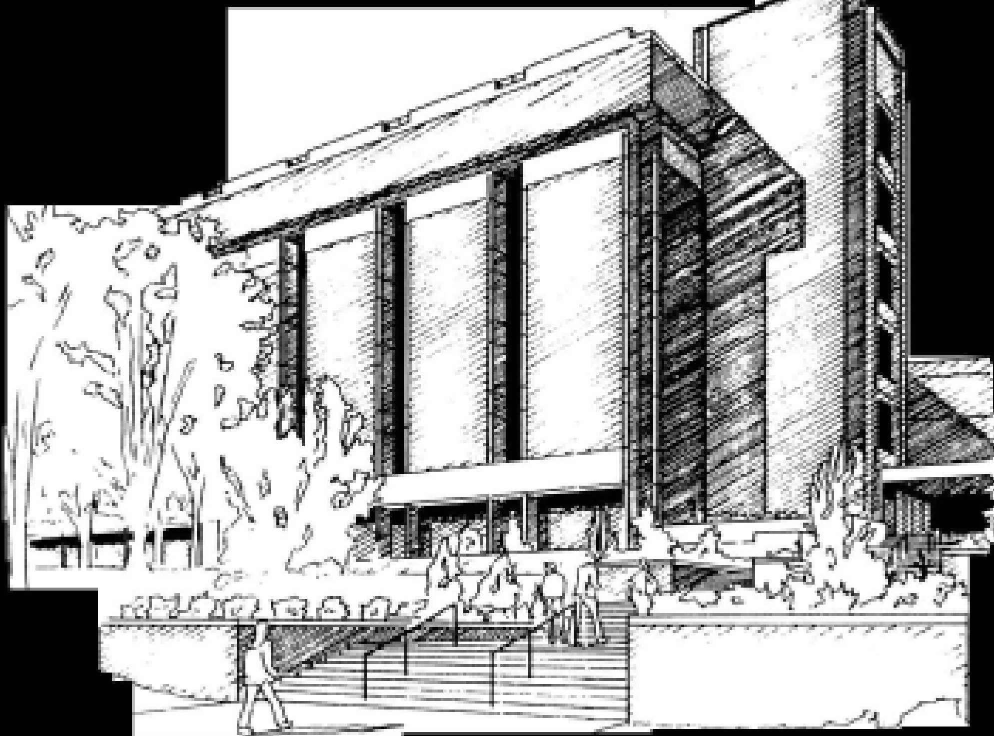

UNIVERSITY OF CINCINNATI
COLLEGE OF ENGINEERING
Department of Civil and Environmental Engineering

Ohio Route 50 Joint Sealant Experiment

State Job No.: 14668(0)

FINAL REPORT

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

April 2002

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16. Abstract

This research project entailed the construction and evaluation to date of a stretch of a four-lane highway near Athens, Ohio. The main purpose of this project has been to evaluate concrete pavement performance in connection with various sealant types and joint configurations in the Wet-Freeze climatic zone. Fifteen different material-joint configuration combinations have been used. The new pavement consists of a 250-mm (10-in.) jointed reinforced concrete slab with 21-ft joint spacing, placed over a 100-mm (4-in.) free-draining base layer, constructed over a 150-mm (6-in.) crushed aggregate subbase, resting over the predominantly silty clay local subgrade. The highway has a twenty year design period, with design traffic level of 11 million ESALs. The eastbound lanes were constructed first and have been open to traffic since Spring 1998, whereas the westbound lanes have been serving traffic only since Spring 1999. Three joint sealant, profilometer and pavement performance surveys are described in this Report. These evaluations were conducted in October 2000, June 2001, and October 2001 in accordance with an evaluation plan developed by the University of Cincinnati research team based on statistical principles. Sealant effectiveness values are calculated and treatments are ranked according to a rating scheme that describes each sealant type very good, good, fair, poor, or very poor. Results from these evaluations are analyzed and compared to those from earlier inspections to delineate the major trends exhibited by the test pavement. During the March 2000 evaluation, a significant flooding event was witnessed. The Hocking River, which runs along the highway, could not handle the amount of water from the storm. Several fields adjacent to the roadway were flooded and the drainage ditches overflowed. Following the flooding several transverse cracks were noticed in the pavement. Both the development of structural distresses and the drainage features of the pavement system are also examined in this Report. It is reported that significant mid-slab cracking has been observed in the test pavement, but that this distress appears unrelated to the performance of the sealant treatments. It is anticipated that pavement and sealant performance monitoring will continue for several years. Several recommendations for future investigations are formulated.

17. Key Words

Sealant; joints; drainage; concrete pavement; HPCP; wet-freeze; field evaluation; profilometer; roughness; open-graded base; midslab cracking

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Ohio Rout 50 Joint Sealant Experiment

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Ohio Department of Transportation and the
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by

University of Cincinnati
Cincinnati Infrastructure Institute
Department of Civil and Environmental Engineering
Cincinnati, OH

April 2002

Research Team: Anastasios M. Ioannides and Issam A. Minkarah *(co-PIs)*
Allen R. Long, Jason A. Sander and Bryan K. Hawkins *(Research Assistants)*

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Ohio Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

FOREWORD

The investigation described in this Report was sponsored by the Ohio Department of Transportation (ODOT) and by the Federal Highway Administration (FHWA) as Ohio State Job No.: 14668(0); Contract No.: 8527, under project "Ohio Route 50 Joint Sealant Experiment." The Principal Investigators were Drs Anastasios M. Ioannides and Issam A. Minkarah, Department of Civil and Environmental Engineering, University of Cincinnati. The ODOT Technical Monitor was Mr Roger Green, the Administrator for the Office of Research and Development at ODOT was Ms. Monique Evans, and the FHWA liaison in Columbus, OH was Mr Herman Rodrigo. The ODOT Site Engineer was Mr Greg Wright, the Site Manager for the Contractor (*Kokosing Construction Company, Inc.*) was Mr John Householder, the Contractor's Supervisor for Sealants was Mr Steve Geb. The assistance, cooperation and friendship of these individuals was a major contributor to the success of the study, and their support is gratefully acknowledged. Special thanks are also extended to the following persons: Messrs Jim Sargent and Brian Schleppi of ODOT, together with their able profilometer crews; Mr Ed Malone and the rest of the Contractor's sealant installation personnel; and MR Kurt D. Smith of *Applied Pavement Technology, Inc.*. The personal communications of Messrs. Greg Wright, Neil McKown, Aric Morse of ODOT, MR Bob McQuiston of FHWA-Columbus, OH, and of MR Lynn D. Evans of *ERES Consultants, Inc.* are acknowledged in the text of this Report.

Portions of this Report will be submitted by Allen R. Long to the Division of Research and Advanced Studies of the University of Cincinnati in partial fulfillment of the requirements for the degree of Master of Science in the Department of Civil and Environmental Engineering, in 2002.

ABSTRACT

This is the third and Final Report for a research project that entailed the construction and evaluation to date of a stretch of a four-lane highway near Athens, Ohio. The main purpose of this project has been to evaluate concrete pavement performance in connection with various sealant types and joint configurations in the Wet-Freeze climatic zone. A detailed description of previous work conducted from Fall 1996 to March 2000 can be found in Hawkins (1999) and in Sander (2002).

Fifteen different material-joint configuration combinations have been used. The new pavement consists of a 250-mm (10-in.) jointed reinforced concrete slab with 21-ft joint spacing, placed over a 100-mm (4-in.) free-draining base layer, constructed over a 150-mm (6-in.) crushed aggregate subbase, resting over the predominantly silty clay local subgrade. The highway has a twenty year design period, with design traffic level of 11 million ESALs. The eastbound lanes were constructed first and have been open to traffic since Spring 1998, whereas the westbound lanes have been serving traffic only since Spring 1999.

Three joint sealant, profilometer and pavement performance surveys are described in this Report. These evaluations were conducted in October 2000, June 2001, and October 2001 in accordance with an evaluation plan developed by the University of Cincinnati research team based on statistical principles. Sealant effectiveness values are calculated and treatments are ranked according to a rating scheme that describes each sealant type very good, good, fair, poor, or very poor. Results from these evaluations are

analyzed and compared to those from earlier inspections to delineate the major trends exhibited by the test pavement.

During the March 2000 evaluation, a significant flooding event was witnessed. Apparently in the days prior to the evaluation substantial amounts of rainfall had occurred. The Hocking River, which runs along the highway, could not handle the amount of water from the storm. Several fields adjacent to the roadway were flooded and the drainage ditches overflowed. The extensive flooding concerned the UC research team and an investigation of the drainage aspects of the test pavement was initiated soon after. Following the flooding several transverse cracks were noticed in the pavement. Both the development of structural distresses and the drainage features of the pavement system are also examined in this Report. It is reported that significant mid-slab cracking has been observed in the test pavement, but that this distress appears unrelated to the performance of the sealant treatments.

It is anticipated that pavement and sealant performance monitoring will continue for several years. Several recommendations for future investigations are formulated.

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LIST OF ABBREVIATIONS

ºC	Degrees Celsius
ºF	Degrees Fahrenheit
AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt Concrete
ADT	Average Daily Traffic
BSG	Bulk Specific Gravity
C	Drainage Coefficient
COV	Coefficient of Variation
EB	Eastbound
EBNV99	November 1999 sealant evaluation in the eastbound lanes
EBMR00	March 2000 sealant evaluation in the eastbound lanes
EBOC00	October 2000 sealant evaluation in the eastbound lanes
EBJN01	June 2001 sealant evaluation in the eastbound lanes
EBOC01	October 2001 sealant evaluation in the eastbound lanes
E_c	Modulus of Elasticity
ESAL	Equivalent Single Axle Load
F	Fair
FDB	Free Draining Base
FHWA	Federal Highway Administration
ft	feet

G	Good
GGBFS	Ground Granulated Blast Furnace Slag
HPCP	High Performance Concrete Pavements
in.	inches
IRI	International Roughness Index
IRIbh	International Roughness Index, both wheel tracks
IRIlf	International Roughness Index, left wheel tracks
IRIrt	International Roughness Index, right wheel tracks
J	Load transfer Coefficient
JPCP	Jointed Plain Concrete Pavements
JRCP	Jointed Reinforced Concrete Pavement
k	Modulus of Subgrade Reaction
km	kilometers
l	Radius of Relative Stiffness
L	Slab Length
m	meters
MAX	Maximum Value
MAYS	Mays Number
MIN	Minimum Value
mm	millimeters
M_R	Modulus of Rupture
NCDC	National Climatic Data Center

NSDB	Non-Stabilized Drainable Base
ODOT	Ohio Department of Transportation
P	Poor
PCC	Portland Cement Concrete
pci	Pounds per Cubic Inch
PEBNV99	November 1999 profilometer survey in the eastbound lanes
PEBMR00	March 2000 profilometer survey in the eastbound lanes
PEBOC00	October 2000 profilometer survey in the eastbound lanes
PEBJN01	June 2001 profilometer survey in the eastbound lanes
PEBOC01	October 2001 profilometer survey in the eastbound lanes
PIARC	Permanent International Association of Road Congresses
psi	Pounds per Square Inch
PSI	Present Serviceability Index
PWBNV99	November 1999 profilometer survey in the westbound lanes
PWBMR00	March 2000 profilometer survey in the westbound lanes
PWBOC00	October 2000 profilometer survey in the westbound lanes
PWBJN01	June 2001 profilometer survey in the westbound lanes
PWBOC01	October 2001 profilometer survey in the westbound lanes
SHRP	Strategic Highway Research Program
SL	Self Leveling
SPS	Specific Pavement Studies
Sta	Station

StDev	Standard Deviation
UC	University of Cincinnati
U.S.	United States
VG	Very Good
VP	Very Poor
WB	Westbound
WBNV99	November 1999 sealant evaluation in the westbound lanes
WBMR00	March 2000 sealant evaluation in the westbound lanes
WBOC00	October 2000 sealant evaluation in the westbound lanes
WBJN01	June 2001 sealant evaluation in the westbound lanes
WBOC01	October 2001 sealant evaluation in the westbound lanes

1 INTRODUCTION

1.1 Introduction

In 1992, a number of state, federal and industry pavement engineers from the United States (U.S.) participated in a tour of several European countries for the purpose of reviewing their practices and experiences with regard to improving Portland cement concrete (PCC) pavement performance. In the aftermath of this tour, a program was formulated by the Federal Highway Administration (FHWA) for assessing the effectiveness of a number of innovative concrete pavement design and construction features. The ultimate aim of the program is the design and construction of high performance concrete pavements (HPCP). These pavements will be characterized by three attributes: incorporation of innovative design and construction features and materials; enhanced construction techniques that lead to increased productivity; and ride quality and prolonged service life, resulting in lower life cycle costs. The immediate goal of the HPCP program is to construct selected highway projects across the U.S. to investigate innovative PCC pavement design and construction concepts. The long-term objective is to improve PCC pavement performance through innovations and research into their design, materials, construction technology and equipment, as well as evaluation of promising pavement technology developments from other countries.

Fifteen projects have been approved for funding under the HPCP program since its inception in 1996, including three in the state of Ohio. All three Ohio projects, developed by the Ohio Department of Transportation (ODOT) in collaboration with the FHWA, are located along a stretch of reconstructed PCC pavement on U.S. 50, outside the city of Athens, Ohio. One of these projects is designed to evaluate PCC pavement performance in connection with various sealant types and joint configurations, including unsealed transverse joints.

Since the early 1940s, joint sealants have been an integral part of practically all jointed plain concrete pavements (JPCP) or jointed reinforced concrete pavements (JRCP). Previous studies in Ohio and elsewhere have demonstrated that joint sealing techniques have the potential of making a significant contribution to the performance of such pavements. Sealants are thought to provide protection to the pavement in two important ways. First, by sealing joints, infiltration of moisture into the pavement base and subgrade is reduced. Such moisture would otherwise lead to softening, pumping, and erosion of these layers, resulting in joint faulting and corner breaks in the slab. Secondly, sealing the joints prevents incompressible materials, such as small stones, from entering them and becoming lodged. Such incompressibles can inhibit thermal slab movement, increasing the stresses in pavement slabs and leading to joint spalling and transverse cracking.

Serious consideration, however, must be given to the practical aspects of joint sealing if the sealant is to work effectively. Most importantly, the process of sealing joints requires careful and experienced installation and inspection. The joint must be washed, sandblasted, and cleaned before the backer rod and sealant are introduced, in order to prepare vertical, intact and clean bonding surfaces that are dry and free of contaminants. If proper construction procedures are not followed carefully, the sealant may not form a good bond with the concrete slab and infiltrating moisture may not be reduced as effectively. Improperly installed sealants are also subject to premature deterioration from the weather and traffic. If the sealants are installed too far below the pavement surface, incompressibles are likely to enter the joints. Conversely, if installed at or slightly above the pavement surface, vehicle tires are likely to damage or destroy the sealant. Moreover, the sealant must be installed under suitable weather conditions, with virtually no moisture present in any form. Given the stringency of cleaning and installation procedures, it is advisable to have someone inspecting these operations as they proceed. Without such inspection, a great deal of effort and money could be wasted on ineffective seals.

This is the Final Report submitted in fulfillment of the contractual obligations of the University of Cincinnati research team, selected by ODOT to conduct the sealant experiment under the TE-30 High Performance Concrete Pavement initiative of the FHWA. The Report describes the design and construction of the U.S. 50 test pavement, together with the experimental design for the sealant investigation. Monitoring activities are discussed and the sealant and pavement performance to date is presented, thereby providing an update to two prior publications published in the technical Literature (Hawkins, *et al.*, 2001; Ioannides, *et al.*, 2001), as well as two previous interim reports submitted to ODOT by the research team (Hawkins, 1999; Sander, 2002).

1.2 Project Objectives

This Report describes the research experiment near Athens, Ohio involving the installation of various joint sealants in the transverse joints of a newly constructed PCC pavement. The experimental design for this project was developed in 1997 by the FHWA and ODOT to provide data for the evaluation of the performance of various joint seals and joint configurations. Fifteen combinations of materials and joint configurations are used in the experiment, which includes unsealed control sections. The purpose of these pavement test sections, located in the Wet-Freeze climatic zone, is to duplicate and complement similar sections constructed in other states under the Strategic Highway Research Program (SHRP) Specific Pavement Studies (SPS)-4 experiment. The test pavement is divided into fifteen test sections, each section typically being 183 m (600 ft) in length, but also includes some longer sections. Each test section incorporates about thirty joints. In accordance with the experimental design, two replicates of each of fifteen chosen material-joint configuration combinations are provided. Two of these combinations involve unsealed joints. In each case, one replicate is in the eastbound lanes, built during the 1997-98 construction season, and the other in the westbound lanes, placed during the 1998-99 construction season. In constructing the test sections, the following objectives were established:

(a) To assess the effectiveness of a variety of joint sealing practices employed after the initial sawing of joints, and to examine their repercussions in terms of reduced construction time and life cycle costs;

(b) To identify those materials and procedures that are most cost effective; and

(c) To determine the effect of joint sealing techniques on pavement performance.

1.3 Literature Survey

1.3.1 Conventional Wisdom

Joint sealants are currently used in highway pavements in order to minimize passage of surface water through joints and cracks, in conjunction with a permeable subbase designed to remove water from the pavement system (Voigt, 1997). This leads to the question of whether both these lines of defense are necessary, or whether it might be more cost effective not to seal the joints, and to rely instead on the permeable subbase and on other associated subsurface drainage features to remove the water. The answer to this question has been the subject of increasing controversy in the U.S. in recent years.

In a survey of state highway agencies (McGhee, 1995), the following philosophies on drainage were recorded. Thirty states strive to seal pavements as well as possible, while also attempting to control the water through use of a drainage layer, other subsurface drainage, or both. Nine states try to seal the pavement as well as possible, but are not concerned with subsurface drainage. The remaining eleven states take the position that water will inevitably enter the pavement system, and seek only to control it through use of a drainage layer, other subsurface drainage, or both, rather than relying on the effectiveness of joint sealants. Only one of these eleven states, Wisconsin, dispenses with joint sealing entirely.

1.3.2 The Wisconsin Experience

The state of Wisconsin has been performing research on the desirability of joint sealing for the past fifty years. They have investigated this problem from a variety of angles, and have considered locations in both urban and rural areas, various traffic levels and weights, base courses and subgrades, joint spacings, load transfer means, and so on. From this voluminous research, the conclusion was drawn that joint sealing does not enhance pavement performance (Shober, 1997) and that contraction joint sealing costs cannot be justified (Shober, 1986). Thus, in 1990 the state of Wisconsin determined there were sufficient data to warrant the decision not to seal cracks or joints in PCC pavements.

The state of Wisconsin began this research by questioning the assertion that joint seals enhance pavement performance by keeping incompressibles out of the joints and by preventing the infiltration of water. It was argued that this theory might have had merit when PCC slabs were constructed above the bare subgrade, but that with the present use of subbase and base courses to provide drainage, it may no longer be entirely true. If an unsealed pavement remains in as good a condition as a sealed pavement, then it is obvious that sealing is not a cost-effective procedure. In their research, Wisconsin investigators evaluated both sealed and unsealed PCC pavements in terms of distress development, ride quality, bridge encroachment, and materials integrity. Their findings indicate that joint sealing has no significant effect on any of these parameters, and reaffirm that pavements with shorter joint spacings perform better than pavements with longer joint spacings (Shober, 1997).

Earlier published literature from Europe had suggested similar conclusions. In 1979, at the 16th World Congress of the Permanent International Association of Road Congresses (PIARC), the Technical Committee on Concrete Roads presented a report, which concluded that for joint spacings of 4 to 6 m (13 to 20 ft), there was no disadvantage in leaving narrow transverse joints unsealed when: (a) traffic is light; (b) traffic is heavy but the climate is dry; and (c) traffic is heavy and the climate is wet, but the pavement is doweled (Ray, 1980).

1.3.3 The SHRP SPS-4 Experiment

The answer to the question of whether or not joint sealing can or does improve pavement performance remains the subject of intense debate. There are many variables at work and a myriad of questions and unknowns surrounding this issue. The SHRP SPS-4 supplemental joint seal experiment was designed to provide valuable information on the subject of joint sealing. Long-term monitoring was performed on six research sites in the western United States (Smith, *et al.*, 1999) . An interesting trend can be observed in the data that reflect the overall performance of transverse joint seals at each site. In preparing the joints for sealant placement, water- and air-blasting were the only means of joint cleaning at three of the test sites (in Utah), whereas at the other test sites sandblasting was required, as well. The three Utah sites clearly exhibit inferior performance compared to the other sites. This suggests that sandblasting is probably an important factor in ensuring high quality, long-lasting sealed joints. It is worth noting that the experimental factorial adopted at the U.S. 50 joint sealant project is intended to replicate the corresponding factorials developed for the SHRP SPS-4 studies, so that comparable data are collected in the Wet-Freeze climatic zone, heretofore absent from similar considerations elsewhere.

1.4 Report Organization

This Report summarizes the monitoring and evaluation activities performed by the University of Cincinnati research team at the U.S. 50 joint sealant test site throughout the contract period (November 1996-May 2002). A brief literature review focusing on the recent controversy regarding the use of joint sealant materials and procedures has been presented in this first Chapter. Chapter 2 provides a description of the U.S. 50 test site, detailing the layout of the project and including the test pavement cross-section and the subdivision of the highway stretch into sealant test sections. Both design considerations and construction procedures are examined. Summarized in Chapter 3 are early sealant and pavement performance evaluations, i.e., two visual inspections undertaken in Fall 1998 and Spring 1999, and two quantitative evaluations performed in Fall of 1999 and Spring 2000. The latter two were conducted in accordance to a performance evaluation plan that calls for the use of specially developed form in monitoring activities and data collection. Chapter 4 presents summaries of the field performance data collected in Fall 2000, Spring 2001 and Fall 2001, pertaining to both the sealant and the overall pavement condition. In Chapter 5, results from a detailed statistical analysis of the sealant and pavement performance data are given. Trends in sealant performance are examined and the effectiveness of each material and joint configuration to date is summarized. An evaluation of the drainage features at the U.S. 50 test site is presented in Chapter 6, along with some recommendations formulated in order to ensure their continued effectiveness. Finally, Chapter 7 summarizes the outcomes of this study and provides a list of recommendations for future investigations.

2 THE U.S. 50 TEST SITE

2.1 Project Location and Description

The test site under investigation is a 3.3-km (2.0-mile) section of a new 10.5-km (6.5-mile), four-lane divided highway constructed along a stretch of United States (U.S.) Route 50 approximately 1.3-km (0.8-mile) east of the city of Athens, in Athens County, southeast Ohio. The experimental pavement is part of a 10.5-km (6.5-mile) stretch of U.S. 50 under reconstruction. The project lies in the Wet-Freeze climatic zone, where the local mean annual precipitation is 980 mm (38.6 in.). Of this, 533 mm (21 in.) usually accumulates between the months of April and September. In the higher elevations of Athens County, winters are cold and snowy, with a mean annual snowfall of 447 mm (17.6 in.). In the valleys, it is also frequently cold, but intermittent thaws prevent a long-lasting snow cover. During the winter months, the average temperature is 0EC (32EF) and the average daily minimum temperature is -6EC (21EF). The average summer temperature is 22EC (71EF), with an average daily maximum temperature of 29EC (85EF). The mean monthly average temperature is 12EC (53EF). The low average monthly temperature is 0EC (32EF), whereas the high average monthly temperature is 24EC (75EF). Construction of the U.S. 50 test site in the Wet-Freeze zone eliminates a gap in the on-going Strategic Highway Research Program (SHRP) Specific Pavement Studies (SPS)-4 experiment, which is investigating the effectiveness of various joint sealing techniques in different climatic regions across the United States.

This reconstructed four-lane highway has a twenty year design period, with current (1993) average daily traffic (ADT) of 7820 and design year (2013) ADT of 10950. The design traffic level is 11 million Equivalent Single Axle Loads (ESALs) and the truck percentage is 9%. The pavement cross-section consists of a 250-mm (10-in.) plain, jointed, wire-reinforced Portland cement concrete (PCC) slab (Item 451), placed over a 100-mm (4-in.) crushed aggregate, free-draining base layer (Item Special), constructed over a 150-mm (6-in.) crushed aggregate subbase (Item 304), resting over the predominantly silty clay local subgrade.

In both the eastbound and westbound directions, the highway consists of two 3.7-m (12-ft) wide lanes having tied PCC shoulders. On the inner (i.e., abutting the median) and outer sides of the pavement, the shoulders are 1.2 and 3-m (4 and 10-ft) wide, respectively. Transverse joints, spaced every 6.4 m (21 ft), are fitted with epoxy-coated steel dowels that are 38 mm (1.5 in.) in diameter and 460 mm (18 in.) in length. The dowels are supported on baskets and are placed 305 mm (12 in.) on center, starting at 150-mm (6-in.) from the shoulder joint. The longitudinal center line and shoulder joints are tied with 16-mm (0.625-in.) diameter, 760 mm (30 in.) long deformed steel bars spaced every 760 mm (30 in.).

In addition to the sealants experiment, the pavement accommodates two other tests, all conducted under the TE-30 High Performance Concrete Pavement (HPCP) initiative of the Federal Highway Administration (FHWA). For the purposes of these tests, 25% of the cement in the PCC slab mix was replaced by ground granulated blast furnace slag. For freeze-thaw durability purposes, the coarse aggregate in the mix was

No. 8 gravel (9.5-mm or 3/8-in. maximum size). Some of the steel dowels in the slab were replaced by fiberglass ones or by stainless steel tubing filled with concrete.

2.2 Joint Sealant Test Sections

Test sections are the numbered portions of the highway pavement that encompass one of fifteen specific sealant material and joint configuration combinations, referred to as a treatments, for some distance or number of joints. For this experiment, the pavement is divided into thirty different test sections, which are typically 183 m (600 ft) in length, with approximately thirty transverse joints per section. In general, two replicate sections of each treatment were constructed, one in the eastbound and the other in the westbound lanes. One of the primary objectives of the experiment is to determine whether or not there is a distinct advantage in using one type of treatment over another as it relates to pavement performance. In the eastbound lanes of the project, the test sections are located between Stations 154+00 and 290+00, while those in the westbound lanes begin at Station 133+60 and end at 290+00. Transverse joints between Stations 231+00 and 260+00 in both directions are not included in the experimental design nor in the performance evaluations. This stretch corresponds to the location of the batch plant and of the headquarters of the project contractor (*Kokosing Construction Company, Inc.*), an area of intense and heavy truck traffic.

Table 2.1 shows the sealant type, test section stations, joint width, length, and number of joints in each of the test sections. Ten different joint sealants are used in the test sections, in addition to those intentionally left unsealed. Of the ten sealant types, two are single component, hot-applied sealants, four are silicone sealants, and three are pre-formed compression seals, as follows: Crafco 221 and Crafco 444; Crafco 903-SL, Dow 890-SL, Crafco 902, and Dow 888; and Delastic V-687, Watson Bowman WB-687 and 812, and Techstar W-050. Four test sections were intentionally left unsealed to evaluate the effects of unsealed joints on pavement performance. In this experiment, six joint configurations or designs (numbered 1 through 6) were used, as shown in Figure 2.1. Only configurations 1, 3 and 5 received a secondary cut, and backer rod was placed in designs 1, 3 and 4 only. Configurations 2 and 6 were used in unsealed test sections, whereas designs 1, 3 and 4 were used for liquid sealants. All transverse joints requiring the use of a compression seal had joint configuration 5. By combining the various sealant materials and joint configurations, a total of fifteen different treatments were formed. A detailed description of each sealant material and joint configuration installed at the U.S. 50 project can be found in Hawkins (1999), which also presents manufacturer supplied product literature in the accompanying appendix.

The two hot-applied sealants are both manufactured by *Crafco Inc.* of Chandler, Arizona. The first is the *Crafco Superseal 444/777*, a fuel resistant sealant specifically intended for sealing PCC pavements in moderate to hot climates. This sealant is initially liquid and is poured into a melter application unit, which heats the sealant to the application temperature. The product data sheet advises that this sealant should only be applied when ambient air temperature is between 10°C (50°F) and 32°C (90° F).
The second hot-applied sealant used is the *Crafco Roadsaver 221*. This petroleum-based

pavement crack and joint sealant is intended for use in moderate to cooler climates. It is initially in solid block form, and is heated before application using either a pressure feed melter applicator unit or a pour pot. The product data sheet recommends that application should be at pavement temperatures of 4ºC (40ºF) or higher, and that the joint should be shaped so that the sealant reservoir depth-to-width ratio does not exceed 2:1.

Of the four silicone sealants used, two are also manufactured by *Crafco, Inc.* The first is *the Roadsaver Silicone SL* (also designated as Crafco 903-SL), a self-leveling, jet-blast resistant, silicone sealant that can be used in all climates. It is applied using a bulk dispensing system unit and requires neither tooling nor the use of primers.

The second silicone joint sealant manufactured by *Crafco, Inc.* is the *Roadsaver Silicone Sealant* (also called Crafco 902). This is a low modulus, non-sag silicone sealant intended for use in PCC pavements without requiring any primers. It possesses the same qualities as the Crafco 903-SL, except that it is not self-leveling but must be tooled to ensure adequate contact and adhesion with the joint walls.

The other two silicone sealants used are manufactured by *Dow Corning Corporation* of Midland, Michigan. The first is the Dow 888, a one-part, cold-applied silicone joint sealant that requires no use of primers and is virtually unaffected by sunlight, rain, snow, ozone or temperature extremes. The product data sheet recommends that the sealant should not be applied to damp concrete or installed in inclement weather. Since it is a non-sag silicone sealant, it must be tooled to ensure adequate contact and adhesion to an appropriate depth. It is applied directly from a bulk container into the joint by a hand- or an air-powered pump.

The last silicone sealant is the self-leveling, one-part, cold-applied Dow 890-SL, which requires no use of primers and is resistant to climatic extremes. It has the same restriction as the Dow 888, i.e., that it should not be applied if moisture is present in any form. Since it is self-leveling, it requires no tooling and is applied using a hand- or air-powered pump.

Turning now to the compression seals included in this experiment, the Delastic V-687 compression seal is manufactured by *The D.S. Brown Company* of North Baltimore, Ohio and has a width of 17.5-mm (11/16-in.). It is a preformed neoprene compression seal and is installed with the help of an adhesive lubricant, either by hand or with the help of an installation machine. The data sheet advises that the seal must be installed with 3% or less stretch to prevent premature failure.

Two of the compression seal types used are manufactured by *Watson Bowman Acme* of Amherst, New York. In the eastbound lanes, the WB-687 compression seal was installed, whereas in the westbound lanes the WB-812 was called for. These are preformed neoprene compression seals, distinguished mainly in their width and height dimensions: the WB-687 is 17 mm (11/16 in.) wide by 17 mm (11/16 in.) high, whereas the WB-812 is 21 mm (13/16 in.) wide by 22 mm (7/8 in.) high. According to the product data sheet, the recommended installation procedures include cleaning the joint with compressed air and applying *BonLastic* adhesive to the inner faces of the joint. The sealant is then placed along the joint and compressed into place to the desired depth.

The Techstar W-050 *W-Seal* is manufactured by *Techstar, Inc.* of Findlay, OH. Strictly speaking, this is not a compression seal, but it is included in this category for the sake of convenience. It is made of Santoprene thermoplastic and is installed after a Techstar adhesive has been applied to the joint. The seal is initially flat but it is folded as it is fed into an installation tool, which inserts the seal into the adhesive-lined joint. The contractor's crew reported some difficulties with the placement of this seal in the eastbound lanes (Steve Geib and Ed Malone, 1998: personal communication); the manufacturer's representatives oversaw its installation in the westbound direction. Information provided by the manufacturer claims that this seal is stretch-proof and requires less recess from the pavement surface than other seals.

2.3 Pavement Design Considerations

2.3.1 Input Parameters

The 1993 American Association of State Highway and Transportation Officials (AASHTO) design procedure for rigid pavements was used by *Parsons Brinkerhoff, Inc.* as contractor to the Ohio Department of Transportation (ODOT) in determining the required slab thickness. Expected 80-kN (18-kip) equivalent single axle loads (ESALs) over the anticipated twenty year design period of the pavement were estimated based on traffic survey data collected in 1991. At the start of the design period, the average daily traffic (ADT) count was 7820 vehicles. At that time, the percentage of trucks, T, in the ADT was 16%. The directional distribution factor, D, was assumed to be 50% for the analysis. The design year (2011) ADT was estimated to be 10,950. Interpolating between the 1991 and 2011 ADTs, the 20-year average (2007) ADT was determined to be 10,324. The U.S. 50 test pavement was given the functional classification rural principal arterial. Based on the information above, it was determined that the pavement would be subjected to approximately 11 million ESALs over the twenty year design life of the pavement.

Design variables unique to concrete pavements include modulus of rupture, M_R, concrete modulus of elasticity, E_c, modulus of subgrade reaction, k, as well as the load transfer coefficient, J, and drainage coefficient, C. Values of E_c and M_R selected for the pavement design were 24.8 GPa (3,600,000 psi) and 4.8 MPa (700 psi), respectively. To characterize subgrade support, a k-value of 27 MN/m^3 (100 pci) was conservatively chosen to represent seasonal changes in the condition of the underlying soil and the impact it may have on design slab thickness. The load transfer coefficient is intended to reflect the ability of a concrete pavement to transfer load across joints and cracks. Due to the presence of tied concrete shoulders and dowel reinforced transverse joints in the pavement, a load transfer coefficient of 2.80 was selected. The quality of drainage and the duration of saturation levels in the underlying granular layers are reflected in the drainage coefficient. A coefficient of 1.0 was selected as appropriate for the drainage provisions at the test pavement, which include an open graded base layer. According to the AASHTO Guide, a value of 1.0 may characterize a material that has good to poor drainage and exhibits saturated moisture levels 1 to 25% of the time.

The level of reliability selected was 85.0%, with a standard deviation of 0.39. Initial and terminal serviceability indices used in the design equations were selected as a function of pavement type and construction quality. Based on the pavement surface texture and expected traffic volumes for the pavement, initial and terminal serviceability indices of 4.20 and 2.50, respectively, were chosen.

2.3.2 Design Features Affecting Pavement Performance

Several key elements of sound pavement design are considered below in order to examine whether the pavement can continue to maintain high performance levels even if joint sealants were to deteriorate, allowing the infiltration of moisture and debris into the subbase, base and subgrade. Conversely, the probability that the pavement might deteriorate rapidly even if all sealants continued to function properly may also be assessed. A more detailed discussion of these and of several additional features affecting pavement performance is provided by Sander (2002).

Drainage

Drainage at the U.S. 50 test pavement is accomplished through the use of a 100-mm (4-in.) open-graded aggregate base course, a 100-mm (4-in.) longitudinal pipe underdrain, as well as transverse collector pipes, spaced at 152 m (500 ft) intervals, evacuating moisture out of the pavement system into adjacent drainage ditches. The ditches are primarily designed to transport storm water away from the pavement and into the nearby Hocking River.

The design for the eastbound and westbound lanes of the test pavement called for the construction of a non-stabilized open-graded drainage base (NSDB), Item Special, placed in a single 100-mm (4-in.) lift directly beneath the 250-mm (10-in.) thick PCC slab (Item 451). The aggregate used for the base is an unbound crushed limestone. In the eastbound lanes, a “New Jersey” type NSDB satisfying the aforementioned specifications was placed, whereas in the westbound lanes, an “Iowa” type NSDB was used, because of its perceived superior long-term performance with regard to cracking of the PCC. Located between the subgrade and base is a blanket of granular subbase material, consisting of 150-mm (6-in.) of crushed aggregate (Item 304), which meets ODOT filter criteria. As an additional line of defense against the migration of silt- and clay-size particles into the overlying drainage base layer, the surface of the subbase was treated with a bituminous prime coat (Item 408), which was sprayed onto the surface of the compacted subbase and allowed to cure before placement of the base. Without this protective coating, the voids in the base might become clogged over time, thereby reducing or completely eliminating the drainage capacity of this layer.

Drainage design details for the test pavement called for the installation of longitudinal drains placed at the bottom of two trenches, one along the edge of the mainline PCC pavement slab and the other parallel to the outer edge of the shoulder. The outermost trench extended to a depth of approximately twice that of the drainage trench located below the PCC slab edge. The deeper trench primarily is intended to drain the subgrade, whereas the shallow trench is designed to evacuate water from the base and subbase layers. The trenches were excavated to a minimum width of twice the pipe diameter, or 205 mm (8 in.), and were lined with filter fabric underdrain wrap to prevent future clogging of the pipe. The filter fabric (Spec. 712.09, Type A) prevents fine-sized soil particles from entering the drain and choking the voids that would allow free passage of water. Granular material was used as backfill in the trenches and was placed to a minimum height of 300 mm (12 in.) above the top of the pipe. All longitudinal drains were constructed using a 102-mm (4-in.) diameter shallow pipe (Item 605) that was installed continuously as it was unwound from a large spool. The underdrain pipes were then connected with transverse outlets spaced at approximately 152 m (500 ft) intervals.

Extensive flooding occurred in March 2000, following several days of intense rainfall. To the south of the pavement, the Hocking River overflowed its banks, with the highway embankment itself serving as the river bank in many locations, where the water level rose to less than 1.5 m (5 ft) of the pavement surface. Extensive flooding was also observed to the north of the test pavement, covering several acres of farmland and woods. The pavement ditches disappeared under the flood pool and seemed unable to conduct the water under the pavement section and into the Hocking River for several days.

Joint Load Transfer

For the pavement-as-built at the U.S. 50 test site, load transfer across transverse joints is accomplished through regularly spaced epoxy-coated steel dowels. For the purposes of another experiment, these dowels are replaced at some of the joints by fiberglass bars or by stainless steel tubes filled with concrete. All dowels are 38-mm (1.5-in.) in diameter and 460-mm (18-in.) in length, are spaced 305 mm (12 in.) on center and are supported on baskets located every 6.4 m (21 ft). To evaluate the effectiveness of this design, finite element computer program *ILSL2* (Ioannides and Khazanovich, 1994) is used to calculate stress and deflection load transfer efficiencies, as well as maximum values of deflection, bending stress, subgrade stress and concrete bearing stress. Adopting typical and reasonable values for the joint opening and the modulus of dowel reaction, calculated values of deflection load transfer efficiency range from 81 to 93%, while those for stress load transfer efficiency vary between 39 and 61%. Bearing stress values as high as 8 MPa (1150 psi) are obtained, the highest values being associated with improved load transfer efficiencies. This may result in concrete crushing under the dowel and may jeopardize the long-term effectiveness of the load transfer system.

Transverse Joint Spacing

Ioannides and Salsilli-Murua (1989) suggested that the spacing of transverse joints should be based on the non-dimensional ratio (L/*l*), of the slab length, L, to the radius of relative stiffness, *l*, of the slab-subgrade system, and recommended joint spacings corresponding to an (L/*l*) ratio ranging between 4 and 6 (with 5 being "a promising alternative"). Subsequently, on the basis of extensive field investigations, Smith, *et al.* (1997) recommended that in order to minimize transverse cracking in jointed plain concrete pavements, slab lengths should be designed such that the (L/*l*) ratio is less than about 4.5. The concrete pavement at the U.S. 50 test site is constructed with transverse contraction joints spaced every 6.4 m (21 ft). In order to assess the impact of this design on pavement performance, the (L/*l*) ratio may be calculated. A range of values, representative of materials at the test site, may be chosen for this purpose. Pavement design parameters noted above included a concrete modulus of elasticity, E_c, of 24.8 GPa (3,600,000 psi) and a modulus of subgrade reaction, k., of 27 MN/m^3 (100 pci) had been assumed. The corresponding (L/*l*) ratio using these values is approximately 6.1. Retaining the k-value noted, the (L/l) ratio is reduced to 5.3 when E_c increases to 41 GPa (6,000,000 psi). On the other hand, (L/*l*) values up to 7 or 8 are also within the realm of reasonable probability. Whether the amount of temperature steel reinforcement provided in the test pavement slab warrants exceeding the recommended (L/*l*) limit so much is rather debatable.

Tied PCC Shoulders

The new highway at the U.S. 50 test site incorporates tied PCC shoulders of variable width. The shoulders are designed with the same thickness as the mainline PCC slab, i.e., 250 mm (10 in.). On the outer side of the pavement (adjoining the driving lane), the shoulders are 3-m (10-ft) wide, whereas on the inner side (adjoining the passing lane), the shoulders are 1.2-m (4-ft) wide. The longitudinal shoulder joints are tied with 16-mm (0.625-in.) diameter steel reinforcing bars, 760 mm (30 in.) in length, and spaced every 760 mm (30 in.). In each slab, tie bars begin and end 305 and 457 mm (12 and 18 in.), respectively, from the transverse joints. A mechanistic analysis using *ILSL2* indicates that shoulder ties lower the free-edge bending stress by about 11 to 20%. Reductions in free-edge deflection range from 27 to 33%, whereas the free-edge subgrade stress is decreased by 26 to 33%. Thus, reductions in the stress and deflection levels experienced by the concrete slab on account of the presence of tied shoulders can be quite significant.

Reliability

The reliability level can be the most significant input parameter in the design because it defines the overall confidence level concerning the primary assertion of the engineer, i.e., that the pavement will serve applied traffic effectively during its projected life. A pavement engineer could produce a strong and economical design, yet a low reliability is certain to undermine confidence that the pavement will last its full design life. Although a lower level of reliability may be attractive because it dictates a thinner pavement slab, consideration of life-cycle costs associated with long-term maintenance often demonstrates the folly of seeking a lower initial cost in this manner. For highways with the functional classification of rural principal arterial, AASHTO recommends a design reliability between 75 and 95%, a range that encompasses the level of reliability selected in the design of the U.S. 50 test pavement.

Using the AASHTO design procedure, analyses are performed to study the effect of the selected reliability level on pavement slab thickness. It is found that upon increasing the reliability to 90%, the design slab thickness remains 250 mm (10 in.). Selecting a 95% level, however, yields a slab thickness greater than 250 mm (10 in.); for 99% reliability, the design slab thickness is over 280 mm (11 in.). Selecting such a low reliability level, therefore, makes the pavement more likely to experience early distress compared to a similar pavement designed using a reliability level of 95% or higher.

Construction Issues

Two pavement construction related issues may contribute to a number of premature signs of distress, such as mid-slab transverse cracks and surface roughness, uncharacteristic of newly constructed pavements. These are the cold weather pouring of the PCC pavement slab and the use of ground granulated blast furnace slag in the mix design.

The PCC slab for the eastbound lane test sections was cast between October 16 and October 22, 1997, while concrete for the westbound test sections was placed from

September 30 to October 7, 1998. National Climatic Data Center (NCDC) air temperature observations recorded from 10/16 to 10/22/97 for the area surrounding Athens, Ohio, show minimum and maximum daily temperatures of -4 and 19^o C (25 and 66^o F), respectively. In the westbound lanes, the minimum and maximum air temperatures recorded between 9/30 and 10/7/98 were 1 and 28^o C (34 and 83^o F), respectively. For such maximum daytime temperatures, the base was probably warm prior to being covered with concrete. As nighttime air temperatures approached and eventually fell below freezing on several occasions, the top of the newly placed concrete slab must have cooled excessively. This may have resulted in a large thermal gradient between the cold concrete surface and the warmer slab bottom, leading to upward curling during curing. Moreover, concrete placed and cured in cold weather may exhibit an increase in the time required to initial set, loss of durability and a slowed rate of strength gain.

