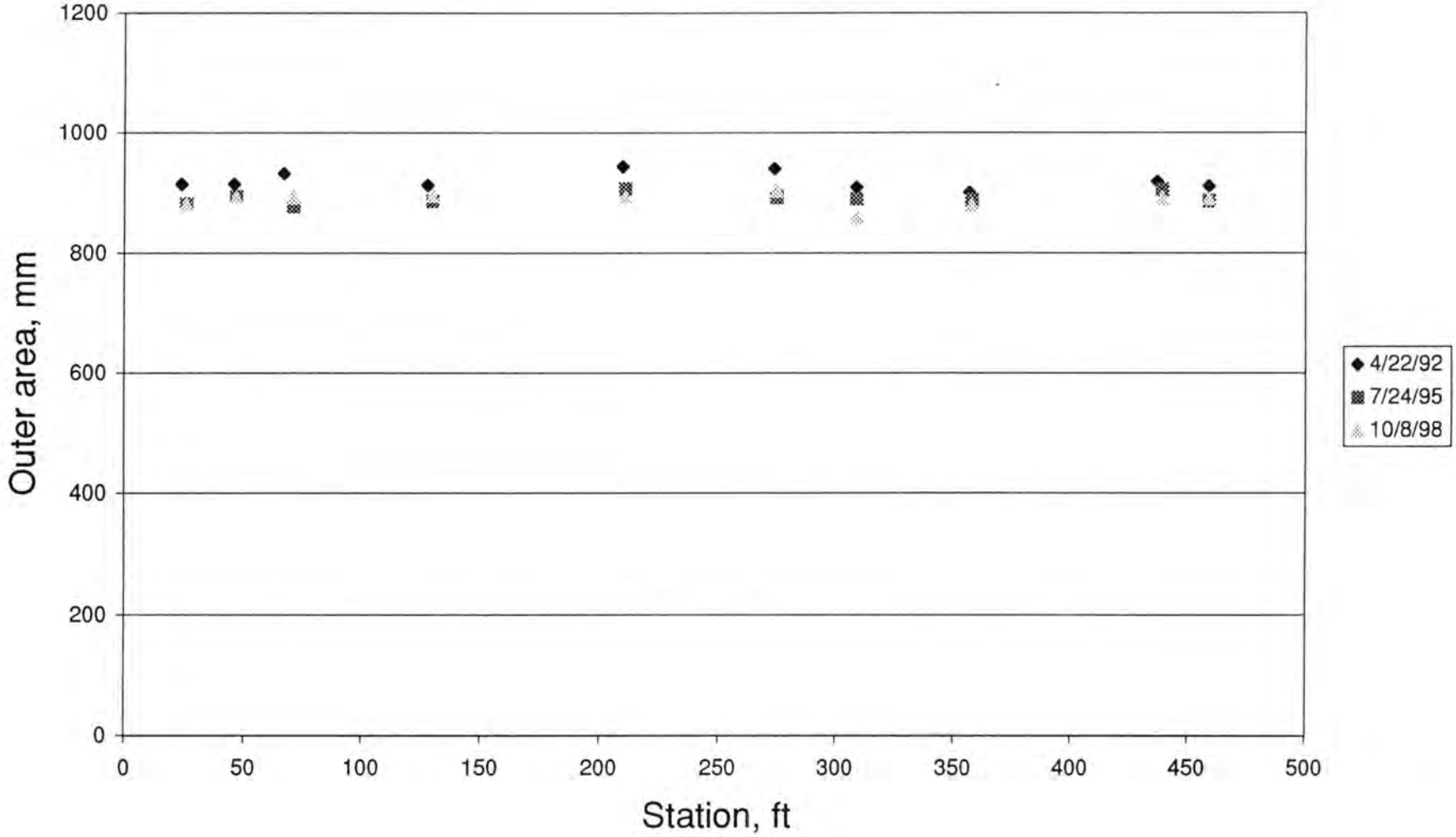
290664


1200
1000
800
600
400
200
0
Outer area, mm
0
50
100
150
200
250
300
350
400
450
500
Station, ft
6/3/92
7/8/92
7/19/95
10/7/98

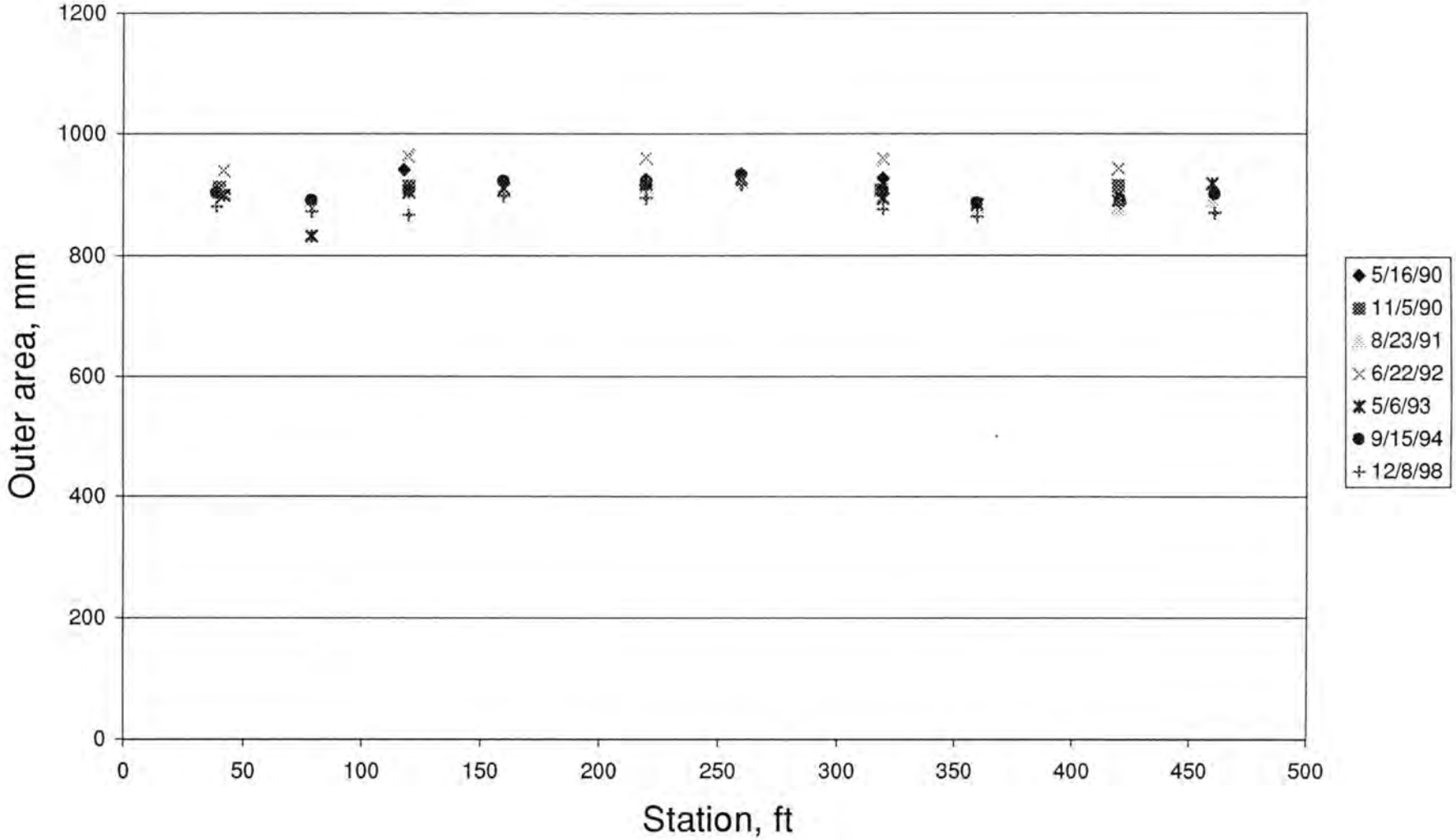
290665


1200
1000
800
600
400
200
0
Outer area, mm
0
50
100
150
200
250
300
350
400
450
500
Station, ft
4/23/92
7/24/95
10/8/98

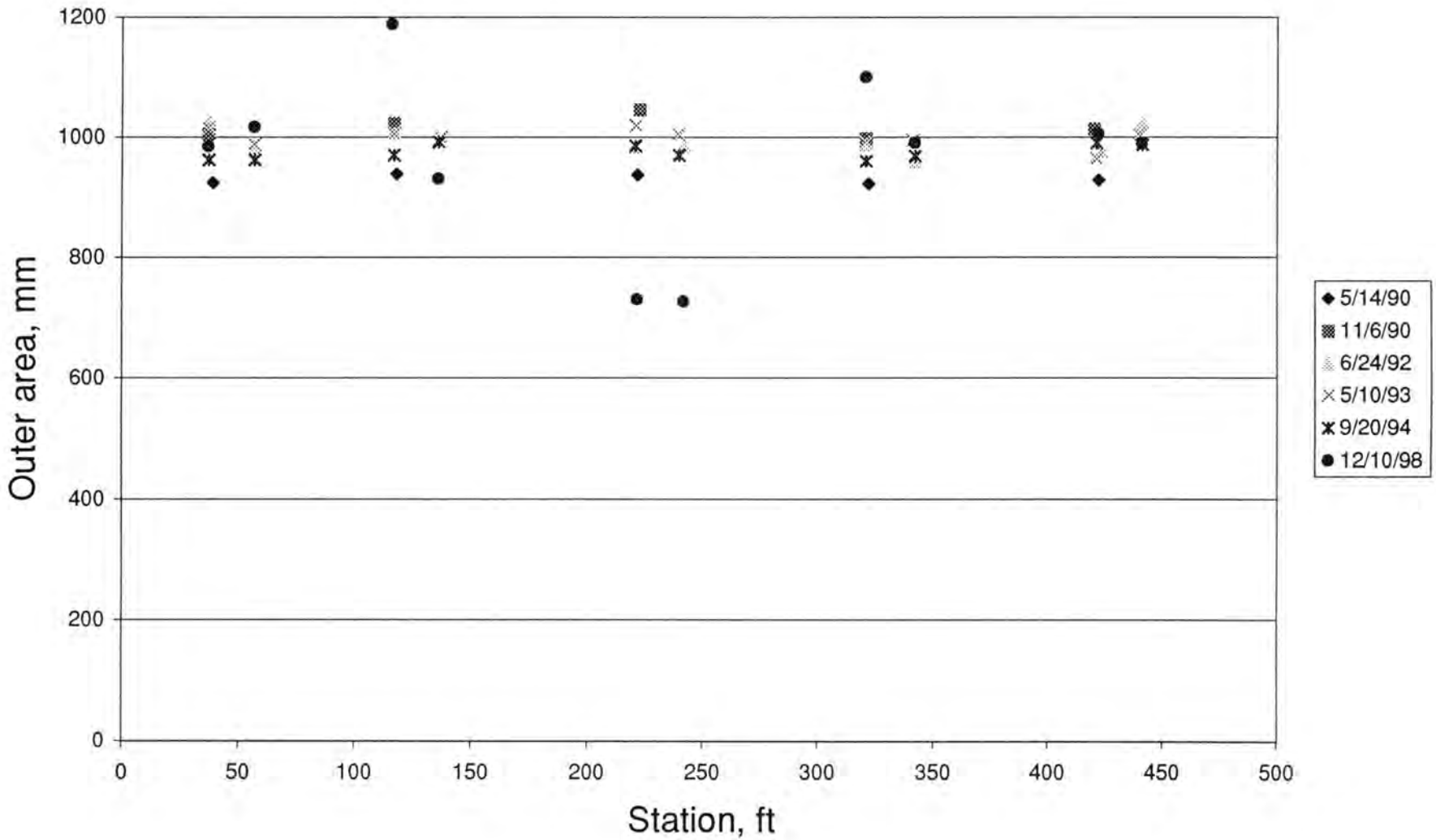
290666


1200
1000
800
600
400
200
0
Outer area, mm
0
50
100
150
200
250
300
350
400
450
500
Station, ft
4/22/92
7/24/95
10/8/98