For the purposes of a separate study at the U.S. 50 test site, the PCC pavement slab was constructed using a mix design in which 25% of the required Portland cement content was replaced with ground granulated blast furnace slag (GGBFS). Blast furnace slag is a by-product from the production of iron and primarily consists of silicates, alumino-silicates and calcium alumina silicates. When crushed or processed to cement fineness, slag has cementitious properties which make it a suitable replacement for Portland cement, and is usually substituted on a 1:1 basis. Use of GGBFS usually improves the workability of fresh concrete, yet at the same time decreases the water demand due to the additional paste volume. The use of slag cement in fresh concrete tends to retard cement hydration, thereby slowing the time to initial set and concomitant rate of strength gain. When compared to normal concrete, the presence of slag cement tends to slow early age strength development, but increases the ultimate strength after 28 days. The delay in setting time caused by the use of GGBFS, coupled with the cold weather conditions during curing, may have contributed to upward slab warping, compounding the curling gradient discussed above.

2.4 Pavement Construction

Construction of the test pavement occurred in two phases, the first involving the eastbound and the second the westbound lanes. Construction of the eastbound lanes began in the Summer of 1997 and these lanes were opened to traffic in Spring of 1998. Concreting and first sawing was completed in October 1997, while the secondary cut—where needed—was made in October and November, and sealing occurred in November. During this construction phase, both directions of traffic were served by the existing pavement, which incorporated a PCC slab with an asphalt concrete (AC) overlay. Subsequently, traffic was diverted from the existing highway to the newly constructed eastbound lanes. This allowed the second phase of construction to begin in the Summer of 1998. Concrete placement occurred between the months of September and October 1998, and secondary joint sawing operations occurred in December 1998. By that time, only eight of the ten joint sealant types had been installed, but sealing was suspended due to low temperatures. The remaining two (hot-pour) sealants were not placed until April 1999, when the slab temperature was above the manufacturer's suggested minimum for installation. The westbound lanes were opened to traffic in May 1999.

2.4.1 Pavement Layers

The test site is located on the flood plain of the Hocking River, in an area of unglaciated uplands. Bedrock in this area typically consists of shales, sandstones, and limestones of the Conemaugh and Monangahela formations, Pennsylvanian age, but it was not encountered in any of the borings made in the vicinity of the test site. The subgrade material present in the vicinity of the test site consists predominantly of reddish brown and grey silty clays and clays, in the A-6(11) and A-7-6(15) AASHTO classifications, with some sand and gravel. The upper 0.3 m (1 ft) of subgrade was compacted and brought to grade. The minimum compaction requirement was 100% of the standard Proctor maximum dry unit weight. Any soft soil encountered was removed and replaced with more desirable material. Compaction of the subgrade was performed using sheepsfoot vibratory rollers.

The subbase consists of a single 150-mm (6-in.) lift of crushed, well-graded aggregate (Item 304), purchased from a local coal strip mine, with gradation as indicated in Table 2.2 (a), .The minimum compaction requirement was set at 98% of the maximum density value obtained from an in situ test that involved the compaction of a test section, 30 m (100 ft) long by 2.5 m (8 ft) wide. The material was delivered in dump-trucks, then spread to grade using a self-propelled spreader. The subbase was compacted using a single, smooth drum vibratory roller with a static weight of 3.6 tonnes (4 tons). To prevent migration of fines into the overlying base layer, a bituminous prime coat (Item 408) was applied to the top of the compacted subbase. A 100-mm (4-in.) pipe underdrain was installed through the subbase layer.

The base for the eastbound lanes consists of a “New Jersey” type non-stabilized drainable base, constructed in a single 100-mm (4-in.) lift. For the westbound lanes, a similar lift of “Iowa” type non-stabilized drainable base was used.. The gradations for both base types are reproduced in Tables 2.2 (b). A procedure similar to that used for the subbase, involving the construction of a test section to determine maximum density and optimum moisture content, was employed. A 100-mm (4-in.) shallow pipe underdrain utilizing filter fabric was installed through this layer. The material was delivered by dump-trucks, was placed using an asphalt paver with automatic grade control in order to minimize segregation, and was compacted to the level specified by ODOT using a smooth drum roller without vibration.

The mix design for the PCC slab as developed by the contractor is presented in Table 2.3, calling for the following material quantities: 244 kg/m^3 (412 lb/yd^3) of Type I cement; 82 kg/m^3 (138 lb/yd^3) of ground granulated blast furnace slag; 847 kg/m^3 (1428 lb/yd^3) of river sand with a bulk specific gravity (BSG) of 2.61; and, 810 kg/m^3 (1365 lb/yd^3) of #8 gravel with a BSG of 2.57. The water/cement ratio was kept at 0.44, with the help of a water reducer (Sargand, 2000). The #8 gravel was used because the #57 gravel originally considered did not pass the freeze-thaw test for this area. For the sake of completeness, it is noted that a control mix without ground granulated blast furnace slag was used between stations 92+34.25 and 104+40 in the westbound lanes, i.e., beyond the limits of the joint sealant experiment. The components of the control mix were as follows: 356 kg/m^3 (600 lb/yd^3) of cement; 762 kg/m^3 (1285 lb/yd^3) of fine aggregate; 967 kg/m^3 (1630 lb/yd^3) of coarse aggregate; and 178 kg/m^3 (300 lb/yd^3) of water (Sargand, 2002).

The concrete was delivered by dump-trucks and the slab was cast by a three-paver slipform train, in an operation that involved a crew of about 25 people. Dowel bars on baskets, wire mesh reinforcement, as well as longitudinal and shoulder tie bars were provided. Artificial turf was dragged over the slab to give texture to the pavement surface, which was subsequently grooved transversely by a self-propelled grooving machine. Finally, a curing compound was sprayed onto the slab to seal its surface. Testing of the concrete was performed by ODOT technicians and consisted of slump and air tests performed in the field, as well as laboratory tests on beams cast in the field. The specified strength of these beams was a modulus of rupture of 4.2 MPa (600 psi), from a third-point loading test. A random sample of ten five-day breaks on these beams yielded an average modulus of rupture of 5.4 MPa (789 psi), with a standard deviation of 0.6 MPa (87 psi).

2.4.2 Pavement Joints

Initial saw cutting took place a few hours after the paving operations, as soon as the concrete had developed enough strength to support the saws. Typically two saws were used, with one operator per saw. As a result of prevailing cold temperatures and the mix design adopted, it was sometimes found that the concrete had not set up uniformly through the slab thickness by the time the original joint cut was made, and this resulted in considerable joint spalling. It appeared that the concrete was setting from the bottom up, since the underside of the slab was warmer than its top, and some shrinkage cracks were initiated prior to the initial cut. After very few joints had been cut, therefore, a lighter Soff-Cut saw was used, which enabled the crew to make the cuts as specified. A number of short sections in which premature shrinkage cracks had formed prior to the first saw-cut, or in which excessive joint spalling had developed, were removed and replaced after the concrete had cured.

The widening cut was made with a 65-HP Core Cut saw, typically one day before sealant installation. Usually two saws were used, with one operator per saw. Following joint widening, the joints were cleaned with pressurized water and air. Joints were first flushed clean with water at 14 MPa (2000 psi), and then air-blasted at 0.7 MPa (100 psi), before being allowed to dry. Sandblasting was not deemed necessary in the interest of practical expediency, since the joints had already been thoroughly cleaned of all residue. Manufacturer specifications for some of the materials used are silent regarding the need for sandblasting, whereas for others they suggest it as an option, or even require it for the purpose of removing "remaining traces of sawing residue". This variability is probably explained by the logistical cost sandblasting will inevitably add to the use of any particular product. The *Plan Notes* from ODOT, reproduced in Figure 2.2, stipulate that sealants "shall be installed in accordance with the manufacturer's recommendations". Backer rod was installed into those cleaned joints that were to be sealed with silicone or hot-applied sealants, after such joints had been allowed to dry, typically overnight. Backer rod sizes of 6, 8 and 13 mm (1/4, 5/16 and ½ in.) were used, depending on the joint configuration. Typically, the backer rod was 3 mm (1/8 in.) larger than the joint opening. The backer rod was laid out across the pavement surface and rolled into place using a special hand tool.

In order to verify compliance with specifications pertaining to joint width and depth to backer rod, several series of measurements were made at randomly selected test section locations, on three separate days during the second construction phase (1998-99 season). Most of the joint widths were within the specified tolerance, but two sections were found to be outside of the specified tolerance, both exceeding the specified dimensions. The average measured depth to backer rod was within the specified dimensions for each of the four sections in which this measurement was made.

2.5 Joint Sealing Operations

2.5.1 Installation of Silicone Joint Sealants

Dow 890-SL

This self-leveling silicone sealant was used in joints of three test sections differing with regard to joint width and backer rod diameter, in each of the two directions. The general installation routine started a few days prior to sealing, when joints were widened (if needed) and then cleaned using water- and air-blasting. After the joints were dry, the backer rod was installed. Immediately before the installation of the sealant, the joints were air-blasted clean again. The placement of this sealant typically involved three laborers. One drove a truck to which the sealant pump was mounted and which towed an air compressor. Another air-blasted joints in front of the truck, while the third sealed joints behind the truck. A supervisor monitored the operation periodically.

Crafco 903-SL

This self-leveling silicone sealant was installed in three test sections in the westbound lanes that differed with regard to joint width and backer rod diameter, but in only two sections in the eastbound lanes. Joints in a third test section in the eastbound lanes were filled with Crafco 902 non-sag silicone sealant, instead. The general installation routine for the Crafco 903-SL and the personnel involved were identical to those pertaining to the Dow 890-SL, described in the preceding section.

Dow 888

Owing to changes in the experimental plan, precipitated by the unavailability of certain specified materials, this non-sag silicone sealant was installed in two identical test sections in each of the two directions. The general installation routine began with water- and air-blasting of the joints after they had been widened, typically several days prior to sealing. Backer rod was placed in clean and dry joints, usually on the day of sealing. Air-blasting was performed again immediately ahead of the sealing operation, which generally involved four laborers. The first drove the truck carrying the sealant pump and towing the air compressor. Another one air-blasted joints in front of the truck, while the third sealed joints behind the truck. A supervisor monitored the operation periodically. A fourth laborer tooled the sealant in the joint, using a piece of rubber-tubing.

Crafco 902

This non-sag silicone sealant was installed only in one eastbound section (Sta 200+00 to 206+00). The installation procedure was identical to that employed for the Dow 888, described in the previous paragraph.

2.5.2 Installation of Hot-Pour Sealants

Crafco 444

This hot-pour, self-leveling sealant was installed in one section in each of the two directions. The sealant was supplied in liquid form and was heated to between 132ºC (270ºF) and 143ºC (290ºF) in the melter applicator unit. Joint widening and cleaning had been performed several days prior to sealing. Backer rod was inserted shortly before sealing. Two laborers were involved in the installation. One drove the truck which towed the melter applicator unit, while the other delivered the sealant using a hose fitted with a special metal tip.

Crafco 221

The second hot-pour, self-leveling sealant included in this experiment was used in one section of joints in each of the two directions. The typical installation procedure was practically identical to that of the Crafco 444, described above. Note, however, that Crafco 221 is supplied in solid block form and must be heated to between 193ºC (380ºF) and 210ºC (410ºF) at installation.

2.5.3 Installation of Preformed Compression Seals

Watson Bowman WB-812 and WB-687

The Watson Bowman WB-812 was installed in one section of the westbound lanes, whereas the WB-687 was installed in one section of the eastbound lanes. The only difference between the two seals is that WB-812 is slightly larger in cross-section than WB-687. The typical installation procedure began with joint widening, followed by cleaning using water- and air-blasting. After the joints were clean and dry, an installation machine was used to apply the adhesive to the preformed seal and insert it into the joint. Three laborers were engaged in sealing: one operated the installation machine and guided it along the joint, while another held the seal as it was drawn into the machine and cut off the excess seal length. The third laborer passed over the seal with a roller device designed to set the seal to the desired depth. Occasionally, problems with the machine were encountered and seal installation was performed manually. Accordingly, one laborer used his hands to coat the seal with adhesive, another squeezed the seal into the joint, and the last used the roller device to set the seal to the appropriate depth.

Delastic V-687

This compression seal was installed in one section in each of the two directions. The typical installation procedure was identical to that for the Watson Bowman seals, described in the previous section.

Techstar W-050

This compression seal was installed in one section in each of the two directions. The joints had been widened and cleaned using water- and air-blasting one or two days prior to sealing, and they were air-blasted again on the day of seal installation. A special adhesive from the seal manufacturer, *Techstar, Inc*., was used to hold the seals in place. The procedure involved two or three laborers, monitored by a supervisor.

Table 2.1 Sealant type, sealant name, joint configuration, stationing and number of joints

(a) Eastbound test sections

Type	**Sealant**	**Joint Config.**	**Stations**	**No. of Joints**
Self-leveling silicone	Crafco 903-SL	1	188+00 to 194+00	29
Self-leveling silicone	Crafco 903-SL	4	206+00 to 213+00	33
Self-leveling silicone	Dow 890-SL	3	166+00 to 172+00	29
Self-leveling silicone	Dow 890-SL	4	213+00 to 219+00	29
Self-leveling silicone	Dow 890-SL	1	266+00 to 272+00	28
Non-sag silicone	Crafco 902	1	200+00 to 206+00	29
Non-sag silicone	Dow 888	1a	272+00 to 284+00	57
Non-sag silicone	Dow 888	1b	284+00 to 290+00	29
Hot-pour	Crafco 221	1	260+00 to 266+00	29
Hot-pour	Crafco 444	1	172+00 to 188+00	76
Compression Seal	Delastic V-687	5	225+00 to 231+00	29
Compression Seal	Watson Bowman WB-687	5	194+00 to 200+00	27
Compression Seal	Techstar W-050	5	154+00 to 160+00	29
Unsealed	No Sealant	6	160+00 to 166+00	29
Unsealed	No Sealant	2	219+00 to 225+00	28

Table 2.1 (continued)

(b) Westbound test sections

Type	Sealant	Joint Config.	Stations	No. of Joints
Self-leveling silicone	Crafco 903-SL	1a	188+00 to 194+00	29
Self-leveling silicone	Crafco 903-SL	1b	194+00 to 200+00	29
Self-leveling silicone	Crafco 903-SL	4	266+00 to 272+00	28
Self-leveling silicone	Dow 890-SL	3	166+00 to 172+00	29
Self-leveling silicone	Dow 890-SL	1	200+00 to 206+00	28
Self-leveling silicone	Dow 890-SL	4	272+00 to 284+00	57
Non-sag silicone	Dow 888	1a	213+00 to 219+00	28
Non-sag silicone	Dow 888	1b	260+00 to 266+00	29
Hot-pour	Crafco 221	1	172+00 to 188+00	76
Hot-pour	Crafco 444	1	206+00 to 213+00	33
Compression Seal	Delastic V-687	5	219+00 to 225+00	29
Compression Seal	Watson Bowman WB-812	5	225+00 to 231+00	28
Compression Seal	Techstar W-050	5	133+60 to 139+60	29
Unsealed	No Sealant	2	139+60 to 166+00	126
Unsealed	No Sealant	6	284+00 to 290+00	29

Table 2.2 Specified aggregate gradations used for the pavement subbase and base materials

a) Gradation specifications for ODOT Item 304 subbase material (ODOT, 1995)

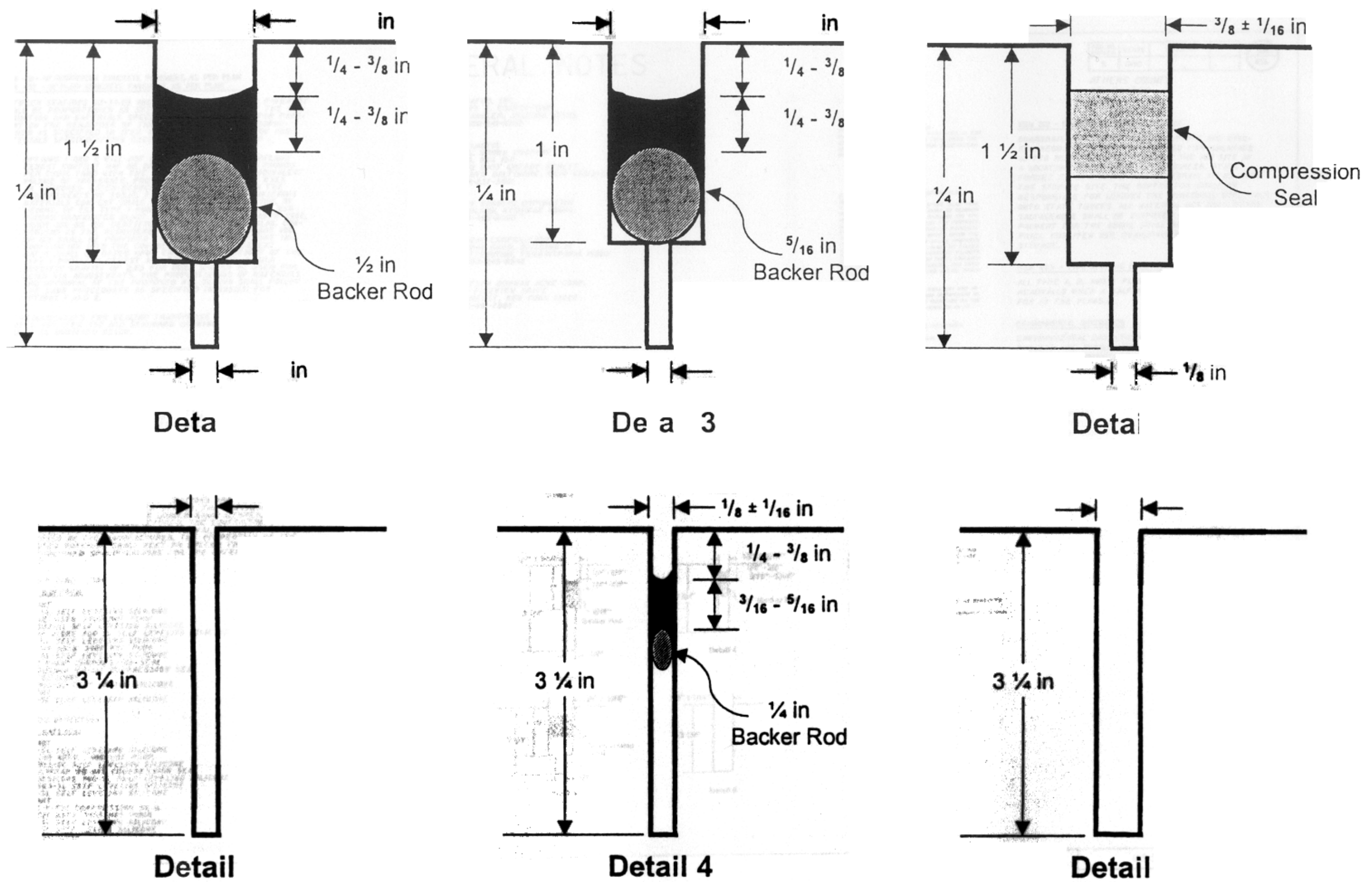
Sieve No.	Allowable % Passing
2 in.	100
1 in.	70 - 100
0.75 in.	50 - 90
No. 4	30 - 60
No. 30	9 - 33
No. 200	0 - 13

b) Gradations and specifications for "New Jersey" (NJ) Type and "Iowa" (IA) Type NSDB materials placed in eastbound and westbound lanes, respectively (Sargand, 2000)

Sieve No.	NJ Type % Passing	NJ Type (Eastbound Lanes) Specified Gradation	IA Type % Passing	IA Type (Westbound Lanes) Specified Gradation
1.5 in.	100	100	-	-
1 in.	100	95 - 100	100	100
0.5 in.	65	60 - 80	56	50 - 80
No. 4	42	40 - 55	31	-
No. 8	14	5 - 25	25	10 - 35
No. 16	4	0 - 8	14	-
No. 50	1	0 - 5	3	0 - 15
No. 200	-	-	1.3	0 - 6

Table 2.3 Portland cement concrete mix design used for the U.S. 50 High Performance Concrete pavement slab (Sargand, 2000)

PCC Mix Component	Quantity
Fine Aggregate (dry) - natural concrete sand -	1428 lb/yd^3
Coarse Aggregate (dry) - #8 gravel -	1365 lb/yd^3
Cement	412 lb/yd^3
Water	316 lb/yd^3
GGBFS	138 lb/yd^3
Water Reducer	2 oz/cwt
Air Entrainer	4.2 oz/cwt



Figu 2. oint configuration details sed the **U.** 50 experiment mith, 2000

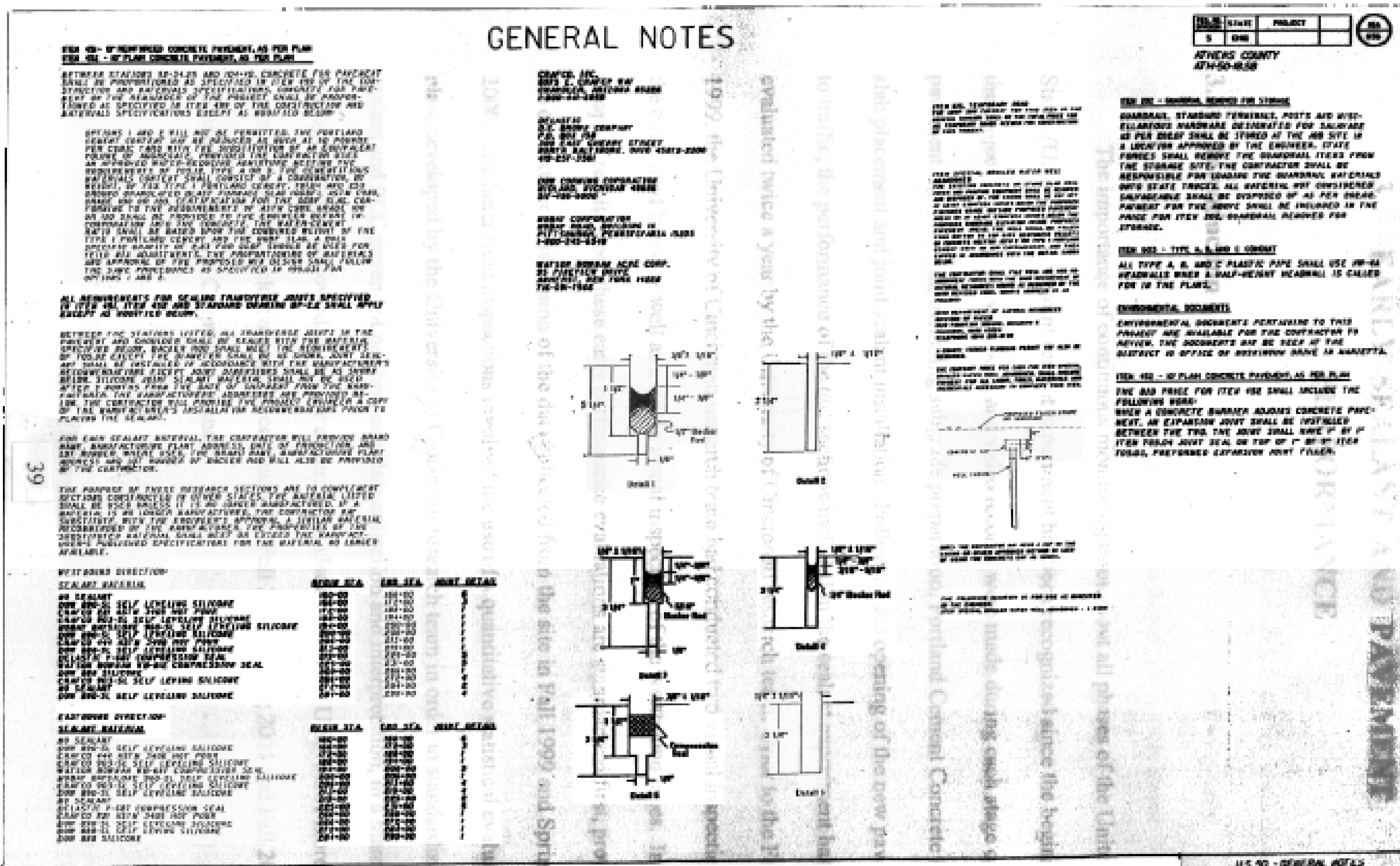


Figure 2.2 General Notes from Project 180/97: US Route 50, Athens, OH (ODOT, 1995)

3 EARLY SEALANT AND PAVEMENT PERFORMANCE

3.1 Introduction

The importance of continuous monitoring throughout all phases of the United States (U.S.) Route 50 joint sealant experiment has been recognized since the beginning of the project. Field notes were kept and video records were made during each stage of pavement construction, including subgrade preparation, Portland Cement Concrete (PCC) slab placement and joint sealant installation. Following the opening of the new pavement to traffic, the performance of the test sections included in the sealant experiment has been evaluated twice a year by the University of Cincinnati research team. Prior to the Fall of 1999, the University of Cincinnati research team had conducted two visual inspections of the eastbound lanes, as well as a single visual inspection of the westbound lanes. In this Chapter, results from these early performance evaluations are summarized first, providing the context for a discussion of the data collected from the site in Fall 1999 and Spring 2000. The latter field inspections involved the use of a quantitative statistical evaluation plan, developed by the University of Cincinnati research team in order to standardize joint sealant and PCC pavement performance data collection and interpretation, in a manner analogous to that followed in similar experiments elsewhere in the U.S. Three more recent quantitative field evaluations conducted in Fall 2000, Spring 2001 and Fall 2001 are discussed in detail in Chapters 4, 5 and 6.

3.2 Visual Inspections (Fall 1998 and Spring 1999)

Visual inspections of the condition of the joint sealants in the test sections were performed on two occasions. Since the project is concerned with the long-term performance and effectiveness of each joint sealant treatment, these early visual inspections provide an indicator of the initial condition, or early age performance.

The first visual inspection occurred in October, 1998, when the University of Cincinnati research team accompanied by Mr Lynn Evans, of *ERES Consultants, Inc.*, surveyed the newly constructed eastbound lanes, from Sta 154+00 to Sta 290+00. Since both lanes served traffic at the time (one in each direction), the inspection was conducted from the shoulder adjacent to the outer (driving) lane. The air temperature was 21°C (70°F) under partly cloudy weather conditions. A second visual inspection, which included both the eastbound and westbound lanes, occurred over two days in May 1999. Both days were hot and dry. The pavement temperature on the first day was recorded as 41°C (105°F) at 4 PM, while on the second day it was 21°C (69°F) at 9 AM, and 27°C (80°F) at 12 noon. The eastbound lanes had been open to traffic for over a year by the time of the second inspection, while the westbound lanes had been operational for about two weeks. Due to continuing striping operations, only one lane was opened to traffic in each direction and the evaluations were conducted again from the shoulder.

Information recorded is primarily in the form of visual observations made on three transverse joints in each test section. The joint sealant condition was described and visual estimates were made of the percentage of observed adhesive, cohesive or spall failures. Also noted was the depth to which the sealant was recessed below the pavement surface and the intrusion of any incompressible debris into the joint.

The following is a summary of the observations concerning the condition of the eastbound lanes only, at the time of the second visual inspection (May 1999).

Crafco 903-SL (Sta 188+00 to 194+00)

The sealant in this section was in fair condition, exhibiting loss of adhesion or sunken seal over about 20% of the joint length. The typical recess was approximately 3 mm (1/8 in.), with the sealant exposed at the surface intermittently.

Crafco 903-SL (Sta 206+00 to 213+00)

The sealant in this section was in poor condition. It was estimated that over about 30% of the joint length, the sealant had developed full-depth adhesion loss and had been pulled away by traffic or had sunk into the joint. The remainder of the sealant was frequently exposed at the pavement surface, exhibiting no recess. The narrow joint design (3 mm =1/8 in.) seems to have hindered proper sealant installation with the conventional sealing devices employed, which was reflected in unsatisfactory sealant condition.

Dow 890-SL (Sta 166+00 to 172+00)

The sealant in this section was in fair condition. The sealant was recessed to less than 3 mm (1/8 in.) over more than 50% of the joint length and was intermittently exposed at the surface of the pavement. Full-depth adhesion loss was evident over about 10% of the joint length, over which the sealant had sunk into the joint.

Dow 890-SL (Sta 213+00 to 219+00)

The sealant in this section was observed to be in poor condition. Some of it had been pulled away by traffic or had sunk completely into the joint. The sealant was exposed at the pavement surface over approximately 50% of the joint length, with the remainder showing a recess of less than 3 mm (1/8 in.). Once again, the narrow design of the joints (3 mm =1/8 in.) seems to have hampered effective sealant installation, resulting in the poor condition noted.

Dow 890-SL (Sta 266+00 to 272+00)

The sealant in this section was in poor condition. Inadequate recess (3 mm =1/8 in., or less) was typically noted, with the sealant exposed to traffic wear over approximately 50% of the joint length. Full-depth adhesion failures were also quite common, typically over 40% of the joint length.

Crafco 902 (Sta 200+00 to 206+00)

This sealant was observed to be in fair condition, reflecting somewhat better sealant installation in the 10 mm (3/8 in.) joints, yet exhibiting many of the same distresses as the previous silicone sealant sections. The sealant had sunk over approximately 20% of the joint length. Elsewhere the sealant material shows uneven recess, sometimes less than 3 mm (1/8 in.), and is intermittently exposed at the slab surface.

Dow 888 (Sta 272+00 to 284+00)

Whereas the design of the two Dow 888 sections is identical, the sealant here appeared to be in worse condition. Full-depth adhesion failure accounted for at least 30% of the joint length, sometimes much more. Inadequate recess was common, with the sealant sometimes exposed to traffic wear.

Dow 888 (Sta 284+00 to 290+00)

The sealant in this section was in fair condition. It had experienced full-depth adhesion failure and had sunk over approximately 20% of the joint length, the remainder typically being recessed about 3 mm (1/8 in.).

Crafco 444 (Sta 172+00 to 188+00)

This hot-pour sealant section was in fair condition. Full-depth adhesion loss was estimated at about 20% of the joint length, and small bubbles were evident in the surface of the sealant. The typical recess was approximately 3 mm (1/8 in.), with the sealant exposed at the pavement surface over approximately 10% of the joint length.

Crafco 221 (Sta 260+00 to 266+00)

The hot-pour sealant in this section was in poor condition. Over a considerable length of the joint (occasionally in excess of 50%) exhibited adhesive failure, with the sealant sometimes not even touching the joint walls. In several places (typically about 20% of the joint length) the sealant had sunk into the joint. Bubbles were evident in the sealant surface.

Watson Bowman WB-687 (Sta 194+00 to 200+00)

In contrast to the preceding silicone sealant sections, the compression seal in this section was in very good condition. No signs of compression set were observed and the seal remained tight and untwisted against the joint walls. The seal was typically recessed 3 to 6 mm (1/8 to 1/4 in.), with a minimal amount of debris accumulation above the seal.

Delastic V-687 (Sta 225+00 to 231+00)

The compression seal in this section was in very good condition with no obvious distresses or signs of compression set. The sealant appeared to be adequately recessed to approximately 3 to 6 mm (1/8 to 1/4 in.), and remained tight and untwisted against the joint walls. Some debris accumulation, consisting of sand and organic matter from nearby trees, was found in most joints.

Techstar W-050 (Sta 154+00 to 160+00)

The condition of the compression seal in these joints was poor. Loss of adhesion between the seal and the joint walls was evident over about 30% of the joint length, with the seal sinking deep into the joint; elsewhere, the seal exhibited a typical recess of 3 mm (1/8 in.). In many locations, the hardened adhesive that used to hold the seal was still visible close to the pavement surface.

No Sealant (Sta 219+00 to 225+00)

The joints were observed to be in very good condition with no signs of spalling or joint related distresses. Only a limited amount of debris accumulation was observed but the joints still remained open, possibly due to the narrow design of the joint. It is recalled that the joints in this section were originally cut to 3 mm (1/8 in.) using a Soff-Cut sawing system and received no additional cut.

No Sealant (Sta 160+00 to 166+00)

The unsealed joints in this section were in very good condition, with no spalling or other distresses observed. In the driving lanes, the joints appeared open and clean with no major infiltration of incompressibles. Over the shoulders width, however, the joints were almost full of sand and other debris.

From this information, conclusions have been made concerning premature aging and the relative rate of joint seal deterioration. It has been pointed out that "serious consideration needs to be given to the joint cleaning and sealant placing operations employed." More specifically, "the most significant shortcomings [at the U.S. 50 test site] appear to have been the omission of sandblasting at placement and inadequate sealant recess" (Hawkins, *et al.*, 2001).

3.3 Performance Evaluation Plan

In the Fall of 1999, the University of Cincinnati research team developed a methodology to be used in acquiring performance data in a consistent and organized fashion (Sander, 2002). Thus, a joint seal evaluation form was generated suitable for recording the types, extents and locations of failure and distress manifestations noted in each sealant, both numerically and schematically. Reproduced in Figure 3.1, the form includes the treatment type, the number and relative location of sampled joints, the beginning and ending stations, as well as measured distress and failure lengths, along with a legend of symbols used. This form was first used during the visual inspection of November 1999, and is to be used for all subsequent evaluations of joint sealant performance.

Because of the large number of transverse joints in each test section, which ranges from as few as 27 to as many as 126, it is necessary to devise a statistical sampling plan for performance monitoring. This allows investigators to evaluate a representative number of joint seals in each test section and to make inferences from these as to the condition of the entire section. To guarantee that no bias will be introduced into the results, the selection of a subset, or sample, is made on the basis of random sampling. The statistical sampling plan used for evaluations at the U.S. 50 project involves the examination of six randomly selected transverse joints in each of the thirty test sections. It is considered that a sample of size six combines the qualities of being large enough to be representative of the entire set, or population, while also being small enough to allow the evaluation of the test sections in two full working days by the available research project personnel. The same six joints in each test section will be evaluated throughout the duration of the experiment. The first, second, second to last and last joints in every test section were intentionally excluded from the selection process in order to eliminate possible overlap effects from adjacent sections.

The methodology developed for visual field inspections entails the following steps. Within each test section, six transverse joints are selected randomly for continual monitoring. Each joint selected is examined for signs of sealant failure and distress over a length of 1.83 m (6 ft), beginning at the outer shoulder joint and covering the right wheel-path of the driving lane. Each failure or distress type is identified according to a list of definitions and carried to the site by the inspector for instant reference (Table 3.1). The length of any noticeable distress or failure is measured and recorded on the field evaluation form in the space allocated to that particular joint. The record includes a schematic indicating the position of each distress feature along the joint length surveyed.

In the case of adhesive and spall distresses, the side of the joint, approach or leave, is also noted. These data collection activities follow closely the model established by similar investigations, primarily studies performed by *ERES Consultants, Inc.* conducted under the Strategic Highway Research Program (SHRP) (Smith, *et al.*, 1999).

The lengths of each observed feature are summed to give the total failure length of that particular joint seal. Dividing the total failure length by the overall length inspected, i.e., 1.83 m (6 ft), the percent overall effectiveness can be determined for each joint. From these values, an average effectiveness figure is determined for each section, and a seal performance rating category is assigned to the section according to the scheme developed by Belangie and Anderson (1985). Sealants exhibiting effectiveness levels between 90 and 100% are classified as being in very good condition, whereas those sealants showing less than 50% overall effectiveness are in very poor condition and are considered to have failed. Performance ratings of poor, fair and good are assigned appropriately to sealants having effectiveness levels ranging between 50 and 90%. Such a system ensures that the performance and condition rankings assigned to each sealant are consistent between evaluations. It is noted that the same ranking scheme was also used during the SHRP H-106 and SPS-4 experiments (Specific Pavement Sections) (Smith, *et al.*, 1999; Evans, *et al.*, 1999). Consequently, results obtained in Ohio will be directly comparable to those from other national studies.

3.4 Quantitative Field Evaluations (Fall 1999 and Spring 2000)

3.4.1 Treatment Effectiveness in the Eastbound Lanes

Quantitative data on joint seal effectiveness in the eastbound lanes in accordance to the aforementioned evaluation plan were first collected in November 1999. This data set is code-named EBNV99. In March 2000, the University of Cincinnati research team collected a second set of performance data in the eastbound lanes. The corresponding data set code-name is EBMR00. These observations are discussed in detail by Sander (2002). The EBNV99 data set indicates that the Watson Bowman WB-687 (Joint Configuration 5) treatment exhibited the highest overall effectiveness (97.8%). The worst performing treatment in this data set was the Crafco 444 (1), which exhibited a sealant effectiveness of only 14.4%. Compression seals, with the exception of the Techstar W-050 (5) treatment, were in very good condition, showing greater than 95% effectiveness. Both of the non-sag silicone sealant treatments, namely the Dow 888 (1) and Crafco 902 (1), showed poor performance, having less than 65% effectiveness. Results from the EBMR00 evaluation show that the Watson Bowman WB-687 (5) and the Delastic V-687 (5) treatments continued to exhibit very little deterioration, both having an overall effectiveness of 95.3%. With an effectiveness of only 9.7%, the Crafco 444 (1) remained the worst performing treatment. The other hot-pour section, Crafco 221 (1), experienced no deterioration over the four month period between evaluations, retaining an effectiveness of 71.9%. The section of Crafco 903-SL (4) between Stations 206+00 and 213+00 exhibited the largest deterioration, decreasing approximately 38 percentage points in effectiveness (from 62.5 to 24.2%), whereas the Crafco 903-SL (1) treatment declined by nearly 14 points (from 66.1 to 51.9%). The three Dow 890-SL silicone treatments (3, 4, 1) continued to show fair to poor performance, ranging between 55.0 and 67.8% in effectiveness.

Another way of evaluating the performance of experimental joint sealants is through analysis of deterioration over time. It is assumed that all treatments exhibited an effectiveness level of 100% immediately after installation. Deterioration is indicative of a sealant treatment's performance with time, and more importantly, of its longevity while maintaining a minimum acceptable level of effectiveness. At the time of the EBNV99 performance evaluation, the eastbound lanes had been exposed to traffic and weather for approximately twenty months. Of the four silicone sealants, the Dow 890-SL (1, 3, 4) treatments showed the best performance, exhibiting the lowest average joint seal deterioration over the four-month period between evaluations. Crafco 903-SL (1, 4) treatments had the second lowest average deterioration at the time of the EBNV99 evaluation, yet deteriorated rapidly in the time period between the EBNV99 and EBMR00 surveys. Performance trends of the Dow 888 (1, 1) and Crafco 902 (1) silicone sealants indicate that their effectiveness has continued to decrease steadily over their approximate twenty four months of service.

The two hot-pour sealant treatments exhibited a significant difference in performance with age. Since installation, the Crafco 444 (1) treatment has shown a considerably faster deterioration as compared to the Crafco 221 (1) treatment. At the age of twenty months, Crafco 221 (1) was undoubtedly the better performing hot-pour sealant in terms of overall effectiveness, maintaining its resistance to environmental factors and traffic. Approximately twenty four months after installation, the Crafco 221 (1) sealant treatment continued to display a constant level of performance, whereas the Crafco 444 (1) deteriorated further, exhibiting a slight decrease in effectiveness over the four month period between evaluations EBNV99 and EBMR00.

Compression seals, with the notable exception of the Techstar W-050 (5) section, experienced minor deterioration over the twenty four month service period. Of the three compression seal sections in the eastbound lanes, the Techstar W-050 (5) treatment had the highest rate of deterioration, casting doubts concerning its long-term durability. In contrast, the other two sections exhibited excellent short-term behavior and are likely to continue to perform well in the future.

Deterioration rates of all three sealant classes installed in the eastbound lanes suggest that silicone and hot-pour sealant treatments deteriorated more rapidly than the compression seals. Compression seal treatments as a group outperformed silicone and hot-pour treatments by about 23 and 33 percentage points, respectively. Hot-pour sealants showed the highest rate of deterioration up to the age of twenty months. In contrast, their performance between twenty and twenty four months was relatively constant, showing very little joint seal deterioration over that time period. Unfortunately, the sealant had already deteriorated into very poor condition.

Each of the 13 sealed treatments may be ranked according to its level of overall effectiveness as of each of the two visual inspection surveys (EBNV99 and EBMR00). Additionally, depending on the percentage deterioration of each treatment in the four months between these inspections, a corresponding deterioration rank may be assigned. Note that a high rank is only desirable with regard to effectiveness, but not with regard to deterioration. The best performing sealant treatment is ranked as No. 1 in Effectiveness, whereas the worst performing one is ranked No. 13. In contrast, the most rapidly deteriorating treatment is ranked as No. 1 in Deterioration, whereas the treatment with the slowest or no deterioration is ranked No. 13. Information collected shows that at the time of the EBNV99 evaluation, the best and worst performing treatments in terms of overall effectiveness were the Watson Bowman WB-687 (5) and the Crafco 444 (1), respectively. In terms of deterioration rate, the Crafco 903-SL (4) treatment was ranked as No. 1 and the Techstar W-050 (5) as No. 2. Crafco 221 (1) treatment exhibited the least amount of deterioration between the EBNV99 and EBMR00 evaluations, earning the most desirable deterioration rank of 13.

These observations reaffirm the preliminary conclusions reached following the early inspections by the research team that "the worst of the sealed sections [are] those with a narrow joint width of 3 mm (1/8 in.). In most joints with such a configuration, the sealant material had overflowed... thereby being exposed to tire traffic... Special nozzles or applicators need to be used, so that the sealant will be placed from the bottom up at a slow rate, so that the joints are not overfilled" (Hawkins, *et al.*, 2001).

3.4.2 Treatment Effectiveness in the Westbound Lanes

At the time of the November 1999 inspection of the westbound lanes (data set: WBNV99), four of the treatments, namely Dow 890-SL (1), Delastic V-687 (5), Watson Bowman WB-687 (5) and Dow 888 (1, Replicate a), showed no distress, having an overall effectiveness of 100%. In fact, ten of the thirteen sealant treatments were found to be in Very Good condition, with an overall effectiveness above 90%, and these included all three compression seal types. This may be explained by the relatively early age of these sections: at the time of the inspection, the westbound lanes had been exposed to traffic for less than six months. The Crafco 903-SL (1) and the Dow 890-SL (4) treatments had an overall effectiveness of 83.9 and 83.3%, respectively, i.e., they were in Good condition. In contrast, hot-pour sealant Crafco 221 (1) treatment exhibited an effectiveness of only 62.5%, and was the only treatment found to be in Poor condition at the time of the WBNV99 evaluation.

The largest decrease in effectiveness occurring in the four months between the WBNV99 observations and the March 2000 inspection of the westbound lanes (data set: WBMR00) was recorded in the Techstar W-050 (5) treatment. Compression seals in this section showed a 29-point reduction in overall effectiveness, dropping from 98.3 to 69.7%. Several sealant treatments continued to remain in Very Good condition, all exhibiting less than a four percentage point decrease in effectiveness at the time of the WBMR00 inspection. These included both silicone sealants, Dow 890-SL (1), Dow 890-SL (3), Crafco 903-SL (1a) and Dow 888 (1a and b), and compression seals, Delastic V-687 (5) and Watson Bowman WB-812 (5). The latter treatment exhibited the smallest decrease in effectiveness, dropping from 100% to 99.7% between the two evaluations. The sealant treatment showing the worst performance was the Crafco 221 (1) hot-pour section. The overall sealant effectiveness of this treatment was 49.7% at the time of the WBMR00 inspection.

Treatments in the westbound lanes may also be ranked according to their overall effectiveness and rate of deterioration. Four treatments shared the No. 1 ranking for effectiveness at the time of the WBNV99 evaluation, namely, Dow 890-SL (1), Dow 888 (1a), Delastic V-687 (5) and Watson Bowman WB-812 (5). Following the WBMR00 inspection, however, only the Watson Bowman WB-812 (5) retained the honor of being No. 1, the other three treatments having fallen to the 4th, 3rd and 6th spots, respectively. The Crafco 221 (1) treatment earned the lowest rank, No. 13, during both westbound lane evaluations. Over the four months between the WBNV99 and WBMR00 inspections, two of the three Dow 890-SL treatments, namely, Dow 890-SL (3) and Dow 890-SL (4) exhibited the smallest deterioration (dropping by less than 1 percentage point), gaining the desirable ranks of Nos. 12 and 13, respectively, for Deterioration. Eleven of the thirteen sealed treatments, including all eight silicone treatments and the Watson Bowman WB-812 (5), showed deterioration rates of fewer than 10 points over the four months between the two evaluations.

3.5 PCC Pavement Performance

To determine whether sealing transverse joints has an effect on concrete pavement performance, the sealant inspection plan calls for the recording of distresses occurring in the immediate vicinity of joints, which may be indicative of joint seal inefficiency or failure. The first signs of such pavement distress were noticed on the first day of the EBMR00 evaluation, primarily in the form of mid-slab transverse cracks revealed in several of the test sections in the eastbound lanes as the wet pavement surface began to dry. The significant frequency and widespread distribution of these transverse cracks, however, did not suggest that their occurrence was necessarily related to the deterioration of any particular sealant treatment. Although their usual location at mid-slab was not as anticipated by the original sealant evaluation plan, it now appeared unjustifiable to simply ignore their presence altogether. Consequently, it was decided to conduct a pilot study into the frequency and distribution of transverse cracks, beginning with the evaluation of the westbound lanes the following day. Accordingly, all transverse cracks and corner breaks occurring in the driving lane over the entire length of the project were counted and recorded by section. It is anticipated that such observations will continue in both the eastbound and westbound directions during future evaluations.

Regarding the development of transverse cracks in jointed reinforced concrete slabs, Yoder and Witczak (1975) indicate that "the designer assumes a crack will form, generally at the center of the slab, and temperature steel is provided to keep this crack intact so that it will not open." Similarly, Bradbury (1938) notes that "the strengthening or so-called 'reinforcing' of concrete members, through the medium of embedded steel, cannot be expected to actually prevent the concrete from cracking, since in any case—whether the structure be a building, a bridge, or a pavement—accomplishment of such a result would require the use of steel at such a low unit stress as to be decidedly uneconomical. Hence, the economical adaptation of reinforcing steel to any type of structure is fundamentally a problem of preventing what may be termed 'objectionable' cracking." Monitoring of transverse cracks at the U.S. 50 test site, therefore, aims at assessing whether such cracks become objectionable from a functional viewpoint and, if so, whether this development is related to sealant performance in any way.

3.5.1 Transverse Cracking

During the WBMR00 evaluation, a distress survey of PCC slabs in the westbound driving lane of the Project, which stretches from Sta 133+60 and to Sta 290+00 skipping the slabs between Sta 231+00 and 260+00, was conducted. A total of 592 slabs were inspected and transverse cracks were observed in ten of the fifteen test sections. In some slabs, cracks had propagated across both the driving and passing lanes, whereas in others, cracking had been arrested by the longitudinal joint. Nearly every crack noted had developed at approximately the middle of the 6.4-m (21-ft) long slabs. The section displaying the greatest frequency of mid-slab cracks and the top percentage of slabs cracked was the one with the Dow 890-SL (1) treatment; a total of 9 cracks were noted, accounting for 33.3% of the 27 slabs. The section sealed with the Watson Bowman WB-687 (5) treatment showed the second highest percentage of cracked slabs, with 18.5% slabs cracked. The following sections exhibited no signs of mid-slab cracking at the time of the WBMR00 evaluation: Crafco 903-SL (1a); Dow 888 (1a); Crafco 903-SL (4); and Dow 890-SL (4). In addition, no transverse cracks were evident in the No Sealant (6) section.

When one considers that the majority of the joint seals in the relatively "young" westbound driving lane were in good to very good condition, it is rather unlikely that the transverse cracks observed in ten of the fifteen westbound test sections were related to poor joint sealant performance. Rather, it appears possible that structural factors may have been responsible for the premature cracking observed in a significant number of slabs. For this reason, a variety of pavement design features affecting pavement performance is discussed in a subsequent section.

3.5.2 Corner Cracking

Every transverse joint in the westbound driving lane of the Project was examined for evidence of corner cracking. There were no visible signs of corner breaks at any of the transverse joints in eight sections, including one that had unsealed joints. These are the two sections with the Crafco 903-SL (1) treatment, both sections with the Dow 888 (1) treatment, as well as the section of Watson Bowman WB-812 installed in joint configuration No. 5; the final unscathed section was the No Sealant (6) section. The other unsealed section in the westbound direction also fared quite well, exhibiting a single corner crack in one of its 125 slabs, accounting for 0.8% slabs cracked. The section with the Dow 890-SL (3) treatment had developed the highest percentage of slabs with corner cracks: four corner breaks were observed in its 28 slabs, accounting for 14.3% slabs cracked.

Table 3.1 Description of joint sealant failure and distress types
(Lynn D. Evans, 1999: personal communication)

Distresses	
Field-Molded Sealants	
Partial Depth Adhesion Loss	Separation of the sealant from one or both edges of the joint, but the separation does not extend through the entire sealant depth.
Partial Depth Spalling	Cracking, breaking, or chipping of a PCC slab from one or both edges within 0.6 m (2 ft) of the joint which does not extend vertically through the depth of the joint sealant.
Partial Depth Cohesion Loss	Splitting of the sealant due to elongation which exceeds the tensile strength of the sealant, but the splitting does not extend vertically through the entire sealant depth. May be either tensile failure, or failure due to bubbles contained within the sealant.
Stone Intrusion	The embedment of stones with a diameter greater than 6 mm (0.25 in.) into the seal material such that they are incapable of being easily removed.
Preformed Compression Seals	
Partial Depth Adhesion Loss	Separation of the sealant from one or both edges of the joint, but the separation does not extend through the entire sealant depth.
Partial Depth Spalling	Cracking, breaking, or chipping of a PCC slab from one or both edges within 0.6 m (2 ft) of the joint which does not extend vertically through the depth of the joint sealant.
Stone Intrusion	The embedment of stones with a diameter greater than 6 mm (0.25 in.) into the seal material such that they are incapable of being easily removed.
Surface Extrusion	The neoprene seal distends above the pavement surface as a result of twisting or high placement.

Table 3.1 (continued)

Failures	
Field-Molded Sealants	
Full Depth Adhesion Loss	The sealant has separated completely from one or both edges of the joint, allowing infiltration of moisture and incompressibles.
Full Depth Spalling	Cracking, breaking, or chipping of a PCC slab edge within 0.6 m (2 ft) of the joint that vertically extends below the depth of the joint sealant.
Full Depth Cohesion Loss	The sealant has split vertically through its entire depth allowing infiltration of moisture and incompressibles.
Sunken Seal	Sealant has completely separated from both edges and sunken into the joint leaving a low area that is not watertight.
Preformed Compression Seals	
Full Depth Adhesion Loss	Compression seal has separated completely from one or both walls of the joint, allowing infiltration of moisture and/or incompressibles.
Full Depth Spalling	Cracking, breaking, or chipping of a PCC slab edge within 0.6 m (2 ft) of the joint that vertically extends below the depth of the compression seal.
Twisted/rolled Seal	Condition in which the neoprene seal is twisted, rolled, or turned in the joint leaving the surface edges of the seal at different elevations.
Compression Set	When the neoprene web structure loses its ability to exert outward pressure as a result of being in compression for a very long duration.
Gap	Joint opens wider than the compression seal is able to span, allowing stones to become lodged between the edge of the compression seal and the edge of the joint.
Sunken Seal	Seal has sunken into the joint leaving a low area that is not watertight.

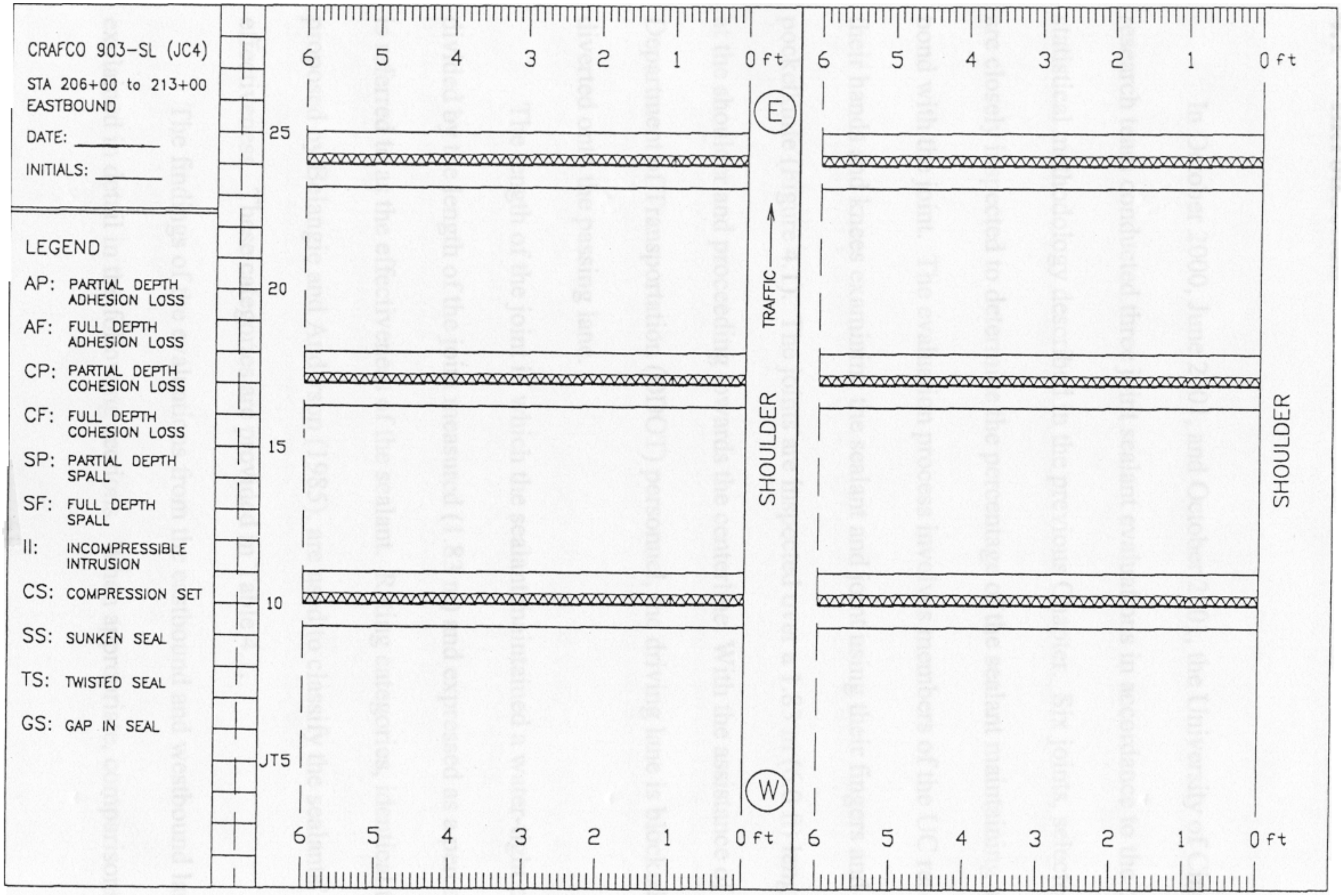


Figure 3.1 Joint sealant evaluation form used during field inspections

4 RECENT PERFORMANCE EVALUATION DATA

4.1 Introduction

In October 2000, June 2001, and October 2001, the University of Cincinnati (UC) research team conducted three joint sealant evaluations in accordance to the quantitative statistical methodology described in the previous Chapter. Six joints, selected randomly, are closely inspected to determine the percentage of the sealant maintaining a water-tight bond with the joint. The evaluation process involves members of the UC research team on their hands and knees examining the sealant and joint using their fingers and a small pocketknife (Figure 4.1). The joints are inspected over a 1.83 m (6.0 ft) length, beginning at the shoulder and proceeding towards the centerline. With the assistance of Ohio Department of Transportation (ODOT) personnel, the driving lane is blocked and traffic is diverted onto the passing lane.

The length of the joint in which the sealant maintained a water-tight bond is divided by the length of the joint measured (1.83 m) and expressed as a percentage, which is referred to as the effectiveness of the sealant. Rating categories, identical to those proposed by Belangie and Anderson (1985), are used to classify the sealants' effectiveness. These categories are provided in Table 4.1.

The findings of the evaluations from the eastbound and westbound lanes are explained in detail in the following sections. When appropriate, comparisons are made between the results of these surveys and two prior evaluations conducted in March 2000 and November 1999, which are described in detail by Sander (2002); the data sets from the latter are code named EBMR00, WBMR00 and EBNV99, WBNV99, respectively. Each sub-section is titled with the name of the sealant, the joint configuration in parentheses, and the stationing interval in brackets. In the case of twin sections, the joint configuration is followed by either an “a” or “b” to distinguish between the two. The treatment evaluations are code-named by their lane direction for the first two letters (EB: eastbound, WB: westbound), and the month and year of the evaluation for the last four digits.

4.2 Fall 2000 Performance Evaluation of the Eastbound Lanes (EBOC00)

The eastbound lanes were surveyed for the third time on Tuesday, October 10, 2000, when the sealants were approximately 35 months old and the pavement had served traffic for 29 months. The survey began at 9:30 a.m. at Station 154+00 and proceeded east. The air temperature was recorded as 8.3°C (47°F) at the early stages of the survey; by the end of the survey (2:15 p.m.), the air temperature had risen to 17.8°C (64°F) under clear skies. The pavement temperature was measured as 9.4°C (49°F) at the beginning of the survey, and 26.1°C (79°F) near the completion of the survey.

4.2.1 Techstar W-050 (5) [Sta 154+00 to 160+00]

The effectiveness of the compression seals in this section has deteriorated by 6%

since the EBMR00 survey. The notation % indicates that performance has decreased from 33 to 27%. The six joints in this section have sunken seals over one-third of the measured length and adhesion failure over 38%. Joints 13, 22, and 26 are by far the worst. Joint 13 has adhesion failure over 95% of the measured span, whereas Joints 22 and 26 experience sunken seal failure over 100 and 93% of the length, respectively. Joints 7, 9, and 11 have no sunken seal failure but averaged 48% adhesion failure.

4.2.2 No Sealant (6) [Sta 160+00 to 166+00]

These unsealed joints are in very good condition; five of the six joints surveyed show no distress. Joint 6 experiences some spalling at two separate locations, totaling 102 mm (4 in.). Joints 6 and 20 opened to a width of 11 mm (7/16 in.) from a nominal width of 6 ± 2 mm (1/4 ± 1/16 in.). A few small incompressibles are noted in all six joints. Some vegetation is growing in Joints 7, 15, and 26, over a total length of 584 mm (23 in.).

4.2.3 Dow 890-SL (3) [Sta 166+00 to 172+00]

The effectiveness of the silicone sealant in this section has deteriorated by 12%, from 68% during EBMR00 to 56% in EBOC00. Joints 22 and 26 have experienced 75 and 80% full-depth adhesion failure, respectively. Joint 25 has some small vegetation growth where the seal has sunk, accounting for 25 mm (1 in.). Joints 5 and 7 have 76 mm (3 in.) and 51 mm (2 in.) of spalling on the lip, respectively. In contrast, during the EBMR00 survey, 102 mm (4 in.) and 51 mm (2 in.) of spalling are recorded for Joints 5 and 7, respectively, suggesting a small inconsistency between successive evaluation crews.

4.2.4 Crafco 444 (1) [Sta 172+00 to 188+00]

This sealant continues to exhibit the lowest effectiveness among the sealants tested. The joints containing this hot-applied sealant are noted to be in very poor condition, achieving an effectiveness rating of only 6%. During the EBMR00 survey, this seal had an effectiveness of 10%, and its deterioration has been 4% since then. Four of the six joints (Joints 31, 40, 44, and 51) currently have an effectiveness of 0%. Joints 5, 31, 40, and 44 each have sunken seal over 30% of the measured length. In Joint 55 over 50% of the seal is completely missing. Some small incompressibles are observed in the portions of the joints where the seal has either sunk into the joint or is completely missing.

4.2.5 Crafco 903-SL (1) [Sta 188+00 to 194+00]

The sealant in these joints is observed to be in very poor condition, having an effectiveness of 48%. This section has lost 4% effectiveness from its previous 52% value, recorded in EBMR00. The six joints surveyed average 47% adhesion failure. Joints 12, 17, and 21 have a combined length of 0.3 m (1 ft) of sunken seal in the joints. Since the EBMR00 survey, Joint 10 has developed some new spalling in the first 51 mm (2 in.) of the joint near the shoulder. No incompressibles are noted in any of the joints.

4.2.6 Watson Bowman 687 (5) [Sta 194+00 to 200+00]

The compression seals in this section have experienced no deterioration since the EBMR00 survey reported by Sander (2002). The effectiveness is, in fact, recorded as 97% in the EBOC00 survey, compared to 95% calculated after the EBMR00 survey. Five of the six joints exhibit no distresses. Joint 23 has 254 mm (10 in.) of the seal missing, but this appears to be the result of poor workmanship rather than deterioration under traffic. Some small incompressibles are noted on top of the seal in all the surveyed joints with the exception of Joint 18.

4.2.7 Crafco 902 (1) [Sta 200+00 to 206+00]

Sealed with non-sag silicone sealant, this section is noted to be in very poor condition. The sealant maintains an effectiveness of 37%, down from 41% measured previously in EBMR00. Individual joints, however, exhibit a wide range of effectiveness. Joints 6 and 11 have failed completely (i.e., exhibit 0% effectiveness) and Joint 8 has an effectiveness of only 5%. These three joints have a combined span of 3.4 m (11 ft) of sunken seal failure, accounting for 62% of the measured length; Joint 6 has 13% of its seal completely missing. In contrast, Joints 16, 19, and 24 has effectiveness ratings of 68, 92, and 58%, respectively.

4.2.8 Crafco 903-SL (4) [Sta 206+00 to 213+00]

The sealants in this section have deteriorated by 18% since the EBMR00 survey. With an effectiveness of only 7%, these silicone-filled joints are observed to be in very poor condition. Joints 8, 10, 15, and 18 exhibit 0% effectiveness, averaging 81% full-depth adhesion and 1% sunken seal failures. Some small vegetation growth is noted in Joint 15 near the shoulder, where the seal has sunk into the joint; sunken seal failure accounts for 23% of this joint's measured length.

4.2.9 Dow 890-SL (4) [Sta 213+00 to 219+00]

Since the EBMR00 survey, these silicone-filled joints have deteriorated the most among all joints surveyed, losing 43% of their effectiveness value. The sealant is observed to be in very poor condition, with an effectiveness of only 13%. Joints 8, 10, and 13 have failed completely, with full-depth adhesion failure accounting for an average of 76% over the span examined. Joints 9 and 24 have effectiveness values of 8 and 10%, respectively. Sunken seal failure is measured over 23% of the length of all six joints surveyed in this section.

4.2.10 No Sealant (2) [Sta 219+00 to 225+00]

The joints in this unsealed section are performing very well. The only distress observed is over a 25-mm (1-in.) segment of Joint 9, where some spalling is noted. This spalling failure has also been noted in both the EBNV99 and EBMR00 surveys and can be attributed to a poor joint cut. At this point, both sides of the joint exhibit spalling failure. All the joints are observed to be clean and tight.

4.2.11 Delastic V-687 (5) [Sta 225+00 to 231+00]

This compression seal has the second highest overall effectiveness among the eastbound sections, maintaining a value of 97%. The seal appears to have gained 2% in effectiveness since the EBMR00 survey, during which an effectiveness of 95% had been recorded. Five of the six joints surveyed exhibit no distresses whatsoever. Joint 15 is observed to have a sunken seal over 15% of the measured length. This may be attributed to poor workmanship during the installation of the seal, as had also been postulated in the previous two surveys (Sander, 2002). A few small incompressibles are noted on top of the seal in Joints 5 and 7.

4.2.12 Crafco 221 (1) [Sta 260+00 to 266+00]

The hot-applied sealants in this section have deteriorated just over 1% since the previous survey; they are observed to be in fair condition with 71% effectiveness. Small bubbles are frequently noted and appear to have contributed to partial-depth cohesion and adhesion failures. In such areas of partial-depth failure, the sealant is still water tight, and its effectiveness rating is not affected. Joints 18, 19, and 25 have effectiveness values of 90, 97, and 98%, respectively. With 38% effectiveness, Joint 8 has some small vegetation growing over 51 mm (2 in.) near the shoulder, where the seal has sunken to the bottom of the joint. Some small incompressibles are also noted on top of the seal. Joint 21 is in very poor condition (27% effectiveness), exhibiting major spalling and corner cracking. The poor appearance of the joint appears to be the result of poor workmanship during the cut. Sealant is present in the corner cracks and in the areas of spalling, confirming that these distresses predate the seal application.

4.2.13 Dow 890-SL (1) [Sta 266+00 to 272+00]

This sealant has an overall effectiveness of 64% and is in poor condition. The silicone-filled joints have deteriorated only 4% since EBMR00. Their effectiveness values range from 52 to 82%. Joints 19 and 23 have seal missing near the shoulder over 51 mm (2 in.) and 127 mm (5 in.), respectively. In the six joints surveyed, the average full-depth adhesion and sunken seal failures are 27 and 8%, respectively. No incompressibles are observed in the joints.

4.2.14 Dow 888 (1a) [Sta 272+00 to 284+00]

The silicone sealants in this section are very poor, maintaining 41% effectiveness. This is down 9% since the EBMR00 survey, when these sealants were described as poor, and had an effectiveness of 50% (Sander, 2002). Full-depth adhesion and sunken seal failures are equally responsible for the loss in effectiveness recorded; no spalling is observed. A small area of incompressibles is noted in Joint 52, whereas the remaining joints contain no incompressibles.

4.2.15 Dow 888 (1b) [Sta 284+00 to 290+00]

The last section of the eastbound lanes is in very poor condition, with an average effectiveness of 41%. These silicone sealants have lost 8% effectiveness since the previous survey, when an effectiveness of 49% had been noted. No spalling is observed in this section either. All of the effectiveness loss is attributed to full-depth adhesion and sunken seal failures, which total 44 and 15% of the measured length, respectively. Effectiveness values range from 13% in Joint 12, to 97% in Joint 26. Some small incompressibles are noted in Joint 12, where the seal has sunken into the joint. No incompressibles are observed in the rest of the joints.

4.3 Spring 2001 Performance Evaluation of the Eastbound Lanes (EBJN01)

The eastbound lanes were surveyed for the fourth time on Monday, June 4, 2001, when the sealants were 43 months old and the pavement had served traffic for 37 months. The survey began at 8:00 a.m. at Station 154+00 and proceeded eastward; the air temperature at this time was 13.3°C (56°F) under sunny skies. By 1:40 p.m., when the survey ended, the air temperature had only risen to 18.9°C (66°F) due to cloudy conditions. The pavement temperature was measured as 16.1°C (61°F) at the beginning of the survey and 25.6°C (78°F) near the completion of the survey, although temperatures up to 29.4°C (85°F) were recorded during the course of the survey.

4.3.1 Techstar W-050 (5) [Sta 154+00 to 160+00]

The seals in this section have the worst performance among the compression seals and nearly the worst one overall, maintaining only 22% effectiveness. These sealants also have the highest deterioration at 5% since the last inspection. Joints 22 and 26 have failures over 100% of the measured length of the joint. In these two joints, the seal is sunken for 1.73 and 1.70 m (5.7 and 5.6 ft.) of the measured length, respectively. Joints

7, 9, and 13 have adhesion failure over 1.40, 1.35, and 1.37 m (4.6, 4.4, and 4.5 ft.) of their respective measured lengths. Several of the joints inspected have large amounts of sand and gravel in their joints.

4.3.2 No Sealant (6) [Sta 160+00 to 166+00]

These unsealed joints are in very good condition; five of the six joints surveyed show no distress. Joint 6 exhibits some minor spalling at two separate locations, totaling 127 mm (5 in.). Joint 20 has small longitudinal cracks forming near the middle of the measured joint length. Most of the joints have large amounts of sand and gravel at their bottoms. Joints 7, 15, and 26 have some vegetation growing in them. Joint 15 is open to a width of 11 mm (7/16 in.) from a nominal width of 6 ± 2 mm (1/4 ± 1/16 in.).

4.3.3 Dow 890-SL (3) [Sta 166+00 to 172+00]

The silicone filled joints in this section are found to be in poor condition, maintaining only 62% effectiveness. Joints 25 and 26 have a combined span of 178 mm (7 in.) over which the sealant is completely missing. Joints 5, 7, and 13 are in relatively good condition, with only a combined loss of adhesion of 762 mm (30 in.), whereas Joints 22, 25, and 26 have a combined adhesion loss of 2.96 m (9.7 ft.).

4.3.4 Crafco 444 (1) [Sta 172+00 to 188+00]

This sealant continues to exhibit the lowest effectiveness among those tested.

The joints containing this hot-applied sealant are in very poor condition, with an effectiveness rating of only 11%. Joints 40 and 51 have 0% effectiveness, and Joint 44 is only 3% effective. These three joints have a combined total of 2.77 m (9.1 ft.) of their sealants completely missing. Joint 40 is found with its backer rod protruding, and with large amounts of sand and gravel in its place. In all the joints, the sealant is very brittle and large pieces of the sealant are found along the shoulder. A 102 mm (4 in.) spall, 13 mm (½ in.) deep, is found in Joint 12. A random measurement indicates that Joint 31 is 11 mm (7/16 in.) wide, a value that is within the nominal width dimensions of 10 ± 2 mm (3/8 ± 1/16 in.).

4.3.5 Crafco 903-SL (1) [Sta 188+00 to 194+00]

This silicone sealant averaged 63% effectiveness, indicating that it is in poor condition. Joints 10 and 21 have a combined 279 mm (11 in.) of their sealant missing. These two joints also have 102 mm (4 in.) of spalling failures, measuring 6 mm (1/4 in.) and 10 mm (3/8 in.) deep, respectively. Joints 12 and 21 exhibit rare cohesion failures, accounting for 102 mm (4 in.) of measured length. Joint 17 has a width of 13 mm (½ in.), which is wider than the nominal 10 ± 2 mm (3/8 ± 1/16 in.). In all the joints, the measured failures are intermittent rather than continuous. No incompressibles are noted in any of the joints.

4.3.6 Watson Bowman 687 (5) [Sta 194+00 to 200+00]

The compression seals in this section remain the most effective sealant treatment, being 95% effective and losing only 3% since EBOC00. Joints 6 and 7 have no distresses at all. Joints 9 and 18 have two spalls accounting for 51 mm (2 in.); both are only 6 mm (1/4 in.) deep. Joint 23 has 152 mm (6 in.) of adhesion failure, but this seems to be the result of a poor cut. One half of the joint is cut wider than the other half, and instead of a smooth transition between the two widths there is a sudden sharp change, making it difficult for the seal to conform to the edge. At this transition point, the wider portion of the joint is measured at a remarkable 22 mm (7/8 in.). No incompressibles are noted in any of the joints.

4.3.7 Crafco 902 (1) [Sta 200+00 to 206+00]

This non-sag silicone sealant maintained nearly all of its effectiveness since the previous survey, losing only 1%. The section remained in very poor condition, however, achieving only 36% effectiveness. Most of the sealants suffer from sunken seal failure, which measures a total of 4.54 m (14.9 ft.) of the 10.97 m (36 ft) measured length. In many of the joints, the sealant wavers as it loses and gains adhesion. Joints 6 and 24 have 483 mm (19 in.) of their sealants completely missing. No incompressibles are noted in any of the joints.

4.3.8 Crafco 903-SL (4) [Sta 206+00 to 213+00]

These sealants are found in poor condition with an effectiveness of 56%. This comes as a surprise since they had been only 7% effective during the last survey, EBOC00. Such a dramatic rise in effectiveness is observed in other sections with joint configuration No. 4 as well and will be explained subsequently. Half on the joints, namely, Joints 5, 15, and 18, have portions of their sealants missing, totaling 279 mm (11 in.). Joints 5, 8, and 10 each have a small spalling failure on their edge, measuring no more than 13 mm (½ in.) deep. No incompressibles are noted in any of the joints.

4.3.9 Dow 890-SL (4) [Sta 213+00 to 219+00]

Between EBMR00 and EBOC00, this section had the largest decrease in effectiveness (43%), yet since EBOC00 this section has had the largest increase in effectiveness (53%). This silicone section has gone from very poor in EBOC00 to a fair rating in EBJN01, currently having an effectiveness value of 65%. No missing sealant or spalling failures are observed in the joints. These sealants have predominantly sunken seal failures, accounting for 3.35 m (11.0 ft.) of the total 3.84 m (12.6 ft.) measured length of failures. Joint 13 has a small spall failure measuring 51 mm (2 in.) long and 13 mm (½ in.) deep. A randomly measured joint width of 3 mm (1/8 in.) in Joint 8 is found to be within the nominal dimension range.

4.3.10 No Sealant (2) [Sta 219+00 to 225+00]

Two spalling failures are found in this section, one in each of Joints 9 and 18. The spall in Joint 18 is 25 mm (1 in.) long and 10 mm (3/8 in.) deep, while the spall in Joint 9 is 25 mm (1 in.) long and 32 mm (1 1/4 in.) deep. Joint 9 is found to have some incompressibles lodged in it, as well. Most of the other joints found in this section are relatively clean, with just a few small incompressibles found at their bottom.

4.3.11 Delastic V-687 (5) [Sta 225+00 to 231+00]

This compression seal has the second highest overall effectiveness in the eastbound lanes, maintaining a value of 94%. Three of the joints exhibit no sealant failures whatsoever. Joints 9, 10, and 15 have a combined length of 559 mm (22 in.) over which the seal has sunken into the joint. Joints 10 and 15 have some minor spalling failures, measuring 25 and 51 mm (1 and 2 in.), respectively. These two joints have maximum widths of 16 and 14 mm (5/8 and 9/16 in.), respectively, which are outside the nominal dimensions of 10 mm ± 2 mm (3/8 in. ± 1/16 in.). A few small incompressibles are noted on top of the seal in Joint 5.

4.3.12 Crafco 221 (1) [Sta 260+00 to 266+00]

The hot-applied sealants in this section have maintained their fair rating, gaining, in fact, nearly 5%. Joints 18, 19, and 25 are in very good condition, maintaining effectiveness values of 97, 98, and 95%, respectively. Joint 25 has a very small spalling failure. Joints 4 and 8 exhibit rare cohesion failures, each measuring 102 mm (4 in.). Joint 21 is badly cut and has 965 mm (38 in.) of spalling failure, as well as 178 mm (7 in.) of adhesion failure. Joints 18 and 19 have partial adhesion and cohesion failures over nearly their entire measured length, attributable to bubbles in the sealant. No incompressibles are noted in any of the joints.

4.3.13 Dow 890-SL (1) [Sta 266+00 to 272+00]

Averaging 79.7% effectiveness, these silicone sealants are in fair condition. During the last survey, they were found to be in poor condition, with an effectiveness of 64%. Joints 18, 19, and 23 have sealants missing over a combined length of 279 mm (11 in.). Joints 8, 12, and 23 have sunken seal failure over 51, 356, and 152 mm (2, 14, and 6 in.), respectively. Joint 17 has a remarkable 406 mm (16 in.) of full-depth cohesion failure. The rest of the effectiveness loss is attributed to adhesion failure. Joint 23 has a measured width of 16 mm, which is more than the nominal width of 10 mm ± 2 mm (3/8 in. ± 1/16 in.). Two very small longitudinal cracks are beginning to form at the edges of Joints 17 and 18. No incompressibles are noted in any of the joints.

4.3.14 Dow 888 (1a) [Sta 272+00 to 284+00]

This silicone sealant section is in poor condition, maintaining 56% effectiveness. During the last survey, these sealants had only a 41% effectiveness value. With the exception of Joint 4, every joint had sunken seal failure, which totaled 3.75 m (12.3 ft.). Joint 52 experiences sunken seal failure over nearly its entire measured length or 1.63 m (5.3 ft.). Joint 4 is in very good condition (95%), but is the only joint to have part of its sealant missing. Joint 20 has 102 mm (4 in.) of cohesion failure. A small spalling failure measuring 25 mm (1 in.) long and 6 mm (1/4 in.) deep is found in Joint 10. Joint 20 has a width of 13 mm (½ in.), slightly wider than its nominal width.

4.3.15 Dow 888 (1b) [Sta 284+00 to 290+00]

The last section of the eastbound lanes is in poor condition, with an average effectiveness of 61%. Like its twin in the previous section, this silicone sealant has improved its effectiveness rating; in this case by 20%. Every joint has experienced some adhesion failure, ranging from 25 mm (1 in.) in Joint 26, to 914 mm (36 in.) in Joint 20. The aforementioned Joint 26 is in very good condition, maintaining 98% effectiveness. Joint 12 is in very poor condition with 1.42 m (4.7 ft.) of sunken seal failure. Joints 4, 5, and 13 have 102, 152, and 203 mm (4, 6, and 8 in.) of sunken seal failure, respectively. Joint 4 has a measured width of 13 mm (½ in.), which is wider than the nominal width. No incompressibles are noted in any of the joints.

4.4 Fall 2001 Performance Evaluation of the Eastbound Lanes (EBOC01)

On Monday, October 15, 2001, the fifth and final test site evaluation for the eastbound lanes was conducted. The sealants are nearly four years old and the pavement has served traffic for 3 1/3 years. The survey began at 8:45 a.m. under partly cloudy skies and an air temperature of 6.7°C (44°F); it was concluded at 2:45 p.m. under sunny skies and an air temperature of 18.3°C (65°F). Pavement temperatures ranged from 7.2°C (45°F) at the beginning of the day to 27.8°C (82°F) at the end. The University of Cincinnati research team began the inspection at Station 154+00, proceeded eastward and finished at Station 290+00. The stretch corresponding to the location of the batch plant and of the headquarters of the project contractor (*Kokosing Construction Company, Inc.*), an area of intense and heavy truck traffic (Stations 231+00 to 260+00), was not included in the evaluation. The paragraphs below give general descriptions of the sealants' condition.

4.4.1 Techstar W-050 (5) [Sta 154+00 to 160+00]

These sealants remain the worst of the pre-formed compression seals, maintaining only 19% effectiveness, which is down 3% from the previous survey (June 2001). Two of the joints, 22 and 26, have failure over 100% of their measured length. Most of their failure is attributed to sunken seal, accounting for 94 and 93%, respectively. The remaining four joints have mostly adhesion failure. Large incompressibles are found on top of all the joints, and some small vegetation growth is seen in Joint 7. Joint 26 has a measured width of 13 mm (½ in.), which is larger than the nominal width of 10 ± 2 mm (3/8 ± 1/16 in.).

4.4.2 No Sealant (6) [Sta 160+00 to 166+00]

These unsealed joints are in very good condition; five of the six joints surveyed show no distress. Joint 6 has some minor spalling at two separate locations, totaling 51 mm (2 in.). Most of the joints have large amounts of sand and gravel at their bottom. Joints 7, 15, and 26 have small amounts of vegetation growing in them. They also had vegetation in them during the last survey. Joint 6 has opened to a width of 11 mm (7/16 in.) from a nominal width of 6 ± 2 mm (1/4 ± 1/16 in.).

4.4.3 Dow 890-SL (3) [Sta 166+00 to 172+00]

These silicone sealants have lost only 5% since the previous survey, but remain in poor condition with an effectiveness value of 57%. Joints 5, 7, and 13 are in good condition (>80%), but the remaining joints, 22, 25, and 26, are less than 40% effective. Nearly all of the failure in this section is attributed to loss of adhesion. Joint 26 has a 25-mm (1-in.) spalling failure. A random measurement of the width of this joint found it to be within its nominal specification.

4.4.4 Crafco 444 (1) [Sta 172+00 to 188+00]

For the fifth consecutive evaluation, the sealants in this section have the lowest effectiveness values in the eastbound lanes. These hot-poured sealants deteriorated 2% to 9% since the previous survey. Two joints, 40 and 44, are 0% effective, and Joints 31 and 51 are only 3 and 7% effective, respectively. The sealants are dry, hard, and brittle, which prevents them from maintaining a bond with the joint wall. Parts of the sealant can be found along the shoulder of the highway. Joints 40, 44, and 51 have missing sealant over a total of 2.90 m (9.5 ft.) of the length inspected. At these locations, the joint is filled with sand and gravel.

4.4.5 Crafco 903-SL (1) [Sta 188+00 to 194+00]

This silicone filled section has lost only 5% since the previous survey, but remains in poor condition with an effectiveness value of 58%. Most of the failure comes from small incremental losses of adhesion, which account for 91% of the length inspected. Joints 10 and 21 have a total of 279 mm (11 in.) of missing sealant. Joint 17 has a joint width of 13 mm (½ in.), which is more than the nominal width of 10 ± 2 mm (3/8 ± 1/16 in.). No incompressibles are noted in any of the joints.

4.4.6 Watson Bowman 687 (5) [Sta 194+00 to 200+00]

These compression seals are no longer the single most effective sealant treatment, as they now share that title with the Delastic V-687 (5) section: both sections have effectiveness values of 94%. The Watson Bowman 687 (5) section has three joints (6, 7, and 9) with no failures whatsoever. Joint 12 is nearly failure free, with only 25 mm (1 in.) of adhesion failure. Joint 23 has some small vegetation growth where the sealant has sunken into the joint. At one location, this joint has been either cut or expanded to a width of 22 mm (7/8 in.); 203 mm (8 in.) of adhesion failure is found here. There is some minor spalling in Joint 18, accounting for 25 mm (1 in.). No incompressibles are found in any of the joints.

4.4.7 Crafco 902 (1) [Sta 200+00 to 206+00]

This section is only 31% effective but has lost only 5% since the previous survey. Two of these non-sag silicone filled joints, 6 and 11, have failed over at least 95% of the length inspected. Most of the failures are attributed to sunken seal in this section. No incompressibles are noted in any of the joints.

4.4.8 Crafco 903-SL (4) [Sta 206+00 to 213+00]

These sealants have by far the largest amount of deterioration (44%) and currently average 12% effectiveness. Joint 5 has failed over its entire length and Joint 8 is only 3% effective. The remaining joints range in effectiveness from 13 to 23%. Several of the joints have rough lips, probably due to their narrow joint width. A random measurement of Joint 13 found its width to be 6 mm (1/4 in.), which is larger than the nominal range of 3 mm ± 2 mm (1/8 in. ± 1/16 in.). Because the joint is completely filled with the sealant, no incompressibles are found in it.

4.4.9 Dow 890-SL (4) [Sta 213+00 to 219+00]

This is another section with the narrow No. 4 joint configuration; it has lost a significant amount of effectiveness (23%) since the previous survey. Effectiveness values varied widely from 32% in Joint 24 to 77% in Joint 25. Sunken seal and adhesion failures account for all loss of effectiveness in this section. Some vegetation growth is observed in Joint 24 near the shoulder. No incompressibles are found in these joints.

4.4.10 No Sealant (2) [Sta 219+00 to 225+00]

There are several small spalling failures in this unsealed section. Joints 9, 12, 18, and 25 each have 25-mm (1-in.) spalls on their edges. No incompressibles or vegetation growth is found in this section. Joint 18 has a joint width of 3 mm (1/8 in.), which is within the nominal range for this joint configuration.

4.4.11 Delastic V-687 (5) [Sta 225+00 to 231+00]

This sealant continues to average a high effectiveness value (94%); no effectiveness has been lost since the previous survey. Joints 7, 9, and 20 have no failures whatsoever. Joints 10 and 15 have a combined length of 508 mm (20 in.) over which the seal has sunk, but this is probably the result of poor installation. A few small incompressibles are noted on top of the seal in Joint 9; no other joint has incompressibles observed in them.

4.4.12 Crafco 221 (1) [Sta 260+00 to 266+00]

These hot-applied sealants essentially maintain their original effectiveness value of 79% measured two years earlier during the EBNV99 survey. Joint 19 is 100% effective, while Joints 4, 18, and 25 are all over 95% effective. Joint 21 is the result of a bad cut and has spalling failures over 60% of its measured length.

4.4.13 Dow 890-SL (1) [Sta 266+00 to 272+00]

The sealants in this section are in fair condition with an effectiveness value of 71%. All of the joints are performing very similarly. With the exception of Joint 18, all the joints range in effectiveness from 67 to 70%; Joint 18 is 88% effective. About half of the effectiveness loss is attributed to adhesion failure. Joints 18, 19, and 23 have a combined measured length of 330 mm (13 in.) of missing sealants. Joint 17 has a rare cohesion failure, measuring 406 mm (16 in.) in length. It appears that the sealant has corroded at this point. No incompressibles are found in any of these joints.

4.4.14 Dow 888 (1a) [Sta 272+00 to 284+00]

The first of two identical silicone sections in this stretch is in very poor condition, achieving only 47% sealant effectiveness. Joints 45 and 52 have 1.52 m (5.0 ft) and 1.65 (5.4 ft.) of sunken seal failure, respectively. Joints 10 and 20 combine for 1.50 m (4.9 ft.) of sunken seal failure. Joint 4 has 127 mm (5 in.) of its sealant missing and Joint 21 has 813 mm (32 in.) of adhesion failure. No incompressibles are noted in these joints.

4.4.15 Dow 888 (1b) [Sta 284+00 to 290+00]

The second Dow 888 section continues to perform like its identical twin. It is 49% effective, losing 12% since the previous survey. Sealant effectiveness values range from 5% in Joint 12 to 90% in Joint 26. Loss of adhesion accounts for 53% of the failures, while sunken seal contributes 43%. Joint 5 has 203 mm (8 in.) of its sealant missing. A random measurement of Joint 4 found its width to be within the tolerances for the No. 1 joint configuration. No incompressibles are found in these joints.