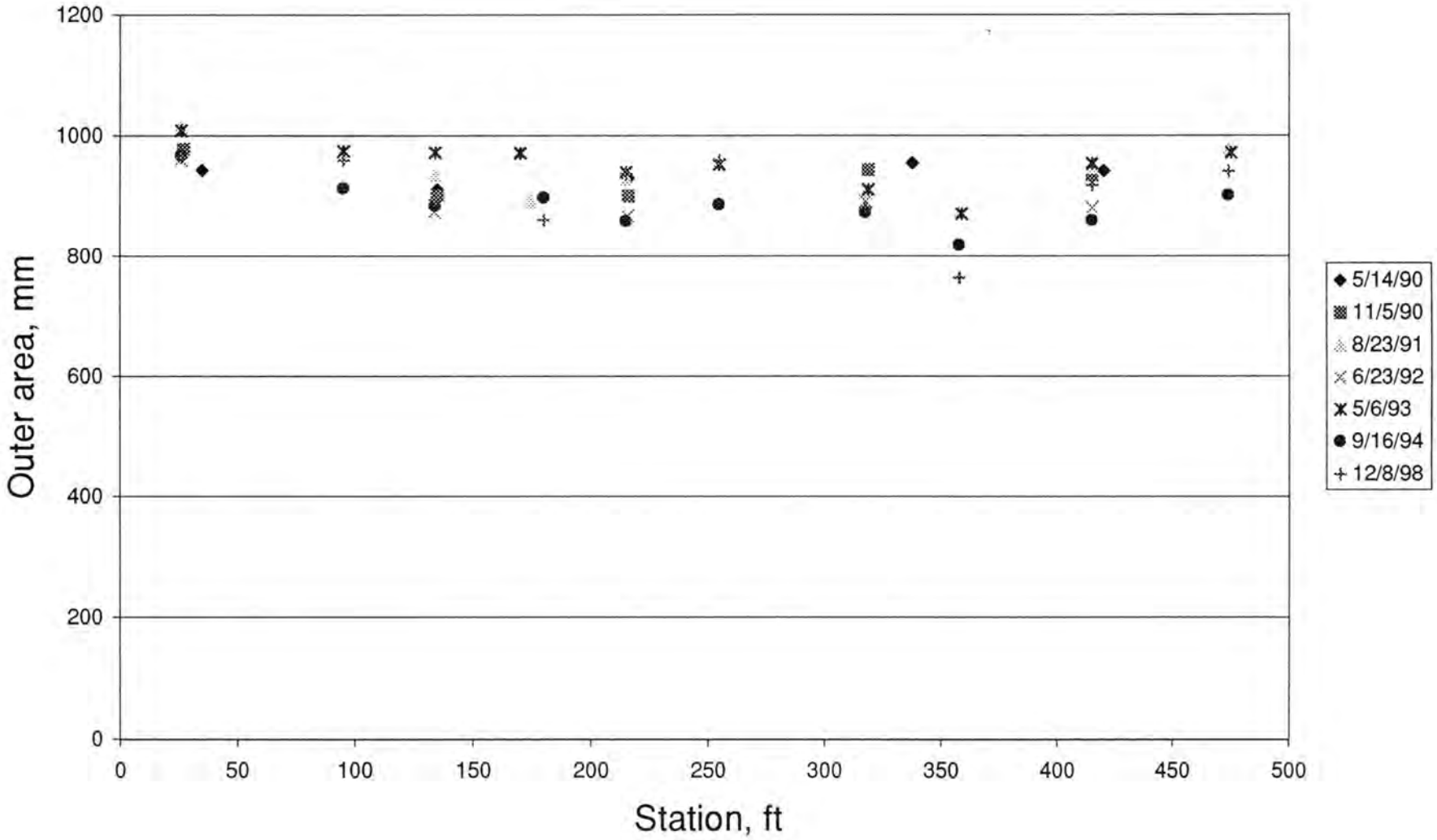
290701


1200
1000
800
600
400
200
0
Outer area, mm
0
50
100
150
200
250
300
350
400
450
500
Station, ft
5/16/90
11/5/90
8/23/91
6/22/92
5/6/93
9/15/94
12/8/98

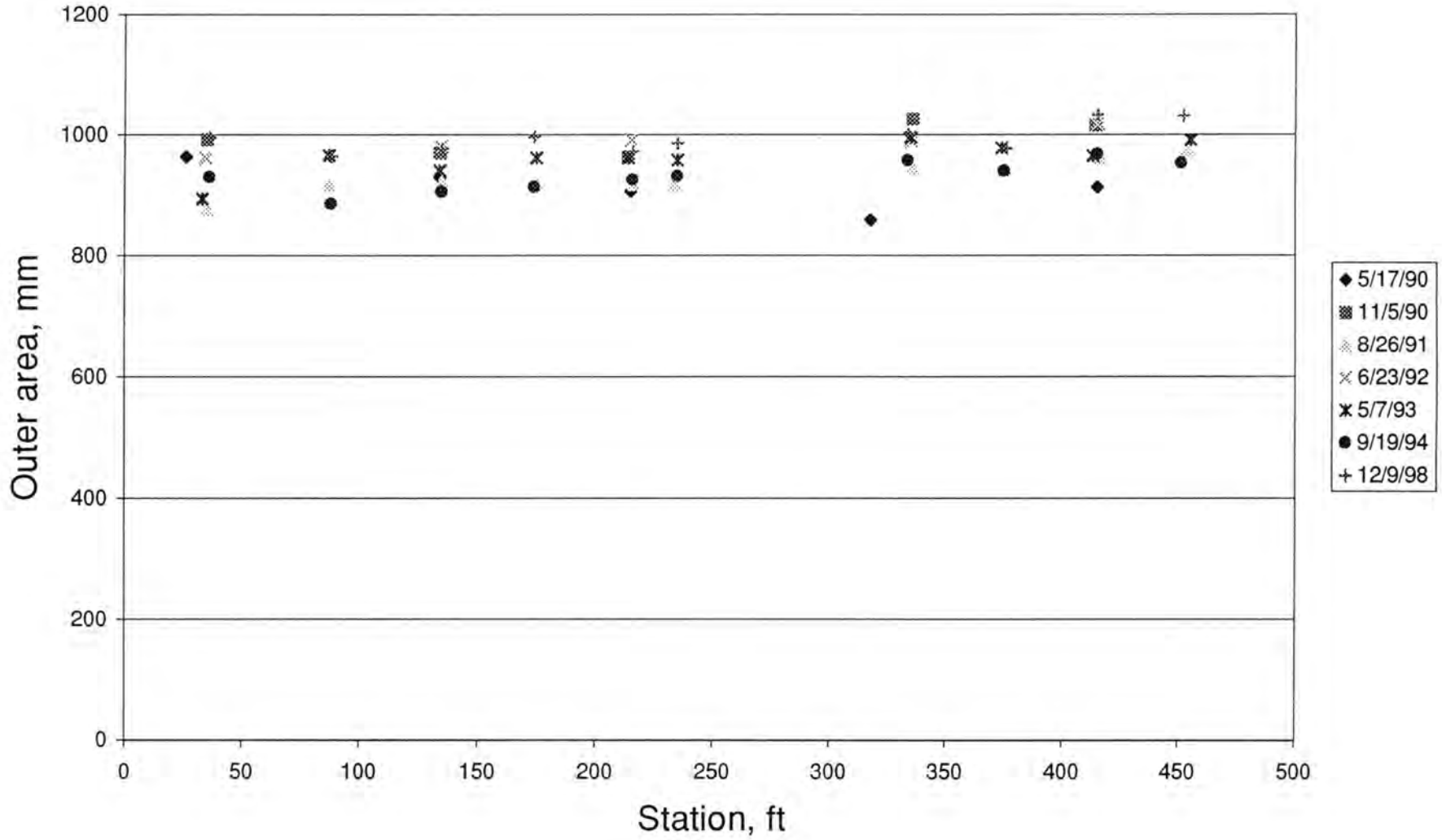
290702


1200
1000
800
600
400
200
0
Outer area, mm
0
50
100
150
200
250
300
350
400
450
500
Station, ft
5/14/90
11/6/90
6/24/92
5/10/93
9/20/94
12/10/98