4.5 Fall 2000 Performance Evaluation of the Westbound Lanes (WBOC00)

The westbound lanes were surveyed for the third time on Wednesday, October 11, 2000, when the sealants were approximately 22 months old and the pavement had served traffic for 17 months. The hot-applied sealants were not installed until 4 months after the others and are that much younger. The survey began at approximately 8:00 a.m. at Station 133+60 and proceeded eastward. The weather was unseasonably cold that morning, with an air temperature of -1.7°C (29°F). This rose to 21.7°C (71°F) by the end of the survey, approximately at 1:30 p.m., under clear skies.

4.5.1 Techstar W-050 (5) [Sta 133+60 to 138 +60]

The compression seals in this section have deteriorated much more rapidly than any of the westbound sections since the previous survey, earning the lowest effectiveness rating of 27%. At the time of WBMR00, the seals had been noted to be in fair condition, with an effectiveness of 70%. Joints 22 and 25 have full-depth adhesion failure of 92 and 100%, respectively. The four other joints average 62% effectiveness. All failures in this section are attributed to full-depth adhesion failure; no sunken seals or spalling failures are encountered. Many incompressibles are observed in all joints in this section.

4.5.2 No Sealant (2) [Sta 139+60 to 166+00]

This section is observed to be in very good condition. Joints 37, 46, 84, and 106 have no visible distresses. Small vegetation growth is observed in Joint 84 over a length of 51 mm (2 in.). Joints 50 and 60 are each observed to have 25 mm (1 in.) of spalling on their leave-sides. These spalling distresses were not recorded in the previous survey. An interesting observation is made in Joint 37: during the WBMR00 survey, a 25-mm (1-in.) spalling failure had been noted, yet during WBOC00 no spalling failure is observed. As long as such inconsistencies are small and infrequent, they have no significant repercussions.

4.5.3 Dow 890-SL (3) [Sta 166+00 to 172+00]

The silicone sealants in this section exhibit essentially no deterioration, averaging 99.7% effectiveness; during the WBMR00 survey, an effectiveness of 99.4% had been measured. Five of the six joints surveyed currently have no distresses. Three of these five joints, however, Joints 11, 15, and 18, have corner breaks, but these do not affect sealant effectiveness since the sealant maintains its water-tight bond with the joint. Joint 10 is the only joint that exhibits some form of sealant distress: it has 25 mm (1 in.) of full-depth adhesion failure.

4.5.4 Crafco 221 (1) [Sta 172+00 to 188+00]

These hot-applied sealants are in very poor condition, maintaining only 46% effectiveness. This is down 4% since the WBMR00 survey, when the section had an effectiveness rating of 50%. The sealant effectiveness varies widely, from zero to 95%. Full-depth adhesion failure occurs over the entire measured length of Joint 22; Joint 40 experiences only 5% full-depth cohesion failure. Joints 60 and 68 have 10 and 8% effectiveness, respectively. Joints 56 and 70 have effectiveness values of 92 and 72%, respectively. Several of the seals are noted to have small bubbles, which account for some partial-depth cohesion loss. These bubbles are also noted in the WBNV99 survey, six months after the installation of the sealant (Sander, 2002).

4.5.5 Crafco 903-SL (1a) [Sta 188+00 to 194+00]

The six silicone sealants evaluated in this section are 98% effective during this survey (WBOC00), whereas during the WBMR00 evaluation they had been only 95% effective. Small differences like this may be considered insignificant, arising from inevitable discrepancies in the rating practices of individual research team members. Joints 4 and 5 have no distresses, and the four other joints (Joints 10, 14, 25, and 26) average 97% effectiveness. Joint 26 has experienced spalling in a 51-mm (2-in.) area, as previously reported in the WBMR00 survey (Sander, 2002). No incompressibles are observed in any of the joints.

4.5.6 Crafco 903-SL (1b) [Sta 194+00 to 200+00]

The silicone sealants in this section have not performed nearly as well as those in their previously discussed twin section. The sealants in this section may be described as fair, with 79% effectiveness, up 2% from 77% measured during the WBMR00 survey. Joint performance ranges from 60% (Joint 26) to 98% (Joint 12). Joint width measurements were randomly taken in Joints 12 and 18, whose widths are both 11 mm (7/16 in.), a value within the specified range for this joint configuration, i.e., 10 mm ± 2 mm (3/8 in. ± 1/16 in.). Joint 26 has a measured width of 16 mm (5/8 in.), which is well outside the corresponding specification, suggesting an expansion of the joint. Joint 10 has a spalling failure measured over 51 mm (2 in.). During the WBMR00 survey, spalling has been observed in Joint 10, as well as in Joints 12 and 26. The latter two joints had been noted as having 203 mm (8 in.) of spalling, but this is not observed in the WBOC00 survey. This discrepancy accounts for the apparent 2% improvement in effectiveness between the two surveys noted above.

4.5.7 Dow 890-SL (1) [Sta 200+00 to 206+00]

The joints in this silicone filled section are performing very well, achieving 97% effectiveness. The sealants have deteriorated only 1% since the WBMR00 survey. Three of the joints (Joints 5, 17, and 24) sustain no distresses over the entire measured length. Joints 4, 9, and 25 have 88, 98, and 97% effectiveness, respectively. Some small incompressibles are noted on top of the seal in Joint 9; no other incompressibles are observed in the section. Joints 4 and 25 have experienced some spalling failure at the joint lips. Only the spalling in Joint 25 had been observed in the WBMR00 survey, as well.

4.5.8 Crafco 444 (1) [Sta 206+00 to 213+00]

These hot-applied sealants are 96% effective, and may be described as very good. Observations in this section suggest the highest effectiveness increase, up 7% since the previous survey. Consequently, the rating description changes from good during the WBMR00 survey, to very good during WBOC00. Most of the difference in effectiveness is attributed to Joints 18 and 25, in which 787 mm (31 in.) and 279 mm (11 in.), respectively, of adhesion failure were noted during WBMR00, yet during WBOC00 there was only 559 mm (22 in.) and 0 mm (0 in.). The field logs for WBOC00 note that these joints have partial-depth adhesion failure over much of their sealants. Recall that this type of sealant distress does not count towards loss of effectiveness.

Four of the six joints surveyed (Joints 4, 21, 24, and 25) suffer from no distresses. Joint 18 has corner breaks on both sides of the joint at the shoulder, yet it maintains 90%

effectiveness with failures in the form of full-depth adhesion failure. Some small incompressibles are noted on top of the seal in Joints 4, 21, 24, and 28.

4.5.9 Dow 888 (1a) [Sta 213+00 to 219+00]

The silicone sealant in this section maintains 96% effectiveness, achieving a very good condition rating. The joints examined have deteriorated only 3% since the previous survey when they were 99% effective. Every joint surveyed has an effectiveness value above 90%; Joint 18 has no recorded distresses. On its approach side, Joint 21 suffers from a spalling failure, which had not been observed in previous surveys.

4.5.10 Delastic V-687 (5) [Sta 219+00 to 225+00]

These compression seals may be described as being in very good condition. They achieve an effectiveness of 99%, which represents an increase of 3% compared to the value of 96% recorded during the WBMR00 survey. Four of the six joints examined have no recorded distresses; these are Joints 8, 10, 18, and 22. The two other joints (Joints 9 and 13) are 93 and 98% effective, respectively. Joint 13 has spalling failure for a measured length of 25 mm (1 in.) on the approach side of the joint; during WBMR00, a gap in the seal was observed, instead. It is apparent that spalling occurred after the WBMR00 survey, as a result of the missing seal. Some small incompressibles are noted on top of the seal in Joints 8, 9, and 13.

4.5.11 Watson Bowman 812 (5) [Sta 225+00 to 231+00)]

No distresses are observed in any of the joints examined and, therefore, this compression seal section achieves a remarkable 100% effectiveness. The same observation had been made in the WBMR00 survey, as well. Joints 19 and 24 are noted to have some small incompressible intrusions, although there are no distresses. The other joints have small incompressibles lying on the top of the seals. Joint 7 has a measured width of 13 mm (½ in.), which is greater than the nominal width of 10 ± 2 mm (3/8 ± 1/16 in.).

4.5.12 Dow 888 (1b) [Sta 260+00 to 266+00]

These silicone sealants have sustained no deterioration since the previous survey, achieving 98% effectiveness. The sealants in Joints 8 and 24 show no distress. The remaining four joints maintain at least 95% effectiveness. Joints 12, 15, and 21 have 25 mm (1 in.) of spalling failure each. The spalling in Joint 12 had been noted in the WBNV99 and WBMR00 surveys, as well, and can be attributed to a poor initial cut. In contrast, the spalling in Joints 15 and 21 is more recent, since no previous mention of it has been made. No incompressibles are observed in any of the joints surveyed.

4.5.13 Crafco 903-SL (4) [Sta 266+00 to 272+00]

The silicone sealants in this section may be described as being in very good condition, having 91% effectiveness. This is up 2% since the WBMR00 survey, when these sealants had been 89% effective and had been described to be in good condition. The recorded increase in effectiveness is insignificant, yet the apparent improvement in rating description may influence an engineer's perception of sealant performance.

The six joints in this section average 8% adhesion failure, the remaining 1% effectiveness loss being due to sunken seal and spalling distresses. Joints 8 and 14 each show 25 mm (1 in.) of spalling over their measured length. Both spalling incidents are recent, occurring since WBMR00. The width of Joint 8 is measured to be 6 mm (1/4 in.), which is larger than the joint's specified cut configuration of 3 ± 2 mm (1/8 ± 1/16 in.). No incompressibles are observed in any of the joints examined.

4.5.14 Dow 890-SL (4) [Sta 272+00 to 284+00]

The silicone sealants in these joints have lost 29% effectiveness since the WBMR00 survey. Following WBOC00, the sealants may be described as poor, being 57% effective. Full-depth adhesion and sunken seal failures account for 34 and 8% loss of effectiveness, respectively; the remaining 1% is due to spalling. Joint 7 causes some concern to the survey team. This joint is in very poor condition, having only 13% effectiveness. The dismal appearance of this joint is evidently the result of very poor workmanship. As noted in previous surveys (Sander, 2002), severe spalling, sunken seal, and full-depth adhesion failures are evident. The width of the joint varies from 0 mm (0 in.) to 32 mm (1 ¼ in.), whereas the nominal width of the joint is 3 ± 2 mm (1/8 ± 1/16 in.). The remainder of the joints average 27 and 7% loss of effectiveness due to full-depth adhesion and sunken seal failures, respectively. No incompressibles are observed in any of the joints surveyed.

4.5.15 No Sealant (6) [Sta 284+00 to 290+00]

Five of the six joints examined show no distresses. Joint 20 suffers from 25 mm (1 in.) of spalling over its measured length, as reported in the previous survey, as well. Some small vegetation growth is observed in Joints 7, 12, 20, and 21, accounting for 4% of the measured length. Several small incompressibles are observed at the bottom of all the joints examined.

4.6 Spring 2001 Performance Evaluation of the Westbound Lanes (WBJN01)

The westbound lanes were surveyed for the fourth time on Tuesday, June 5, 2001, when the sealants were 30 months old and the pavement had served traffic for 25 months. Recall that the hot-applied sealants are 4 months younger than the other sealants due to a later installation date. The survey began at approximately 8:05 a.m. at Station 133+60 and proceeded eastward. Under partly cloudy skies, the air temperature was recorded at 16.7°C (62°F), whereas the pavement temperature was slightly higher, at 17.8°C (64°F). With variable cloudiness throughout the day, the air temperature was 23.9°C (75°F) when the survey was concluded, at approximately 1:30 p.m. The pavement temperature, warmed by periods of clear skies, had risen to a maximum of 31.7°C (89°F).

4.6.1 Techstar W-050 (5) [Sta 133+60 to 138 +60]

These compression seals are the worst performing sealants in the westbound lanes and have also deteriorated more than any other section since the last survey. This section has an average effectiveness of 14%, down 13% from the previous survey. Joints 23 and 25 have failed completely and Joint 22 is only 3% effective. Joint 23 even has some small vegetation growth in it. The majority of the failure comes in the form of adhesion loss, which combines to 3.44 m (11.3 ft.). Joints 5 and 15 each have 25 mm (1 in.) long spalling failures. Many incompressibles are noted in some of the joints.

4.6.2 No Sealant (2) [Sta 139+60 to 166+00]

This section is observed to be in very good condition. No spalls are noted in any of the joints, although Joint 50 and 60 are observed to have very rough lips, which may appear as minor spalling. Joints 37 and 46 are found to be nearly filled to the surface with sand and fine gravel. No vegetation growth is noted in any of the joints.

4.6.3 Dow 890-SL (3) [Sta 166+00 to 172+00]

These silicone sealants remain in very good condition, maintaining 98% effectiveness and losing only less than 2% effectiveness since the previous survey. Four of the six joints have no distresses (Joints 7, 11, 15, and 18). Joint 10 has 152 mm (6 in.) of adhesion failure and Joint 22 has 104 (4 in.) of sunken seal failure. Joints 11 and 18 have corner breaks measuring 610 x 152 mm (24 x 6 in.) and 76 x 51 mm (3 x 2 in.), respectively, but these corner breaks do not count against effectiveness values. In most of the joints, the sealant is found to be near or at the surface of the pavement, yet no failures are occurring at these locations, which is remarkable.

4.6.4 Crafco 221 (1) [Sta 172+00 to 188+00]

These hot-applied sealants averaged 58% effectiveness, up 12% from the last survey. This apparent rise in effectiveness improved the rating category from very poor to poor. The bond between the sealant and joint wall is very weak. When inspecting the sealant, it is very easy to break the bond, which makes it very difficult to distinguish between full- or partial-depth adhesion loss. This may be the cause of the apparent increase in effectiveness.

Joints 60, 68, and 70 have 203, 432, and 203 mm (8, 17, and 8 in.) of sunken seal failure, respectively. Joint 60 has 330 mm (13 in.) of its sealant missing. Joint 22 has full-depth adhesion loss over nearly all of its length. All of the joints have small bubbles in their sealants; the sealants are also brittle. No spalls or incompressibles have been observed in any of the joints.

4.6.5 Crafco 903-SL (1a) [Sta 188+00 to 194+00]

The six silicone sealants evaluated in this section remain in very good condition. They have only lost 2% effectiveness since the last survey, giving them a 96% effectiveness value. The joints have a combined 279 mm (51 in.) of adhesion failure. Joint 14 has two 25 mm (1 in.) long spalling failures, measuring no more than 13 mm (½ in.) deep. Joint 26 has a 51 mm (2 in.) long spalling failure, also less than 13 mm (½ in.) deep. Joint 5 is the only joint suffering from sunken seal failure, with only 25 mm (1 in.)

measured. No incompressibles are observed in any of the joints.

4.6.6 Crafco 903-SL (1b) [Sta 194+00 to 200+00]

The silicone sealants in this duplicate section have not deteriorated very much either, but continue to perform inferior to their counterparts in the previous section. The sealants have lost less than 1% effectiveness, but are still only 79% effective. Joints 18 and 24 have 152 mm (6 in.) and 51 mm (2 in.) of sunken seal failure, respectively. Both Joints 10 and 26 have 51 mm (2 in.) long spalling failures measuring no more than 6 mm (1/4 in.) deep. Joint 12 has no sealant failures whatsoever. No incompressibles are observed in any of the joints.

4.6.7 Dow 890-SL (1) [Sta 200+00 to 206+00]

The joints in this silicone filled section are performing very well, achieving 97% effectiveness. The sealants have deteriorated less than 1% since the WBOC00 survey. Joints 9 and 17 sustain no distresses over their entire measured length. The remaining joints (4, 5, 17, and 25) are all 95% effective. Joints 5, 24, and 25 all have 102 mm (4 in.) of spalling failure. Joint 5 has two spalls, measuring 25 and 51 mm (1 and 2 in.) long and each 13 mm (½ in.) deep. Joint 24 also has two spalls, measuring 25 and 51 mm (1 and 2 in.) long and each 6 mm (1/4 in.) deep. Joint 25 has one spalling failure measuring 102 mm (4 in.) long and 13 mm (½ in.) deep. This joint also has some incompressibles lodged in its sealant. Joint width measurements in Joints 4 and 17 indicate that the joints are within the given tolerances. With the exception of Joint 25, no incompressibles are observed in any of the joints.

4.6.8 Crafco 444 (1) [Sta 206+00 to 213+00]

These hot-applied sealants are 98% effective, and may be described as very good. During the previous survey these sealants had been found to be 96% effective. Four of the six joints measured (21, 24, 25, and 28) have no distresses in their sealants. The only sealant distresses are found in Joints 4 and 18 in the form of full-depth adhesion failure, which measures 25 and 178 mm (1 and 7 in.), respectively. Joint 18 also has corner breaks on both sides of the joint at the northern shoulder. These breaks are 51 and 102 mm (2 and 4 in.) long and both 76 mm (3 in.) wide. The sealant in all joints is very soft due to the high pavement temperatures ranging from 28.3 to 29.4°C (83 to 85°F). Joint 24 has some small incompressibles lodged in its sealant.

4.6.9 Dow 888 (1a) [Sta 213+00 to 219+00]

The sealants in these silicone section are in very good condition, maintaining 99.7% effectiveness. This is up from 96.4% measured during the previous survey. The only distress observed is a 25 mm (1 in.) spalling failure in Joint 21, which is 13 mm (½ in.) deep. Joint width measurements in Joints 7 and 20 reveal widths of 10 mm and 8 mm (3/8 and 5/16 in.), respectively. Both of these are within the nominal width range of 10 ± 2 mm (3/8 ± 1/16 in.). Joint 20 has a small incompressible lodged in it; no other incompressibles are observed in any of the joints.

4.6.10 Delastic V-687 (5) [Sta 219+00 to 225+00]

These compression seals have maintained 99.7% effectiveness, up 1% from WBOC00. These seals are in very good condition, only Joint 13 has a sealant distress. A 25 mm (1 in.) spalling failure, measuring less than 6 mm (1/4 in.) is found. Some standing water is found on top of the seal in Joint 18, verifying its water tightness. Joint 22 has some of its seal at the pavement surface, but the joint is distress free. Joint 9 has a few incompressibles on top of its seal, but no other incompressibles are observed in any of the joints.

4.6.11 Watson Bowman 812 (5) [Sta 225+00 to 231+00)]

Like the previous section, this compression seal section only has one distress in one of its joints, making it 99.7% effective. Joint 20 has the only distress, 25 mm (1 in.) of adhesion loss. Some incompressibles are found on top of the seal in many of the joints. Moisture is also found on the surface of the sealants, confirming the effectiveness of the seal in preventing water infiltration. A measurement of Joint 24's width found it to be 11 mm (7/16 in.), within the tolerable dimensions.

4.6.12 Dow 888 (1b) [Sta 260+00 to 266+00]

Like those in the other Dow 888 (1) section, these silicone sealants are in very good condition. The sealants average 98.1% effectiveness, essentially experiencing no loss since the previous survey. Joints 8 and 24 have no distresses whatsoever, remaining 100% effective. Joints 15 and 22 have 25 and 127 mm (1 and 5 in.) of adhesion failure, respectively. Joints 12 and 21 each have 25 mm (1 in.) of spalling failure, measuring no more than 6 mm (1/4 in.) deep. Both spalls had been noted during the WBOC00 survey. No incompressibles are observed in any of the joints.

4.6.13 Crafco 903-SL (4) [Sta 266+00 to 272+00]

The silicone sealants in this section are in very good condition, having an effectiveness of 96%, up 5% since WBOC00. Joints 8, 13, and 17 have a combined adhesion loss length of 152 mm (6 in.). Joints 7 and 11 have 25 and 279 mm (1 and 11 in.) of sunken seal failure, respectively. In most of the joints, the sealant is observed to be at the surface of the joint. Joint 7 has a measured width of 5 mm (3/16 in.), which is within the nominal joint width of 3 ± 2 mm (1/8 ± 1/16 in.).

4.6.14 Dow 890-SL (4) [Sta 272+00 to 284+00]

The silicone sealants in these joints averaged 79% effectiveness, rating their condition as fair. This section has increased in effectiveness by 23% since the previous survey when their condition was described as poor. All of the sealants have a wavy, "up-and-down" pattern to them, indicating that the sealant suffers from small incremental sunken seal failures; this form of distress accounts for 1.63 m (5.3 ft.). Only Joints 7 and 43 exhibit adhesion failure, measuring 25 and 102 mm (1 and 4 in.), respectively. Joint 7 has 559 mm (22 in.) of spalling failure and is the result of a poor initial cut. The joint lip is very rough and the joint width varies from 0 mm (0 in.) to 19 mm (3/4 in.). A width measurement of Joint 31 reveals it to be 6 mm (1/4 in.), which is more than the tolerable amount. Some surface extrusion is found in the sealants of many of the joints surveyed. No incompressibles are observed in any of the joints.

4.6.15 No Sealant (6) [Sta 284+00 to 290+00]

Five of the six joints examined show no distresses. Joint 20 suffers from 51 mm (2 in.) of spalling over its measured length. Some small vegetation growth is also observed in this joint. Several small incompressibles are observed at the bottom of all the joints examined. Joint 21 is observed to have a large amount of sand and gravel in the bottom. A joint width of 6 mm (1/4 in.) exists in Joint 12; the nominal width is 6 ± 2 mm (1/4 ± 1/16 in.).

4.7 Fall 2001 Performance Evaluation of the Westbound Lanes (WBOC01)

The westbound lanes were surveyed for the fifth and final time on Tuesday, October 16, 2001. The sealants in this direction are nearly three years old and the pavement has served traffic for about 2 ½ years. The survey did not begin until 10:00 a.m. due to rainy weather. The remainder of the day was cold and blustery, with short periods of rainfall. The air temperature at the beginning of the survey was 9.4°C (49°F), and ranged from 7.8°C (46°F) to 10.6°C (51°F) throughout the day under cloudy skies. The survey concluded at 3:00 p.m. with an air temperature of 8.3°C (47°F). Pavement temperatures ranged from 8.3°C (47°F) to 13.9°C (57°F). As in previous surveys, the current evaluation started at Station 133+60, proceeded eastward, and finished at Station

290+00. The stretch corresponding to the location of the batch plant and of the headquarters of the project contractor (*Kokosing Construction Company, Inc.*), an area of intense and heavy truck traffic (Stations 231+00 to 260+00), was not included in the evaluation.

4.7.1 Techstar W-050 (5) [Sta 133+60 to 138 +60]

These pre-formed compression seals are the worst performing seals anywhere on the project. Only 4% of the measured length of these sealants remains effective. The section continues to deteriorate; it is down 10% from the previous survey. Three joints, 22, 23, and 25, have failures over 100% of their length. The remaining joints, 4, 5, and 15, are 8, 2, and 17% effective, respectively. Adhesion failure accounts for 94% of the failures in this section. A spalling failure, measuring 51 mm (2 in.), is found in Joint 15. Joints 4, 5, and 15 are filled with sand and gravel. A random joint width measurement in Joint 22 found it to be within the specified tolerances of 10 ± 2 mm (3/8 ± 1/16 in.).

4.7.2 No Sealant (2) [Sta 139+60 to 166+00]

No spalling failures are observed in this section, although Joint 46 has a segment exhibiting a rough lip. Joints 37 and 106 are nearly filled to the top with sand and gravel. Standing water is visible in Joint 84 from a passing shower that halted the survey temporarily. A measurement of Joint 46 found its joint width to be within the allowable limits of 3 ± 2 mm (1/8 ± 1/16 in.). No vegetation growth is noted in any of the joints.

4.7.3 Dow 890-SL (3) [Sta 166+00 to 172+00]

This section, whose joints contain a self-leveling silicone sealant, is the best performing one in the westbound lanes. Only 51 mm (2 in.) of failure are found, giving the section an effectiveness value of 99%, which is essentially unchanged since the previous survey. Joints 7 and 10 each have 25-mm (1-in.) adhesion failures, which are the only failures in this section. Some minor chipping is observed in the corners of Joints 15 and 18 along the shoulder. No incompressible are found in these joints. Standing water is observed on top of all the sealants.

4.7.4 Crafco 221 (1) [Sta 172+00 to 188+00]

This hot-pour section has suffered the second largest effectiveness loss (15%) since the previous survey making its current effectiveness value 43%. Joint 22 is completely failed and Joint 68 is 97% ineffective. Joint 40 is in very good condition with only 25 mm (1 in.) of adhesion failure and 102 mm (4 in.) of spalling failure, the latter being due to a poor cut. Joints 56 and 79 have tiny bubbles in their sealants, created during the installation of the sealant. No incompressibles are found in these joints.

4.7.5 Crafco 903-SL (1a) [Sta 188+00 to 194+00]

These silicone sealants have essentially lost no effectiveness since the last survey, maintaining their 96% value. Every measured joint in this section has an effectiveness value above 90%; in fact, Joint 5 is 100% effective. Nearly all of the failures are small incremental losses of adhesion ($\leq$ 25 mm). Joint 25 is the only one with a substantial length of failure: a 127-mm (5-in.) span of adhesion failure. Joint 26 has 51 mm (2 in.) of spalling failure. No incompressibles are observed in this section.

4.7.6 Crafco 903-SL (1b) [Sta 194+00 to 200+00]

This duplicate sealant section is identical to the previous one, but continues to perform less adequately. It has deteriorated 6% since the previous survey to exhibit 72% effectiveness and receive a fair rating. All failures are attributed to loss of adhesion. Individual joint sealant effectiveness values range from 45% in Joint 18 to 97% in Joint 12. No incompressibles are found in this section.

4.7.7 Dow 890-SL (1) [Sta 200+00 to 206+00]

The sealants in this section have not deteriorated at all since the previous survey and maintain a 97% effectiveness value. Every joint has sealants that are more than 90% effective, including Joint 25, which is 100% effective. The most common failure, however, is spalling. Joints 5, 17, and 24 have spalls of 51 mm (2 in.), 25 mm (1 in.), and 152 mm (6 in.), respectively. Joints 4 and 9 have 127 mm (5 in.) and 25 mm (1 in.) of adhesion failure, respectively. No joints are observed to have incompressibles.

4.7.8 Crafco 444 (1) [Sta 206+00 to 213+00]

Unlike its counterpart in the eastbound lanes, this hot-pour section is performing very well. These sealants have lost only 6% effectiveness and currently have a 93% value. Three of the joints have no failures at all; these are Joints 4, 21, and 25. Joints 24 and 28 are 93 and 98% effective, respectively. Joint 18 is the exception in this section with an effectiveness of only 63%. Along with its 660 mm (26 in.) of adhesion failure, it exhibits a corner break at the shoulder joint. All failures in all of these sealants are attributed to loss of adhesion. No incompressibles are found in these joints.

4.7.9 Dow 888 (1a) [Sta 213+00 to 219+00]

These silicone sealants lost 9% since the WBJN01 survey, but are still in very good condition with a 91% effectiveness value. The joint sealants in this section are all performing very similarly, ranging from 88% to 97% effectiveness. Nearly all of the failure is due to loss of adhesion. Joint 21 has a small 25-mm (1-in.) spalling failure. No incompressibles are noted in this section.

4.7.10 Delastic V-687 (5) [Sta 219+00 to 225+00]

These pre-formed compression seals continue to comprise one of the best performing sections. Only 3% effectiveness has been lost since the last survey and this section now has a 97% value. Every joint is at least 90% effective and Joints 8, 13, and 22 have no failures whatsoever. Adhesion failure is the only contributor to loss of effectiveness. No incompressibles are found in these joints.

4.7.11 Watson Bowman 812 (5) [Sta 225+00 to 231+00)]

Also containing compression seals, this section has the second largest effectiveness value in the westbound lanes at 98%. These seals have lost only 2% since

WBJN01. Joints 10 and 24 are 100% effective, while the remaining joint sealants are at least 95% effective. The lone failure type found in all of the joints is loss of adhesion. No incompressibles are present on these seals.

4.7.12 Dow 888 (1b) [Sta 260+00 to 266+00]

This section has essentially lost no effectiveness since the previous survey, maintaining 98% effectiveness. Every joint is in very good condition ($\geq$ 90%) and two joints, namely Joints 8 and 21, have no failures at all. Joint 12 has 51 mm (2 in.) of spalling failure. All other failures in this sealant section are attributed to loss of adhesion. No incompressibles are noted in these joints.

4.7.13 Crafco 903-SL (4) [Sta 266+00 to 272+00]

These silicone sealants are in good condition after losing 11% effectiveness since the last survey; they currently stand at 85%. Mostly adhesion failure is found in these sealants, although Joint 11 has 254 mm (10 in.) of sunken seal and 25 mm (1 in.) of spalling failure. Joint 7 also has 25 mm (1 in.) of spalling failure. Sealant effectiveness values range from 77% in Joint 13 to 95% in Joint 14. No incompressibles are found in any of the selected joints.

4.7.14 Dow 890-SL (4) [Sta 272+00 to 284+00]

This section has the largest decrease in effectiveness, losing 35% since June 2001. This section is currently averaging 44% effectiveness, rating it as very poor. Joints 31, 43, and 54 account for a total of 610 mm (24 in.) of sunken seal failure. All joints average 46% of adhesion failure. Joint 7 is the result of a very poor cut, and exhibits 508 mm (20 in.) of spalling failure and 1.07 m (3.5 ft.) of adhesion failure. In most of these sealants, a color difference is observed in those portions where adhesion failure has taken place. The normal color for these sealants is light gray, but the failed portions are black.

4.7.15 No Sealant (6) [Sta 284+00 to 290+00]

Only one joint in this section shows any sign of distress: Joint 20 has a 51-mm (2-in.) spalling failure. All of the joints have large amounts of sand and gravel at their bottoms. Joints 12, 20, and 25 have small vegetation growing in them.

4.8 Profilometer Surveys

Along with the sealant evaluations, pavement surface profilometer surveys were conducted. These surveys were performed by ODOT personnel at about the same time as the sealant evaluations, using the K.J. Law Non-Contact Inertial Profilometer, Model 690DNC. The profilometer van made three passes along the driving and three along the passing lane, in each of the eastbound and westbound directions, recording relative pavement surface elevations every 50 mm (2 in.) of distance traveled. Through the use of a mathematical algorithm, these elevation data permit the calculation of the left wheel-track International Roughness Index (IRIlf), of the right wheel-track International Roughness Index (IRIrt), and of the average of both values of International Roughness

Index (IRIbh). Additional mathematical manipulations can then be used to establish supplementary indices, purporting to simulate the Mays Number (MAYS)–originally obtained using a suspension response vehicle–as well as the highly empirical Present Serviceability Index (PSI), originally established with reference to road user panel ratings that were correlated through statistical regression to measured pavement distresses. The data generated in this manner on each occasion at the U.S. 50 joint sealant test pavement were later sent by ODOT to the University of Cincinnati research team for analysis. Values are recorded over the entire length of the test pavement (Stations 133+60 to 260+00), except for the stretch corresponding to the location of the batch plant and of the headquarters of the project contractor (*Kokosing Construction Company, Inc.*), an area of intense and heavy truck traffic (Stations 231+00 to 260+00). Higher profilometer index values are associated with rougher surfaces, except when PSI values are considered: these decrease with increasing roughness. It is noted, however, that for the sake of convenience and clarity in the discussion below, a rougher surface is referred to as having a "higher" index (i.e., a "higher-roughness" index), even when the PSI is concerned (for which such an index is numerically lower). A detailed yet succinct presentation of the profilometer data from each traveling lane collected during the three most recent surveys, conducted in October 2000, June 2001 and October 2001, is provided below. In each case, values are calculated of the average, maximum and minimum values, standard deviation, and coefficient of variation for the five indices noted above, as well as of the average, maximum and minimum values for each sealant section. It is acknowledged that unlike the IRI, for which the relationship between profile variations and its values is linear, the PSI and Mays Number are highly non-linear indices (Karamihas, 1998). This introduces an inherent shortcoming in any discussion of changes in the value of these two measures, and in any calculation of their statistics, such as the mean and the standard deviation. Such mathematical figures are presented here for the sake of completeness, and need not introduce any confusion if they are interpreted merely as such. Hawkins (1999) and Sander (2002) have each presented similar information from two earlier profilometer evaluations, performed in June 1998, May 1999, December 1999, and March 2000, respectively. It is recalled that the June 1998 survey included only the eastbound lanes, since the westbound lanes had not been constructed yet.

4.8.1 Fifth Profile Survey of Eastbound Lanes (PEBOC00)

Table 4.2 presents a statistical analysis of the profilometer readings for the fifth profile survey of the eastbound lanes, the data set from which is code-named PEBOC00. The top portion of the Table gives averages, maximum and minimum values, standard deviations, and coefficients of variation for the five indices noted above. The lower portion of Table 4.2 contains average values for each sealant section. The maximum and minimum values of the section averages are also provided.

Data for the eastbound driving lane is listed in Tables 4.2 (a) and (b). It is difficult to compare the various profile indices for each section, although there are a few sections that stand out. The Crafco 221 (1) section in the driving lane, located between

Stations 260+00 and 266+00, is the roughest section. Four out of its five indices captured the highest roughness rating, even though the sealant has the third best effectiveness ranking with 71%. The smoothest section observed is the No Sealant (6) section located between Stations 160+00 to 166+00; four of its five indices attain the lowest roughness ratings. This section achieved the smoothest ride without containing any sealants in its joints.

Tables 4.2 (c) and (d) show the results from the eastbound passing lane, which exhibits similar trends to those found in the driving lane. As in the driving lane, the Crafco 221 (1) section exhibits the roughest surface, but in the passing lane the Delastic V-687 (5) section is the smoothest.

The preceding examples show that a correlation between sealant effectiveness and surface roughness does not exist. The section with the highest amount of roughness contains the third most effective sealant, and the section that has the lowest measured roughness contains no sealants whatsoever. This would lead the research team to believe that the degree of roughness or smoothness is unrelated to joint sealant ineffectiveness.

4.8.2 Sixth Profile Survey of Eastbound Lanes (PEBJN01)

Data collected in the driving lane during the PEBJN01 survey are averaged and compared in Tables 4.3 (a) and (b). The section containing Dow 890-SL (4) between Stations 213+00 and 219+00 is the smoothest section, as indicated by all but one indices (IRIrt). The roughest section in this lane is found between Stations 260+00 and 266+00, and is sealed with Crafco 221 (1). All five indices recorded attain their highest values in this section, and these values are significantly higher than in any other section. This stretch has also had significantly higher values in all previous surveys to date (Hawkins, 1999; Sander, 2002). A review of the raw data collected from the profilometer shows very large values (e.g., IRI between 105 and 135) towards the latter half of this section, between Stations 263+00 and 266+00. Some of these are more than twice the measured overall average of the test pavement. Figure 4.2 shows Joint 21, which is poorly cut with several large cracks and spalls. This joint is located within the latter half of the section, yet it cannot be the only source of these high profilometer values. Interestingly, transverse and corner cracking levels in this section are among the lowest. It is postulated that other contributors to roughness include faulting, warping, curling, and built-in gradients at the time of construction. The Crafco 221 (1) and Dow 890-SL (4) sections have similar sealant effectiveness rankings (viz. fourth and fifth, respectively), yet their profilometer values could not be more different. This is further evidence that sealant effectiveness does not correlate to surface smoothness.

Tables 4.3 (c) and (d) list the results from the data taken in the passing lane and show that the Crafco 221 (1) section exhibits the roughest surface, as well. All five indices reach their highest averages here. The passing lane in this section also had the highest roughness measurement during the previous profilometer survey.

The smoothest section recorded in Table 4.3 (d) is Delastic V-687 (5), in which three of the five indices (MAYS, IRIrt, and IRIbh) attain their lowest values. This section also had the smoothest average in the previous survey (PEBOC00). In both the previous and current surveys, this section has had a sealant effectiveness above 94%, evincing a match between surface smoothness and sealant effectiveness in this case.

4.8.3 Seventh Profile Survey of Eastbound Lanes (PEBOC01)

On Tuesday, October 9, 2001, profilometer data were collected by an ODOT crew from all traffic lanes. The statistical summary of the seventh profilometer survey conducted in the eastbound driving lane is presented in Tables 4.4 (a) and (b).

The roughest section continues to be Crafco 221 (1). Four of the five indices recorded their highest values here, while the fifth, PSI, attained the second roughest value. The smoothest section is No Sealant (6), between Stations 160+00 and 166+00. The MAYS and IRIlf recorded their smoothest value here. In PEBOC00, this section was also the smoothest one, but it was not the smoothest during the previous survey (PEBJN01).

Considering the passing lane, Tables 4.4 (c) and (d) show that Crafco 221 (1) has again the roughest surface. All indices exhibit their roughest values here. This section has been the roughest in both directions for all profilometer surveys to date, i.e., the three in this Report, and all the previous ones reported by Hawkins (1999) and Sander (2002). Delastic V-687 (5) exhibits the smoothest profile, as it did in the previous survey; three indices (MAYS, IRIrt, and IRIbh) record their smallest values in this section.

4.8.4 Fourth Profile Survey of Westbound Lanes (PWBOC00)

The profilometer survey of October 2000 (PWBOC00) is the fourth one conducted in the westbound lanes. The results from the survey are listed in Tables 4.5 (a) and (b). The driving lane section between Stations 260+00 and 266+00, containing Dow 888 (1b), exhibits the roughest surface. Three of the five indices reach their highest averages in this section. The Watson Bowman 812 (5) compressive seal section, located between Stations 225+00 and 231+00, has the smoothest surface in Table 4.5 (b). Three of the five indices have their lowest averages in this section. The westbound driving lane is significantly rougher than the passing lane.

The passing lane Dow 888 (1b) section located between Stations 260+00 and 266+00 also exhibits the highest amount of roughness, yet it has a sealant effectiveness of 98%. The Crafco 903-SL (1a) section between Stations 188+00 and 194+00 also shows an effectiveness of 98%, but exhibits the lowest amount of roughness in the passing lane. These two sealant sections have identical joint configurations and effectiveness values, yet their respective surface roughness profiles are completely different.

4.8.5 Fifth Profile Survey of Westbound Lanes (PWBJN01)

The results of the fifth profilometer survey in the westbound lanes, conducted in June 2001, are presented in Table 4.6. The roughest section in the driving lane again is found between Stations 260+00 and 266+00, where it is filled with Dow 888 (1b) sealant. All but one indices (PSI) achieved their highest values in this section. It is noted that the International Roughness Indices in the two wheel-paths are practically identical. The values of the IRIlf and IRIrt are 73.35 and 73.63, respectively. The IRIbh, which is the average of these two, is therefore also very similar, with a value of 73.49. This trend persists throughout the entire length of the test pavement. The averages for IRIlf, IRIrt, and IRIbh over the length of the project in Table 4.6 (a) are 66.60, 65.40, and 66.00, respectively.

The smoothest driving lane section is Crafco 903-SL (1b), for which four of the five indices (MAYS, IRIlf, IRIrt, and IRIbh) show their lowest values. This section is located between Stations 194+00 and 200+00. Recall that Crafco 903-SL (1a), the twin of this section and located adjacent to it, had the smoothest section during PWBOC00. The Techstar W-050 (5) section, is a close second in terms of smoothness in the driving lane.

In the passing lane, the section containing the sealant Dow 888 (1b) between Stations 260+00 and 266+00 is once again the roughest section: all indices but the PSI show their highest roughness averages in this section. In contrast, the sealants in this stretch exhibited an effectiveness of 98%, which is the fourth highest value in the westbound lanes.

The smoothest section is found between Stations 133+60 and 139+60, which contains Techstar W-050 (5). Three of the five indices (MAYS, PSI, and IRIrt) show their lowest roughness values here. Recall that this section has the worst sealant performance in the westbound lanes, maintaining only 14% effectiveness.

4.8.6 Sixth Profile Survey of Westbound Lanes (PWBOC01)

The results of the sixth profilometer survey in the westbound lanes are tabulated in Table 4.7. The averages for the westbound driving lane are given in Table 4.7 (a), and the statistics for each individual sealant section are presented in Table 4.7 (b). It is apparent that the roughest section is Dow 890-SL (4). The IRIlf and IRIbh record their highest values in this section, while the MAYS, PSI, and IRIrt record their second roughest values here. The Dow 888 (1b) section had been the roughest section for the three previous surveys.

The smoothest section is again Crafco 903-SL (1b). Three of the five indices (MAYS, IRIrt, and IRIbh) exhibit their lowest values in this section, which is located between Stations 194+00 and 200+00. During the current sealant survey, this section exhibits one of the lowest effectiveness values (72%).

Table 4.7 (c) and (d) lists the results of the profilometer survey in the westbound passing lane. The Dow 888 (1b) section is again the roughest, as it had been for all four preceding surveys to date in the westbound passing lane. Four of the five indices (MAYS, IRIlf, IRIrt, and IRIbh) show their highest values in this section, which has the second highest effectiveness ranking 98%. Recall that this lane could not be visually evaluated in detail at the time of the first profilometer survey (PWBMR99), due to continuing construction activity (Hawkins, 1999).

Whereas in the westbound driving lane Crafco 903-SL (1b) is the smoothest section, its twin, Crafco 903-SL (1a), claims the honor in the passing lane, exhibiting slightly smoother values for all but the PSI measure. This has been the smoothest section during two of the three most recent surveys (PWBOC00 and PWBOC01), and followed as a close second smoothest the Techstar W-050 section during the third (PWBJN01).

Table 4.1 Sealant performance rating categories (Belangie and Anderson, 1985)

Rating	Overall Effectiveness Level, %
Very Good	90 to 100
Good	80.0 to 89.9
Fair	65.0 to 79.9
Poor	50.0 to 64.9
Very Poor (Failed)	0 to 49.9

Table 4.2 Statistical summary of profile survey PEBOC00 of the eastbound lanes

a) Statistics of individual values for all three passes in the driving lane

	MAYS	PSI	IRIlf	IRIrt	IRIbh
Average	64.28	3.94	69.66	65.31	67.49
Maximum	138.53	4.33	145.30	147.40	145.17
Minimum	36.20	2.95	38.50	34.87	40.37
StDev	15.22	0.18	16.15	16.09	15.30
COV%	23.69	4.56	23.19	24.63	22.68

b) Statistics of the means for each test section in the driving lane

Station	Material	MAYS	PSI	IRIlf	IRIrt	IRIbh
188+00 - 194+00	Crafco 903-SL (1)	67.63	3.95	74.33	66.25	70.29
206+00 - 213+00	Crafco 903-SL (4)	66.79	4.00	73.70	65.02	69.35
166+00 - 172+00	Dow 890-SL (3)	59.24	3.92	65.20	59.89	62.54
213+00 - 219+00	Dow 890-SL (4)	62.98	4.04	67.31	64.36	65.84
266+00 - 272+00	Dow 890-SL (1)	66.15	3.87	69.53	67.53	68.52
200+00 - 206+00	Crafco 902 (1)	62.62	3.88	66.51	66.81	66.66
272+00 - 284+00	Dow 888 (1a)	58.95	4.04	63.03	60.61	61.82
284+00 - 290+00	Dow 888 (1b)	61.17	3.96	62.65	64.71	63.69
260+00 - 266+00	Crafco 221 (1)	82.11	3.81	88.55	84.27	86.41
172+00 - 188+00	Crafco 444 (1)	67.46	3.92	73.90	66.96	70.43
225+00 - 231+00	Delastic V-687 (5)	63.44	3.95	66.40	66.82	66.59
194+00 - 200+00	Watson Bowman 687 (5)	65.35	3.93	70.46	66.90	68.68
154+00 - 160+00	Techstar W-050 (5)	69.08	3.76	70.09	75.00	72.54
219+00 - 225+00	No Sealant (2)	65.68	3.86	71.94	65.85	68.89
160+00 - 166+00	No Sealant (6)	56.10	3.95	60.54	58.46	59.51
	AVG	64.98	3.92	69.61	66.63	68.12
	MAX	82.11	4.04	88.55	84.27	86.41
	MIN	56.10	3.76	60.54	58.46	59.51

Table 4.2 (continued)

c) Statistics of individual values for all three passes in the passing lane

	MAYS	PSI	IRIlf	IRIrt	IRIbh
Average	75.29	3.81	86.06	69.93	78.00
Maximum	177.20	4.29	179.43	220.20	179.57
Minimum	38.80	2.21	42.97	37.27	41.70
StDev	18.20	0.23	20.15	19.79	18.14
COV%	24.18	5.94	23.42	28.27	23.25

d) Statistics of the means for each test section in the passing lane

Station	Material	MAYS	PSI	IRIlf	IRIrt	IRIbh
188+00 - 194+00	Crafco 903-SL (1)	74.08	3.90	82.15	70.26	76.21
206+00 - 213+00	Crafco 903-SL (4)	74.16	3.93	80.13	72.80	76.47
166+00 - 172+00	Dow 890-SL (3)	68.11	3.90	80.15	62.53	71.35
213+00 - 219+00	Dow 890-SL (4)	65.51	4.01	72.32	63.34	67.84
266+00 - 272+00	Dow 890-SL (1)	71.29	3.83	82.78	64.00	73.38
200+00 - 206+00	Crafco 902 (1)	79.25	3.73	91.32	72.08	81.70
272+00 - 284+00	Dow 888 (1a)	66.90	3.92	76.93	60.91	68.92
284+00 - 290+00	Dow 888 (1b)	63.63	3.92	76.07	56.46	66.27
260+00 - 266+00	Crafco 221 (1)	94.43	3.61	107.39	86.79	97.08
172+00 - 188+00	Crafco 444 (1)	77.04	3.81	85.36	74.15	79.75
225+00 - 231+00	Delastic V-687 (5)	57.05	4.04	66.74	54.35	60.55
194+00 - 200+00	Watson Bowman 687 (5)	77.30	3.79	86.94	72.75	79.84
154+00 - 160+00	Techstar W-050 (5)	67.09	3.83	75.87	64.08	69.98
219+00 - 225+00	No Sealant (2)	72.28	3.89	79.01	70.81	74.91
160+00 - 166+00	No Sealant (6)	72.14	3.76	87.12	65.19	76.16
	AVG	72.02	3.86	82.02	67.37	74.69
	MAX	94.43	4.04	107.39	86.79	97.08
	MIN	57.05	3.61	66.74	54.35	60.55

Table 4.3 Statistical summary of profile survey PEBJN01 of the eastbound lanes

a) Statistics of individual values for all three passes in the driving lane

	MAYS	PSI	IRIlf	IRIrt	IRIbh
Average	66.15	3.88	70.13	67.78	68.96
Maximum	142.10	4.28	148.10	141.90	143.70
Minimum	31.10	3.08	31.40	36.70	36.60
StDev	16.26	0.21	16.77	16.63	15.81
COV%	24.58	5.42	23.91	24.53	22.93

b) Statistics of the means for each test section in the driving lane

Station	Material	MAYS	PSI	IRIlf	IRIrt	IRIbh
188+00 - 194+00	Crafco 903-SL (1)	65.56	3.89	68.98	68.03	68.48
206+00 - 213+00	Crafco 903-SL (4)	55.55	4.08	62.63	54.83	58.74
166+00 - 172+00	Dow 890-SL (3)	66.72	3.79	70.05	68.84	69.46
213+00 - 219+00	Dow 890-SL (4)	54.97	4.10	60.74	55.29	58.02
266+00 - 272+00	Dow 890-SL (1)	79.00	3.71	82.52	79.66	81.08
200+00 - 206+00	Crafco 902 (1)	67.99	3.79	68.32	73.94	71.12
272+00 - 284+00	Dow 888 (1a)	63.81	3.93	68.12	64.41	66.27
284+00 - 290+00	Dow 888 (1b)	62.55	3.90	64.38	66.24	65.29
260+00 - 266+00	Crafco 221 (1)	93.46	3.63	98.77	92.27	95.52
172+00 - 188+00	Crafco 444 (1)	65.20	3.91	71.26	64.60	67.93
225+00 - 231+00	Delastic V-687 (5)	63.25	3.94	65.41	66.43	65.92
194+00 - 200+00	Watson Bowman 687 (5)	70.05	3.86	74.43	71.16	72.79
154+00 - 160+00	Techstar W-050 (5)	65.02	3.75	65.58	71.25	68.42
219+00 - 225+00	No Sealant (2)	63.34	3.83	68.73	65.07	66.90
160+00 - 166+00	No Sealant (6)	59.64	3.87	61.51	63.92	62.71
	AVG	66.41	3.87	70.09	68.40	69.24
	MAX	93.46	4.10	98.77	92.27	95.52
	MIN	54.97	3.63	60.74	54.83	58.02

Table 4.3 (continued)

c) Statistics of individual values for all three passes in the passing lane

	MAYS	PSI	IRIlf	IRIrt	IRIbh
Average	70.67	3.87	83.28	63.94	73.61
Maximum	136.40	4.33	162.10	136.40	141.00
Minimum	32.50	3.06	33.60	29.30	34.50
StDev	16.57	0.20	19.42	15.40	16.46
COV%	23.45	5.17	23.32	24.09	22.36

d) Statistics of the means for each test section in the passing lane

Station	Material	MAYS	PSI	IRIlf	IRIrt	IRIbh
188+00 - 194+00	Crafco 903-SL (1)	68.61	3.92	81.16	62.06	71.60
206+00 - 213+00	Crafco 903-SL (4)	63.48	4.03	70.12	62.11	66.10
166+00 - 172+00	Dow 890-SL (3)	69.79	3.90	85.09	62.13	73.62
213+00 - 219+00	Dow 890-SL (4)	60.82	4.05	70.64	57.04	63.84
266+00 - 272+00	Dow 890-SL (1)	75.25	3.79	88.51	67.01	77.76
200+00 - 206+00	Crafco 902 (1)	78.96	3.75	93.34	69.55	81.44
272+00 - 284+00	Dow 888 (1a)	68.73	3.89	79.63	62.07	70.85
284+00 - 290+00	Dow 888 (1b)	63.98	3.91	78.47	55.31	66.89
260+00 - 266+00	Crafco 221 (1)	92.94	3.64	108.47	83.18	95.83
172+00 - 188+00	Crafco 444 (1)	74.10	3.83	85.24	68.66	76.95
225+00 - 231+00	Delastic V-687 (5)	59.94	3.96	72.89	52.68	62.79
194+00 - 200+00	Watson Bowman 687 (5)	79.48	3.73	95.42	70.58	83.00
154+00 - 160+00	Techstar W-050 (5)	63.97	3.85	75.35	59.70	67.52
219+00 - 225+00	No Sealant (2)	62.42	4.00	73.75	56.92	65.33
160+00 - 166+00	No Sealant (6)	72.93	3.76	91.72	62.62	77.18
	AVG	70.36	3.87	83.32	63.44	73.38
	MAX	92.94	4.05	108.47	83.18	95.83
	MIN	59.94	3.64	70.12	52.68	62.79

Table 4.4 Statistical summary of profile survey PEBOC01 of the eastbound lanes

a) Statistics of individual values for all three passes in the driving lane

	MAYS	PSI	IRIlf	IRIrt	IRIbh
Average	65.86	3.90	72.31	64.95	68.63
Maximum	139.70	4.29	142.20	141.90	140.60
Minimum	37.30	2.63	40.00	37.80	42.10
StDev	15.41	0.19	15.66	16.09	15.02
COV%	23.40	5.00	21.66	24.78	21.88

b) Statistics of the means for each test section in the driving lane

Station	Material	MAYS	PSI	IRIlf	IRIrt	IRIbh
188+00 - 194+00	Crafco 903-SL (1)	66.87	3.94	74.92	63.95	69.43
206+00 - 213+00	Crafco 903-SL (4)	61.27	4.01	72.49	55.62	64.04
166+00 - 172+00	Dow 890-SL (3)	64.14	3.85	69.15	64.40	66.78
213+00 - 219+00	Dow 890-SL (4)	60.31	4.05	67.19	59.70	63.44
266+00 - 272+00	Dow 890-SL (1)	73.77	3.77	76.18	75.45	75.81
200+00 - 206+00	Crafco 902 (1)	66.96	3.82	70.61	70.18	70.39
272+00 - 284+00	Dow 888 (1a)	60.26	4.01	65.87	59.67	62.77
284+00 - 290+00	Dow 888 (1b)	62.79	3.91	66.69	64.38	65.54
260+00 - 266+00	Crafco 221 (1)	84.78	3.75	91.33	84.03	87.68
172+00 - 188+00	Crafco 444 (1)	66.53	3.92	75.97	62.65	69.31
225+00 - 231+00	Delastic V-687 (5)	63.42	3.95	66.93	64.62	65.77
194+00 - 200+00	Watson Bowman 687 (5)	68.16	3.91	76.50	65.15	70.82
154+00 - 160+00	Techstar W-050 (5)	69.12	3.71	72.07	71.73	71.92
219+00 - 225+00	No Sealant (2)	64.07	3.87	72.32	62.21	67.27
160+00 - 166+00	No Sealant (6)	59.97	3.88	65.67	60.78	63.22
	AVG	66.16	3.89	72.26	65.63	68.94
	MAX	84.78	4.05	91.33	84.03	87.68
	MIN	59.97	3.71	65.67	55.62	62.77

Table 4.4 (continued)

c) Statistics of individual values for all three passes in the passing lane

	MAYS	PSI	IRIlf	IRIrt	IRIbh
Average	69.39	3.88	81.86	62.17	72.01
Maximum	136.80	4.43	155.10	130.30	142.70
Minimum	30.30	3.18	35.00	31.30	33.10
StDev	17.30	0.22	20.30	15.94	17.14
COV%	24.93	5.60	24.80	25.64	23.80

d) Statistics of the means for each test section in the passing lane

Station	Material	MAYS	PSI	IRIlf	IRIrt	IRIbh
188+00 - 194+00	Crafco 903-SL (1)	66.18	3.92	79.82	58.18	69.00
206+00 - 213+00	Crafco 903-SL (4)	59.72	4.09	67.72	56.74	62.23
166+00 - 172+00	Dow 890-SL (3)	66.91	3.93	82.57	56.84	69.71
213+00 - 219+00	Dow 890-SL (4)	58.77	4.08	68.92	54.04	61.48
266+00 - 272+00	Dow 890-SL (1)	78.98	3.72	92.48	70.32	81.41
200+00 - 206+00	Crafco 902 (1)	78.47	3.74	90.46	70.93	80.70
272+00 - 284+00	Dow 888 (1a)	67.19	3.90	78.18	60.04	69.11
284+00 - 290+00	Dow 888 (1b)	66.42	3.87	80.91	56.34	68.62
260+00 - 266+00	Crafco 221 (1)	93.15	3.65	107.44	84.06	95.73
172+00 - 188+00	Crafco 444 (1)	72.99	3.84	84.65	66.71	75.68
225+00 - 231+00	Delastic V-687 (5)	57.09	4.00	69.44	50.79	60.12
194+00 - 200+00	Watson Bowman 687 (5)	77.98	3.73	92.35	69.79	81.06
154+00 - 160+00	Techstar W-050 (5)	61.36	3.86	72.01	56.88	64.44
219+00 - 225+00	No Sealant (2)	61.52	4.00	72.76	56.06	64.40
160+00 - 166+00	No Sealant (6)	70.32	3.78	87.78	58.76	73.28
	AVG	69.14	3.88	81.83	61.77	71.80
	MAX	93.15	4.09	107.44	84.06	95.73
	MIN	57.09	3.65	67.72	50.79	60.12

Table 4.5 Statistical summary of profile survey PWBOC00 of the westbound lanes

a) Statistics of individual values for all three passes in the driving lane

	MAYS	PSI	IRIlf	IRIrt	IRIbh
Average	73.55	3.77	78.39	75.44	76.91
Maximum	147.50	4.14	151.03	163.27	152.13
Minimum	42.23	2.99	47.87	43.07	46.90
StDev	15.21	0.17	15.38	16.19	14.89
COV%	20.68	4.49	19.62	21.46	19.36

b) Statistics of the means for each test section in the driving lane

Station	Material	MAYS	PSI	IRIlf	IRIrt	IRIbh
188+00 - 194+00	Crafco 903-SL (1a)	65.88	3.80	70.97	66.49	68.73
194+00 - 200+00	Crafco 903-SL (1b)	65.64	3.80	70.79	67.15	68.97
266+00 - 272+00	Crafco 903-SL (4)	66.89	3.83	72.08	68.87	70.48
166+00 - 172+00	Dow 890-SL (3)	67.08	3.80	74.65	66.75	70.70
200+00 - 206+00	Dow 890-SL (1)	69.23	3.87	73.24	69.27	71.26
272+00 - 284+00	Dow 890-SL (4)	80.29	3.71	85.42	82.23	83.82
213+00 - 219+00	Dow 888 (1a)	66.68	3.82	72.10	69.31	70.70
260+00 - 266+00	Dow 888 (1b)	80.79	3.78	85.75	82.76	84.25
172+00 - 188+00	Crafco 221 (1)	68.74	3.63	76.04	71.46	73.76
206+00 - 213+00	Crafco 444 (1)	68.82	3.86	73.38	69.99	71.68
219+00 - 225+00	Delastic V-687 (5)	68.06	3.63	69.57	73.93	71.75
225+00 - 231+00	Watson Bowman 812 (5)	64.22	3.79	70.76	64.33	67.54
133+60 - 139+60	Techstar W-050 (5)	80.86	3.79	84.89	80.55	82.72
139+60 - 166+00	No Sealant (2)	74.08	3.81	78.84	74.55	76.70
284+00 - 290+00	No Sealant (6)	75.84	3.73	77.81	82.38	80.10
	AVG	70.87	3.78	75.75	72.67	74.21
	MAX	80.86	3.87	85.75	82.76	84.25
	MIN	64.22	3.63	69.57	64.33	67.54

Table 4.5 (continued)

c) Statistics of individual values for all three passes in the passing lane

	MAYS	PSI	IRIlf	IRIrt	IRIbh
Average	62.51	3.92	66.83	66.13	66.48
Maximum	230.37	4.40	409.60	124.80	247.90
Minimum	27.47	1.56	27.30	37.73	36.23
StDev	18.69	0.25	29.28	14.14	19.02
COV%	29.92	6.27	43.74	21.38	28.61

d) Statistics of the means for each test section in the passing lane

Station	Material	MAYS	PSI	IRIlf	IRIrt	IRIbh
188+00 - 194+00	Crafco 903-SL (1a)	53.30	3.96	56.06	57.92	56.99
194+00 - 200+00	Crafco 903-SL (1b)	55.16	3.98	59.13	58.02	58.57
266+00 - 272+00	Crafco 903-SL (4)	55.27	3.97	58.32	58.59	58.45
166+00 - 172+00	Dow 890-SL (3)	60.25	4.02	61.82	64.22	63.02
200+00 - 206+00	Dow 890-SL (1)	57.66	3.99	61.30	60.98	61.14
272+00 - 284+00	Dow 890-SL (4)	66.67	3.88	69.02	69.74	69.38
213+00 - 219+00	Dow 888 (1a)	61.34	3.91	64.46	64.68	64.58
260+00 - 266+00	Dow 888 (1b)	71.41	3.88	74.23	75.54	74.89
172+00 - 188+00	Crafco 221 (1)	59.20	3.92	63.16	62.70	62.93
206+00 - 213+00	Crafco 444 (1)	57.24	3.95	62.49	63.09	62.79
219+00 - 225+00	Delastic V-687 (5)	55.78	3.88	60.12	59.42	59.78
225+00 - 231+00	Watson Bowman 812 (5)	59.17	3.92	61.02	63.51	62.27
133+60 - 139+60	Techstar W-050 (5)	71.10	3.90	74.22	70.86	72.53
139+60 - 166+00	No Sealant (2)	64.87	3.97	67.50	66.59	67.04
284+00 - 290+00	No Sealant (6)	59.91	3.92	78.46	63.35	70.90
	AVG	60.56	3.94	64.75	63.95	64.35
	MAX	71.41	4.02	78.46	75.54	74.89
	MIN	53.30	3.88	56.06	57.92	56.99

Table 4.6 Statistical summary of profile survey PWBJN01 of the westbound lanes

a) Statistics of individual values for all three passes in the driving lane

	MAYS	PSI	IRIlf	IRIrt	IRIbh
Average	63.27	3.84	66.60	65.40	66.00
Maximum	151.30	4.29	147.00	167.90	156.30
Minimum	30.10	2.80	32.50	33.30	34.10
StDev	15.61	0.21	15.89	16.53	15.57
COV%	24.67	5.47	23.85	25.28	23.59

b) Statistics of the means for each test section in the driving lane

Station	Material	MAYS	PSI	IRIlf	IRIrt	IRIbh
188+00 - 194+00	Crafco 903-SL (1a)	58.96	3.82	63.50	59.94	61.72
194+00 - 200+00	Crafco 903-SL (1b)	52.73	3.90	57.86	53.72	55.79
266+00 - 272+00	Crafco 903-SL (4)	57.40	3.86	59.97	59.71	59.84
166+00 - 172+00	Dow 890-SL (3)	67.75	3.79	73.25	67.29	70.27
200+00 - 206+00	Dow 890-SL (1)	59.56	3.93	63.11	59.58	61.34
272+00 - 284+00	Dow 890-SL (4)	67.05	3.79	68.48	70.75	69.62
213+00 - 219+00	Dow 888 (1a)	62.62	3.88	66.22	64.35	65.28
260+00 - 266+00	Dow 888 (1b)	70.41	3.85	73.35	73.63	73.49
172+00 - 188+00	Crafco 221 (1)	67.06	3.61	71.31	69.65	70.48
206+00 - 213+00	Crafco 444 (1)	63.26	3.88	67.99	62.81	65.40
219+00 - 225+00	Delastic V-687 (5)	62.38	3.69	64.73	68.03	66.38
225+00 - 231+00	Watson Bowman 812 (5)	64.44	3.75	71.21	62.56	66.87
133+60 - 139+60	Techstar W-050 (5)	55.65	4.02	58.60	57.09	57.84
139+60 - 166+00	No Sealant (2)	58.63	3.93	61.55	60.95	61.25
284+00 - 290+00	No Sealant (6)	60.69	3.90	64.21	63.73	63.97
	AVG	61.91	3.84	65.69	63.59	64.64
	MAX	70.41	4.02	73.35	73.63	73.49
	MIN	52.73	3.61	57.86	53.72	55.79

Table 4.6 (continued)

c) Statistics of individual values for all three passes in the passing lane

	MAYS	PSI	IRIlf	IRIrt	IRIbh
Average	57.73	3.98	62.56	61.79	62.18
Maximum	115.20	4.57	133.20	145.30	120.60
Minimum	23.10	3.25	30.40	25.00	36.10
StDev	13.89	0.19	14.69	14.27	13.11
COV%	24.07	4.71	23.49	23.10	21.08

d) Statistics of the means for each test section in the passing lane

Station	Material	MAYS	PSI	IRIlf	IRIrt	IRIbh
188+00 - 194+00	Crafco 903-SL (1a)	51.83	3.98	54.56	56.83	55.70
194+00 - 200+00	Crafco 903-SL (1b)	51.36	3.99	54.82	56.87	55.85
266+00 - 272+00	Crafco 903-SL (4)	53.73	3.94	56.23	57.67	56.96
166+00 - 172+00	Dow 890-SL (3)	56.47	4.11	65.21	62.37	63.79
200+00 - 206+00	Dow 890-SL (1)	55.98	4.01	59.49	58.59	59.03
272+00 - 284+00	Dow 890-SL (4)	61.54	3.92	63.71	65.26	64.48
213+00 - 219+00	Dow 888 (1a)	60.18	3.96	67.31	61.62	64.48
260+00 - 266+00	Dow 888 (1b)	65.59	3.92	68.54	71.24	69.89
172+00 - 188+00	Crafco 221 (1)	58.81	3.95	67.04	64.56	65.81
206+00 - 213+00	Crafco 444 (1)	56.70	3.99	61.68	59.90	60.79
219+00 - 225+00	Delastic V-687 (5)	56.27	3.88	64.78	56.83	60.80
225+00 - 231+00	Watson Bowman 812 (5)	59.15	3.91	59.28	65.76	62.51
133+60 - 139+60	Techstar W-050 (5)	50.26	4.15	61.08	53.73	57.40
139+60 - 166+00	No Sealant (2)	52.48	4.13	64.16	55.04	59.60
284+00 - 290+00	No Sealant (6)	55.26	4.01	56.25	60.09	58.17
	AVG	56.37	3.99	61.61	60.42	61.02
	MAX	65.59	4.15	68.54	71.24	69.89
	MIN	50.26	3.88	54.56	53.73	55.70

Table 4.7 Statistical summary of profile survey PWBOC01 of the westbound lanes

a) Statistics of individual values for all three passes in the driving lane

	MAYS	PSI	IRIlf	IRIrt	IRIbh
Average	69.25	3.75	75.97	68.87	72.42
Maximum	169.30	4.20	301.50	180.10	186.30
Minimum	37.10	1.63	40.20	33.20	38.80
StDev	17.92	0.31	23.44	17.66	18.33
COV%	25.87	8.33	30.85	25.65	25.31

b) Statistics of the means for each test section in the driving lane

Station	Material	MAYS	PSI	IRIlf	IRIrt	IRIbh
188+00 - 194+00	Crafco 903-SL (1a)	62.91	3.66	74.84	58.26	66.56
194+00 - 200+00	Crafco 903-SL (1b)	59.95	3.71	70.86	57.05	63.95
266+00 - 272+00	Crafco 903-SL (4)	64.04	3.79	67.48	65.79	66.64
166+00 - 172+00	Dow 890-SL (3)	65.38	3.82	72.59	62.94	67.76
200+00 - 206+00	Dow 890-SL (1)	63.35	3.91	68.72	62.44	65.57
272+00 - 284+00	Dow 890-SL (4)	76.81	3.62	84.85	76.04	80.44
213+00 - 219+00	Dow 888 (1a)	66.81	3.77	72.72	67.60	70.15
260+00 - 266+00	Dow 888 (1b)	77.06	3.80	81.03	79.05	80.04
172+00 - 188+00	Crafco 221 (1)	67.07	3.61	72.22	69.55	70.89
206+00 - 213+00	Crafco 444 (1)	64.26	3.85	71.31	63.05	67.17
219+00 - 225+00	Delastic V-687 (5)	64.51	3.65	69.54	67.48	68.51
225+00 - 231+00	Watson Bowman 812 (5)	62.72	3.78	70.99	60.13	65.56
133+60 - 139+60	Techstar W-050 (5)	69.53	3.89	74.87	67.88	71.38
139+60 - 166+00	No Sealant (2)	68.83	3.85	74.22	68.56	71.39
284+00 - 290+00	No Sealant (6)	68.25	3.80	76.72	68.01	72.36
	AVG	66.76	3.77	73.53	66.26	69.89
	MAX	77.06	3.91	84.85	79.05	80.44
	MIN	59.95	3.61	67.48	57.05	63.95

Table 4.7 (continued)

c) Statistics of individual values for all three passes in the passing lane

	MAYS	PSI	IRIlf	IRIrt	IRIbh
Average	59.26	3.96	63.91	61.15	62.53
Maximum	114.50	4.30	122.20	115.20	116.40
Minimum	32.00	3.35	31.80	33.60	34.50
StDev	13.63	0.15	15.12	13.57	13.46
COV%	23.00	3.90	23.66	22.19	21.53

d) Statistics of the means for each test section in the passing lane

Station	Material	MAYS	PSI	IRIlf	IRIrt	IRIbh
188+00 - 194+00	Crafco 903-SL (1a)	49.93	4.01	54.10	53.01	53.56
194+00 - 200+00	Crafco 903-SL (1b)	51.19	4.00	56.40	53.72	55.06
266+00 - 272+00	Crafco 903-SL (4)	52.59	3.96	56.99	54.22	55.61
166+00 - 172+00	Dow 890-SL (3)	59.78	4.00	63.62	62.36	62.99
200+00 - 206+00	Dow 890-SL (1)	54.26	4.03	57.78	56.68	57.23
272+00 - 284+00	Dow 890-SL (4)	62.45	3.92	66.39	64.23	65.31
213+00 - 219+00	Dow 888 (1a)	60.24	3.96	67.73	60.58	64.15
260+00 - 266+00	Dow 888 (1b)	67.47	3.91	71.90	70.62	71.26
172+00 - 188+00	Crafco 221 (1)	61.04	3.88	66.87	62.42	64.65
206+00 - 213+00	Crafco 444 (1)	55.83	3.99	60.38	60.44	60.40
219+00 - 225+00	Delastic V-687 (5)	58.43	3.86	67.88	56.67	62.28
225+00 - 231+00	Watson Bowman 812 (5)	58.91	3.92	62.66	62.86	62.76
133+60 - 139+60	Techstar W-050 (5)	58.40	4.06	62.56	58.00	60.28
139+60 - 166+00	No Sealant (2)	58.95	4.02	64.55	58.41	61.48
284+00 - 290+00	No Sealant (6)	56.38	4.00	58.01	59.65	58.84
	AVG	57.72	3.97	62.52	59.59	61.06
	MAX	67.47	4.06	71.90	70.62	71.26
	MIN	49.93	3.86	54.10	53.01	53.56

Figure 4.1 Members of the UC research team examining a joint

Figure 4.2 Severe cracking and spalling in Joint 21 of the eastbound Crafco 221 (1) section

5 ANALYSIS OF RECENT FIELD PERFORMANCE DATA

5.1 General Information

Since the inception of this project, there have been two initial visual surveys of the eastbound lanes and one of the westbound (Hawkins, 1999), in addition to five subsequent detailed statistical performance evaluations in both directions. Two of the latter have been described in detail by Sander (2002); the three most recent surveys, conducted in October 2000, June 2001, and October 2001, are documented in this Report. Sealant condition as encountered during these three evaluations was detailed in Chapter 4, above.

This Chapter presents an analysis of the data collected during these three most recent surveys. The information is examined to delineate trends in sealant and pavement performance, and to assess a possible correlation between the two. Statistical analyses were conducted immediately following each evaluation and were completed before the next excursion of the research team to the site. Comments in the paragraphs below, therefore, represent opinions and ideas formulated at the time of each performance monitoring activity.

The data sets from the three evaluations considered in this Chapter are code-named EBOC00, EBJN01 and EBOC01 for the eastbound and WBOC00, WBJN01 and WBOC01 for the westbound lanes, respectively. The data collection, analysis and interpretation techniques first used on this project by Sander (2002) are also implemented for the three surveys conducted in the Fall 2000, Spring 2001 and Fall 2001, respectively.

5.2 Joint Sealant Treatment Effectiveness

Joint sealant treatment is defined herein as the combination of a specific sealant type and joint configuration. Each such treatment is referred to by the name of the sealant followed by the joint configuration in parentheses. The following sub-sections analyze the effectiveness of the joint sealant treatments in the eastbound and westbound lanes as encountered during each survey. The effectiveness of a sealant is expressed as a percentage by dividing the measured length of sealant that remains watertight by the total length measured. For this project, a total length of 1.83 m (6 ft) in each of six joints from each of the test sections was selected for inspection; this length represents the outer half-width of the driving lane in each direction. Failures that suggest watertight conditions are no longer present include full-depth adhesion or cohesion failures, sunken seal, missing seal, and spalling at the joint. Deficiencies in the sealant that may still preserve watertight conditions include partial-depth adhesion or cohesion failures, and intrusion of incompressibles.

5.2.1 Treatment Effectiveness in the Eastbound Lanes during the EBOC00 Survey

On Tuesday, October 10, 2000, the University of Cincinnati research team performed the third survey of the condition of the joint sealant in the eastbound driving lane. The data set collected is code-named EBOC00. The evaluation was conducted in the manner described previously by Sander (2002). The effectiveness of the sealants is shown in the bar graph of Figure. 5.1. The sealants are categorized by sealant type, (silicone, hot-applied, or pre-formed compression), for which average effectiveness values are listed. The joint configuration for each sealant is denoted by the number in parentheses.

It is observed that in general the compression seals are performing far better than the hot-applied or silicone sealants. During this survey, the former averaged 74% effectiveness, while each of the latter averaged 38%. This is partly attributable to the fact that compression seals do not rely on adhesive binders for maintaining a bond with the joint walls. Although an adhesive is used with compression seals, it is not the only mechanism for preserving this bond. The compression seal, as its name implies, remains in compression as it expands and contracts, and thus always maintains contact with the joint wall. It is interesting to note that the Techstar W-050 (5) compression seal, which relies partially on the adhesive for maintaining contact with the face of the joint, is not performing as well as the other two compression seals. The deterioration of the Techstar seals to an effectiveness of only 27% as of the EBOC00 survey gives rise to concerns with regard to the procedures used during installation in the eastbound lanes. Even though an employee of *Techstar Inc.* supervised the installation of the seals in the westbound lanes (Hawkins, 1999), a similar deterioration was observed for that section, as well. It is recalled that this is the first installation of Techstar seals in a concrete pavement; the material is manufactured as a sealant for bridge decks. In the case of hot-applied and silicone sealants, a chemical bond is responsible for maintaining contact with the joint wall. They are thus more susceptible to adhesion failure over time.

The silicone sealants are in very poor condition, averaging only 38% effectiveness. Figure 5.1 suggests that their value is influenced greatly by the joint configuration. In general, silicone sealants with the wider joint configuration No. 1 seem to perform significantly better than those with the narrower joint configuration No. 4. The former are averaging 46% effectiveness, compared to only 10% for the latter. Moreover, self-leveling silicones appear superior to non-sag ones, even when the somewhat narrower joint configuration No. 3 is used: the Dow 890-SL (3) section has an effectiveness value of 56%. Joint configurations 1, 3, and 4 have nominal widths of 10 ± 2 mm (3/8 ± 1/16 in.), 6 ± 2 mm (1/4 ± 1/16 in.), and 3 ± 2 mm (1/8 ± 1/16 in.), respectively.

The two hot-applied sealant sections have very different effectiveness ratings. The Crafco 221 (1) section is 71% effective, whereas the Crafco 444 (1) section is rated at only 6%. The latter is the worst performing sealant in the eastbound sections at the time of EBOC00. Such a difference in effectiveness is surprising, since both sections have identical joint configurations. An explanation may be found in the intended use for each of the two sealants: Crafco 221 is intended for use in moderate to cooler climates, whereas Crafco 444 is intended for moderate to hot climates (Hawkins, 1999). This suggests that Crafco 221 may be better suited for the weather found in the region of the test site than Crafco 444 is, but this assertion is not corroborated by observations in the westbound lanes, which are discussed in a subsequent section.

Figure 5.2 presents a comparison between results obtained during the EBOC00 survey and those collected in the previous one, conducted in Spring 2000 (code-named EBMR00). The values shown in the Figure are listed in Table 5.1. Each sealant section is ranked according to effectiveness. A ranking of 1 in the Table is assigned to the section with the highest effectiveness and a ranking of 13 to the one with the lowest. The corresponding effectiveness rating category, in accordance with a scheme proposed by Belangie and Anderson (1985), is given in parentheses next to each effectiveness value. The rating categories are: very good (VG), good (G), fair (F), poor (P), and very poor (VP). The last two columns in Table 5.1 examine the percentage reduction in effectiveness (or deterioration) that occurred in each section between the two evaluations. The loss of effectiveness in each section is also ranked. A ranking of 1 corresponds to the sealant with the greatest loss of effectiveness and a ranking of 13 corresponds to the one with the smallest deterioration. A negative loss of effectiveness would suggest a self-healing tendency. Because it is unlikely that a joint would be able to heal itself, such discrepancies can be attributed to small incompatibilities in the survey procedures employed by the two different crews responsible for these surveys. As long as these discrepancies account for a small percentage in the effectiveness (i.e., less than 3%), they are considered negligible. The notation % indicates a percentage point change: for example, 20% to 23% represents a 3% rise.

The two superior compression seal sections, Delastic V-687 (5) and Watson Bowman WB-687 (5), have the least loss in effectiveness, retaining values above 97% as of EBOC00. The remaining compression seal, Techstar W-050 (5), has the sixth highest loss of effectiveness.

Albeit very different in their respective effectiveness values, the two hot-applied sections have experienced a similar loss of effectiveness from the previous survey, amounting to less than 5%. The small loss of effectiveness of the Crafco 444 (1) section, however, requires clarification. The section had only 10% effectiveness during the EBMR00 survey; this fact made it difficult to lose much more.

The two self-leveling silicone sections with a No. 4 joint configuration suffered the highest deterioration losses. In fact, Dow 890-SL (4) has lost over three-fourths of its effectiveness since the EBMR00 survey, dropping by 42%, from 55 to 13%. The two identical sections sealed with the non-sag silicone sealant Dow 888 (1) exhibit a similar performance. They have lost 8 and 9%, respectively, leaving each with 41% effectiveness. The similarity in effectiveness of these twin sections validates the consistency of the evaluation process.

In order to reach sound conclusions regarding the effectiveness of each sealant, monitoring must continue for a substantial period of time. Figure 5.3 shows the effectiveness trends for all sealant sections emerging from the three surveys conducted as of EBOC00. Separate Figures for each sealant type, i.e. compression, hot-applied, and silicone, are provided as well (Figures 5.4 to 5.6).

As noted earlier, the compression seals are exhibiting the smallest degree of deterioration. Two of the compression seal sections, Delastic V-687 (5) and Watson Bowman WB-687 (5), have had essentially no deterioration since the first survey in November 1999 as shown in Figure 5.4. The reliance of the compression seals on mechanical rather than chemical bonding appears to be the major attribute that makes these seals withstand the toll of time.

Figure 5.5 indicates that the Crafco 221 (1) section has experienced no loss of effectiveness since November 1999, yet its current effectiveness is only 71%. This gives rise to a concern that poor workmanship during installation may have resulted in a rather low initial effectiveness. A visual inspection conducted from the pavement shoulder in October 1998, however, indicated an initial effectiveness of this sealant in excess of 95%; by May 1999, this value had decreased significantly (Hawkins, 1999). Evidently, there was a very rapid, if brief, deterioration in the earliest stages of this sealant's service life, but it is not possible to ascertain whether poor workmanship was exclusively responsible for this behavior.

The other hot-applied sealant section, Crafco 444 (1), had a very low effectiveness rating (only 14%) at the time of the earliest of the three surveys (November 1999). Visual inspections conducted from the shoulder in October 1998 and May 1999 suggest that the effectiveness at those times was about 90% and 70%, respectively (Hawkins, 1999). A shallow recess and air bubbles in the sealant had been observed in those early inspections. These characteristics may be responsible for the rapid deterioration of the sealant during the summer of 1999. The current (Fall 2000) sealant effectiveness in this section is 6%.

Silicone sealant sections with the joint configuration No. 1 appear to be undergoing a slow deterioration over time (Figure 5.6). The effectiveness loss of these sealants over the preceding twelve months is only about 10%. Their current mediocre effectiveness seems primarily to be due to the rapid deterioration that occurred prior to the first survey under this Project (Fall 1999). Deficiencies in installation workmanship, reported by Hawkins (1999), appear to be largely responsible for these observations. In contrast, the two silicone sections with joint configuration No. 4 have exhibited rapid loss of effectiveness since the first survey, deteriorating from about 70% to about 10% during the last year of service. The narrower joint configuration width, No. 4, is the most likely attribute responsible for this difference. Among the three sealant types included in this experiment, silicone sealants have suffered the most drastic deterioration since the November 1999 survey, averaging a 13% effectiveness loss as of EBOC00.

5.2.2 Treatment Effectiveness in the Eastbound Lanes during the EBJN01 Survey

On Monday, June 4, 2001, the University of Cincinnati research team performed the fourth survey of the joint sealants condition in the eastbound driving lane. The data set collected is code-named EBJN01. The evaluation was conducted in the manner described previously by Sander (2002). The effectiveness of the sealants is shown in the bar graph of Figure. 5.7. The sealants are categorized by sealant type, (silicone, hot-applied, or pre-formed compression), for which average effectiveness values are listed. The joint configuration for each sealant is denoted by the number in parentheses.

In general, it is observed that the pre-formed compression seals are superior to the hot-applied and silicone sealants. The average effectiveness of the compression, hot-applied, and silicone sealants are 70, 43, and 60%, respectively. The average of the compression seals, however, rise to 95% with the exclusion of Techstar W-050 (5), which exhibits a very poor effectiveness of 22%. The Watson Bowman 687 (5) and Delastic V-687 (5) compression seals are by far the best performing seals in the eastbound lane; they exhibit 95 and 94%, respectively.

The two hot-applied sealant sections continue to show a remarkable difference in performance. The Crafco 221 (1) section has an effectiveness of 75%, yet the section containing Crafco 444 (1) is exhibiting only 11%, which is the worst effectiveness value in the eastbound lanes. The average effectiveness of these sections is 43%, but since the two values are so different, the average is not very meaningful.

The silicone sealant sections average 60% effectiveness and have a much lower variance than the hot-applied. Dow 890-SL (1) is the best silicone sealant with an effectiveness of 80%, while Crafco 902 (1) is the worst at 36%. The correlation between joint width and sealant performance encountered in the EBOC00 survey is no longer evident. The average effectiveness values for the silicone sealants with joint configuration 1, 3, and 4 are 59, 62, and 61%, respectively. The discussion below will elucidate this observation.

The results of the previous two surveys are shown in Figure 5.8. Table 5.2 lists the effectiveness values for the past two surveys and ranks them accordingly. Differences between the two surveys are also tabulated and ranked; a rank of 1 indicates the greatest loss of effectiveness and a rank of 13 means the least. The most striking observation is that nine of the thirteen sections exhibit increases in effectiveness. The increase is mainly in the silicone and hot-applied sections. The compression seals show a decrease of effectiveness of less than 5%.

The two hot-applied sections (Crafco 221 and Crafco 444) show limited increases in effectiveness (5%). These apparent improvements are too small to cause any concern to the research team.

Several of the silicone sealants, however, exhibit much larger increases in effectiveness. The two sections with joint configuration No. 4 are most notable, displaying 49 and 53% increases of effectiveness, respectively. The effectiveness value of Dow 890-SL (4) rose from 13 to 65%, while that of Crafco 903-SL (4) rose from 7 to 56%. With one exception, the other silicone filled sections reveal somewhat smaller increases in effectiveness, ranging from 6 % in the Dow 890-SL (3) section to 20% in the Dow 888 (1b) section. Crafco 902 (1) is the only silicone section that shows a small decrease in effectiveness (1%).

Effectiveness increases in so many sections are a great concern to the University of Cincinnati research team. The larger increases are confined to the silicone sections, which shows how difficult to evaluate this type of sealant. The very large increases (about 50%) are found in the sections with No. 4 joint configurations. These joints are the narrowest of the test joints, with a nominal width of 3 ± 2 mm (1/8 ± 1/16 in.), a feature that makes it difficult to determine objectively and with confidence whether a water-tight bond exists between the joint walls and the sealant. It should be noted that for the sake of objectivity the University of Cincinnati research team does not refer to previous data sets prior to collecting a new one.

A possible explanation for the apparent improvements in effectiveness is offered in Figure 5.9, which shows the field logs for Joint 15 in the Crafco 903-SL (4) section, recorded during the EBOC00 and EBJN01 evaluations. The latter appears to be more detailed, revealing a series of increments of sunken seal or adhesion failures, interspersed with short intact segments. In contrast, the earlier log shows longer increments of failure with no intact segments. It is apparent from this example that the scale and degree of detail of the observations, as well as the subjective opinion of the evaluator, may play a more significant role than previously realized.

Figure 5.10 graphs the results of all sealant sections and all surveys to date. Figure 5.11 shows the deterioration of the preformed compression seals since their installation. As expected, the two superior seals (Watson Bowman 687 and Delastic V-687) continue to maintain most of their original effectiveness. Techstar W-050, on the other hand, continues to deteriorate, albeit more slowly after each survey.

Figure 5.12 illustrates the corresponding trends for the hot-applied sealants, Crafco 221 (1) and Crafco 444 (1). Both have fluctuated very little since the first survey and have remained within 5$\pm$% of their EBNV99 value. This lack of variation seems to reinforce the hypothesis that these sections were never at 100% effectiveness, even immediately after installation.

The deterioration of the silicone sealants is plotted in Figure 5.13. The sudden increase in effectiveness recorded in June 2001 does not fit the previous downward trend of these sections. The two No. 4 section configurations regained nearly all of the effectiveness they lost since the first survey. The sections containing Dow 890-SL (1) and Dow 888 (1a) increased to values above their initial EBNV99 values. Only Crafco 902 (1) continues to follow a steady but slow deterioration path.

5.2.3 Treatment Effectiveness in the Eastbound Lanes during the EBOC01 Survey

On Monday, October 15, 2001, the University of Cincinnati research team performed the fifth and final sealant survey in the eastbound lanes. This evaluation, code-named, EBOC01, was conducted in the manner described previously (Sander, 2002). The effectiveness of the sealants is shown in the bar graph of Figure 5.14. The sealants are categorized by sealant type, as silicone sealants, hot-applied sealants, or compression seals, and also by joint configuration, which is denoted by the number in parentheses. Average effectiveness values for each sealant type are listed in the text box.

Excluding Techstar W-050 (5) , the compression seals are once again outstanding, averaging 94% effectiveness. Techstar W-050 (5) is only 19% effective, whereas Watson Bowman 687 (5) and Delastic V-687 (5) are both at 94%.

The two hot-applied sealants continue to differ quite dramatically from one another. Crafco 221 (1) has the third highest effectiveness value (79%), yet Crafco 444 (1) has the lowest value (9%). These two sections average 44% effectiveness, the lowest among the three sealant types.