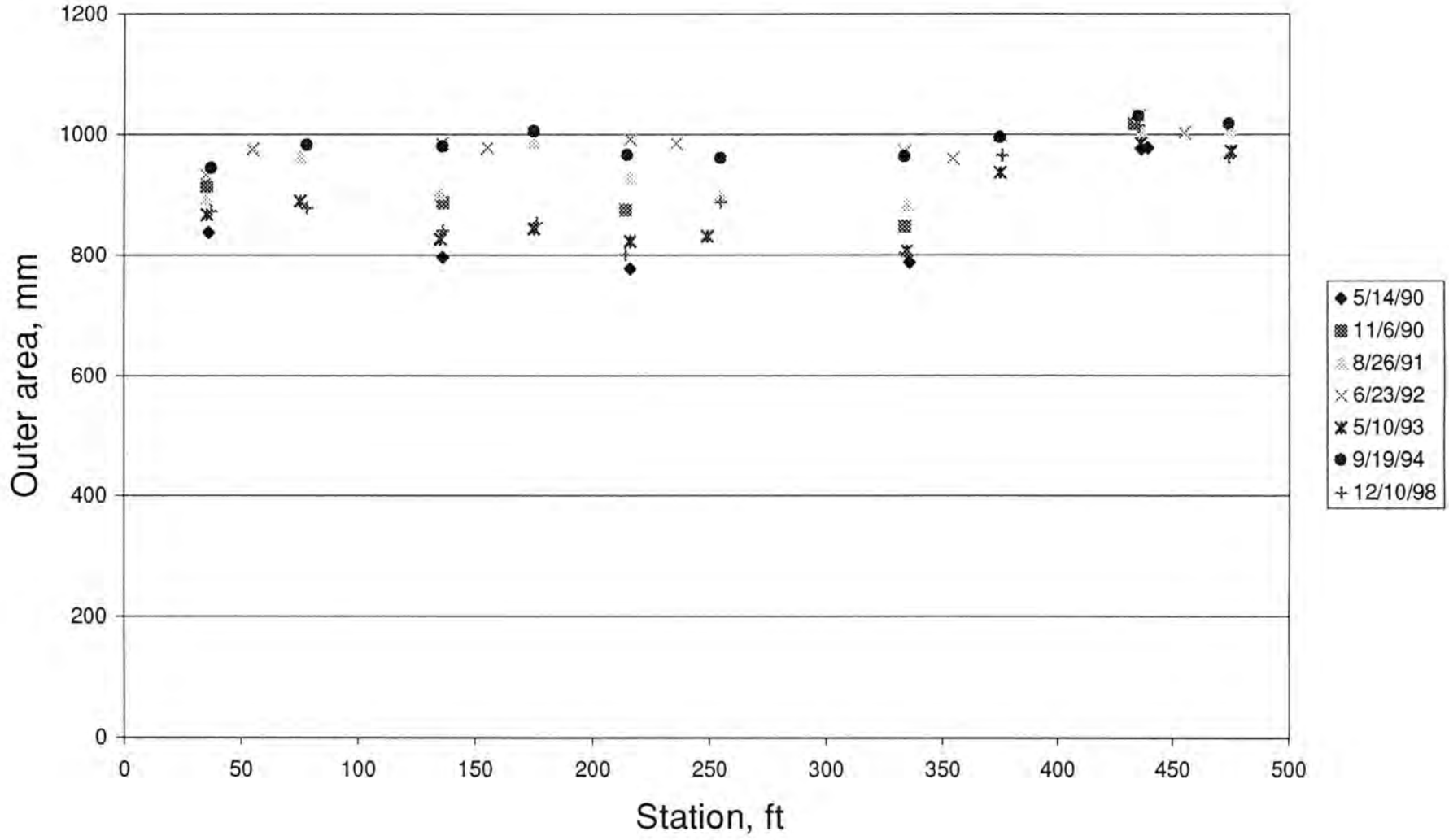
290703


1200
1000
800
600
400
200
0
Outer area, mm
0
50
100
150
200
250
300
350
400
450
500
Station, ft
5/14/90
11/5/90
8/23/91
6/23/92
5/6/93
9/16/94
12/8/98

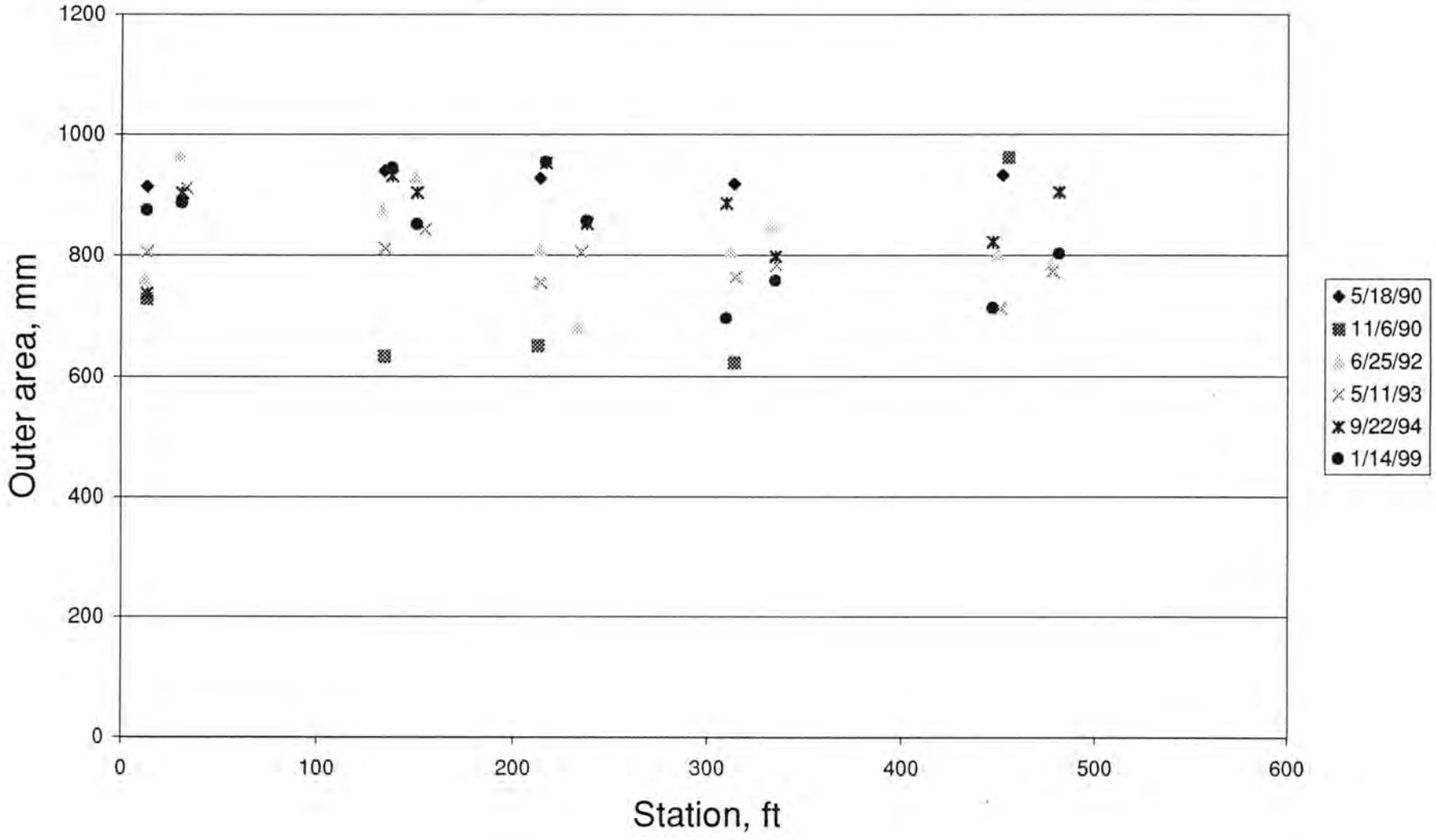
290704


1200
1000
800
600
400
200
0
Outer area, mm
0
50
100
150
200
250
300
350
400
450
500
Station, ft
5/17/90
11/5/90
8/26/91
6/23/92
5/7/93
9/19/94
12/9/98

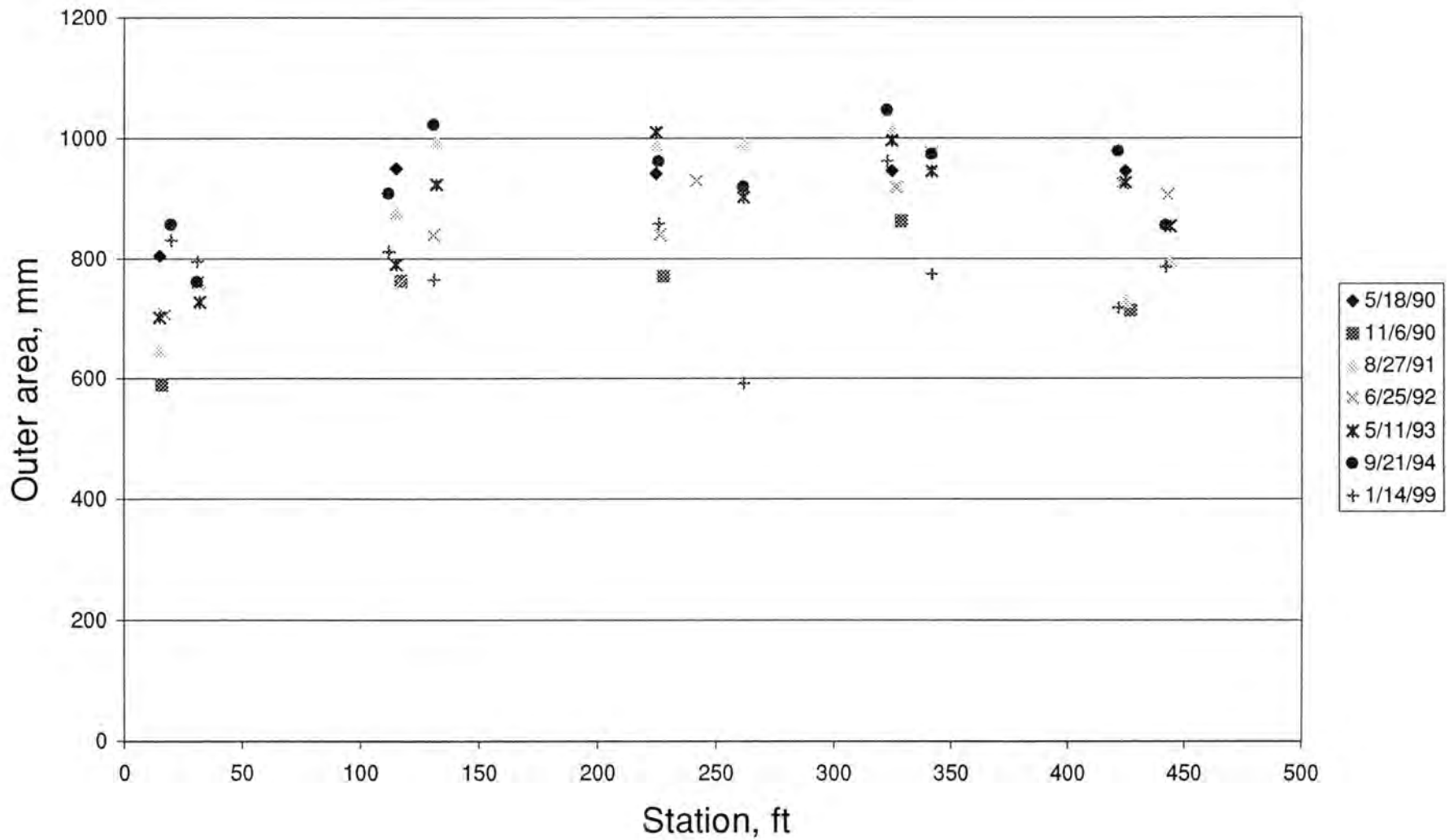
290705


1200
1000
800
600
400
200
0
Outer area, mm
0
50
100
150
200
250
300
350
400
450
500
Station, ft
5/14/90
11/6/90
8/26/91
6/23/92
5/10/93
9/19/94
12/10/98