The silicone sealants average 46% effectiveness, which is only slightly better than the hot-applied. The two self-leveling sealants with the No. 1 joint configuration are the best performing silicone sections to date. Dow 890-SL (1) and Crafco 903-SL (1) have effectiveness values of 71 and 58%, respectively. Only one other silicone section is above 50%, namely Dow 890-SL (3), which is 57% effective. The remaining five sections are below 50% effectiveness, including Crafco 903-SL (4), which is only 12% effective. Any correlation between joint configuration and sealant performance continues to be faint; there is considerably more variance within identical joint configuration sections than in previous surveys.

Figure 5.15 shows the results of the current survey, which are compared to the previous evaluation. Table 5.3 lists the effectiveness values and corresponding rankings for these two surveys, as well as the deterioration of the sealants from the previous survey with corresponding rankings.

The three compression seals lost only a total of 4% effectiveness, although most of this is attributable to the Techstar W-050 (5) section, which lost 3%. Delastic V-687 (5) gained an insignificant 0.2% in effectiveness. The only other section exhibiting an increase in effectiveness is Crafco 221 (1), which gained 4%. Crafco 444 (1) dropped below 10% by losing 2% and has practically no intact sealant left.

The silicone sealants display decreased effectiveness values ranging from 5 to 44%. The largest decreases are found in the two narrow No. 4 joint section configurations, which lost 23 and 44%. Much of the apparent gain in effectiveness recorded during the previous survey (EBJN01) appears to have dissipated. The twin sections of Dow 888 (1) lost 9 and 12%, respectively, while the remaining silicone sections lost less than 10% in effectiveness.

The effectiveness values for all sections and surveys to date are shown in Figure 5.16, which clearly portrays the performance trend over time for these sealants. Similarly, Figure 5.17 tracks the performance of the compression seals. Since a thorough evaluation of the sealants was not possible immediately after their installation (Hawkins, 1999), all effective values are assumed to have been 100% to begin with. This assumption is brought into question by the results of several sections, but it is used for practical purposes. The performance, or lack thereof, of Techstar W-050 (5) is evident, as it falls precipitously well below that of the other compression seals. The Watson Bowman 687 (5) and Delastic V-687 (5) seals emulate each other's excellent performance. The effectiveness values of these two seals never differ by more than 1%. Their long-term performance looks promising, whereas Techstar W-050 (5) seems doomed for a quick ultimate failure.

The performance to date of the hot-applied sealant sections is shown in Figure 5.18. It is apparent that Crafco 444 (1) began deteriorating at a faster rate than the other hot-applied sealant, Crafco 221 (1). The former appears to be at a terminal effectiveness level since it does not have much more effectiveness to lose. The latter is maintaining an effectiveness between 70 and 80%.

Figure 5.19 displays the effectiveness values of the silicone sealants over their life-span to date. The effectiveness increases observed during EBJN01 make the graph difficult to decipher. The majority of the effectiveness apparently gained during the last survey (EBJN01) appears to have been lost during the current survey (EBOC01) and throws into doubt the results of the former survey. Only Crafco 902 (1) exhibits no effectiveness increases at all during its lifetime. The current effectiveness values for almost all sections are still above those from a year ago (EBOC00). Most of the sections, however, are only a few percentage points above their October 2000 value.

5.2.4 Treatment Effectiveness in the Westbound Lanes during the WBOC00 Survey

On Wednesday, October 11, 2000, the University of Cincinnati research team performed the third joint sealant evaluation in the westbound driving lane. The data set collected is code-named WBOC00, and was performed in the same manner as previously described by Sander (2002). Effectiveness values calculated from the results of this survey are shown in Figure 5.20. The sections are grouped by sealant type: silicone, hot-applied, or compression seals. The joint configuration for each sealant is denoted by the number in parentheses. Average effectiveness values for the three sealant types are also displayed in the Figure.

The westbound lanes have been open to traffic for approximately thirteen months fewer than the eastbound lanes, and the sealants here have generally suffered less damage. In the westbound lanes, the silicone sealants have maintained 90% effectiveness, higher than any other sealant type in the westbound lanes. The compression seals and hot-applied sealants average 75 and 71% effectiveness, respectively.

The relatively poor performance of the compression seals compared to the silicone sealants is attributable exclusively to the very poor effectiveness rating of the Techstar W-050 (5) section. As in the eastbound lanes, Techstar W-050 (5) is performing very poorly, achieving only 27% effectiveness. In contrast, the other two compression seals maintain 100 and 99% effectiveness, respectively. If the effectiveness value of Techstar W-050 (5) is excluded from the compression seal average these seals have a nearly perfect effectiveness average (99.5%), which surpasses that of the silicone sealants. The consistent poor performance of the Techstar W-050 seal in both the eastbound and westbound lanes demonstrates its inadequacy as a sealant in a Portland cement concrete (PCC) pavement.

The two hot-applied sealants have very different effectiveness values. The Crafco 444 (1) sealant maintains more than twice the effectiveness of Crafco 221 (1). The former averages 96% effectiveness, while the latter maintains only 46%. In contrast, recall that in the eastbound lanes Crafco 221 (1) performed far better than Crafco 444 (1). Consequently, the argument proposed earlier that Crafco 221 (1) is better suited to the temperature regime at the test site no longer holds.

The majority of the silicone-filled joints maintain at least 90% sealant effectiveness. The Dow 890-SL (3) section exhibits a remarkably high 99.7% effectiveness rating. The correlation between poor sealant performance and joint configuration is again present, although it is not as pronounced here as in the eastbound lanes. Dow 890-SL (4) sealants have the lowest effectiveness among the silicone sections, exhibiting 57% effectiveness. With one exception, there is little difference among the sealants placed in joints with the wider No. 1 configuration. Four of the five silicone sealants with joint configuration No. 1 vary from 96 to 98% effectiveness. The fifth, Crafco 903-SL (1b) has only 79% effectiveness.

As in the previous section, a table is provided to compare the effectiveness of each sealant from the Fall 2000 survey to the previous survey conducted in Spring 2000. Table 5.4 lists the loss of effectiveness and ranks the sealants in a manner analogous to what was described earlier. The rating categories are included again for the reader's convenience. Figure 5.21 graphs these effectiveness values so that the reader can gain a better understanding of the results.

As is the case for the eastbound lanes, the Watson Bowman and Delastic compressive seals are performing better than almost all of the sealants, ranking first and third in the westbound lanes, respectively. The other compression seal, Techstar W-050 (5), is the worst seal in terms of effectiveness and also loss of effectiveness since the previous survey.

The Dow 890-SL (4) silicone sealant section is the only section other than Techstar W-050 (5) to experience significant deterioration (i.e., more than 5%): it has lost 29% of its effectiveness. Most sections have somewhat higher effectiveness values than what was observed in the previous survey. As mentioned previously, these limited increases are the result of inevitable discrepancies in the rating practices of individual research team members.

Figure 5.22 shows the effectiveness trend for each sealant since the first survey conducted in Fall 1999. With few exceptions, all sections have experienced little or no loss in effectiveness.

The deterioration of the compression seals is displayed in Figure 5.23. The Watson Bowman 812 (5) and Delastic V-687 (5) compressive seals continue to exhibit superior effectiveness values, with very little or no deterioration. The former shows no loss of effectiveness in any of the inspected joints. The Techstar W-050 (5) section, on the other hand, is again the exception among the compression seals, losing 43% since Spring 2000 and 72% since Fall 1999.

Due to the fact that the westbound sealants are one year younger than those in the eastbound sections, they can provide valuable information concerning early age performance. The westbound Techstar W-050 (5) section initially had a high effectiveness value but began deteriorating immediately. Therefore, it may be concluded that the poor performance initially observed in the eastbound lanes is a result of rapid sealant deterioration rather than poor installation, as previously suspected.

The two hot-applied sealants have very different deterioration rates again, as shown in Figure 5.24. The Crafco 444 (1) section has experienced no loss of sealant effectiveness since the original survey, whereas the Crafco 221 (1) section has lost nearly 20%. Incidentally, these two sealants are the youngest ones: they were installed four months after the rest in the westbound lanes.

A concern about the installation of the Crafco 221 (1) sealant was discussed earlier, but it is still difficult to decipher if the relatively poor performance of the sealant is due to poor installation or sealant deterioration. The initial evaluation of the sealant in the eastbound lane (EBNV99) was conducted when the sealant had already been in place for two years, and, therefore, the loss of effectiveness could have been caused by distresses related to vehicle traffic. An evaluation of the Crafco 221 (1) sealant in the westbound lanes during the WBNV99 survey allows an evaluation of the sealant at a relatively young age (seven months). In the WBNV99 survey, the Crafco 221 (1) section is found to have maintained only 63% of its effectiveness, a value similar to the initial effectiveness found in the eastbound lane (71%). This may give some additional evidence that the installation of the Crafco 221 sealant may not have yielded an initial effectiveness at or near 100%.

Similar concerns were discussed earlier in conjunction with the silicone sections in the eastbound lanes. Again, the westbound lanes are used as an indication of the sealants' early age performance. The silicone sealants in the westbound lanes are generally observed to have high initial effectiveness values and experience little or no loss of effectiveness in later surveys (Figure 5.25). In view of the lack of deterioration in the westbound lanes, it is likely that it is poor installation led to the loss of effectiveness in the silicone sealants in the eastbound lanes.

The effectiveness on the westbound sections is in great contrast to those in the eastbound lanes. This difference is only partly due to the relative age of the sealants; the sealants in the westbound lanes were installed approximately one year after those in the eastbound lanes and, consequently, the latter have been exposed to the harsh environment for a longer period of time. To evaluate performance at the same age, data from the WBOC00 survey are compared to those from the EBNV99 survey, when both sealants were approximately two years old. A graphical illustration of this comparison is shown in Figure 5.26. In general, the 2-year old westbound sealants (WBOC00) performed much better than the 2-year old eastbound sealants (EBNV99). Note that in Figure 5.26, the comparison in some cases is between similar but not identical sections, in view of small differences in the experimental layout of the eastbound and westbound sealant sections. Thus, Watson Bowman 687 (5) is compared to Watson Bowman 812 (5), and Crafco 902 (1) is contrasted to Crafco 903-SL (1a).

The performance of the westbound compressive seals manufactured by Watson Bowman and Delastic is very similar to their counterparts in the opposite lane direction since none has experienced an effectiveness loss. The Techstar W-050 (5) seals offer one of the few exceptions found in Figure 5.26. The eastbound Techstar seals performed much better than those in the westbound lanes. The former maintained 60% effectiveness and the latter only 27%, despite the fact that the manufacturer's representative was present during installation in the westbound lanes.

The eastbound section of the Crafco 221 (1) sealant achieved 71% effectiveness whereas the westbound attained only 46%. The other hot-applied sections, Crafco 444 (1), are significantly different. The westbound section maintained nearly all of its effectiveness with 96%, yet the eastbound section exhibited only 14% effectiveness.

All but one of the westbound silicone sections exceeded the effectiveness of their counterparts in the eastbound lanes. The WBOC00 sections have surpassed the EBNV99 ones by an average of 17%. Only the westbound Dow 890-SL (4) section achieved a lower effectiveness value than the corresponding eastbound section, maintaining 57 and 76%, respectively.

The superior performance of the westbound over the eastbound sealant sections, even when comparing similar ages, suggests that favorable conditions exist in the westbound lanes. Possible factors contributing to this difference in sealant performance include the experience of the installation crew and weather conditions during sealant installation.

5.2.5 Treatment Effectiveness in the Westbound Lanes during the WBJN01 Survey

On Tuesday, June 5, 2001, the University of Cincinnati research team performed the fourth sealant evaluation in the westbound driving lane. The survey was performed in the same manner as previous inspections (Sander, 2002), and the data set collected is code-named WBJN01. Effectiveness values calculated are shown in Figure 5.27. The sections are grouped by sealant type: silicone, hot-applied, or compression, for which average effectiveness values are listed. The joint configuration is denoted by the number in parentheses.

The compression seals, with the exception of Techstar W-050 (5), have lost very little effectiveness. Watson Bowman 812 (5) and Delastic V-687 (5) have effectiveness values of 99.7%, with only 25 mm (1 in.) of failure in each. The Techstar W-050 (5) seal continues to perform poorly with an effectiveness value of only 14%. The three compression seals average 71% effectiveness, which is not representative of the excellent performance of the two superior compression seals.

The average effectiveness of the hot-applied sealants is 78%. Crafco 444 (1) is 98% effective and Crafco 221 (1) is at 58%. The former value is in great contrast to the effectiveness value in the corresponding eastbound section, which is only 11%. Such a large disparity has been observed in every survey to date. If it is assumed that conditions in the eastbound lane are identical to those in the westbound lane, this would suggest a possible flaw in the installation process in the eastbound section. On the other hand, there is a considerable age difference between the two Crafco 444 (1) sections; this will be discussed subsequently in more detail.

The silicone sealants are far superior to the hot-applied materials and to the Techstar W-050 (5) compression seal. Six silicone sections have effectiveness values above 95%; the other two, Crafco 903-SL (1b) and Dow 890-SL (4), have values of 79% each. In this case, there is no apparent correlation between sealant effectiveness and joint configuration.

The silicone sealants in the westbound lane have two pairs of identical sections; two Dow 888 (1) and two Crafco 903-SL (1) sections. The Dow 888 (1) sections are performing very similarly: one is 99.7% effective and the other 98%. The performance of the Crafco 903-SL sections, however, show a considerable difference in effectiveness. Crafco 903-SL (1a), located between stations 188+00 and 194+00, is 96% effective, whereas Crafco 903-SL (1b), between stations 194+00 and 200+00, is only 79% effective. This is peculiar since both were installed on the same day, immediately following one another (Hawkins, 1999). The sealant installation crew moved eastward and installed Crafco 903-SL (1b) before Crafco 903-SL (1a). It is postulated that the crew gained useful experience with the installation of the former and applied it to the installation of the latter.

The results of the last two surveys are compared in Figure 5.28. Table 5.5 also lists the effectiveness values and differences from the previous two surveys and ranks the sections accordingly. Techstar W-050 (1) lost more effectiveness (13%) than all other sealant sections. The effectiveness values for the compression seal sections, Watson Bowman 812 (5) and Delastic V-687 (5), has varied by only 1%. Both of the hot-applied sections have increased in effectiveness. The 12% increase in Crafco 221 (1) is the second highest; the Crafco 444 (1) apparently improved by 2%. The large increases in effectiveness observed previously in the eastbound lanes are generally nonexistent in the westbound lanes; this is because most of the latter sections are already near 100% effectiveness. Six of the eight silicone sections had previous effectiveness values above 90%, and of these six sections, only three exhibit small increases in effectiveness. Both silicone sections involving a No. 4 joint configuration display increases in effectiveness. Crafco 903-SL (4) has only a 5<u>%</u> increase, but its previous effectiveness was 91%. Dow 890-SL (4) has the largest increase: 23<u>%</u> since the previous survey.

The deterioration of all westbound sealant sections since the first survey (Fall 1999) is displayed in Figure 5.29. The long-term loss of effectiveness for the pre-formed compression seals is also shown in Figure 5.30. Watson Bowman 812 (5) and Delastic V-687 (5) continue to maintain most of their effectiveness. It is unlikely that these two superior seals will lose much effectiveness in the near future. Techstar W-050 (5) has already failed and continues to decline toward 0% effectiveness. After failing in just a short period of time, the Techstar seals in both the eastbound and westbound lanes have no long-term durability.

Figure 5.31 illustrates the results of the past four surveys for the hot-applied sealants. The section containing Crafco 444 (1) has increased slightly in effectiveness during the past two surveys, but this total increase accounts to only 9<u>%</u>. Crafco 221 (1) was thought to be steadily losing effectiveness but it seems to have stabilized and even shows a slight increase.

The trendline for the silicone sealants over the past four surveys is shown in Figure 5.32. With the exception of Dow 890-SL (4) at the time of WBOC00, all of these sections have maintained most of their effectiveness as measured during the first survey

(WBNV99). The performance of these sealants is unlike the performance of their counterparts in the eastbound lanes, where a steady loss of effectiveness is observed.

The eastbound and westbound lanes need to be compared at a similar age for the evaluation to be more meaningful. The westbound sealants are approximately one year younger than those in the eastbound lane. As done for the previous survey, the results of the current survey for the westbound lanes (WBJN01) are compared to the results of the survey of the eastbound lanes conducted one year earlier (EBMR00). The age of the sealants at the time of these two surveys is approximately 2.5 years.

Results from these two surveys are compared in Figure 5.33, which shows that the sealants in the westbound lane continue to outperform those in the eastbound. This trend is the same as had been observed in the last comparison. All but two of the westbound sections retain greater effectiveness values than their eastbound counterparts. In fact, the difference between the two lane directions is more pronounced now than before. The average difference is now 31%, up from 17% in the last comparison. This shows that the westbound sealants are not deteriorating nearly as rapidly their counterparts in the eastbound lanes.

The eastbound and westbound performance of the two superior compression seals, Watson Bowman 812/687 (5) and Delastic V-687 (5), remains excellent and very similar since neither seal has deteriorated significantly. The eastbound Techstar W-050 (5) section is performing better than the westbound section, although the difference has decreased since the last survey. This section is one of the few exceptions to the general trend of superior performance in the westbound lanes. The other exception in this comparison is offered by the Crafco 221 (1) sections, for which the eastbound is outperforming the westbound by 14%.

The largest difference in effectiveness is displayed by the Crafco 444 (1) sections; the westbound is nearly 90% more effective. It is noted that because the hot-poured sealants were installed later than the other westbound sections, they are five months younger than the corresponding eastbound sections. It is unlikely, however, that this age difference accounts for the observed disparity. Although it is not possible to ascertain at this time the cause of this large discrepancy, it is reasonable to attribute it to differences in weather conditions and quality of workmanship during installation. It is assumed that traffic loads and other distress causing factors are similar in both directions. The disparity in the hot-poured sealants and possibly other sealant types may be weather related. The installation of the westbound hot-poured sealants was delayed waiting for warmer temperatures; the pavement temperature was recorded at 16º C (61º F), which is within the Crafco specifications of 10-32º C (50-90º F) (Hawkins, 1999). In contrast, since the eastbound hot-poured sections were installed in November, it is possible that the pavement temperature was below the minimum specified temperature, and as a result the sealant did not create a good bond with the joint walls. No pavement temperatures are available for the November 1999 installation. Also, the Crafco 444 sealant applied in the westbound lane was heated to a temperature of 143<C (290<F), which is within the recommended temperature range (Hawkins, 1999). Unfortunately no additional information is available describing the installation process of Crafco 444 in the eastbound lanes.

The silicone-filled sections average a difference of 42% between the westbound and eastbound directions. The largest contrast is found in the Crafco 903-SL (4) sections (72%). The causes of so many large differences in effectiveness between the eastbound and westbound silicone sections are not clearly understood. The manufacturers' specifications for the silicone sealants make no mention of required temperature ranges (Hawkins, 1999). If temperature is indeed not a factor affecting the performance of these materials, then poor workmanship may be to blame.

5.2.6 Treatment Effectiveness in the Westbound Lanes during the WBOC01 Survey

On the day following the inspection of the eastbound lanes, i.e., on Tuesday, October 16, 2001, the westbound lanes were inspected. Code-named WBOC01, this evaluation was the fifth and final evaluation for these materials. The results of the current survey are presented in Figure 5.34, where the sealants are separated into compression, hot-applied, and silicone sealants, and are further arranged according to their joint configuration. The average effectiveness values for each sealant type are also provided.

The compression seals, with the exception of Techstar W-050 (5), continue to perform exceptionally well. Watson Bowman 812 (5) and Delastic V-687 (5) are 98 and 97% effective, respectively. The average of the compression seals (66%) is depressed due to the ineffectiveness of the Techstar W-050 (5) section. Excluding this section yields an average of 98%, which is best amongst all the sealants. The difference in effectiveness between the two superior compression seal sections and Techstar W-050 (5) could not be greater. The latter is only 4% effective, which indicates that the sealant has failed since it cannot keep any water out of the joint.

The difference between the two hot-applied sections continues to increase: Crafco 444 (1) is 93% effective, yet Crafco 221 (1) is only 43% making the difference 50%. During the previous survey this difference was 40%.

The silicone sealants average 85% effectiveness, which is the best for the westbound lanes (when Techstar W-050 is included for the compression seals). All silicone sealants with the No. 1 configuration, with the exception of Crafco 903-SL (1), are in very good condition ($\geq$ 90%). The only No. 3 configured section, Dow-SL 890 (3), has the highest effectiveness value (99%) out of all the westbound sections. The two No. 4 configured silicone sections, Crafco 903-SL (4) and Dow 890-SL (4), have effectiveness values of 85 and 44%, respectively. It is apparent that the No. 4 joint configuration continues to produce poor effectiveness values.

In Figure 5.35, the results of the current survey are compared to those from the previous one. Numerical values for effectiveness and deterioration, as well as corresponding rankings, are listed in Table 5.6. Watson Bowman 812 (5) and Delastic V-687 (5), which were both 99.7% effective during WBJN01, maintained their excellent performance, each decreasing by only 2%. Techstar W-050 (5), which had little effectiveness left, lost 10%, falling to 4% effectiveness. The Crafco 444 (1) section lost 6%, but it is still in very good condition ($\geq$ 90%). Crafco 221 (1) fell from a poor to very poor rating by losing 15%, and so ranks second in terms of lost effectiveness. The section containing Dow 890-SL (4) exhibits the largest decrease in effectiveness (35%), down from the unexpectedly high value recorded during the previous survey. The other No. 4 configured section, Crafco 903-SL (4), also lost all of its previous apparent gain in effectiveness; it lost 11% since the previous survey. The remaining silicone sections lost less than 10%; Dow 888 (1a), which was 99.7% effective during the last survey (WBJN01), dropped 9% during the current survey (WBOC01). The only section exhibiting an increase in effectiveness is Dow 890-SL (3), which gained 2%.

The performance of all the westbound sections over their entire life to date is shown in Figure 5.36. The sealant type sections are also displayed individually in Figures 5.37 to 5.39 and are examined in detail in the following paragraphs.

Figure 5.37 indicates that Techstar W-050 (5) may have at one time been 100% effective, but deteriorated quickly soon after its installation. It is clear that this section has been steadily declining in effectiveness over the past three years and has virtually no effectiveness left. The other two compression seals, Watson Bowman 812 (5) and Delastic V-687 (5), have maintained nearly all of their original effectiveness and promises excellent performance in the future.

The performance of the hot-applied sealants is shown in Figure 5.38. These sealants were not installed until April 1999, whereas all other seals in the westbound lanes had been installed in December 1998. Unlike the eastbound lanes, where Crafco 444 (1) began deteriorating very rapidly and dramatically, the corresponding westbound section has lost very little in effectiveness. It has generally maintained effectiveness values above 90% for its lifetime. Crafco 221 (1) deteriorated rapidly early on, but more recently it has maintained a steady effectiveness value, the June 2001 evaluation, which produced many effectiveness increases, notwithstanding.

Most of the silicone sealants have maintained much of their original effectiveness throughout their lifetime as shown by Figure 5.39. Four sections, Dow 890-SL (3), Dow 888 (1b), Dow 890-SL (1), and Crafco 903-SL (1a), have never dropped below 95% effectiveness. Dow 888 (1a) recently dropped to 91%, but it had been above 95% in all previous surveys. Crafco 903-SL (4) and Crafco 903-SL (1b) had deteriorated to 89% and 77%, respectively, during EBMR00, but they have essentially maintained those values since then. The two identical Crafco 903-SL (1) sections are performing quite differently. Crafco 903-SL (1a), which is between Stations 188+00 and 194+00, is outperforming its twin by approximately 20% throughout the time span considered. The effectiveness value of Dow 890-SL (4) fluctuates dramatically since it is very hard to survey due to the very narrow joint width, which makes it difficult to determine adhesion failure.

The westbound sections are still performing significantly better than the eastbound sections, even after accounting for the difference in their ages. Figure 5.40 compares the current westbound survey (WBOC01) to the eastbound survey conducted one year earlier (EBOC00). At the time of these two evaluations, all sections were approximately three years old.

The superior performance of the westbound sections is glaring, especially when considering the silicone sealants, where every westbound section outperforms its corresponding eastbound counterpart by at least 30%. The largest difference among silicone sealants is found in the Crafco 903-SL (4) joints, where the westbound lanes are

78% higher than the corresponding eastbound lanes. The largest overall difference is between the two Crafco 444 (1) sections. The westbound section is outperforming the eastbound by 86%, which is actually down from 88% observed during the June 2001 evaluation. The other hot-applied sealant, Crafco 221 (1), does not follow the same trend: the eastbound is outperforming the westbound section by 28%. Similarly, the Techstar W-050 (5) eastbound section is outperforming its westbound counterpart by 23%. The other two compression seals are performing identically in both directions. The Watson Bowman sections are both achieving 98% effectiveness, while both the Delastic V-687 (5) sections are maintaining 97% effectiveness.

It is now possible to compare the eastbound and westbound sections over an extended period of time. The effectiveness of the compression seals in the eastbound and westbound lanes is plotted in Figure 5.41. The ordinate is age in months, measured since the time of installation. The Watson Bowman and Delastic seals in the eastbound and westbound lanes are performing extremely well. The eastbound Techstar section is outperforming its westbound counterpart, but the effectiveness trends of both sections are pitifully poor. In both directions, this material exhibits less than 20% effectiveness, and continues to deteriorate.

Figure 5.42 depicts the hot-applied sealants in the same manner. The large discrepancy between the two Crafco 444 (1) sections is again evident. The eastbound section never performed as well as the westbound, which hints at possible deficiencies in the installation of the former. It is possible that the construction crew gained experience with the installation of the eastbound section, and used this effectively during installation in the westbound sections. Moreover, it is possible that delaying the westbound installation until the following Spring was very beneficial. The Crafco 221 (1) sections, however, do not support these postulates. Just the opposite is observed in these sections, albeit to a much lesser degree: the eastbound are outperforming the westbound. The difference in effectiveness here is about 25%, whereas for the Crafco 444 (1) sections this difference is about 80%.

To elucidate the behavior of the silicone sealants, their performance trends are shown in three separate figures. Figure 5.43 shows the self-leveling sealants with the No. 1 joint configuration. Note, however, that whereas there are two duplicate sections of Crafco 903-SL (1) in the westbound lanes, there is only one such section in the eastbound direction. Consequently, the westbound Crafco 903-SL (1b) section is compared to the eastbound section sealed using Crafco 902 (1), ignoring the fact that the latter is a non-sag silicone sealant. To date, all of the westbound sections are outperforming their eastbound counterparts by a large margin. It is apparent that all eastbound sections never performed as well as their westbound counterparts.

Figure 5.44 displays the performance of the four non-sag Dow 888 (1) sections. It is observed again that the westbound sections are outperforming the eastbound by a considerable margin. The former have never dropped below 90% effectiveness, whereas the latter deteriorated drastically very early on and are about 50% below the westbound lanes as of the WBOC01 survey. This graph strongly suggests that poor workmanship is responsible for the dismal performance of the eastbound silicone sealants.

The performance of the No. 3 and 4 configured self-leveling silicone sealants in the east- and westbound lanes is shown in Figure 5.45. Despite the fluctuations in values from survey to survey, this graph also shows the continuing superior performance trend of the westbound sections. Westbound Dow 890-SL (3) and Crafco 903-SL (4) have outperformed their eastbound counterparts over the entire time span considered. The Dow 890-SL (3) section has maintained an effectiveness of at least 95% in the westbound lanes, yet its counterpart in the eastbound direction has deteriorated steadily to below 60%. The westbound Crafco 903-SL (4) section has never dropped below 80%, yet the corresponding eastbound section began deteriorating quickly and never came close to the westbound performance. The eastbound section of Dow 890-SL (4) had better effectiveness values than the westbound section in early life, yet at approximately 25 months, it began to lose effectiveness very quickly and has since dropped below the latter. Additional surveys are needed to further study the performance of these sealants in view of the strong fluctuations in effectiveness values.

5.3 PCC Pavement Performance

Collection of data pertaining to PCC pavement performance was initiated during the Spring 2000 evaluation, after several mid-slab cracks had been noticed (Sander, 2002). Only the westbound driving lane was included at this initial survey, results from which are discussed by Sander (2002). During the Fall 2000 evaluation, the initial pavement performance survey of the eastbound driving lane and the second such survey of the westbound driving lane were conducted. Additional surveys were conducted during the Spring 2001 and Fall 2001 evaluations; all three data sets are described subsequently. The number of slabs containing transverse cracks and slabs with corner breaks are recorded; examples of these distresses are shown in Figures 5.46 and 5.47, respectively. Slabs containing more than one transverse crack or corner break are counted as just one. The degree of joint spalling, measured by length, is calculated as well; examples of this type of deterioration are shown in Figure 5.48. These three pavement distresses are analyzed in the following subsections.

5.3.1 Pavement Distresses in the Eastbound Lanes during the EBOC00 Survey

The initial pavement performance evaluation in the eastbound lanes was conducted on Wednesday, October 11, 2000. Analysis of the extents of transverse cracking, corner breaking, and joint spalling is provided below.

Transverse Cracking

Table 5.7 shows a summary of transverse cracking observations recorded during the EBOC00 survey in the eastbound lanes. This is the first such pavement performance evaluation in this direction. Every section exhibits transverse cracking to some extent and the test pavement as a whole has 24% cracked slabs.

The section of the non-sag silicone sealant Dow 888 (1a) displays the most transverse cracking (48%). The other non-sag silicone filled sections, Dow 888 (1b) and Crafco 902 (1), have 25 and 32% of the slabs cracked, respectively.

The unsealed section between Stations 219+00 and 225+00 shows the second largest amount of transverse cracking at 48%, as well as the most corner breaks, as noted in a subsequent paragraph. The two Crafco 903-SL sections have the least transverse cracking: Crafco 903-SL (1) has 7% slabs cracked and Crafco 903-SL (4) only 6%.

There is no bias with respect to sealant type when transverse cracking is considered. The top four pavement sections in terms of percentage of cracked slabs, viz. Dow 888 (1a), No Sealant (2), Watson Bowman WB-687 (5) and Crafco 221 (1), each have a different sealant type (silicone, unsealed, compression seal, and hot-applied), as well as a wide range of effectiveness values (41, 0, 98, 71%, respectively). Note that the unsealed section is assigned a 0% sealant effectiveness to facilitate the comparison.

Corner Breaking

The pavement performance evaluation conducted in Fall 2000 was the first time corner breaks were counted in the eastbound lanes. Table 5.8 shows the number of corner breaks and percentage of corner breaks in the eastbound driving lane encountered during the EBOC00 survey.

Corner breaks are observed only in two sections, Techstar W-050 (5) and No Sealant (2). Two broken slabs are found in the former, accounting for 7%. The latter has six slabs with corner breaks, accounting for a remarkably high 22% of the slabs in this section. No other unsealed section in either the eastbound or the westbound lanes was observed to have any corner breaks.

Spalling

Table 5.9 lists the measured length of spalling, spalling increases, and rankings for each sealant section. The total recorded length for this survey is also provided. There are six sections that currently have spalling distresses observed in their joints. Of these, two are silicone filled, two are hot-applied, and two are unsealed. Recall that there are only two hot-applied and two unsealed sections in the eastbound lanes. None of the three compression sections have any spalling failures.

Crafco 221 (1) has significantly more spalling than any other section; it measures 1.25 m (4.1 ft). As shown in Figure 5.48 (a), Joint 21 was poorly cut and exhibits 1.19 m (3.9 ft) of spalling, which accounts for over 95% of the total spalling failure length in this section. The section with the second highest degree of spalling is Dow 890-SL (3), which has a total 152 mm (6 in.) and is limited to just two joints, 5 and 7. Only four other sections have spalling distress in their joints: No Sealant (6), Crafco 444 (1), Crafco 903-SL (1), and No Sealant (2), which have 102 mm (4 in.), 51 mm (2 in.), 51 mm (2 in.), and 25 mm (1 in.), respectively.

A concern to the University of Cincinnati research team is the fluctuations in the measured spalling length. A careful investigation into this problem revealed that nine of the fifteen sections exhibit a decrease in spalling distress length at one time or another. Three of these involve a decrease of only 25 mm (1 in.). The following questions are raised: Are the distresses being overlooked; is the definition of a spall dependent on the inspector; or is it a matter of the length of the spall being measured? Through the investigation of previous surveys, several measuring inconsistencies were found. Of the nine sections containing spalling decreases, four were determined to be length differences. For example, a spalling distress was measured as 51 mm (2 in.) in Spring 2000. During the next survey, the same spall was measured as only 25 mm (1 in.), which causes a decrease in the measured length. The five remaining increases were either overlooked or considered not to be spalling distresses.

5.3.2 Pavement Distresses in the Eastbound Lanes during the EBJN01 Survey

The second pavement performance evaluation in the eastbound lanes was conducted on Monday, June 4, 2001. Analysis of the degree of transverse cracking, corner breaking, and joint spalling is provided below.

Transverse Cracking

The number of transverse cracks, slab percentage, and corresponding rank for the eastbound driving lane is listed in Table 5.10 (a). The No Sealant (2) section, between Stations 219+00 and 225+00, has the largest percentage of cracked slabs with 66.7%. The other unsealed section, found between Stations 160+00 and 166+00, has the fourth highest percentage with 54%. These sections are performing worse than their westbound counterparts, which rank eleventh and fifteenth, respectively. The section with the lowest cracked slab percentage is Crafco 444 (1), which contains ten cracked slabs accounting for only 13% of the slabs in this section. Recall that this section had the lowest effectiveness value (11%) at the same time (June 2001).

Table 5.10 (b) shows the increases in transverse cracks from the previous survey. Negative values indicate a decrease in observed cracking. Ranking is according to percentage of cracked slabs. The Techstar W-050 (5) section has the largest increase in transverse cracks (29%). A different compression seal section, Watson Bowman V-687 (5), has no increase in transverse cracks. The two hot-applied sections, Crafco 221 (1) and Crafco 444 (1), exhibit very little increase in transverse cracking. The two sections each have increases of 4%, ranking 14 and 13, respectively. The two Dow 888 sections also show similar increases with respect to each other. Dow 888 (1a) has a 13% increase and Dow 888 (1b) a 14% increase. These increases rank these sections at 9 and 8, respectively. No section exhibits a decrease in transverse cracks.

Corner Breaking

The number of corner breaks found in the eastbound driving lane is presented in Table 5.11 (a). No Sealant (2) and Techstar W-050 (5) have two corner breaks, more than the other sections, but since the former has one slab less than the latter, its slab percentage is slightly larger. The only other section that exhibits corner breaking is Crafco 902 (1), which has one corner break that accounts for 4% of the slabs.

Table 5.11 (b) lists the increase in breaks from the previous survey. The No Sealant (2) section has a decrease of four corner breaks from the previous survey. A review of the field logs is not insightful because none of the corner breaks are found in any of the evaluated joints. The four missing breaks can be attributed to either oversight or classification interpretation. Chipping can often be mistaken for small corner breaks and may be the reason for the decrease.

The Crafco 902 (1) section is the only one to have an increase in breaks; it has one additional break since the previous survey. Techstar W-050 (5) has the same number of breaks as before.

Spalling

The measured length of spalling failures, as well as the increase in length of spalling, in each section are ranked in Table 5.12. The Crafco 221 (1) section, between Stations 260+00 and 266+00, continues to exhibit more spalling than any other one. This fact is not a surprise because during the previous survey it had at least 1.10 m (3.6 ft) more spalling failure than the other sections. Joint 21 remains in poor condition and is still believed to be the result of poor workmanship. Only 1.00 m (3.3 ft) of spalling failure was measured in this section during this survey, compared to 1.25 m (4.1 ft) measured in October 2000. This discrepancy is due to the extremely bad shape of Joint 21, which is often difficult to evaluate due to its dismal condition. The Dow 890-SL (3) section is also observed to have a significant decrease in spalling failure. The severity of the spalls in this section is so small that the evaluator discounted them during the next survey. In October 2000, five separate spalling failures were found in Joints 5 and 7, accounting for 152 mm (6 in.). During the June 2001 survey, the evaluator noted that there was very minor spalling in these joints and that it is too small to be considered spalling failure. Unfortunately, this example shows how the discretion of the evaluator can affect the outcome of the data.

Five sections have spalling failures that have not been previously recorded. These include Crafco 903-SL (4), Dow 890-SL (4), Dow 888 (1a), and Delastic V-687 (5). The total length of spalling is up by 127 mm (5 in.) since the previous survey, to a current length of 1.78 m (5.8 ft).

5.3.3 Pavement Distresses in the Eastbound Lanes during the EBOC01 Survey

The third and final pavement performance evaluation in the eastbound lanes was conducted on Monday, October 15, 2001. Analysis of the degree of transverse cracking, corner breaking, and joint spalling is provided below.

Transverse Cracking

Table 5.13 (a) lists the number of transverse cracks, percentage of slabs cracked, and corresponding ranking for the eastbound sections. Overall, the eastbound lanes are in better condition than the westbound lanes. This fact is surprising because the eastbound lanes are approximately one year older than the westbound lanes. The eastbound lanes have 39% of their slabs cracked, compared to 44% in the westbound lanes. In the eastbound lanes, there are no sections with more than 75% cracked slabs and only four sections with more than 50%; eleven sections have 25% or more of their slabs cracked.

The compression sealed sections are performing similar to each other, Watson Bowman 687 (5) and Techstar W-050 (5) have 50% of their slabs cracked and Delastic V-687 (5) has 43% cracked. These values rank the two former at fifth and the latter at seventh.

The two unsealed sections are performing on the opposite end of the spectra as their westbound counterparts, which have very little cracking. The eastbound sections rank first and fourth in terms of transverse cracking. The No Sealant (2) section has two out of every three slabs cracked (67%) and No Sealant (6) has 54% cracked.

As stated previously, there does not appear to be a correlation between sealant effectiveness and pavement performance. For example, Dow 890-SL (1) has the fourth highest effectiveness value (71%), but has the largest degree of transverse cracks (67%). Crafco 444 (1), which has the lowest effectiveness value (9%), has a transverse cracking rank of thirteen with 15% of its slabs cracked. These examples, with others, suggest that poor sealant effectiveness does not imply poor pavement performance.

Table 5.13 (b) lists the increase in the number of cracked slabs, increased percentage, and corresponding ranking since the previous survey. The Watson Bowman 687 (5) section, which showed virtually no decrease in effectiveness, has the largest increase in cracked slabs (15%). Delastic V-687 (5) exhibits a 7% increase and Techstar W-050 (5) shows no increase at all. The unsealed sections show no increase in transverse cracking. Four sections, Crafco 903-SL (4), Dow 890-SL (3), Crafco 902 (1), and Dow 888 (1b), exhibit decreases in cracking of 6, 4, 11, and 4%, respectively. Most of the sections exhibit an increase in cracking of less than 10%.

Corner Breaking

Table 5.14 (a) lists the number of slabs experiencing corner breaks, as well as the percentage of slabs with cracks, and the corresponding ranking. As had also been the case during the previous survey, only Crafco 902 (1), Techstar W-050 (5), and No Sealant (2) sections have corner breaks. In fact, Table 5.14 (b) indicates that there have been no changes in the number of corner breaks observed in any of the sealant sections since the previous survey.

Spalling

The length of spalling observed during the EBOC01 evaluation is listed in Table 5.15. The Crafco 221 (1) section continues to exhibit the largest degree of spalling.

Recall that this section includes Joint 21, which currently has 1.12 m (3.7 ft) of spalling and accounts for 100% of the observed spalling in this section. This joint is the result of either a bad cut or an end of the day construction joint.

Dow 890-SL (3), which previously did not have any spalling, is observed to have 25 mm (1 in.) of such failure. No Sealant (2), which had 51 mm (2 in.), now has 102 mm (4 in.) and ranks second among the eastbound sections. The increase is the result of two additional spalling failures located in separate joints. The other unsealed section, No Sealant (6), has the third largest degree of spalling with 51 mm (2 in.). It is possible that the lack of sealant may cause spalling in these sections.

Overall, the eastbound joints exhibit 1.47 m (4.8 ft) of spalling, which is 305 mm (12 in.) less than what was observed in the previous survey. Seven sections exhibit decreases in spalling length. The Crafco 903-SL (4) section has the largest decrease in spalling with 152 mm (6 in.); no spalling was observed here during this survey. In the previous survey, three joints accounted for the 152 mm (6 in.) of spalling. It is noted in the field logs that some joints have rough lips, but they are not recorded as spalling failures; previously, however, it was noted that the spalling was minor. This fact shows that a classification discrepancy exists, rather than a lack of care in the evaluation process.

After reviewing all seven sections that have decreases in spalling, three, including Crafco 903-SL (4), are definitely classification discrepancies, three are most likely such discrepancies, and one is a measuring discrepancy, in which spalling failures where recognized but the lengths were measured less than the previous survey.

5.3.4 Pavement Distresses in the Westbound Lanes during the WBOC00 Survey

The second pavement performance evaluation in the westbound lanes was conducted on Wednesday, October 11, 2000. Analysis of the degree of transverse cracking, corner breaking, and joint spalling is provided below.

Transverse Cracking

Table 5.16 (a) lists the number of transverse cracks, percentage of slabs cracked, and corresponding ranking. A slab that exhibits two or more cracks is counted as only one cracked slab. All but two sections in the westbound driving lane have transverse cracking in their slabs; these are Dow 890-SL (4) and No Sealant (6). In contrast, only ten of the fifteen sections had experienced transverse cracking during the previous survey (WBMR00).

The appearance of cracking is minimal in the hot-applied sealant and unsealed sections. In the former category, Crafco 444 (1) and Crafco 221 (1) rank 12th and 13th, respectively, whereas the two unsealed sections rank 10th and 14th, respectively. The majority of the cracking is observed in the superior compressive seal sections, Delastic V-687 (5) and Watson Bowman 812 (5), which rank 1st and 3rd, respectively. This suggests that there is no correlation between sealant performance and transverse cracking, since these seals are highly effective.

The increase in transverse cracking and percentage of slabs cracked from the previous survey are listed and ranked accordingly in Table 5.16 (b). The number of increased slabs cracked, percentage of slabs cracked, and corresponding rank are provided as well. Dow 888 (1a) exhibits the largest increase in transverse cracking

(22%). The other Dow 888 (1) section, Dow 888 (1b), has 14% more of its slabs cracked, ranking it the fourth highest. Dow 890-SL (4) and No Sealant (6) have the same number of cracked slabs as in the previous survey. Dow 890-SL (1), Crafco 221 (1), and Crafco 444 (1) have slightly fewer cracks.

Corner Breaking

The number of corner breaks in each section, percentage of slabs cracked, and corresponding rank are presented in Table 5.17 (a). Only four sections in the westbound driving lane exhibit corner breaks: Dow 890-SL (3), Dow 888 (1a), Crafco 444 (1), and Techstar W-050 (5). Among these, Dow 890-SL (3) has the most corner breaks (11%). A total of seven breaks are observed in all the sections.