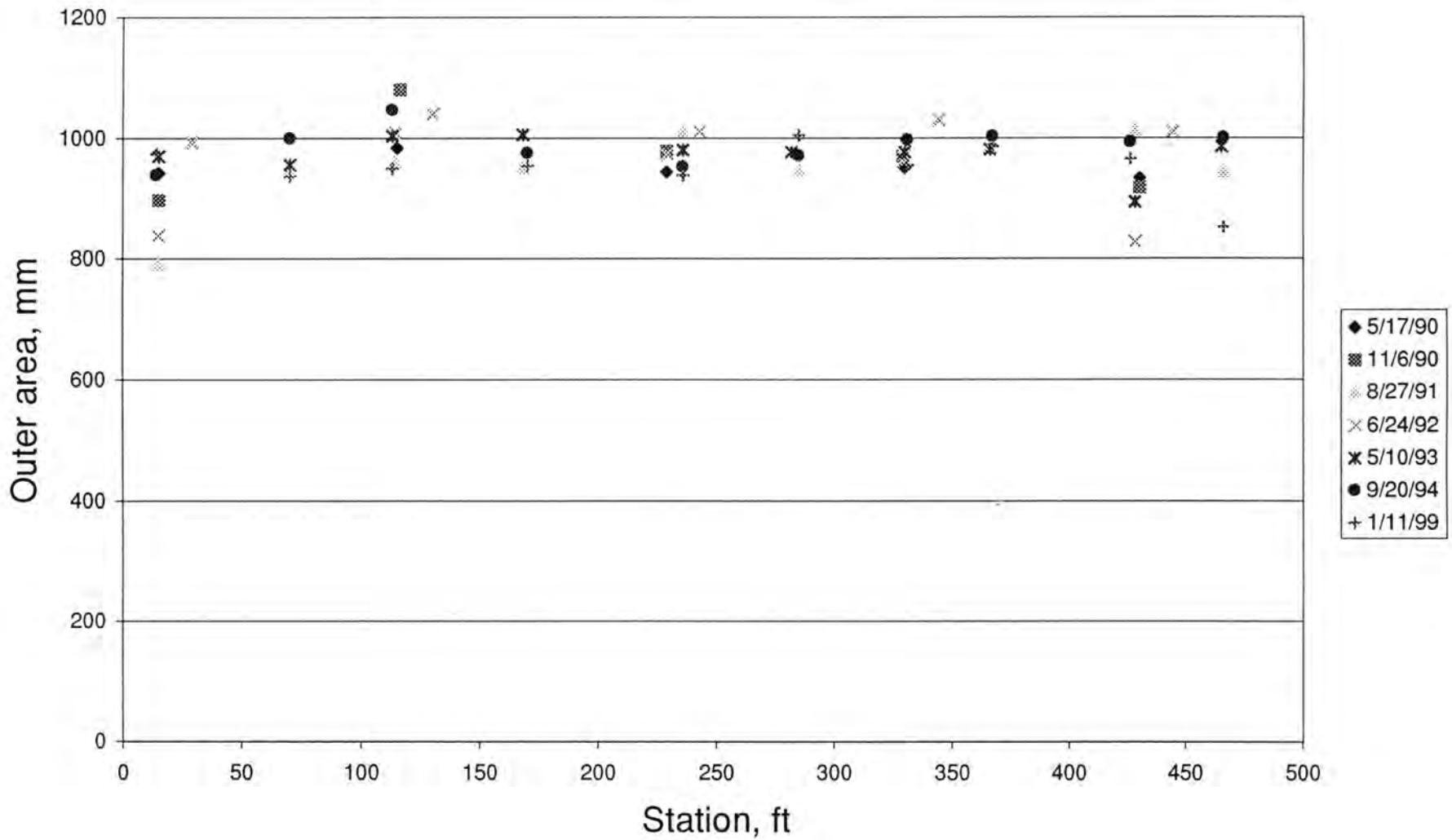
290706


1200
1000
800
600
400
200
0
Outer area, mm
0
100
200
300
400
500
600
Station, ft
5/18/90
11/6/90
6/25/92
5/11/93
9/22/94
1/14/99

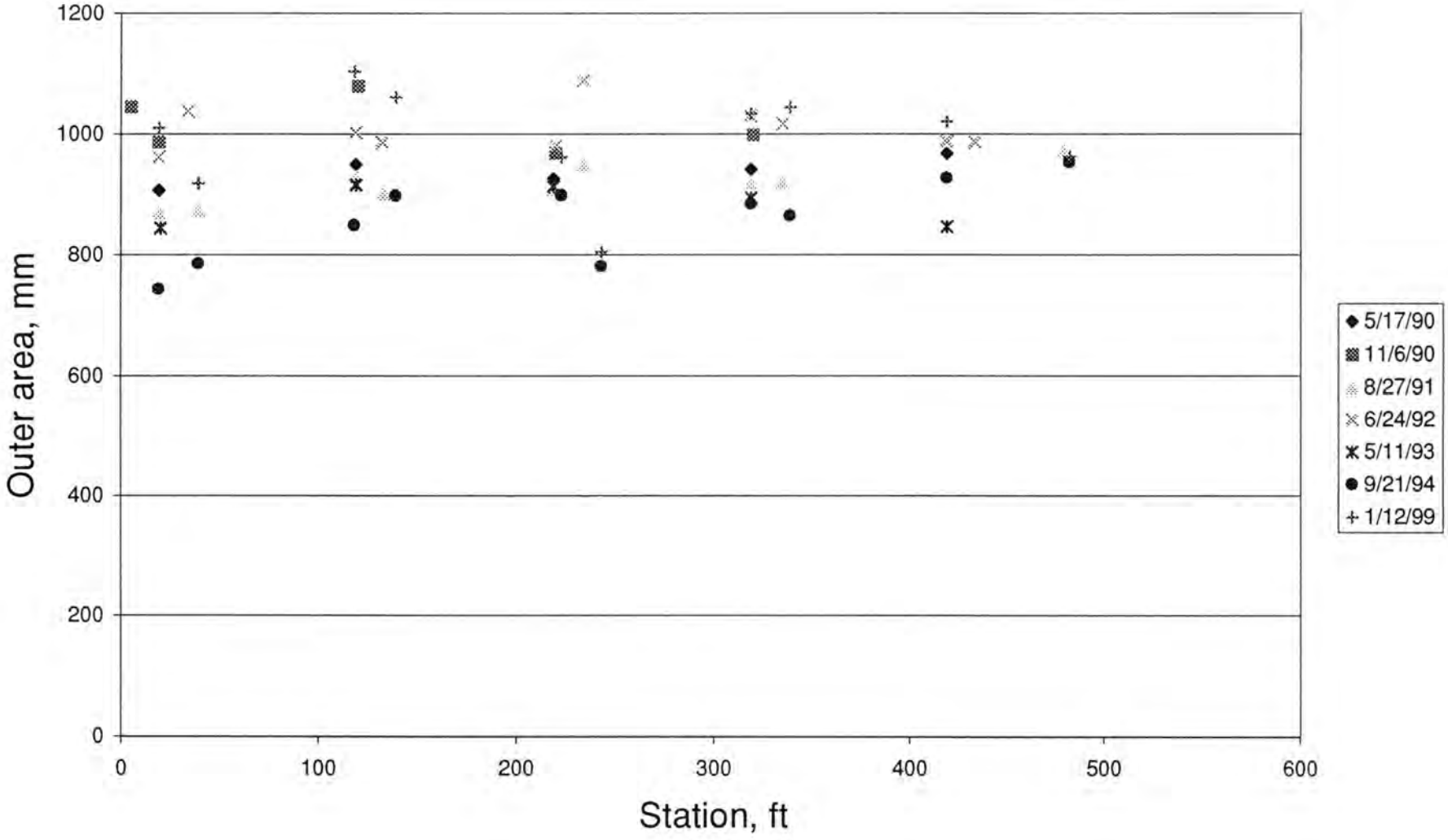
290707


1200
1000
800
600
400
200
0
Outer area, mm
0
50
100
150
200
250
300
350
400
450
500
Station, ft
5/18/90
11/6/90
8/27/91
6/25/92
5/11/93
9/21/94
1/14/99

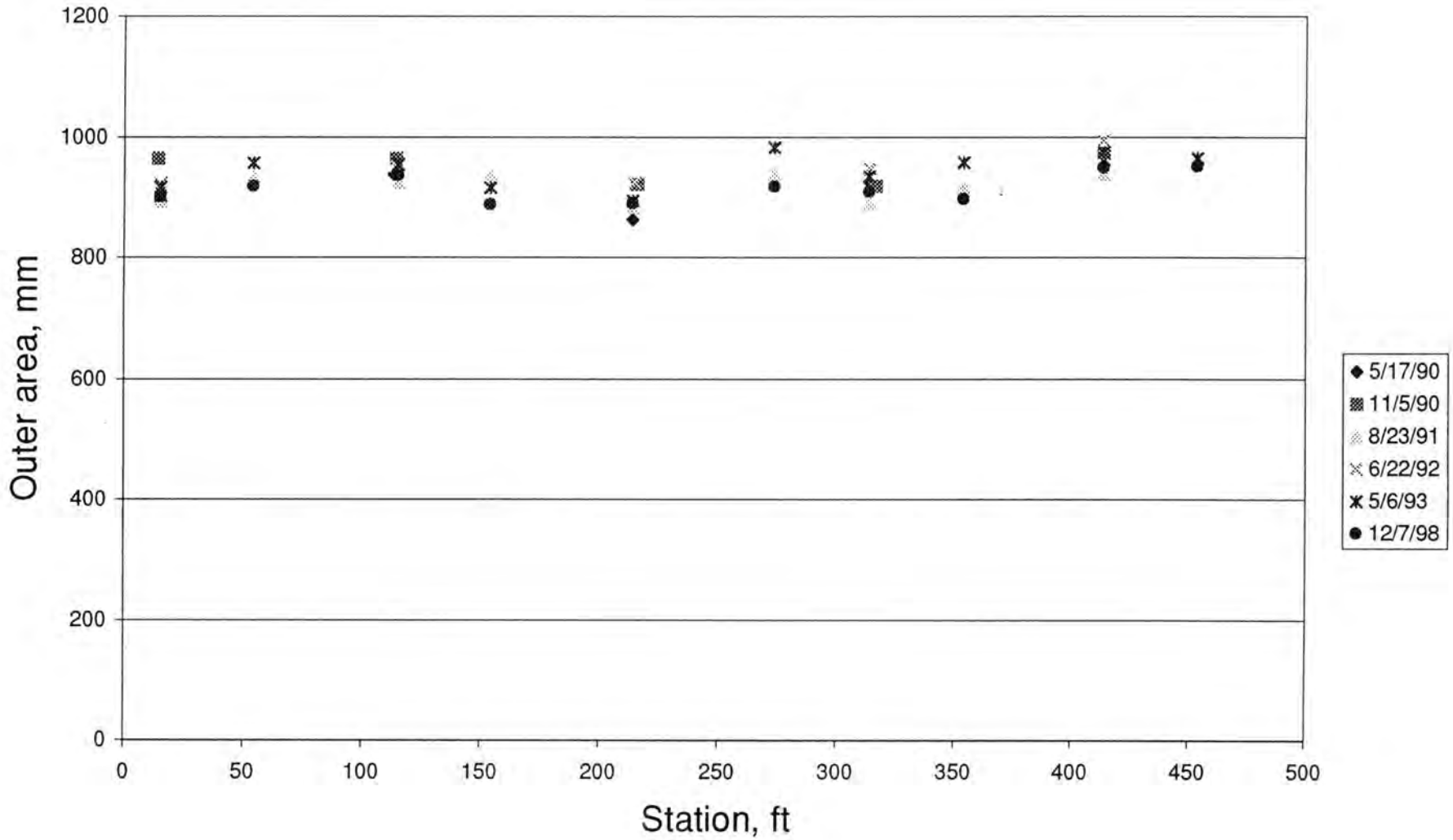
290708


1200
1000
800
600
400
200
0
Outer area, mm
0
50
100
150
200
250
300
350
400
450
500
Station, ft
5/17/90
11/6/90
8/27/91
6/24/92
5/10/93
9/20/94
1/11/99

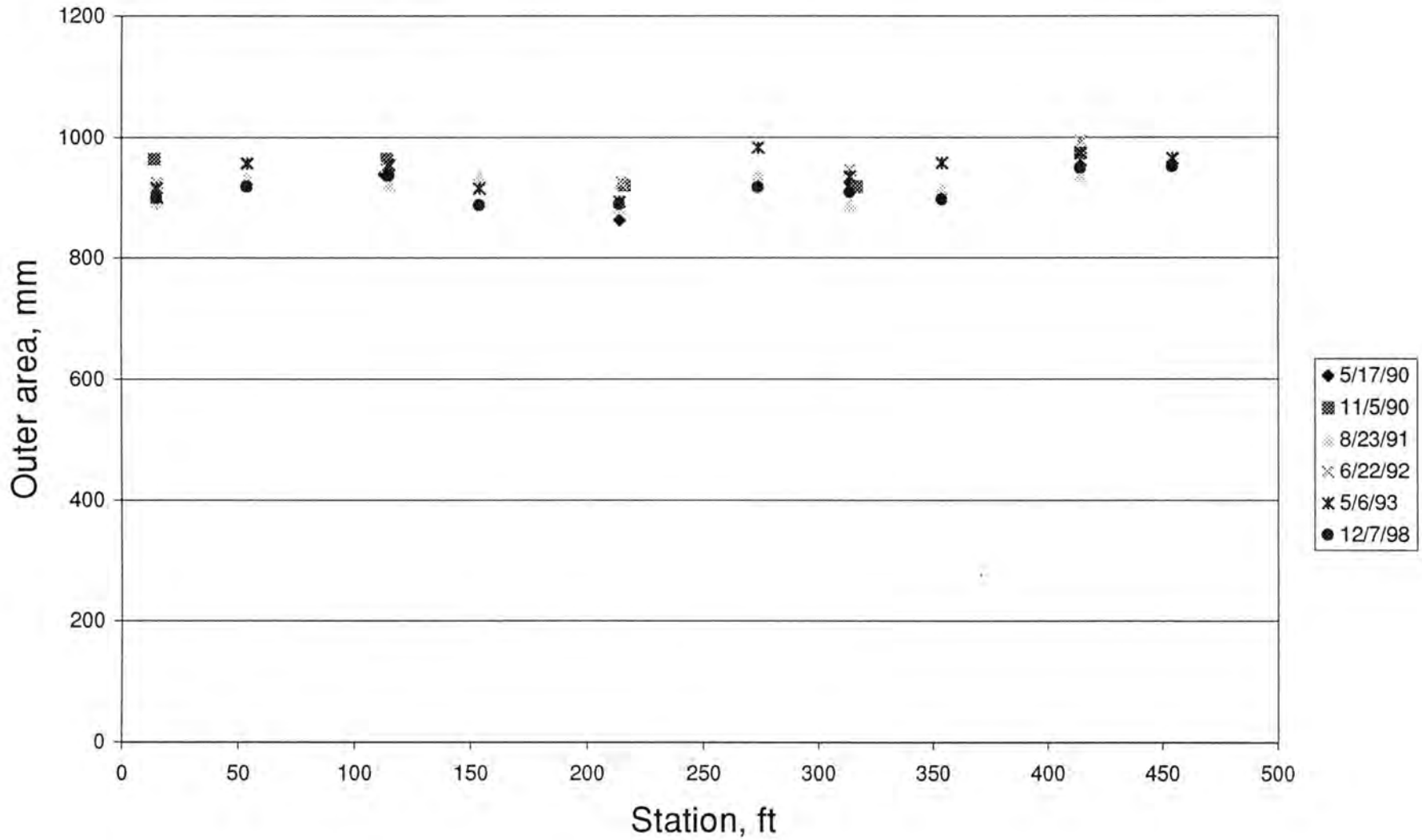
290709


1200
1000
800
600
400
200
0
Outer area, mm
0
100
200
300
400
500
600
Station, ft
5/17/90
11/6/90
8/27/91
6/24/92
5/11/93
9/21/94
1/12/99

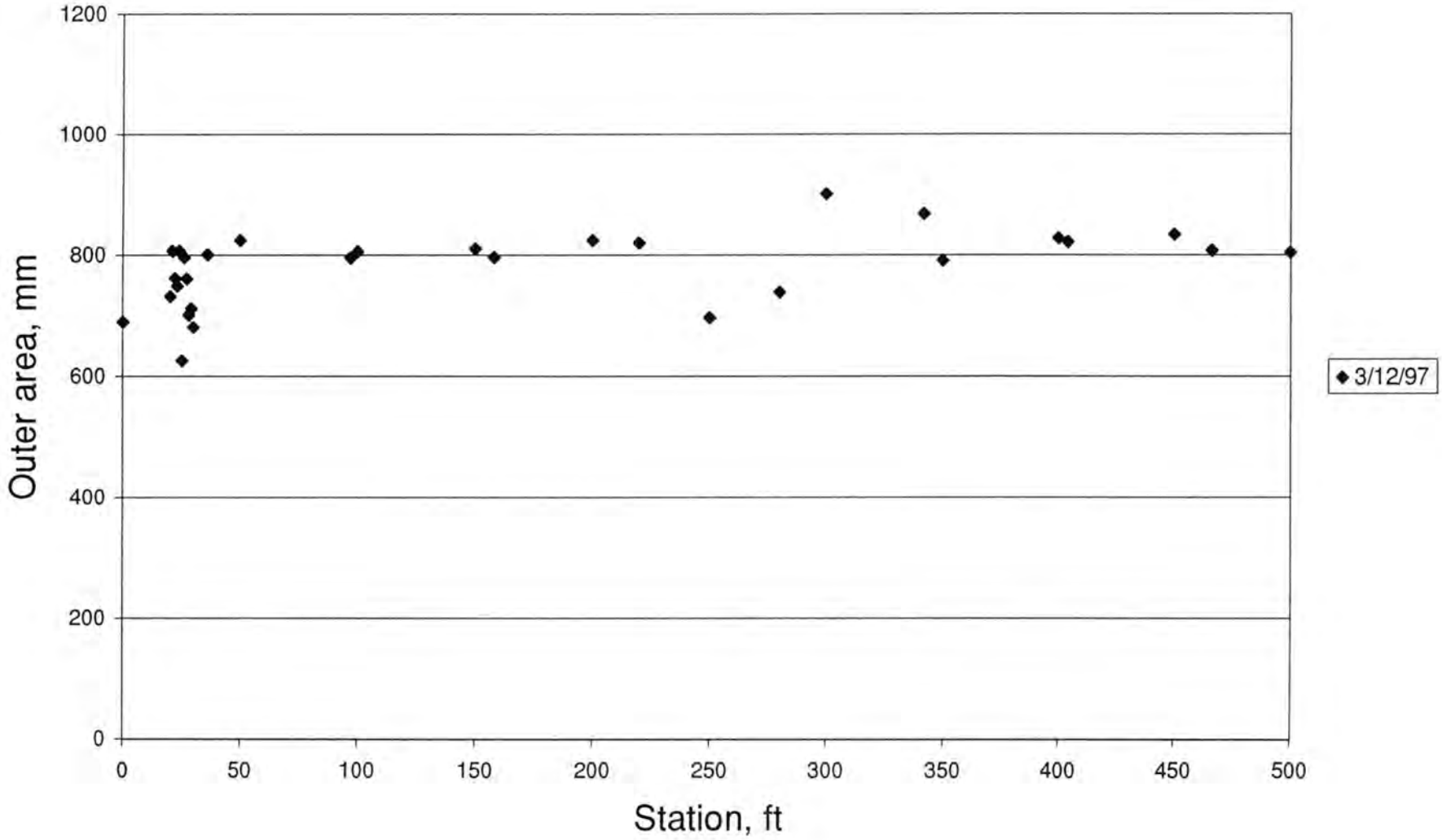
290759


1200
1000
800
600
400
200
0
Outer area, mm
0
50
100
150
200
250
300
350
400
450
500
Station, ft
5/17/90
11/5/90
8/23/91
6/22/92
5/6/93
12/7/98