The occurrence of corner breaks does not appear to correlate with sealant type because the four sections containing corner breaks are well distributed: two silicone sealant sections, one hot-applied sealant section, and one compressive seal section. Also, the effectiveness of the sealant does not appear to be a major factor in the appearance of corner breaks. The sections containing corner breaks, Dow 890-SL (3), Dow 888 (1a), Crafco 444 (1), and Techstar W-050 (5), have effectiveness ratings of 100, 96, 96, and 27%, respectively. Even though the Techstar W-050 (5) section has a very poor effectiveness value, the occurrence of corner breaks in the other highly effective sections suggest that sealant effectiveness is not necessarily a factor.

The increase in observed corner breaks, percentage point increase, and corresponding rank are listed in Table 5.17 (b). Only Dow 888 (1a) and Crafco 444 (1) exhibit increases in the number of breaks. Five sections have fewer corner breaks:

Crafco 903-SL (4), Dow 890-SL (3), Crafco 221 (1), Delastic V-687 (5), and No Sealant (2). All of these sections have one fewer break.

Spalling

Table 5.18 lists the measured length and increase in length of spalling in the westbound sections. The total length of spalling in all the sections is also given in the Table.

There are ten sections exhibiting some degree of spalling. Among these, seven are sealed with a silicone and one with a compression seal, whereas the other two are left unsealed. Neither of the two hot-applied sections shows any spalling distress. The Dow 890-SL (4) section has 203 mm (8 in.) of spalling failure, which is the highest in the westbound lanes, however, all of the measured spalling length is found in Joint 7, which is believed to be the result of a very poor initial cut rather than normal pavement deterioration. The Dow 890-SL (1) silicone section exhibits the second largest degree of spalling; 127 mm (5 in.) were recorded. There has been a steady increase in spalling in this section. No spalls were measured in the Fall 1999 survey, 51 mm (2 in.) of spalling in Spring 2000, and now 127 mm (5 in.) in this survey.

Dow 888 (1b) has the third highest degree of spalling with 102 mm (4 in.). There are four sections that have 51 mm (2 in.) of spalling: all three Crafco silicone sections and the No Sealant (6) section. One of these Crafco sections, Crafco 903-SL (1b), has significant differences in measured failure lengths among the three surveys. This section has recordings of 356 mm (14 in.), 279 mm (11 in.), and 51 mm (2 in.), in Fall 2000, Spring 2001, and Fall 2001 surveys, respectively. The decrease of 305 mm (12 in.) from the first survey to this one is a major concern for the research team. The majority of the spalling is located in Joint 10, which was noted to have 305 mm (12 in.) of spalling during the Fall 1999 survey, but only 51 mm (2 in.) in Fall 2000. The difference in length is a combination of a measured length discrepancy and a spalling classification dissimilarity. Of the ten sections containing spalling distresses, six have decreases in spalling at one point in the surveys. After a thorough investigation, it appears four of these discrepancies were due to differences in length measurement, and two were due to disparities in spall classification.

5.3.5 Pavement Distresses in the Westbound Lanes during the WBJN01 Survey

The third pavement performance evaluation in the westbound lanes was conducted on Tuesday, June 15, 2001. Analysis of the degree of transverse cracking, corner breaking, and joint spalling is provided below.

Transverse Cracking

Table 5.19 (a) lists the number slabs with transverse cracking, percentage of slabs with transverse cracks, and corresponding ranking. The Delastic V-687 (5) section, between Stations 219+00 and 225+00, has the highest percentage of cracked slabs (64%), which accounts for eighteen slabs. This section, however, has a nearly perfect sealant effectiveness (99.7%). The other two compression sealed sections have similar pavement performance results. Techstar W-050 (5) and Watson Bowman 812 (5) have 61 and 48% of their slabs cracked, respectively. Clearly, highly effective sealants do not prevent the occurrence of transverse cracks in the slabs, which is governed more by spacing of the joints as well as other factors.

The unsealed sections remain in good condition. The No. 6 configured section, between Stations 284+00 and 290+00, remains crack free. No transverse cracks were found in this section during the October 2000 survey either. The other unsealed section has 26% of its slabs cracked, ranking it 11 out of the 15 sections.

Table 5.19 (b) compares the number of transverse cracks from the current survey (WBJN01) to the previous one (WBOC00). The section that exhibits the largest increase in cracks is Techstar W-050 (5), which also has the largest increase in the eastbound lanes. Thirteen new cracks, which raise its percentage from 14 to 61%, were observed. The other two sections with compression seals exhibit increases of 32 and 26%, respectively. Twelve of the fifteen sections show increases of at least 15%. No section exhibits a decrease in cracked slabs.

Corner Breaking

The number of corner breaks observed in each section of the westbound driving lane are listed in Table 5.20 (a), along with the percentage of slabs cracked and corresponding rank. The section with the largest percentage of corner breaks is Dow 890-SL (3), between Stations 166+00 and 172+00. This stretch of pavement exhibits two corner breaks, accounting for 7.1% of the slabs. Dow 890-SL (4), between Stations 272+00 and 284+00, also has two corner breaks but since this section is twice as long as Dow 890-SL (3) the percentage of slabs cracked is half as much. Four other sections have only one corner break observed: Dow 888 (1b), Crafco 444 (1), Delastic V-687 (5), and the No Sealant (2) section between Stations 139+60 and 166+00.

Table 5.20 (b) shows the incremental gain or loss of corner breaks since the last survey. It is apparent that four sections exhibit increases in corner breaks, yet four other sections show decreases in breaks. Dow 890-SL (4), Dow 888 (1b), and Delastic V-687 (5) display the largest percentage increase (4%). In addition to these three sections, No Sealant (2) exhibits a small increase in corner breaks (1%). Four sections have one fewer break observed: Dow 890-SL (3), Dow 888 (1a), Crafco 444 (1), and Techstar W-050 (5).

Spalling

The recorded length of spalling failures in each section and the corresponding rank of each section in the westbound driving lane are listed in Table 5.21. The Dow-890 SL (4) section has an additional 635 mm (25 in.) of spalling, which is attributed to newly observed spalling on the north end of Joint 7. Recall that this joint is poorly cut and as a result contains several distresses. As in the previous survey, this section contains the most spalling failure, which measures 864 mm (34 in.). Another section with a significant increase in spalling is Dow 890-SL (1), which has 152 (6 in.) of additional failure. Joints 5 and 24, which were previously free of spalling, have a combined 152 mm (6 in.) of newly developed failure.

In the first survey, conducted in November 1999, 102 mm (4 in.) of spalling was observed in Joint 15 of the Techstar W-050 (5) section. No spalling was observed in any subsequent surveys until this one, which measures 127 mm (5 in.). Crafco 903-SL (4) exhibits a decrease of 51 mm (2 in.); No Sealant (2) and Delastic V-687 (5) show decreases of 25 mm (1 in.) each. Dow-890 SL (3), Crafco 221 (1), Crafco 444 (1), and

Watson Bowman 812 (5) all continue to exhibit no spalling failures. Although there are many increases and decreases in the measured spalling length throughout the Project, the total length remains unchanged from the previous survey.

5.3.6 Pavement Distresses in the Westbound Lanes during the WBOC01 Survey

The fourth pavement performance evaluation in the westbound lanes was conducted on Tuesday, October 16, 2001. Analysis of the degree of transverse cracking, corner breaking, and joint spalling is provided below.

Transverse Cracking

Table 5.22 (a) lists the number slabs with transverse cracking, percentage of slabs, and corresponding rank for the westbound driving lane. The three sections containing compression seals exhibit the most mid-slab transverse cracking. Recall that with the exception of Techstar W-050 (5), these seals have some of the highest effectiveness values. Watson Bowman 812 (5), Techstar W-050 (5), and Delastic V-687 (5) have 89, 82, and 79% of their slabs cracked, respectively. Although it is highly unlikely that the compression seals are aiding premature cracking, it is an issue that may need to be investigated more closely.

The two unsealed sections, which are essentially 0% effective, exhibit some of the lowest transverse cracking. The No Sealant (6) and No Sealant (2) sections have 25 and 30% of their slabs cracked, respectively, which ranks them twelfth and fourteenth. The section with the least transverse cracking is Dow 890-SL (4), which exhibits 16%.

Six sections, including those with compression seals, have over 50% (1 in 2 slabs) of their slabs cracked; eleven of the fifteen sections have at least 33% (1 in 3 slabs); and all but one section have at least 25% (1 in 4 slabs). Overall, 274 of the 592 (44%) slabs are found to have at least one transverse crack.

The degree of cracking increase is shown in Table 5.22 (b). The compression seal Watson Bowman 812 (5) has 11 additional cracks, accounting for a 41% increase. Another compression section, Techstar W-050 (5), exhibits a 21% increase, which ranks it third. The No Sealant (6) section, between Stations 284+00 and 290+00, has the second highest increase with 25%. The other unsealed section, between Stations 139+60 and 166+00, only shows a 4% increase. Two sections, namely Dow 888 (1b) and Dow 890-SL (3), show a small decrease in the number of cracked slabs.

Corner Breaking

The number of corner breaks observed per section in the westbound driving lane is listed in Table 5.23 (a). Also listed is the percentage of slabs with corner breaks and the corresponding rank. Dow 890-SL (3) and Delastic V-687 (5) have the highest percentage of corner breaks (7%). Recall that both of these sections have effectiveness values above 97%. Three other sections, Dow 890-SL (4), Crafco 444 (1), and No Sealant (2), have two corner breaks but lower percentage values. Five other sections have just one corner break, Crafco 903-SL (1a), Crafco 903-SL (1b), Dow 888 (1b), Crafco 221 (1), and Techstar W-050 (5). All of these sections have percentages less than 4%. The remaining five sections, Crafco 903-SL (4), Dow 890-SL (1), Dow 888 (1a), Watson Bowman 812 (5), and No Sealant (6), have no corner breaks at all. The data presented above suggest no correlation between corner breaks and sealant type.

Table 5.23 (b) lists the sealant sections with corner break increases, percentage point increase, and corresponding rank. Seven of the fifteen sections exhibit increases in corner breaks although no section has an increase of more than one break. Crafco 903-SL (1a), Crafco 903-SL (1b), Crafco 221 (1), and Techstar W-050 (5) developed their first corner break, while Crafco 444 (1), Delastic V-687 (5), and No Sealant (2) developed their second.

Spalling

The measured length of spalling failure in each section and the corresponding rank of each section for the westbound driving lane are listed in Table 5.24. Overall, the westbound lanes have 1.19 m (3.9 ft) of such failure, which is a decrease of 457 mm (18 in.) since the previous survey in June 2001. Most of the decrease in failure comes from the Dow 890-SL (4) section, which has a 330 mm (13 in.) decrease. This decrease is attributed to Joint 7. Recall that this joint is the result of a poor cut or an end of the day construction joint, which is so badly disfigured that it is difficult to measure. Four other sections have decreases as well and most of these are due to classification discrepancies. The discrepancy in the Dow 890-SL (1) section is due to measurement, although it is a decrease of just 25 mm (1 in.) from the previous survey.

Two sections have increases in spalling failure; both of these did not have any spalling recorded during the previous survey. Crafco 221 (1) and Crafco 903-SL (4) were observed with 102 mm (4 in.) and 51 mm (2 in.) of spalling, respectively. The failure in the former, however, appears to have been present before sealing because the sealant is present around it, as shown in Figure 5.48 (b).

5.4 Pavement Surface Profile

At approximately the same time period that the sealant and pavement evaluations are conducted, surface profilometer surveys are performed by Ohio Department of Transportation (ODOT) personnel. Data are collected in the driving and passing lanes in both directions by a profilometer van, which makes three passes in each lane. The data are later sent by ODOT to the University of Cincinnati research team for analysis. Included are three measures of pavement surface roughness calculated using a mathematical algorithm from relative surface elevation data collected using ODOT's K.J. Law Non-Contact Inertial Profilometer, Model 690DNC. These are the left wheel-track International Roughness Index (IRIlf), the right wheel-track International Roughness Index (IRIrt), and the average of both values of International Roughness Index (IRIbh). In addition to these indices, two supplementary sets of values are presented referred to as the Mays Number (MAYS) and the Present Serviceability Index (PSI). This terminology reflects the expectation that these mathematically determined measures somehow simulate the corresponding conventional indices, which should be established instead using a suspension response vehicle, or with reference to road user panel ratings that have been correlated through statistical regression to measured pavement distresses, respectively. Presented below is a detailed analysis of the profilometer data collected since Fall 2000. Hawkins (1999) and Sander (2002) have discussed similar information from four earlier profilometer evaluations.

5.4.1 Profile Trends in the Eastbound Lanes as of October 2000 (PEBOC00)

Table 5.25 shows a comparison of the profilometer values collected during the current (PEBOC00) evaluation, to those from the previous survey (PEBMR00), presented by Sander (2002). The values listed are percentage changes; negative values indicate a rougher surface than the previous survey and positive values represent a smoother surface. The signs in front of the PSI values have been switched so that an increase in smoothness or roughness is shown in the same manner as the other indices.

Table 5.25 (a) lists the percentage change for the passing lane, which exhibits a rougher surface in all the scales. The PSI and IRIrt scales have small percentage decreases in smoothness with 0.94 and 0.36%, respectively. IRIlf has the largest decrease; it measures 14.19%. The MAYS and IRIbh indices record 7.96 and 7.55% decreases, respectively.

The section containing Crafco 903-SL (4) has the largest decrease in smoothness; all but one of the indices exhibit their largest decrease. Percentage decreases range from 2.88% in the PSI to 26.91% in the IRIlf. The largest increase in smoothness is found between Stations 266+00 and 272+00, which contains Dow 890-SL (1). Three of the indices record their largest increase; values range from 0.51 to 10.55%.

The difference and the variability in the indices make it difficult to determine what exactly is happening to the pavement surface in terms of roughness. Some indices may be more sensitive to pavement curling than others, while others are more sensitive to surface texture or cracking. Temperature differences can affect the degree of curling. On the morning of October 10, 2000, the pavement temperature was 9.4° C (49° F). Later on the same day, the pavement temperature was recorded as high as 26.1° C (79° F). This would suggest that the degree of curling in the pavement would vary throughout the day and may influence the results of the profilometer readings.

The pavement surface is expected to get rougher with time (i.e. after several years). The time period between profilometer readings in this project is approximately 6 months, which may not be long enough to observe pavement deterioration; the change in the indices may only be showing the results of cyclic curling. An evaluation of the profilometer data over several years is needed to give an understanding of the condition of the pavement surface.

As of the October 2000 survey (PEBOC00), there have been four profilometer surveys in the eastbound passing lane. A survey in this lane was not conducted in Spring 1999 because it had been closed to traffic. Figure 5.49 presents the profilometer data as a trendline, which plots all five indices versus time. The indices are normalized so that the scale is more representative. For each survey, every index is divided by its respective original value (PEBJN98), because it is assumed that the initial condition of the pavement surface is at 100% of its smoothness potential. The roughness indices (MAYS, IRIrt, IRIlf, and IRIbh) were inverted to represent a downward trend for deterioration. A clearer understanding of the deterioration of the pavement surface can now be obtained. All indices, with the exception of IRIrt, show a general decline in pavement smoothness. The IRIrt continues to show readings above its original profilometer value. Three of the indices, MAYS, IRIlf, and IRIbh, seem to follow a similar trend, meaning if one index increases slightly in roughness so do the others. The IRIrt and PSI, however, do not follow the trend of the other indices. The former increases between June 1998 and December 1999 when the other indices decline, and after December 1999 it changes very little even though the other indices fluctuate somewhat. The latter, after decreasing initially like the three other indices, does not substantially change after December 1999. Given the wavy appearance of the profilometer trendlines, it is difficult to determine how much or at what rate the pavement surface is deteriorating.

Percentage changes for the driving lane are listed in Table 5.25 (b). The Mays Number, IRIlf, and IRIbh show small decreases in smoothness, while the PSI and IRIrt measure increases in smoothness. Observed percentage decreases for the MAYS, IRIlf, and IRIbh are 0.88, 5.25, and 1.07%, respectively. Percentage increases for the PSI and IRIrt indices are 0.61 and 3.05%, respectively.

The Techstar W-050 (5) section displays the largest decrease in smoothness as every index shows its largest decrease here. All of the roughness indices (MAYS, IRIlf, IRIrt, and IRIbh) record changes above 13%, the PSI records a change of only 1.96%. This section, along with Crafco 903-SL (3), has some of the largest decreases in smoothness in both of the eastbound lanes. The section sealed with Crafco 902 (1) shows the largest increase in smoothness. All indices but the IRIlf record their largest increase in this section. Values range from 2.90% in the PSI to 13.66% in the IRIrt.

As of the October 2000 survey, five profilometer surveys have been completed in the eastbound driving lane. The overall profilometer readings from each of these surveys are plotted versus time in Figure 5.50. The IRIrt index increases in smoothness initially, as it also does in the eastbound passing lane (Figure 5.49); all other indices show gradual smoothness decreases. After its initial rise, the IRIrt index follows the trend of the other indices until the survey in March 2000, after which it increases in smoothness again while most of the other indices decrease. Generally, the MAYS, PSI, IRIlf, and IRIbh follow the same trend as they do in the eastbound passing lane.

5.4.2 Profile Trends in the Eastbound Lanes as of June 2001 (PEBJN01)

Table 5.26 (a) lists the percentage change of the profilometer data taken in the eastbound passing lane from PEBOC00 to PEBJN01. Overall, the pavement surface here has gotten smoother, rather than rougher. The average over the entire test pavement ranges from 1.39 to 8.57% in the PSI and IRIrt scales, respectively. The section with the most deterioration is Dow 890-SL (1), which is located between Stations 266+00 and 272+00. Three of the five indices (MAYS, IRIrt, and IRIbh) produce their highest percentage change in this section, with values ranging from -0.96 to -6.93%. Recall, during the previous survey this section had the largest increase in smoothness. Although the pavement surface deteriorated more than any other section during this survey, the sealants in this section have the largest increase in effectiveness. This and other examples like it show the lack of correlation between sealant deterioration and pavement surface deterioration. The largest increase in smoothness is located in the Crafco 903-SL (4) section, which had the largest decrease during the previous survey. This section and Dow 890-SL (1) show the extreme fluctuations in the profilometer data.

Over a span of three years, five profilometer surveys have been collected in this lane. Figure 5.51 plots these results normalized to their original profilometer reading.

The roughness indices (MAYS, IRIrt, IRIlf, and IRIbh) are inverted so that a downward trend represents a deterioration of the pavement surface. Over the time span of the entire project, most of the indices show a somewhat downward trend in smoothness. Only the IRIrt scale remains above its original value, which was recorded in June 1998. This scale only decreased in smoothness two times, both of which accounted for less than 0.5% of the previously recorded value. The IRIrt index is currently 25% above its original value. The other four indices are following a wavy pattern, which means that they decrease in smoothness but then increase after the next survey and so on. After a large initial decrease, they continue to remain below their original profilometer reading. The MAYS and IRIlf, which have respective values of 70 and 64% currently, are considerably lower than the other indices. The PSI and IRIbh are just slightly down from their original reading with values of 92 and 90%, respectively.

Table 5.26 (b) compares the current profilometer readings to those from the previous survey for the eastbound driving lane. Dow 890-SL (1), which is between Stations 266+00 and 272+00, exhibits the largest degree of deterioration. Four of the five indices (MAYS, IRIlf, IRIrt, and IRIbh) show their largest percentage decrease in this section. The decreases for all indices in this section range from 4.34% in the PSI scale to 19.42% in the MAYS scale. Recall that the Dow 890-SL (1) sections in the passing lane also has the largest decrease in smoothness.

The section with the largest increase in smoothness is Crafco 903-SL (4), which is between Stations 206+00 and 213+00. All five scales show their largest increase in smoothness in this section, ranging from 2.07% in the PSI to 16.83% in the MAYS scale.

This section also has the largest increase in the passing lane.

Figure 5.52 shows the long-term performance of the pavement surface. The eastbound driving lane has more profilometer surveys than any other lane; a total of six have been conducted. Because of the larger number of profilometer runs, it is easier to get a feel of its long-term performance. All of the indices are currently below their original profilometer readings, but exhibit large increases between the December 1999 and March 2000 surveys, which are only three months apart. The MAYS and PSI scales continue to increase after the March 2000 survey but show a decrease in the current survey (June 2001). The remaining International Roughness Indices (IRIlf, IRIrt, and IRIbh) decline after the March 2000 survey and continue to do so.

5.4.3 Profile Trends in the Eastbound Lanes as of October 2001 (PEBOC01)

Table 5.27 (a) lists the percentage change of the profilometer data taken in the eastbound passing lane from PEBJN01 to PEBOC01. The average profile of the entire passing lane in all five indices has increased in smoothness since the previous survey. Values range from 0.25% in the PSI, to 2.77% in the IRIrt. The Dow 890-SL (1) section exhibits the largest decrease in smoothness, as it did in the previous survey. All five indices measure their largest decrease in this section. Values are very similar in all indices except for the PSI; these values range from -4.48 to -4.96%, whereas the PSI is -1.84%. The Crafco 903-SL (4) section exhibits the largest increase in smoothness in all but one of the indices (IRIlf). This section had the largest increase during the previous survey as well. Although the surface in this section shows the largest improvement, the sealant has the largest decrease in effectiveness (44%).

The current profilometer survey is the sixth in the eastbound passing lane. The averages of all five indices for all six surveys are plotted in Figure 5.53. For the second straight survey, all five indices show an increase in smoothness. Four of these, however, remain below their original reading. Only IRIrt is above its original value; it has increased in smoothness more times than it has decreased and is currently at 128%. The PSI and IRIbh are both at 92% of their original readings, MAYS and IRIlf are at 71 and 64%, respectively.

Table 5.27 (b) compares the current profilometer readings to those from the previous survey for the eastbound driving lane. Crafco 903-SL (4) has the largest decrease in smoothness for this lane. Recall that the same section in the passing lane also has the largest increase in smoothness. It is peculiar that two identical adjacent sections can behave so differently. The data were collected on the same day for both traffic lanes so curling and warping effects would be nearly identical. It is unclear at this point why there is such a discrepancy. The Crafco 444 (1) section exhibits the largest increase in smoothness for the driving lane. Four of the indices (MAYS, PSI, IRIrt, and IRIbh) show their maximum values in this section. Values range from 3.27 to 9.29% in the PSI and MAYS, respectively.

Figure 5.54 shows the long-term performance of the pavement surface by plotting the results of the past seven surveys, which is more than the other three lanes. Since PEBOC00, the profilometer values for all indices have remained relatively stable. All indices except for IRIrt are below their original readings. The IRIrt scale has risen to

102% in the current survey and is the only index to exhibit an increase in smoothness.

5.4.4 Profile Trends in the Westbound Lanes as of October 2000 (PWBOC00)

The percentage changes for the westbound lanes from the previous survey to PWBOC00 are presented in Table 5.28. The passing lane in the westbound direction generally exhibits a decrease in smoothness from the previous survey, as seen in Table 5.28 (a). All but the PSI scale record a decrease in smoothness; the IRIlf scale records the highest change (11.08%). The other two IRI scales, IRIrt and IRIbh, record decreases of 2.65 and 6.73%, respectively. The PSI scale exhibits only a slight increase in smoothness (0.14%), while the MAYS measures a 6.91% decrease.

The unsealed section between Stations 284+00 and 290+00 has the largest decrease in smoothness. Three of the five scales, PSI, IRIlf, and IRIbh, measure their highest percentage decrease in this section. These three have decreases in smoothness of 2.75, 36.04, and 19.89%, respectively. The MAYS and IRIrt record decreases of 5.42 and 4.49%, respectively.

The section with the largest increase in smoothness contains the self-leveling sealant Crafco 903-SL (1a). The Mays Number, IRIlf, and IRIbh record their highest smoothness increases in this section. Values range from 2.13% in the PSI to 13.05% in the IRIrt.

Figure 5.55 is a plot of the results of the three profilometer surveys versus time. Very little can be ascertained because of the relatively short time span it covers. All of the indices increase in smoothness after the second survey and then decrease after the third. Only the IRIrt drops below its initial value.

The percentage change for the westbound driving lane is shown in Table 5.28 (b). This lane has significantly more surface deterioration since the previous survey than the other lanes in both directions. All profilometer measurements average decreases in smoothness. The highest of these is IRIlf, which has a 21.59% decrease, the MAYS and IRIbh follow with decreases of 15.30 and 14.25%, respectively, and the IRIrt and PSI exhibit smoothness decreases of 7.50 and 1.46%, respectively.

As in the passing lane, the unsealed section between Stations 284+00 and 290+00 experienced the highest degree of surface deterioration. All indices but the IRIlf record their largest value here. The MAYS and IRI scales have decreases over 30%, while the PSI has only a 6.81% decrease.

The section containing Crafco 903-SL (1a) has the highest increase in smoothness. All of the indices, with the exception of IRIlf, show increases. The highest value is found in the IRIrt scale, which measures an 8.96% increase in smoothness. The MAYS, PSI, and IRIbh report increases of 1.40, 2.73, and 2.75%, respectively. The IRIlf exhibits a 3.87% decrease in smoothness.

The trendlines for the four profilometer surveys to date are presented in Figure 5.56. All measurements, except for the PSI scale, follow the same pattern and are remarkably close to each other. The PSI scale, however, does not fluctuate very much. All sections decline in smoothness after March 1999, increase after December 1999, and then decline again after March 2000. The PSI is currently at 98% of its original value and the remaining indices range from 79% to 85%.

5.4.5 Profile Trends in the Westbound Lanes as of June 2001 (PWBJN01)

Table 5.29 (a) lists the percentage changes found in the previous two surveys for the westbound passing lane. Most of the sections exhibit increases in smoothness, only a few show decreases. The averages for the entire test pavement show increases in smoothness for all indices. The Delastic V-687 (5) section located between Stations 219+00 and 225+00 shows slightly more deterioration than the other sections, as measured by the MAYS and IRIlf scales. The percentage changes are -0.88 and -7.76, respectively. Recall that this section has one of the best performing sealants. The section with the largest increase in smoothness is more pronounced. Four of the five indices (MAYS, PSI, IRIrt, and IRIbh) record their largest percentage change in the Techstar W-050 (5) section. Values range from 6.28 to 29.32% in the PSI and MAYS indices, respectively. This section saw the largest decrease in sealant effectiveness over the past two surveys, yet the pavement surface shows the largest increase in smoothness.

The westbound passing lane has the fewest number of profilometer surveys conducted on it due to various construction related reasons (Hawkins, 1999). It is difficult to evaluate the long-term performance of this lane because only 1.5 years have passed since its original survey. Figure 5.57 shows the results of the four surveys conducted to date.

After the current survey, all of the indices are above the their original values.

This may be misleading because the original survey, conducted in December 1999, produced very low smoothness values. All four lanes recorded their smoothest values during the December 1999 survey. Because all surveys are normalized to the initial survey, which in this case is very low, it makes subsequent surveys appear to be high. There is very little variation between the MAYS and IRIbh scales, as well as between the PSI and IRIrt scales. Since the original survey, the difference between the MAYS and IRIbh scales is never more than 1%, and 4% for the PSI and IRIrt scales.

Table 5.29 (b) lists the percentage changes for the driving lane. As in the passing lane, the driving lane shows mostly increases in smoothness. Only three sections exhibit some decrease in smoothness in any of the indices: Dow 890-SL (3), Crafco 221 (1) and Watson Bowman 812 (5). The latter section, located between Stations 225+00 and 231+00, exhibits the largest degree of deterioration. Three indices (MAYS, PSI, and IRIlf) record small decreases of 0.35, 0.91, and 0.64%, respectively.

By far the largest increase in smoothness is found in the Techstar W-050 (5) section. All five indices record their largest smoothness increases in this section. The percentages calculated in this section are more than twice the overall averages of the entire project length. Increases in this section range from 6.24 to 31.18% and averages for the entire pavement range from 1.88 to 15.03%.

The results of the past five profilometer surveys are presented in Figure 5.58. The wavy nature of these surveys is very apparent. Each large decline in smoothness is followed by a nearly equal increase in smoothness. The PSI scale increases and decreases as well, although not to the degree of the other scales. It is uncertain if these fluctuations are attributable to seasonal temperature changes. Pavement temperatures can vary widely during a day. Recall that during the WBOC00 survey, pavement temperatures ranged from 1.1 to 21.7º C (34 to 71º F).

5.4.6 Profile Trends in the Westbound Lanes as of October 2001 (PWBOC01)

Table 5.30 (a) lists the percentage changes in the westbound passing lane from the previous survey. Generally, this lane has decreased slightly in surface smoothness. Four of the five indices suggest a decline, while the IRIrt shows an increase. Values range from -2.64 in the MAYS to 1.03 in the IRIrt. The section with the largest decrease in smoothness is Techstar W-050 (5). Three indices (MAYS, IRIrt, and IRIbh) show their largest decrease in this section; values range from -2.06 (PSI) to -16.20% (MAYS). The Crafco 903-SL (1a) section has the largest increase in smoothness; all indices except for the IRIlf scale measure their largest gain. Increases range from 0.84 to 6.73% in the IRIlf and IRIrt, respectively.

The five profilometer surveys to date are shown in Figure 5.59. All five indices remain above their original value and all but one declined during this current survey, which follows the up-and-down pattern that has been observed to date.

Table 5.30 (b) lists the percentage changes for the driving lane. This lane has decreased in smoothness much more than the other three lanes. Values range from -2.22% in the PSI to -14.06% in the IRIlf. The largest decrease in smoothness is found in the Techstar W-050 (5) section. During the previous survey, this section exhibited the largest increase in smoothness, which would suggest that cyclic curling and warping conditions existed in the pavement slab. The indices range in value from -3.28 (PSI) to -27.75% (IRIlf). Dow 890-SL (3) exhibits the largest increase in smoothness; all five indices record their highest gain in this section. Values range from 0.72 to 6.46% in the PSI and IRIrt, respectively.

The results of the past six profilometer surveys are shown in Figure 5.60. As in the passing lane, the wavy nature of the surveys are apparent but to a larger degree. All five indices decreased in smoothness during this survey, yet during the previous survey all five increased. This pattern is repeated throughout the life of the pavement, which would suggest cyclic warping and curling effects as postulated for the passing lane.

Table 5.1 Effectiveness rankings for eastbound lane treatments during the EBOC00 survey

Sealant Type	Description	% Eff in EBMR00	% Eff Rank	% Eff in EBOC00	% Eff Rank	% Deterioration	Rank of % Deterioration
Silicone	Crafco 903-SL (1)	51.9 (P)	7	48.1 (VP)	6	3.8	8
	Crafco 903-SL (4)	24.2 (VP)	12	6.7 (VP)	12	17.5	2
	Dow 890-SL (3)	67.5 (F)	5	55.8 (P)	5	11.7	3
	Dow 890-SL (4)	55.0 (P)	6	12.5 (VP)	11	42.5	1
	Dow 890-SL (1)	67.8 (F)	4	63.6 (P)	4	4.2	7
	Crafco 902 (1)	40.8 (VP)	10	37.2 (VP)	9	3.6	9
	Dow 888 (1a)	50.0 (P)	8	40.6 (VP)	8	9.4	4
	Dow 888 (1b)	48.9 (VP)	9	41.1 (VP)	7	7.8	5
Hot-Applied	Crafco 221 (1)	71.9 (F)	3	70.6 (F)	3	1.3	11
	Crafco 444 (1)	9.7 (VP)	13	6.1 (VP)	13	3.6	9
Compression	Delastic V-687 (5)	95.3 (VG)	1	97.2 (VG)	2	-1.9	12
	Watson Bowman 687 (5)	95.3 (VG)	1	97.8 (VG)	1	-2.5	13
	Techstar W-050 (5)	32.8 (VP)	11	26.9 (VP)	10	5.9	6

Rating	**Overall Effectiveness Level, %**
Very Good (VG)	90 to 100
Good (G)	80.0 to 89.9
Fair (F)	65.0 to 79.9
Poor (P)	50.0 to 64.9
Very Poor (VP)	0 to 49.9

Table 5.2 Effectiveness rankings for eastbound lane treatments during the EBJN01 survey

Sealant Type	Description	% Eff in EBOC00	% Eff Rank	% Eff in EBJN01	% Eff Rank	% Deterioration	Rank of % Deterioration
Silicone	Crafco 903-SL (1)	48.1 (VP)	6	62.8 (P)	6	-14.7	8
	Crafco 903-SL (4)	6.7 (VP)	12	56.1 (P)	9	-49.4	12
	Dow 890-SL (3)	55.8 (P)	5	62.2 (P)	7	-6.4	7
	Dow 890-SL (4)	12.5 (VP)	11	65.0 (F)	5	-52.5	13
	Dow 890-SL (1)	63.6 (P)	4	79.7 (F)	3	-16.1	10
	Crafco 902 (1)	37.2 (VP)	9	35.8 (VP)	11	1.4	4
	Dow 888 (1a)	40.6 (VP)	8	56.1 (P)	9	-15.5	9
	Dow 888 (1b)	41.1 (VP)	7	60.8 (P)	8	-19.7	11
Hot-Applied	Crafco 221 (1)	70.6 (F)	3	75.3 (F)	4	-4.7	5
	Crafco 444 (1)	6.1 (VP)	13	11.1 (VP)	13	-5.0	6
Compression	Delastic V-687 (5)	97.2 (VG)	2	94.2 (VG)	2	3.0	2
	Watson Bowman 687 (5)	97.8 (VG)	1	95.0 (VG)	1	2.8	3
	Techstar W-050 (5)	26.9 (VP)	10	21.9 (VP)	12	5.0	1

Rating	**Overall Effectiveness Level, %**
Very Good (VG)	90 to 100
Good (G)	80.0 to 89.9
Fair (F)	65.0 to 79.9
Poor (P)	50.0 to 64.9
Very Poor (VP)	0 to 49.9

Table 5.3 Effectiveness rankings for eastbound lane treatments during the EBOC01 survey

Sealant Type	Description	% Eff in EBJN01	% Eff Rank	% Eff in EBOC01	% Eff Rank	% Deterioration	Rank of % Deterioration
Silicone	Crafco 903-SL (1)	62.8 (P)	6	57.8 (P)	5	5.0	7
	Crafco 903-SL (4)	56.1 (P)	9	11.9 (VP)	12	44.2	1
	Dow 890-SL (3)	62.2 (P)	7	56.9 (P)	6	5.3	6
	Dow 890-SL (4)	65.0 (F)	5	42.5 (VP)	9	22.5	2
	Dow 890-SL (1)	79.7 (F)	3	70.8 (F)	4	8.9	5
	Crafco 902 (1)	35.8 (VP)	11	31.1 (VP)	10	4.7	8
	Dow 888 (1a)	56.1 (P)	9	46.7 (VP)	8	9.4	4
	Dow 888 (1b)	60.8 (P)	8	48.9 (VP)	7	11.9	3
Hot-Applied	Crafco 221 (1)	75.3 (F)	4	79.2 (F)	3	-3.9	13
	Crafco 444 (1)	11.1 (VP)	13	9.4 (VP)	13	1.7	10
Compression	Delastic V-687 (5)	94.2 (VG)	2	94.4 (VG)	1	-0.2	12
	Watson Bowman 687 (5)	95.0 (VG)	1	94.4 (VG)	1	0.6	11
	Techstar W-050 (5)	21.9 (VP)	12	18.6 (VP)	11	3.3	9

Rating	**Overall Effectiveness Level, %**
Very Good (VG)	90 to 100
Good (G)	80.0 to 89.9
Fair (F)	65.0 to 79.9
Poor (P)	50.0 to 64.9
Very Poor (VP)	0 to 49.9

Table 5.4 Effectiveness rankings for westbound lane treatments after the WBOC00 survey

Sealant Type	Description	% Eff in WBMR00	% Eff Rank	% Eff in WBOC00	% Eff Rank	% Deterioration	Rank of % Deterioration
Silicone	Crafco 903-SL (1a)	95.0 (VG)	7	97.8 (VG)	5	-2.8	11
	Crafco 903-SL (1b)	76.7(F)	11	78.9 (F)	10	-2.2	9
	Crafco 903-SL (4)	88.6 (G)	9	90.8 (VG)	9	-2.2	9
	Dow 890-SL (3)	99.4 (VG)	2	99.7 (VG)	2	-0.3	6
	Dow 890-SL (1)	98.1 (VG)	4	97.2 (VG)	6	0.9	5
	Dow 890-SL (4)	86.1 (G)	10	56.7 (P)	11	29.4	2
	Dow 888 (1a)	99.2 (VG)	3	96.4 (VG)	7	2.8	4
	Dow 888 (1b)	97.8 (VG)	5	98.3 (VG)	4	-0.5	8
Hot-Applied	Crafco 221 (1)	49.7 (VP)	13	46.1 (VP)	12	3.6	3
	Crafco 444 (1)	89.2 (G)	8	96.1 (VG)	8	-6.9	13
Compression	Delastic V-687 (5)	95.6 (VG)	6	98.6 (VG)	3	-3.0	12
	Watson Bowman 812 (5)	99.7 (VG)	1	100.0 (VG)	1	-0.3	6
	Techstar W-050 (5)	69.7 (F)	12	26.7 (VP)	13	43.0	1

Rating	**Overall Effectiveness Level, %**
Very Good (VG)	90 to 100
Good (G)	80.0 to 89.9
Fair (F)	65.0 to 79.9
Poor (P)	50.0 to 64.9
Very Poor (VP)	0 to 49.9

Table 5.5 Effectiveness rankings for westbound lane treatments during the WBJN01 survey

Sealant Type	Description	% Eff in WBOC00	% Eff Rank	% Eff in WBJN01	% Eff Rank	% Deterioration	Rank of % Deterioration
Silicone	Crafco 903-SL (1a)	97.8 (VG)	5	96.1 (VG)	8	1.7	3
	Crafco 903-SL (1b)	78.9 (F)	10	78.6 (F)	11	0.3	5
	Crafco 903-SL (4)	90.8 (VG)	9	95.8 (VG)	9	-5.0	11
	Dow 890-SL (3)	99.7 (VG)	2	97.8 (VG)	6	1.9	2
	Dow 890-SL (1)	97.2 (VG)	6	96.7 (VG)	7	0.6	4
	Dow 890-SL (4)	56.7 (P)	11	79.2 (F)	10	-22.5	13
	Dow 888 (1a)	96.4 (VG)	7	99.7 (VG)	1	-3.3	10
	Dow 888 (1b)	98.3 (VG)	4	98.1 (VG)	4	0.2	7
Hot-Applied	Crafco 221 (1)	46.1 (VP)	12	57.8 (P)	12	-11.7	12
	Crafco 444 (1)	96.1 (VG)	8	98.1 (VG)	4	-1.9	9
Compression	Delastic V-687 (5)	98.6 (VG)	3	99.7 (VG)	2	-1.1	8
	Watson Bowman 812 (5)	100.0 (VG)	1	99.7 (VG)	2	0.3	5
	Techstar W-050 (5)	26.7 (VP)	13	14.2 (VP)	13	12.5	1

Rating	**Overall Effectiveness Level, %**
Very Good (VG)	90 to 100
Good (G)	80.0 to 89.9
Fair (F)	65.0 to 79.9
Poor (P)	50.0 to 64.9
Very Poor (VP)	0 to 49.9

Table 5.6 Effectiveness rankings for westbound lane treatments during the WBOC01 survey

Sealant Type	Description	% Eff in WBJN01	% Eff Rank	% Eff in WBOC01	% Eff Rank	% Deterioration	Rank of % Deterioration
Silicone	Crafco 903-SL (1a)	96.1 (VG)	8	95.8 (VG)	6	0.3	10
	Crafco 903-SL (1b)	78.6 (F)	11	72.2 (F)	10	6.4	6
	Crafco 903-SL (4)	95.8 (VG)	9	84.7 (G)	9	11.1	3
	Dow 890-SL (3)	97.8 (VG)	6	99.4 (VG)	1	-1.6	13
	Dow 890-SL (1)	96.7 (VG)	7	96.7 (VG)	5	0.0	12
	Dow 890-SL (4)	79.2 (F)	10	43.9 (VP)	11	35.3	1
	Dow 888 (1a)	99.7 (VG)	1	90.8 (VG)	8	8.9	5
	Dow 888 (1b)	98.1 (VG)	4	97.8 (VG)	3	0.3	10
Hot-Applied	Crafco 221 (1)	57.8 (P)	12	42.8 (VP)	12	15.0	2
	Crafco 444 (1)	98.1 (VG)	4	92.5 (VG)	7	5.6	7
Compression	Delastic V-687 (5)	99.7 (VG)	2	97.2 (VG)	4	2.5	8
	Watson Bowman 812 (5)	99.7 (VG)	2	97.8 (VG)	2	1.9	9
	Techstar W-050 (5)	14.2 (VP)	13	4.4 (VP)	13	9.8	4

Rating	**Overall Effectiveness Level, %**
Very Good (VG)	90 to 100
Good (G)	80.0 to 89.9
Fair (F)	65.0 to 79.9
Poor (P)	50.0 to 64.9
Very Poor (VP)	0 to 49.9

Table 5.7 EBOC00 survey of transverse cracks in the eastbound lanes

Sealant Material (Joint Configuration)	No. of Slabs	Stations	Transverse Cracks	% Slabs Cracked	Rank
Crafco 903-SL (1)	28	188+00 - 194+00	2	7.1	13
Crafco 903-SL (4)	32	206+00 - 213+00	2	6.3	15
Dow 890-SL (3)	28	166+00 - 172+00	2	7.1	13
Dow 890-SL (4)	28	213+00 - 219+00	8	28.6	7
Dow 890-SL (1)	27	266+00 - 272+00	8	29.6	6
Crafco 902 (1)	28	200+00 - 206+00	9	32.1	4
Dow 888 (1a)	56	272+00 - 284+00	27	48.2	1
Dow 888 (1b)	28	284+00 - 290+00	7	25.0	9
Crafco 221 (1)	28	260+00 - 266+00	9	32.1	4
Crafco 444 (1)	75	172+00 - 188+00	7	9.3	12
Delastic V-687 (5)	28	225+00 - 231+00	3	10.7	11
Watson Bowman 687 (5)	26	194+00 - 200+00	9	34.6	3
Techstar W-050 (5)	28	154+00 - 160+00	6	21.4	10
No Sealant (2)	27	219+00 - 225+00	13	48.1	2
No Sealant (6)	28	160+00 - 166+00	8	28.6	7

Table 5.8 EBOC00 survey of corner breaks in the eastbound lanes

Sealant Material (Joint Configuration)	No. of Slabs	Stations	Corner Breaks	% Slabs Cracked	Rank
Crafco 903-SL (1)	28	188+00 - 194+00	0	0.0	3
Crafco 903-SL (4)	32	206+00 - 213+00	0	0.0	3
Dow 890-SL (3)	28	166+00 - 172+00	0	0.0	3
Dow 890-SL (4)	28	213+00 - 219+00	0	0.0	3
Dow 890-SL (1)	27	266+00 - 272+00	0	0.0	3
Crafco 902 (1)	28	200+00 - 206+00	0	0.0	3
Dow 888 (1a)	56	272+00 - 284+00	0	0.0	3
Dow 888 (1b)	28	284+00 - 290+00	0	0.0	3
Crafco 221 (1)	28	260+00 - 266+00	0	0.0	3
Crafco 444 (1)	75	172+00 - 188+00	0	0.0	3
Delastic V-687 (5)	28	225+00 - 231+00	0	0.0	3
Watson Bowman 687 (5)	26	194+00 - 200+00	0	0.0	3
Techstar W-050 (5)	28	154+00 - 160+00	2	7.1	2
No Sealant (2)	27	219+00 - 225+00	6	22.2	1
No Sealant (6)	28	160+00 - 166+00	0	0.0	3