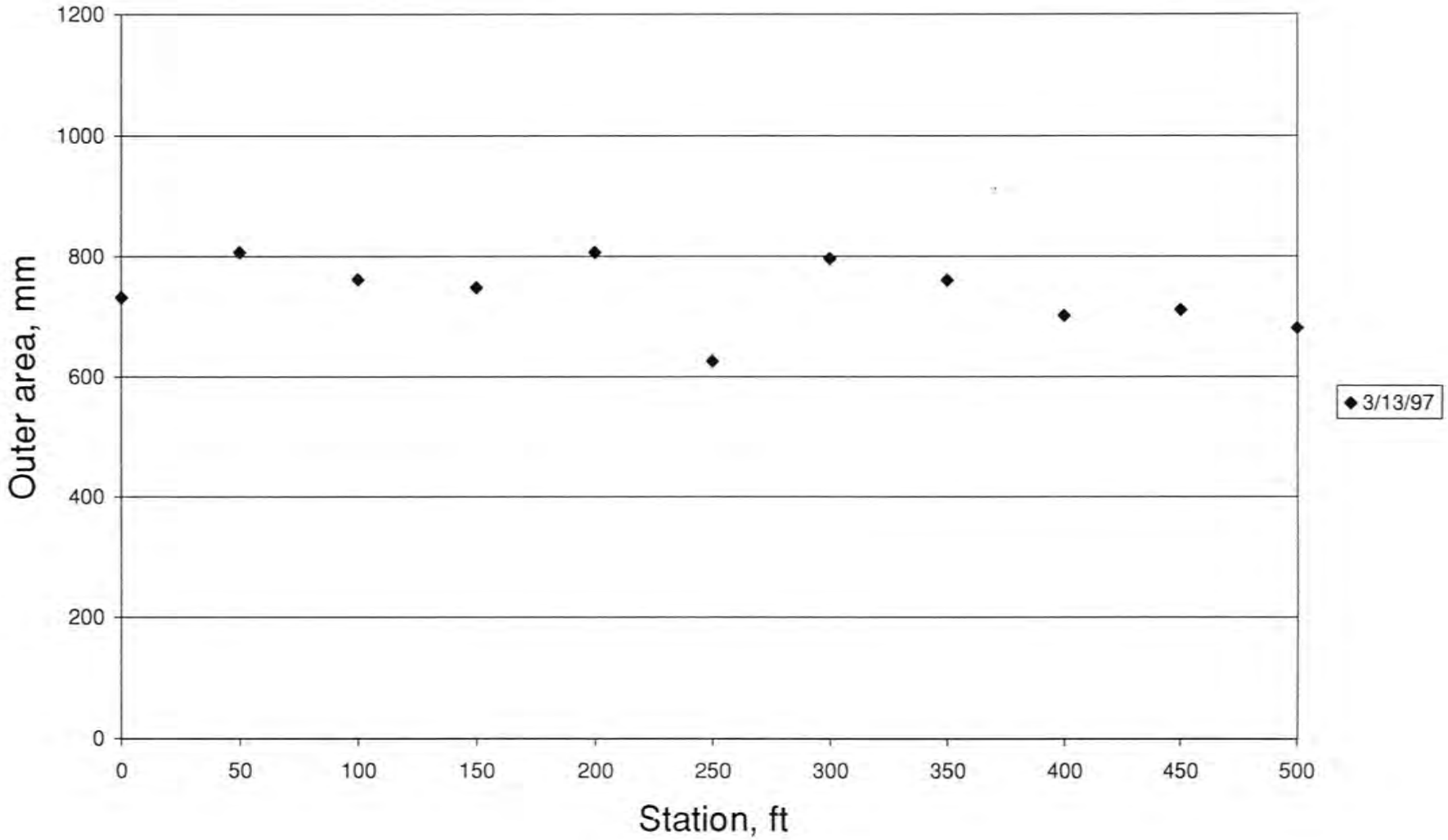
290760


1200
1000
800
600
400
200
0
Outer area, mm
0
50
100
150
200
250
300
350
400
450
500
Station, ft
5/17/90
11/5/90
8/23/91
6/22/92
5/6/93
12/7/98

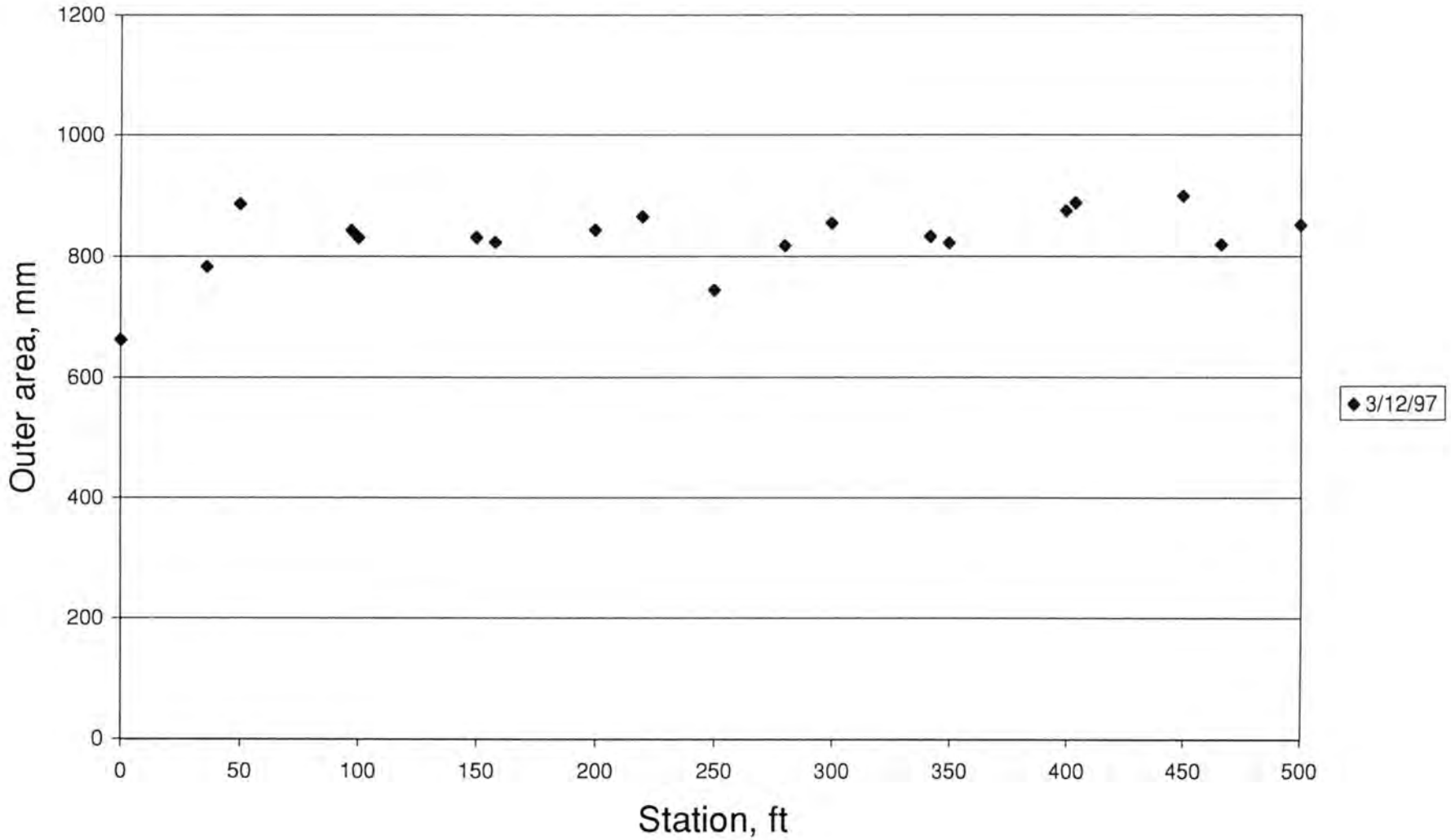
290901


1200
1000
800
600
400
200
0
Outer area, mm
0
50
100
150
200
250
300
350
400
450
500
Station, ft
3/12/97

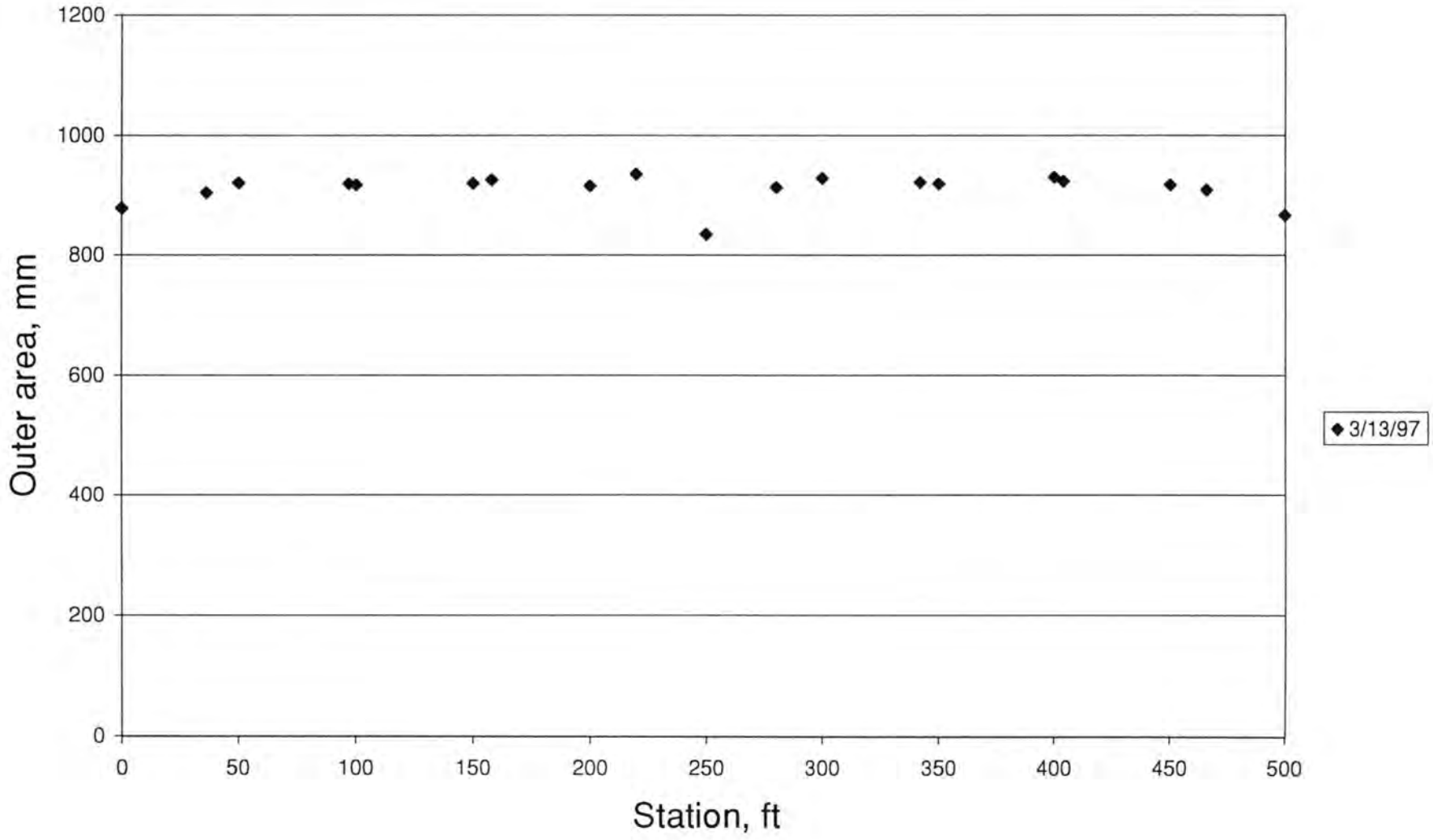
290902


1200
1000
800
600
400
200
0
Outer area, mm
0
50
100
150
200
250
300
350
400
450
500
Station, ft
3/13/97

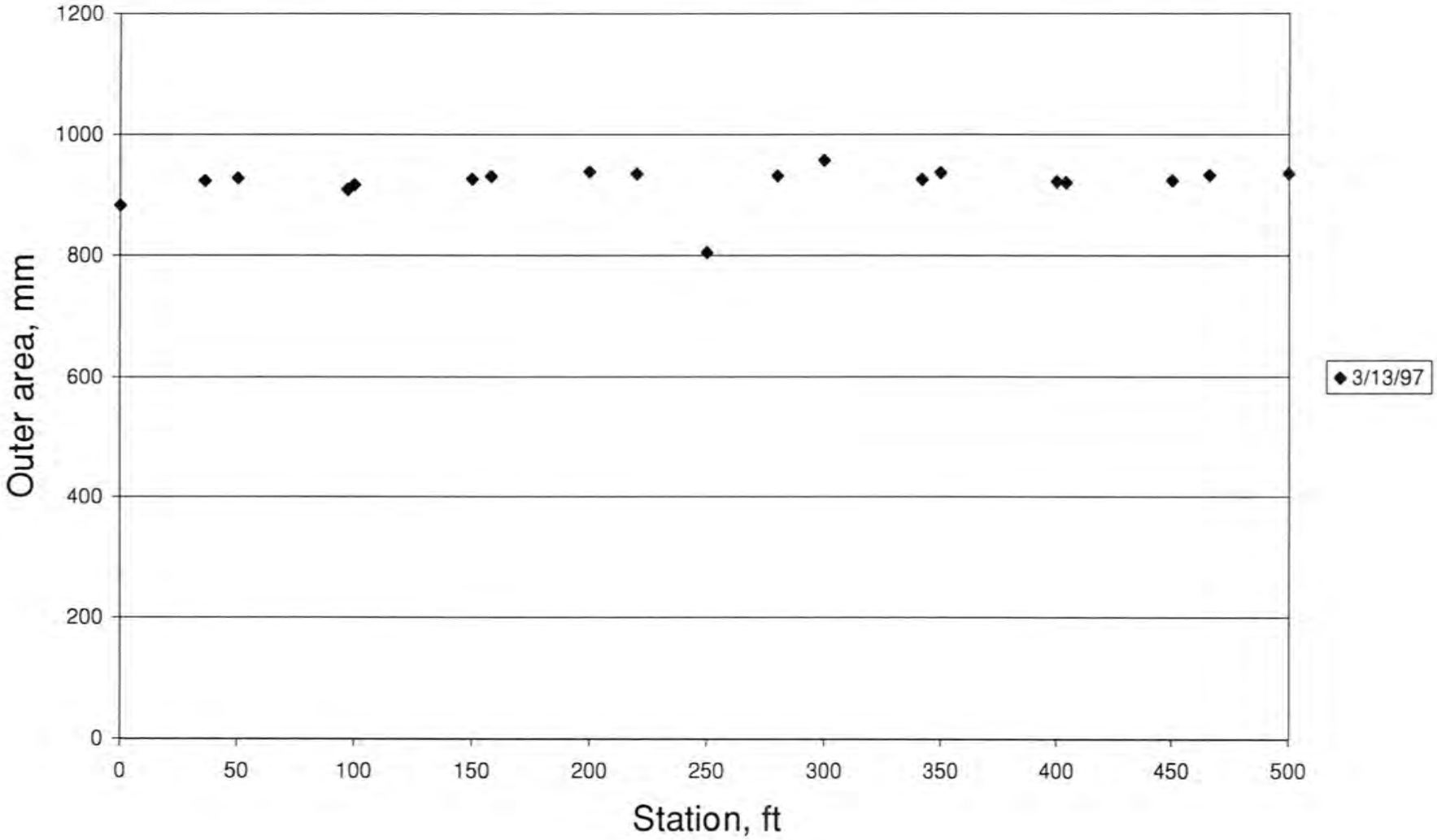
290903


1200
1000
800
600
400
200
0
Outer area, mm
0
50
100
150
200
250
300
350
400
450
500
Station, ft
3/12/97

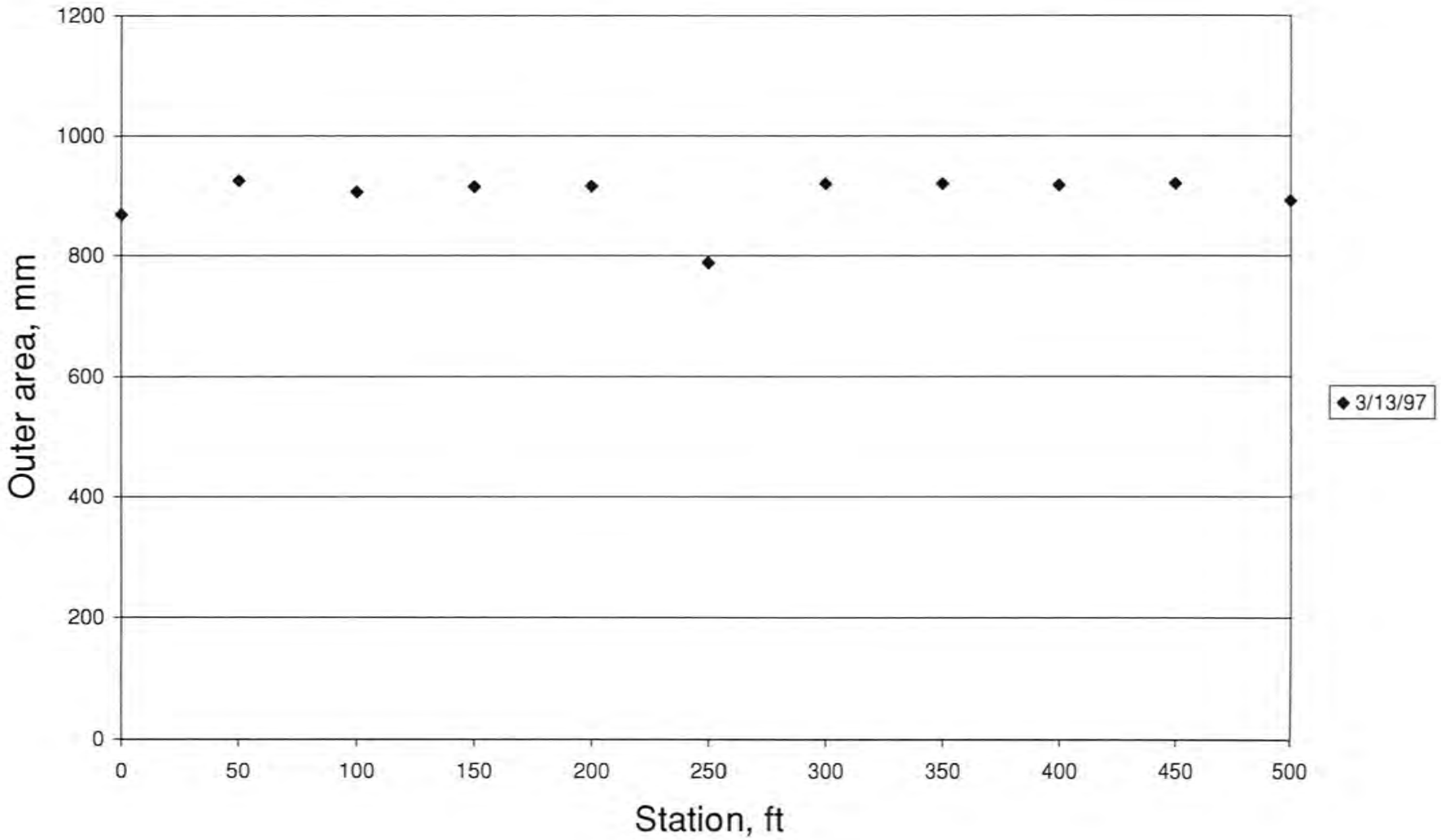
290959


1200
1000
800
600
400
200
0
Outer area, mm
0
50
100
150
200
250
300
350
400
450
500
Station, ft
3/13/97

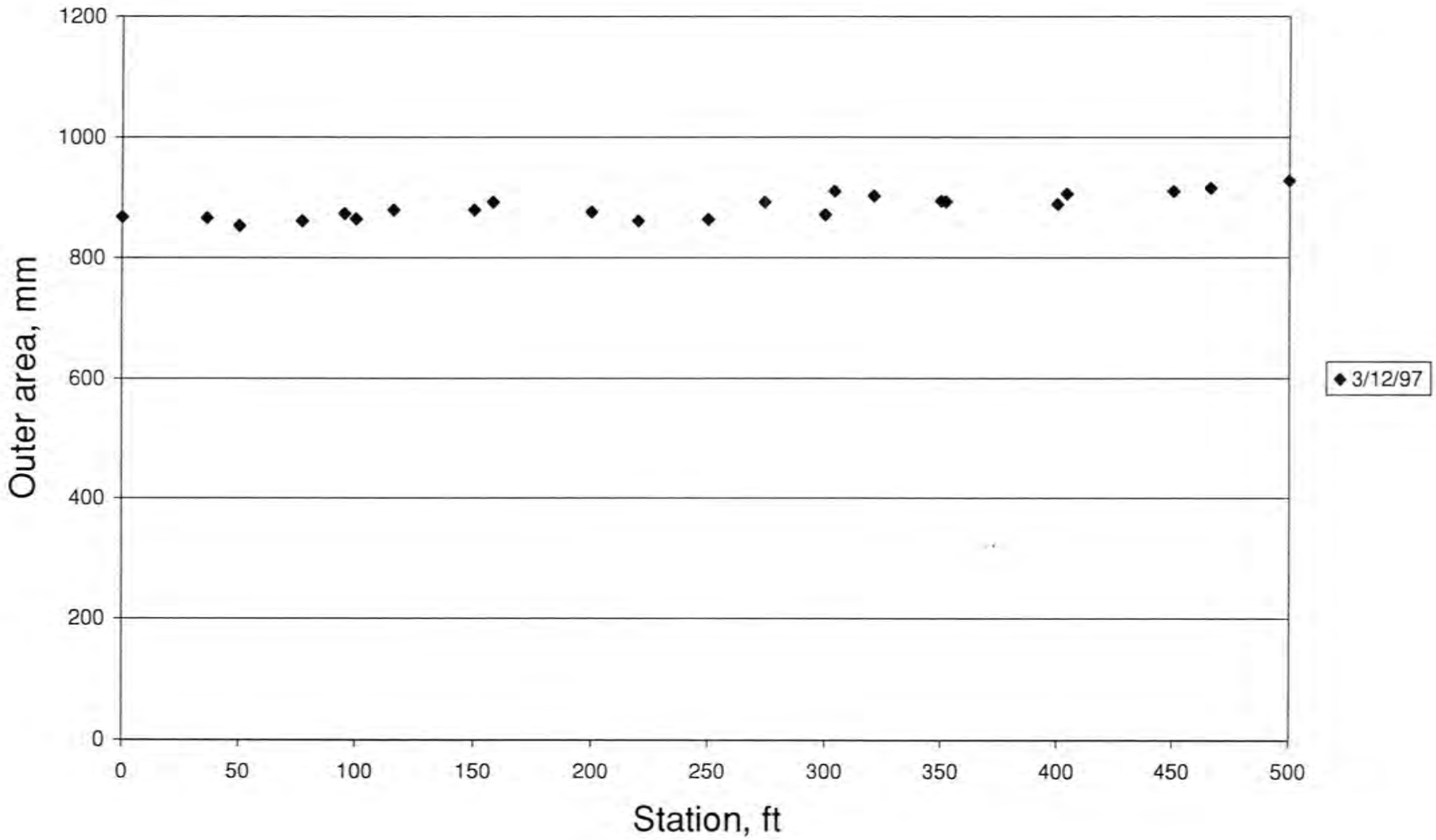
290960


1200
1000
800
600
400
200
0
Outer area, mm
0
50
100
150
200
250
300
350
400
450
500
Station, ft
3/13/97

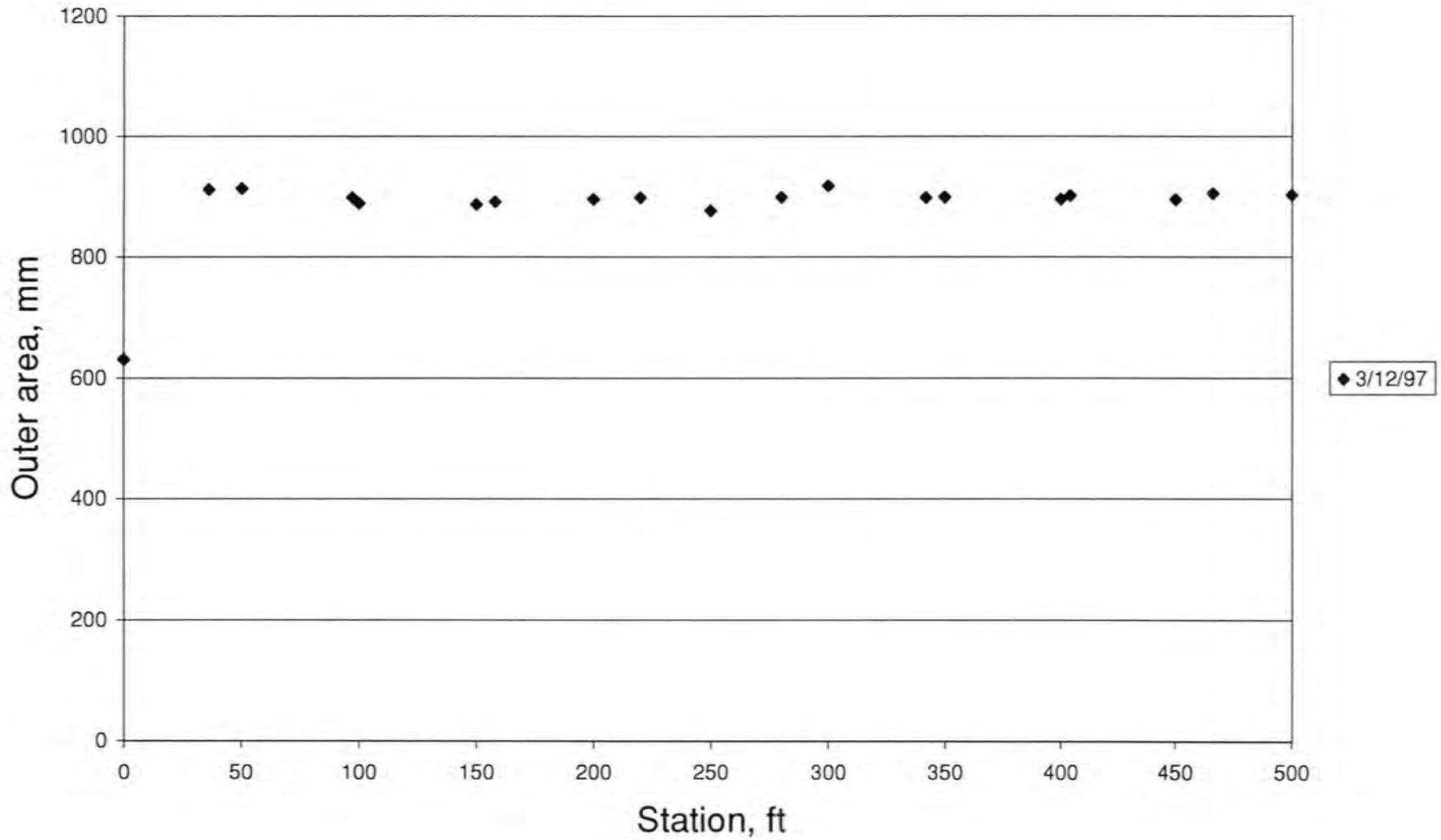
290961


1200
1000
800
600
400
200
0
Outer area, mm
0
50
100
150
200
250
300
350
400
450
500
Station, ft
3/13/97

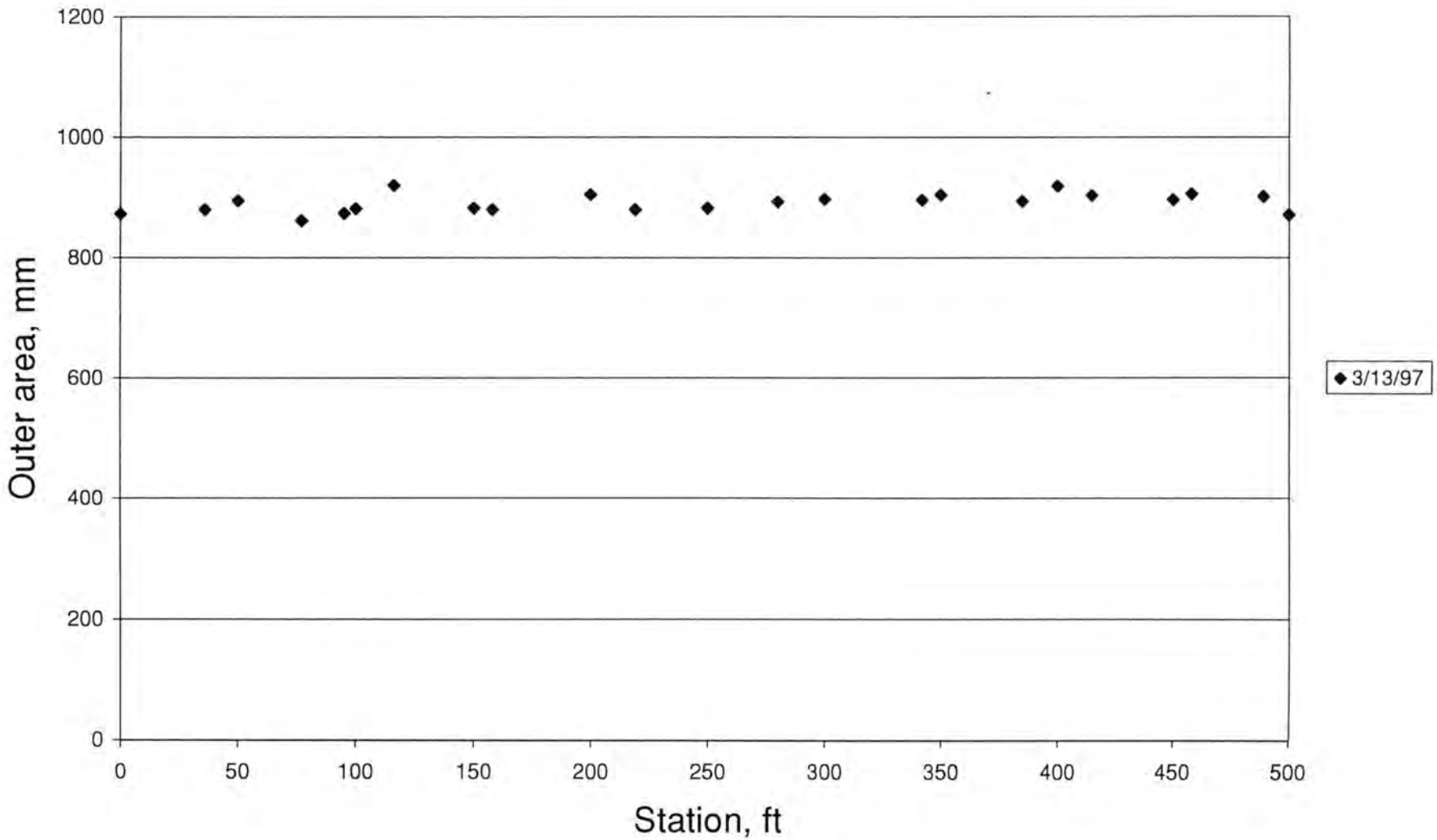
290962


1200
1000
800
600
400
200
0
Outer area, mm
0
50
100
150
200
250
300
350
400
450
500
Station, ft
3/12/97

290963


1200
1000
800
600
400
200
0
Outer area, mm
0
50
100
150
200
250
300
350
400
450
500
Station, ft
3/12/97

290964


1200
1000
800
600
400
200
0
Outer area, mm
0
50
100
150
200
250
300
350
400
450
500
Station, ft
3/13/97