Table 5.9 EBOC00 survey of observed spalling in the eastbound lanes

	Sealant	Stations	Fall '00 (ft)	Fall '00 Rank	Increase (ft)	Increase Rank
Silicone	Crafco 903-SL (1)	188+00 - 194+00	0.2	4	0.2	1
	Crafco 903-SL (4)	206+00 - 213+00	0	7	-0.7	15
	Dow 890-SL (3)	166+00 - 172+00	0.5	2	-0.3	11
	Dow 890-SL (4)	213+00 - 219+00	0	7	0	2
	Dow 890-SL (1)	266+00 - 272+00	0	7	0	2
	Crafco 902 (1)	200+00 - 206+00	0	7	0	2
	Dow 888 (1a)	272+00 - 284+00	0	7	0	2
	Dow 888 (1b)	284+00 - 290+00	0	7	0	2
Hot-Applied	Crafco 221 (1)	260+00 - 266+00	4.1	1	-0.5	14
	Crafco 444 (1)	172+00 - 188+00	0.2	4	-0.1	8
Compression	Delastic V-687 (5)	225+00 - 231+00	0	7	-0.3	10
	Watson Bowman 687 (5)	194+00 - 200+00	0	7	-0.4	13
	Techstar W-050 (5)	154+00 - 160+00	0	7	0	2
Unsealed	No Sealant (2)	219+00 - 225+00	0.1	6	-0.1	9
	No Sealant (6)	160+00 - 166+00	0.3	3	-0.4	12
		Σ	5.4	-	-2.6	-

Table 5.10 (a) EBJN01 survey of transverse cracks in the eastbound lanes

Sealant Material (Joint Configuration)	No. of Slabs	Stations	Transverse Cracks	% Slabs Cracked	Rank
Crafco 903-SL (1)	28	188+00 - 194+00	4	14.3	13
Crafco 903-SL (4)	32	206+00 - 213+00	7	21.9	12
Dow 890-SL (3)	28	166+00 - 172+00	4	14.3	13
Dow 890-SL (4)	28	213+00 - 219+00	11	39.3	7
Dow 890-SL (1)	27	266+00 - 272+00	15	55.6	3
Crafco 902 (1)	28	200+00 - 206+00	14	50.0	5
Dow 888 (1a)	56	272+00 - 284+00	34	60.7	2
Dow 888 (1b)	28	284+00 - 290+00	11	39.3	7
Crafco 221 (1)	28	260+00 - 266+00	10	35.7	9
Crafco 444 (1)	75	172+00 - 188+00	10	13.3	15
Delastic V-687 (5)	28	225+00 - 231+00	10	35.7	9
Watson Bowman 687 (5)	26	194+00 - 200+00	9	34.6	11
Techstar W-050 (5)	28	154+00 - 160+00	14	50.0	5
No Sealant (2)	27	219+00 - 225+00	18	66.7	1
No Sealant (6)	28	160+00 - 166+00	15	53.6	4

Table 5.10 (b) Increase in transverse cracks since previous survey

Sealant Material (Joint Configuration)	No. of Slabs	Stations	Transverse Cracks Inc.	% Slabs Cracked Inc.	Rank
Crafco 903-SL (1)	28	188+00 - 194+00	2	7.1	11
Crafco 903-SL (4)	32	206+00 - 213+00	5	15.6	7
Dow 890-SL (3)	28	166+00 - 172+00	2	7.1	11
Dow 890-SL (4)	28	213+00 - 219+00	3	10.7	10
Dow 890-SL (1)	27	266+00 - 272+00	7	25.9	2
Crafco 902 (1)	28	200+00 - 206+00	5	17.9	6
Dow 888 (1a)	56	272+00 - 284+00	7	12.5	9
Dow 888 (1b)	28	284+00 - 290+00	4	14.3	8
Crafco 221 (1)	28	260+00 - 266+00	1	3.6	14
Crafco 444 (1)	75	172+00 - 188+00	3	4.0	13
Delastic V-687 (5)	28	225+00 - 231+00	7	25.0	3
Watson Bowman 687 (5)	26	194+00 - 200+00	0	0.0	15
Techstar W-050 (5)	28	154+00 - 160+00	8	28.6	1
No Sealant (2)	27	219+00 - 225+00	5	18.5	5
No Sealant (6)	28	160+00 - 166+00	7	25.0	3

Table 5.11 (a) EBJN01 survey of corner breaks in the eastbound lanes

Sealant Material (Joint Configuration)	No. of Slabs	Stations	Corner Breaks	% Slabs Cracked	Rank
Crafco 903-SL (1)	28	188+00 - 194+00	0	0.0	4
Crafco 903-SL (4)	32	206+00 - 213+00	0	0.0	4
Dow 890-SL (3)	28	166+00 - 172+00	0	0.0	4
Dow 890-SL (4)	28	213+00 - 219+00	0	0.0	4
Dow 890-SL (1)	27	266+00 - 272+00	0	0.0	4
Crafco 902 (1)	28	200+00 - 206+00	1	3.6	3
Dow 888 (1a)	56	272+00 - 284+00	0	0.0	4
Dow 888 (1b)	28	284+00 - 290+00	0	0.0	4
Crafco 221 (1)	28	260+00 - 266+00	0	0.0	4
Crafco 444 (1)	75	172+00 - 188+00	0	0.0	4
Delastic V-687 (5)	28	225+00 - 231+00	0	0.0	4
Watson Bowman 687 (5)	26	194+00 - 200+00	0	0.0	4
Techstar W-050 (5)	28	154+00 - 160+00	2	7.1	2
No Sealant (2)	27	219+00 - 225+00	2	7.4	1
No Sealant (6)	28	160+00 - 166+00	0	0.0	4

Table 5.11 (b) Increase in corner breaks since previous survey

Sealant Material (Joint Configuration)	No. of Slabs	Stations	Corner Breaks Inc.	% Slabs Cracked Inc.	Rank
Crafco 903-SL (1)	28	188+00 - 194+00	0.0	0.0	2
Crafco 903-SL (4)	32	206+00 - 213+00	0.0	0.0	2
Dow 890-SL (3)	28	166+00 - 172+00	0.0	0.0	2
Dow 890-SL (4)	28	213+00 - 219+00	0.0	0.0	2
Dow 890-SL (1)	27	266+00 - 272+00	0.0	0.0	2
Crafco 902 (1)	28	200+00 - 206+00	1.0	3.6	1
Dow 888 (1a)	56	272+00 - 284+00	0.0	0.0	2
Dow 888 (1b)	28	284+00 - 290+00	0.0	0.0	2
Crafco 221 (1)	28	260+00 - 266+00	0.0	0.0	2
Crafco 444 (1)	75	172+00 - 188+00	0.0	0.0	2
Delastic V-687 (5)	28	225+00 - 231+00	0.0	0.0	2
Watson Bowman 687 (5)	26	194+00 - 200+00	0.0	0.0	2
Techstar W-050 (5)	28	154+00 - 160+00	0.0	0.0	2
No Sealant (2)	27	219+00 - 225+00	-4.0	-14.8	15
No Sealant (6)	28	160+00 - 166+00	0.0	0.0	2

Table 5.12 EBJN01 survey of observed spalling in the eastbound lanes

	Sealant	Stations	Spring '01 (ft)	Spring '01 Rank	Increase (ft)	Increase Rank
Silicone	Crafco 903-SL (1)	188+00 - 194+00	0.3	4	0.1	8
	Crafco 903-SL (4)	206+00 - 213+00	0.5	2	0.5	1
	Dow 890-SL (3)	166+00 - 172+00	0	11	-0.5	14
	Dow 890-SL (4)	213+00 - 219+00	0.2	7	0.2	3
	Dow 890-SL (1)	266+00 - 272+00	0	11	0	10
	Crafco 902 (1)	200+00 - 206+00	0	11	0	10
	Dow 888 (1a)	272+00 - 284+00	0.1	10	0.1	6
	Dow 888 (1b)	284+00 - 290+00	0	11	0	10
Hot-Applied	Crafco 221 (1)	260+00 - 266+00	3.3	1	-0.8	15
	Crafco 444 (1)	172+00 - 188+00	0.3	4	0.1	8
Compression	Delastic V-687 (5)	225+00 - 231+00	0.3	4	0.3	2
	Watson Bowman 687 (5)	194+00 - 200+00	0.2	7	0.2	3
	Techstar W-050 (5)	154+00 - 160+00	0	11	0	10
Unsealed	No Sealant (2)	219+00 - 225+00	0.2	7	0.1	6
	No Sealant (6)	160+00 - 166+00	0.4	3	0.1	5
		Σ	5.8	-	0.4	-

Table 5.13 (a) EBOC01 survey of transverse cracks in the eastbound lanes

Sealant Material (Joint Configuration)	No. of Slabs	Stations	Transverse Cracks	% Slabs Cracked	Rank
Crafco 903-SL (1)	28	188+00 - 194+00	4	14.3	14
Crafco 903-SL (4)	32	206+00 - 213+00	5	15.6	12
Dow 890-SL (3)	28	166+00 - 172+00	3	10.7	15
Dow 890-SL (4)	28	213+00 - 219+00	11	39.3	8
Dow 890-SL (1)	27	266+00 - 272+00	18	66.7	1
Crafco 902 (1)	28	200+00 - 206+00	11	39.3	8
Dow 888 (1a)	56	272+00 - 284+00	35	62.5	3
Dow 888 (1b)	28	284+00 - 290+00	10	35.7	11
Crafco 221 (1)	28	260+00 - 266+00	11	39.3	8
Crafco 444 (1)	75	172+00 - 188+00	11	14.7	13
Delastic V-687 (5)	28	225+00 - 231+00	12	42.9	7
Watson Bowman 687 (5)	26	194+00 - 200+00	13	50.0	5
Techstar W-050 (5)	28	154+00 - 160+00	14	50.0	5
No Sealant (2)	27	219+00 - 225+00	18	66.7	1
No Sealant (6)	28	160+00 - 166+00	15	53.6	4

Table 5.13 (b) Increase in transverse cracks since previous survey

Sealant Material (Joint Configuration)	No. of Slabs	Stations	Transverse Cracks Inc.	% Slabs Cracked Inc.	Rank
Crafco 903-SL (1)	28	188+00 - 194+00	0	0.0	7
Crafco 903-SL (4)	32	206+00 - 213+00	-2	-6.3	14
Dow 890-SL (3)	28	166+00 - 172+00	-1	-3.6	13
Dow 890-SL (4)	28	213+00 - 219+00	0	0.0	7
Dow 890-SL (1)	27	266+00 - 272+00	3	11.1	2
Crafco 902 (1)	28	200+00 - 206+00	-3	-10.7	15
Dow 888 (1a)	56	272+00 - 284+00	1	1.8	5
Dow 888 (1b)	28	284+00 - 290+00	-1	-3.6	12
Crafco 221 (1)	28	260+00 - 266+00	1	3.6	4
Crafco 444 (1)	75	172+00 - 188+00	1	1.3	6
Delastic V-687 (5)	28	225+00 - 231+00	2	7.1	3
Watson Bowman 687 (5)	26	194+00 - 200+00	4	15.4	1
Techstar W-050 (5)	28	154+00 - 160+00	0	0.0	7
No Sealant (2)	27	219+00 - 225+00	0	0.0	7
No Sealant (6)	28	160+00 - 166+00	0	0.0	7

Table 5.14 (a) EBOC01 survey of corner breaks in the eastbound lanes

Sealant Material (Joint Configuration)	No. of Slabs	Stations	Corner Breaks	% Slabs Cracked	Rank
Crafco 903-SL (1)	28	188+00 - 194+00	0	0.0	4.0
Crafco 903-SL (4)	32	206+00 - 213+00	0	0.0	4.0
Dow 890-SL (3)	28	166+00 - 172+00	0	0.0	4.0
Dow 890-SL (4)	28	213+00 - 219+00	0	0.0	4.0
Dow 890-SL (1)	27	266+00 - 272+00	0	0.0	4.0
Crafco 902 (1)	28	200+00 - 206+00	1	3.6	3.0
Dow 888 (1a)	56	272+00 - 284+00	0	0.0	4.0
Dow 888 (1b)	28	284+00 - 290+00	0	0.0	4.0
Crafco 221 (1)	28	260+00 - 266+00	0	0.0	4.0
Crafco 444 (1)	75	172+00 - 188+00	0	0.0	4.0
Delastic V-687 (5)	28	225+00 - 231+00	0	0.0	4.0
Watson Bowman 687 (5)	26	194+00 - 200+00	0	0.0	4.0
Techstar W-050 (5)	28	154+00 - 160+00	2	7.1	2.0
No Sealant (2)	27	219+00 - 225+00	2	7.4	1.0
No Sealant (6)	28	160+00 - 166+00	0	0.0	4.0

Table 5.14 (b) Increase in corner breaks since previous survey

Sealant Material (Joint Configuration)	No. of Slabs	Stations	Corner Breaks Inc.	% Slabs Cracked Inc.	Rank
Crafco 903-SL (1)	28	188+00 - 194+00	0	0	1
Crafco 903-SL (4)	32	206+00 - 213+00	0	0	1
Dow 890-SL (3)	28	166+00 - 172+00	0	0	1
Dow 890-SL (4)	28	213+00 - 219+00	0	0	1
Dow 890-SL (1)	27	266+00 - 272+00	0	0	1
Crafco 902 (1)	28	200+00 - 206+00	0	0	1
Dow 888 (1a)	56	272+00 - 284+00	0	0	1
Dow 888 (1b)	28	284+00 - 290+00	0	0	1
Crafco 221 (1)	28	260+00 - 266+00	0	0	1
Crafco 444 (1)	75	172+00 - 188+00	0	0	1
Delastic V-687 (5)	28	225+00 - 231+00	0	0	1
Watson Bowman 687 (5)	26	194+00 - 200+00	0	0	1
Techstar W-050 (5)	28	154+00 - 160+00	0	0	1
No Sealant (2)	27	219+00 - 225+00	0	0	1
No Sealant (6)	28	160+00 - 166+00	0	0	1

Table 5.15 EBOC01 survey of observed spalling in the eastbound lanes

	Sealant	Stations	Fall '01 (ft)	Fall '01 Rank	Increase (ft)	Increase Rank
Silicone	Crafco 903-SL (1)	188+00 to 194+00	0	7	-0.3	13
	Crafco 903-SL (4)	206+00 to 213+00	0	7	-0.5	15
	Dow 890-SL (3)	166+00 to 172+00	0.1	6	0.1	3
	Dow 890-SL (4)	213+00 to 219+00	0	7	-0.2	11
	Dow 890-SL (1)	266+00 to 272+00	0	7	0	4
	Crafco 902 (1)	200+00 to 206+00	0	7	0	4
	Dow 888 (1a)	272+00 to 284+00	0	7	-0.1	10
	Dow 888 (1b)	284+00 to 290+00	0	7	0	4
Hot-Applied	Crafco 221 (1)	260+00 to 266+00	3.7	1	0.4	1
	Crafco 444 (1)	172+00 to 188+00	0	7	-0.3	13
Compression	Delastic V-687 (5)	225+00 to 231+00	0.2	3	-0.1	9
	Watson Bowman 687 (5)	194+00 to 200+00	0.2	3	0	4
	Techstar W-050 (5)	154+00 to 160+00	0	7	0	4
Unsealed	No Sealant (2)	219+00 to 225+00	0.4	2	0.2	2
	No Sealant (6)	160+00 to 166+00	0.2	3	-0.2	11
		Σ	4.8	-	-1.0	-

Table 5.16 (a) WBOC00 survey of transverse cracks in the westbound lanes

Sealant Material (Joint Configuration)	No. of Slabs	Stations	Transverse Cracks	% Slabs Cracked	Rank
Crafco 903-SL (1a)	28	188+00 - 194+00	1	3.6	11
Crafco 903-SL (1b)	28	194+00 - 200+00	5	17.9	7
Crafco 903-SL (4)	27	266+00 - 272+00	5	18.5	6
Dow 890-SL (3)	28	166+00 - 172+00	6	21.4	5
Dow 890-SL (1)	27	200+00 - 206+00	8	29.6	2
Dow 890-SL (4)	56	272+00 - 284+00	0	0.0	14
Dow 888 (1a)	27	213+00 - 219+00	6	22.2	3
Dow 888 (1b)	28	260+00 - 266+00	5	17.9	7
Crafco 221 (1)	75	172+00 - 188+00	1	1.3	13
Crafco 444 (1)	32	206+00 - 213+00	1	3.1	12
Delastic V-687 (5)	28	219+00 - 225+00	9	32.1	1
Watson Bowman 812 (5)	27	225+00 - 231+00	6	22.2	3
Techstar W-050 (5)	28	133+60 - 139+60	4	14.3	9
No Sealant (2)	125	139+60 - 166+00	11	8.8	10
No Sealant (6)	28	284+00 - 290+00	0	0.0	14

Table 5.16 (b) Increase in transverse cracks since previous survey

Sealant Material (Joint Configuration)	No. of Slabs	Stations	Transverse Cracks	% Slabs Cracked	Rank
Crafco 903-SL (1a)	28	188+00 - 194+00	1	3.6	8
Crafco 903-SL (1b)	28	194+00 - 200+00	1	3.6	8
Crafco 903-SL (4)	27	266+00 - 272+00	5	18.5	2
Dow 890-SL (3)	28	166+00 - 172+00	3	10.7	5
Dow 890-SL (1)	27	200+00 - 206+00	-1	-3.7	15
Dow 890-SL (4)	56	272+00 - 284+00	0	0.0	11
Dow 888 (1a)	27	213+00 - 219+00	6	22.2	1
Dow 888 (1b)	28	260+00 - 266+00	4	14.3	4
Crafco 221 (1)	75	172+00 - 188+00	-2	-2.7	13
Crafco 444 (1)	32	206+00 - 213+00	-1	-3.1	14
Delastic V-687 (5)	28	219+00 - 225+00	5	17.9	3
Watson Bowman 812 (5)	27	225+00 - 231+00	1	3.7	7
Techstar W-050 (5)	28	133+60 - 139+60	2	7.1	6
No Sealant (2)	125	139+60 - 166+00	4	3.2	10
No Sealant (6)	28	284+00 - 290+00	0	0.0	11

Table 5.17 (a) WBOC00 survey of corner breaks in the westbound lanes

Sealant Material (Joint Configuration)	No. of Slabs	Stations	Corner Breaks	% Slabs Cracked	Rank
Crafco 903-SL (1a)	28	188+00 - 194+00	0	0.0	5
Crafco 903-SL (1b)	28	194+00 - 200+00	0	0.0	5
Crafco 903-SL (4)	27	266+00 - 272+00	0	0.0	5
Dow 890-SL (3)	28	166+00 - 172+00	3	10.7	1
Dow 890-SL (1)	27	200+00 - 206+00	0	0.0	5
Dow 890-SL (4)	56	272+00 - 284+00	0	0.0	5
Dow 888 (1a)	27	213+00 - 219+00	1	3.7	3
Dow 888 (1b)	28	260+00 - 266+00	0	0.0	5
Crafco 221 (1)	75	172+00 - 188+00	0	0.0	5
Crafco 444 (1)	32	206+00 - 213+00	2	6.3	2
Delastic V-687 (5)	28	219+00 - 225+00	0	0.0	5
Watson Bowman 812 (5)	27	225+00 - 231+00	0	0.0	5
Techstar W-050 (5)	28	133+60 - 139+60	1	3.6	4
No Sealant (2)	125	139+60 - 166+00	0	0.0	5
No Sealant (6)	28	284+00 - 290+00	0	0.0	5

Table 5.17 (b) Increase in corner breaks since previous survey

Sealant Material (Joint Configuration)	No. of Slabs	Stations	Corner Breaks Inc.	% Slabs Cracked Inc.	Rank
Crafco 903-SL (1a)	28	188+00 - 194+00	0	0.0	3
Crafco 903-SL (1b)	28	194+00 - 200+00	0	0.0	3
Crafco 903-SL (4)	27	266+00 - 272+00	-1	-3.7	15
Dow 890-SL (3)	28	166+00 - 172+00	-1	-3.6	13
Dow 890-SL (1)	27	200+00 - 206+00	0	0.0	3
Dow 890-SL (4)	56	272+00 - 284+00	0	0.0	3
Dow 888 (1a)	27	213+00 - 219+00	1	3.7	1
Dow 888 (1b)	28	260+00 - 266+00	0	0.0	3
Crafco 221 (1)	75	172+00 - 188+00	-1	-1.3	12
Crafco 444 (1)	32	206+00 - 213+00	1	3.1	2
Delastic V-687 (5)	28	219+00 - 225+00	-1	-3.6	13
Watson Bowman 812 (5)	27	225+00 - 231+00	0	0.0	3
Techstar W-050 (5)	28	133+60 - 139+60	0	0.0	3
No Sealant (2)	125	139+60 - 166+00	-1	-0.8	11
No Sealant (6)	28	284+00 - 290+00	0	0.0	3

Table 5.18 WBOC00 survey of observed spalling in the westbound lanes

	Sealant	Stations	Fall '00 (ft)	Fall '00 Rank	Increase (ft)	Increase Rank
Silicone	Crafco 903-SL (1a)	188+00 - 194+00	0.2	4	-0.1	13
	Crafco 903-SL (1b)	194+00 - 200+00	0.2	4	-0.7	15
	Crafco 903-SL (4)	266+00 - 272+00	0.2	4	0.2	2
	Dow 890-SL (3)	166+00 - 172+00	0	11	0	8
	Dow 890-SL (1)	200+00 - 206+00	0.4	2	0.2	2
	Dow 890-SL (4)	272+00 - 284+00	0.7	1	0.5	1
	Dow 888 (1a)	213+00 - 219+00	0.1	8	0.1	5
	Dow 888 (1b)	260+00 - 266+00	0.3	3	0.2	4
Hot-Applied	Crafco 221 (1)	206+00 - 213+00	0	11	0	8
	Crafco 444 (1)	172+00 - 188+00	0	11	0	8
Compression	Delastic V-687 (5)	219+00 - 225+00	0.1	8	0.1	5
	Watson Bowman 812 (5)	133+60 - 139+60	0	11	0	8
	Techstar W-050 (5)	225+00 - 231+00	0	11	0	8
Unsealed	No Sealant (2)	139+60 - 166+00	0.1	8	-0.1	14
	No Sealant (6)	284+00 - 290+00	0.2	4	0.1	5
		Σ	2.5	-	0.5	-

Table 5.19 (a) WBJN01 survey of transverse cracks in the westbound lanes

Sealant Material (Joint Configuration)	No. of Slabs	Stations	Transverse Cracks	% Slabs Cracked	Rank
Crafco 903-SL (1a)	28	188+00 - 194+00	7	25.0	12
Crafco 903-SL (1b)	28	194+00 - 200+00	16	57.1	3
Crafco 903-SL (4)	27	266+00 - 272+00	8	29.6	10
Dow 890-SL (3)	28	166+00 - 172+00	15	53.6	6
Dow 890-SL (1)	27	200+00 - 206+00	15	55.6	4
Dow 890-SL (4)	56	272+00 - 284+00	2	3.6	14
Dow 888 (1a)	27	213+00 - 219+00	15	55.6	4
Dow 888 (1b)	28	260+00 - 266+00	11	39.3	8
Crafco 221 (1)	75	172+00 - 188+00	18	24.0	13
Crafco 444 (1)	32	206+00 - 213+00	10	31.3	9
Delastic V-687 (5)	28	219+00 - 225+00	18	64.3	1
Watson Bowman 812 (5)	27	225+00 - 231+00	13	48.1	7
Techstar W-050 (5)	28	133+60 - 139+60	17	60.7	2
No Sealant (2)	125	139+60 - 166+00	33	26.4	11
No Sealant (6)	28	284+00 - 290+00	0	0.0	15

Table 5.19 (b) Increase in transverse cracks since previous survey

Sealant Material (Joint Configuration)	No. of Slabs	Stations	Transverse Cracks Inc.	% Slabs Cracked Inc.	Rank
Crafco 903-SL (1a)	28	188+00 - 194+00	6	21.4	10
Crafco 903-SL (1b)	28	194+00 - 200+00	11	39.3	2
Crafco 903-SL (4)	27	266+00 - 272+00	3	11.1	13
Dow 890-SL (3)	28	166+00 - 172+00	9	32.1	5
Dow 890-SL (1)	27	200+00 - 206+00	7	25.9	7
Dow 890-SL (4)	56	272+00 - 284+00	2	3.6	14
Dow 888 (1a)	27	213+00 - 219+00	9	33.3	3
Dow 888 (1b)	28	260+00 - 266+00	6	21.4	11
Crafco 221 (1)	75	172+00 - 188+00	17	22.7	9
Crafco 444 (1)	32	206+00 - 213+00	9	28.1	6
Delastic V-687 (5)	28	219+00 - 225+00	9	32.1	4
Watson Bowman 812 (5)	27	225+00 - 231+00	7	25.9	8
Techstar W-050 (5)	28	133+60 - 139+60	13	46.4	1
No Sealant (2)	125	139+60 - 166+00	22	17.6	12
No Sealant (6)	28	284+00 - 290+00	0	0.0	15

Table 5.20 (a) WBJN01 survey of corner breaks in the westbound lanes

Sealant Material (Joint Configuration)	No. of Slabs	Stations	Corner Breaks	% Slabs Cracked	Rank
Crafco 903-SL (1a)	28	188+00 - 194+00	0	0.0	7
Crafco 903-SL (1b)	28	194+00 - 200+00	0	0.0	7
Crafco 903-SL (4)	27	266+00 - 272+00	0	0.0	7
Dow 890-SL (3)	28	166+00 - 172+00	2	7.1	1
Dow 890-SL (1)	27	200+00 - 206+00	0	0.0	7
Dow 890-SL (4)	56	272+00 - 284+00	2	3.6	2
Dow 888 (1a)	27	213+00 - 219+00	0	0.0	7
Dow 888 (1b)	28	260+00 - 266+00	1	3.6	2
Crafco 221 (1)	75	172+00 - 188+00	0	0.0	7
Crafco 444 (1)	32	206+00 - 213+00	1	3.1	5
Delastic V-687 (5)	28	219+00 - 225+00	1	3.6	2
Watson Bowman 812 (5)	27	225+00 - 231+00	0	0.0	7
Techstar W-050 (5)	28	133+60 - 139+60	0	0.0	7
No Sealant (2)	125	139+60 - 166+00	1	0.8	6
No Sealant (6)	28	284+00 - 290+00	0	0.0	7

Table 5.20 (b) Increase in corner breaks since previous survey

Sealant Material (Joint Configuration)	No. of Slabs	Stations	Corner Breaks Inc.	% Slabs Cracked Inc.	Rank
Crafco 903-SL (1a)	28	188+00 - 194+00	0	0.0	5
Crafco 903-SL (1b)	28	194+00 - 200+00	0	0.0	5
Crafco 903-SL (4)	27	266+00 - 272+00	0	0.0	5
Dow 890-SL (3)	28	166+00 - 172+00	-1	-3.6	13
Dow 890-SL (1)	27	200+00 - 206+00	0	0.0	5
Dow 890-SL (4)	56	272+00 - 284+00	2	3.6	1
Dow 888 (1a)	27	213+00 - 219+00	-1	-3.7	15
Dow 888 (1b)	28	260+00 - 266+00	1	3.6	1
Crafco 221 (1)	75	172+00 - 188+00	0	0.0	5
Crafco 444 (1)	32	206+00 - 213+00	-1	-3.1	12
Delastic V-687 (5)	28	219+00 - 225+00	1	3.6	1
Watson Bowman 812 (5)	27	225+00 - 231+00	0	0.0	5
Techstar W-050 (5)	28	133+60 - 139+60	-1	-3.6	13
No Sealant (2)	125	139+60 - 166+00	1	0.8	4
No Sealant (6)	28	284+00 - 290+00	0	0.0	5

Table 5.21 WBJN01 survey of observed spalling in the westbound lanes

	Sealant	Stations	Spring '01 (ft)	Spring '01 Rank	Increase (ft)	Increase Rank
Silicone	Crafco 903-SL (1a)	188+00 - 194+00	0.4	3	0.2	4
	Crafco 903-SL (1b)	194+00 - 200+00	0.4	3	0.2	4
	Crafco 903-SL (4)	266+00 - 272+00	0	9	-0.2	15
	Dow 890-SL (3)	166+00 - 172+00	0	9	0	6
	Dow 890-SL (1)	200+00 - 206+00	0.9	2	0.5	2
	Dow 890-SL (4)	272+00 - 284+00	2.8	1	2.1	1
	Dow 888 (1a)	213+00 - 219+00	0.1	8	0	6
	Dow 888 (1b)	260+00 - 266+00	0.2	6	-0.1	12
Hot-Applied	Crafco 221 (1)	206+00 - 213+00	0	9	0	6
	Crafco 444 (1)	172+00 - 188+00	0	9	0	6
Compression	Delastic V-687 (5)	219+00 - 225+00	0	9	-0.1	13
	Watson Bowman 812 (5)	133+60 - 139+60	0	9	0	6
	Techstar W-050 (5)	225+00 - 231+00	0.4	3	0.4	3
Unsealed	No Sealant (2)	139+60 - 166+00	0	9	-0.1	13
	No Sealant (6)	284+00 - 290+00	0.2	6	0	6
		Σ	5.4	-	2.9	-

Table 5.22 (a) WBOC01 survey of transverse cracks in the westbound lanes

Sealant Material (Joint Configuration)	No. of Slabs	Stations	Transverse Cracks	% Slabs Cracked	Rank
Crafco 903-SL (1a)	28	188+00 - 194+00	10	35.7	9
Crafco 903-SL (1b)	28	194+00 - 200+00	21	75.0	4
Crafco 903-SL (4)	27	266+00 - 272+00	9	33.3	11
Dow 890-SL (3)	28	166+00 - 172+00	12	42.9	8
Dow 890-SL (1)	27	200+00 - 206+00	20	74.1	5
Dow 890-SL (4)	56	272+00 - 284+00	9	16.1	15
Dow 888 (1a)	27	213+00 - 219+00	19	70.4	6
Dow 888 (1b)	28	260+00 - 266+00	10	35.7	9
Crafco 221 (1)	75	172+00 - 188+00	21	28.0	13
Crafco 444 (1)	32	206+00 - 213+00	14	43.8	7
Delastic V-687 (5)	28	219+00 - 225+00	22	78.6	3
Watson Bowman 812 (5)	27	225+00 - 231+00	24	88.9	1
Techstar W-050 (5)	28	133+60 - 139+60	23	82.1	2
No Sealant (2)	125	139+60 - 166+00	38	30.4	12
No Sealant (6)	28	284+00 - 290+00	7	25.0	14

Table 5.22 (b) Increase in transverse cracks since previous survey

Sealant Material (Joint Configuration)	No. of Slabs	Stations	Transverse Cracks Inc.	% Slabs Cracked Inc.	Rank
Crafco 903-SL (1a)	28	188+00 - 194+00	3	10.7	10
Crafco 903-SL (1b)	28	194+00 - 200+00	5	17.9	5
Crafco 903-SL (4)	27	266+00 - 272+00	1	3.7	13
Dow 890-SL (3)	28	166+00 - 172+00	-3	-10.7	15
Dow 890-SL (1)	27	200+00 - 206+00	5	18.5	4
Dow 890-SL (4)	56	272+00 - 284+00	7	12.5	8
Dow 888 (1a)	27	213+00 - 219+00	4	14.8	6
Dow 888 (1b)	28	260+00 - 266+00	-1	-3.6	14
Crafco 221 (1)	75	172+00 - 188+00	3	4.0	11
Crafco 444 (1)	32	206+00 - 213+00	4	12.5	9
Delastic V-687 (5)	28	219+00 - 225+00	4	14.3	7
Watson Bowman 812 (5)	27	225+00 - 231+00	11	40.7	1
Techstar W-050 (5)	28	133+60 - 139+60	6	21.4	3
No Sealant (2)	125	139+60 - 166+00	5	4.0	12
No Sealant (6)	28	284+00 - 290+00	7	25.0	2

Table 5.23 (a) WBOC01 survey of corner breaks in the westbound lanes

Sealant Material (Joint Configuration)	No. of Slabs	Stations	Corner Breaks	% Slabs Cracked	Rank
Crafco 903-SL (1a)	28	188+00 - 194+00	1	3.6	4
Crafco 903-SL (1b)	28	194+00 - 200+00	1	3.6	4
Crafco 903-SL (4)	27	266+00 - 272+00	0	0.0	11
Dow 890-SL (3)	28	166+00 - 172+00	2	7.1	1
Dow 890-SL (1)	27	200+00 - 206+00	0	0.0	11
Dow 890-SL (4)	56	272+00 - 284+00	2	3.6	4
Dow 888 (1a)	27	213+00 - 219+00	0	0.0	11
Dow 888 (1b)	28	260+00 - 266+00	1	3.6	4
Crafco 221 (1)	75	172+00 - 188+00	1	1.3	10
Crafco 444 (1)	32	206+00 - 213+00	2	6.3	3
Delastic V-687 (5)	28	219+00 - 225+00	2	7.1	1
Watson Bowman 812 (5)	27	225+00 - 231+00	0	0.0	11
Techstar W-050 (5)	28	133+60 - 139+60	1	3.6	4
No Sealant (2)	125	139+60 - 166+00	2	1.6	9
No Sealant (6)	28	284+00 - 290+00	0	0.0	11

Table 5.23 (b) Increase in corner breaks since previous survey

Sealant Material (Joint Configuration)	No. of Slabs	Stations	Corner Breaks Inc.	% Slabs Cracked Inc.	Rank
Crafco 903-SL (1a)	28	188+00 - 194+00	1	3.6	1
Crafco 903-SL (1b)	28	194+00 - 200+00	1	3.6	1
Crafco 903-SL (4)	27	266+00 - 272+00	0	0.0	8
Dow 890-SL (3)	28	166+00 - 172+00	0	0.0	8
Dow 890-SL (1)	27	200+00 - 206+00	0	0.0	8
Dow 890-SL (4)	56	272+00 - 284+00	0	0.0	8
Dow 888 (1a)	27	213+00 - 219+00	0	0.0	8
Dow 888 (1b)	28	260+00 - 266+00	0	0.0	8
Crafco 221 (1)	75	172+00 - 188+00	1	1.3	6
Crafco 444 (1)	32	206+00 - 213+00	1	3.1	5
Delastic V-687 (5)	28	219+00 - 225+00	1	3.6	1
Watson Bowman 812 (5)	27	225+00 - 231+00	0	0.0	8
Techstar W-050 (5)	28	133+60 - 139+60	1	3.6	1
No Sealant (2)	125	139+60 - 166+00	1	0.8	7
No Sealant (6)	28	284+00 - 290+00	0	0.0	8

Table 5.24 WBOC01 survey of observed spalling in the westbound lanes

	Sealant	Stations	Fall '01 (ft)	Fall '01 Rank	Increase (ft)	Increase Rank
Silicone	Crafco 903-SL (1a)	188+00 - 194+00	0.2	4	-0.2	12
	Crafco 903-SL (1b)	194+00 - 200+00	0	10	-0.4	14
	Crafco 903-SL (4)	266+00 - 272+00	0.2	4	0.2	2
	Dow 890-SL (3)	166+00 - 172+00	0	10	0	3
	Dow 890-SL (1)	200+00 - 206+00	0.8	2	-0.1	11
	Dow 890-SL (4)	272+00 - 284+00	1.7	1	-1.1	15
	Dow 888 (1a)	213+00 - 219+00	0.1	9	0	3
	Dow 888 (1b)	260+00 - 266+00	0.2	4	0	3
Hot-Applied	Crafco 221 (1)	206+00 - 213+00	0.3	3	0.3	1
	Crafco 444 (1)	172+00 - 188+00	0	10	0	3
Compression	Delastic V-687 (5)	219+00 - 225+00	0	10	0	3
	Watson Bowman 812 (5)	133+60 - 139+60	0	10	0	3
	Techstar W-050 (5)	225+00 - 231+00	0.2	4	-0.2	12
Unsealed	No Sealant (2)	139+60 - 166+00	0	10	0	3
	No Sealant (6)	284+00 - 290+00	0.2	4	0	3
		Σ	3.9	-	-1.5	-

Table 5.25 Percent change in surface roughness for the eastbound lanes
(PEBMR00 to PEBOC00)

(a) Eastbound passing lane

	MAYS	PSI	IRIlf	IRIrt	IRIbh
AVG	-7.96	-0.94	-14.19	-0.36	-7.55
MAX	-36.20	-2.11	-24.87	-59.45	-28.72
MIN	-44.24	-27.39	-32.61	-30.30	-29.91
STD	-3.64	-0.10	-5.81	-14.52	-4.65
COV%	4.00	0.87	7.34	-14.00	2.69

Station	Material	MAYS	PSI	IRIlf	IRIrt	IRIbh
188+00 - 194+00	Crafco 903-SL (1)	-15.52	-1.89	-19.28	-7.36	-13.47
206+00 - 213+00	Crafco 903-SL (4)	-19.43	-2.88	-26.91	-11.28	-18.94
166+00 - 172+00	Dow 890-SL (3)	-0.13	0.80	-4.05	2.10	-1.26
213+00 - 219+00	Dow 890-SL (4)	-15.77	-1.71	-21.52	-6.32	-13.93
266+00 - 272+00	Dow 890-SL (1)	4.39	1.54	0.51	10.55	5.16
200+00 - 206+00	Crafco 902 (1)	-0.74	0.44	-10.03	10.40	0.03
272+00 - 284+00	Dow 888 (1a)	2.66	1.88	-3.12	9.92	3.09
284+00 - 290+00	Dow 888 (1b)	1.15	2.01	-6.33	11.58	2.13
260+00 - 266+00	Crafco 444 (1)	4.09	1.71	-2.32	10.03	3.60
172+00 - 188+00	Crafco 221 (1)	-5.32	-0.18	-9.77	0.57	-4.70
225+00 - 231+00	Delastic V-687 (5)	-0.17	0.60	-5.96	5.91	-0.31
194+00 - 200+00	Watson Bowman 687 (5)	1.53	1.55	-4.57	8.19	1.67
154+00 - 160+00	Techstar W-050 (5)	-10.46	-0.18	-12.99	-6.16	-9.76
219+00 - 225+00	No Sealant (2)	-16.69	-1.98	-19.22	-11.99	-15.69
160+00 - 166+00	No Sealant (6)	2.11	1.14	-3.50	4.77	0.20
	AVG	-4.55	0.19	-9.94	2.06	-4.15
	MAX	4.39	2.01	0.51	11.58	5.16
	MIN	-19.43	-2.88	-26.91	-11.99	-18.94

Table 5.25 (continued)

(b) Eastbound driving lane

	MAYS	PSI	IRIlf	IRIrt	IRIbh
AVG	-0.88	0.61	-5.25	3.05	-1.07
MAX	-3.93	-0.48	-0.69	-5.66	-5.12
MIN	-10.03	-10.33	-16.67	-5.02	-9.99
STD	-3.92	-1.87	-10.13	0.21	-5.80
COV%	-3.03	-2.47	-4.66	-2.94	-4.70

Station	Material	MAYS	PSI	IRIlf	IRIrt	IRIbh
188+00 - 194+00	Crafco 903-SL (1)	-7.17	-1.19	-12.13	-1.18	-6.69
206+00 - 213+00	Crafco 903-SL (4)	-12.00	-0.86	-13.00	-8.81	-11.00
166+00 - 172+00	Dow 890-SL (3)	4.56	0.82	2.52	6.59	4.51
213+00 - 219+00	Dow 890-SL (4)	-14.02	-1.55	-14.68	-10.89	-12.82
266+00 - 272+00	Dow 890-SL (1)	5.54	1.68	-1.61	11.98	5.58
200+00 - 206+00	Crafco 902 (1)	9.35	2.90	3.15	13.66	8.71
272+00 - 284+00	Dow 888 (1a)	1.33	1.35	-3.77	6.55	1.55
284+00 - 290+00	Dow 888 (1b)	-3.69	0.57	-7.79	1.75	-2.74
260+00 - 266+00	Crafco 444 (1)	4.50	2.28	0.18	6.38	3.31
172+00 - 188+00	Crafco 221 (1)	-4.74	-0.41	-7.48	-0.87	-4.23
225+00 - 231+00	Delastic V-687 (5)	-0.06	-0.08	-2.65	-0.62	-1.60
194+00 - 200+00	Watson Bowman 687 (5)	5.34	0.95	3.43	6.12	4.76
154+00 - 160+00	Techstar W-050 (5)	-14.94	-1.96	-15.28	-13.91	-14.57
219+00 - 225+00	No Sealant (2)	-7.42	-1.16	-12.64	-1.87	-7.22
160+00 - 166+00	No Sealant (6)	-1.95	0.45	-5.18	-0.96	-3.09
	AVG	-2.36	0.25	-5.80	0.93	-2.37
	MAX	9.35	2.90	3.43	13.66	8.71
	MIN	-14.94	-1.96	-15.28	-13.91	-14.57

Table 5.26 Percent change in surface roughness for the eastbound lanes
(PEBOC00 to PEBJN01)

(a) Eastbound passing lane

	MAYS	PSI	IRIlf	IRIrt	IRIbh
AVG	6.13	1.39	3.23	8.57	5.63
MAX	23.02	0.83	9.66	38.06	21.48
MIN	16.24	38.76	21.80	21.38	17.27
STD	8.94	-11.82	3.61	22.18	9.23
COV%	2.99	-13.05	0.39	14.80	3.82

Station	Material	MAYS	PSI	IRIlf	IRIrt	IRIbh
188+00 - 194+00	Crafco 903-SL (1)	7.39	0.64	1.20	11.68	6.04
206+00 - 213+00	Crafco 903-SL (4)	14.40	2.68	12.50	14.69	13.56
166+00 - 172+00	Dow 890-SL (3)	-2.47	-0.03	-6.17	0.64	-3.18
213+00 - 219+00	Dow 890-SL (4)	7.15	0.95	2.32	9.94	5.89
266+00 - 272+00	Dow 890-SL (1)	-5.56	-0.96	-6.93	-4.70	-5.96
200+00 - 206+00	Crafco 902 (1)	0.37	0.56	-2.21	3.51	0.32
272+00 - 284+00	Dow 888 (1a)	-2.74	-0.73	-3.51	-1.91	-2.80
284+00 - 290+00	Dow 888 (1b)	-0.56	-0.23	-3.15	2.04	-0.94
260+00 - 266+00	Crafco 444 (1)	1.57	1.01	-1.01	4.15	1.29
172+00 - 188+00	Crafco 221 (1)	3.82	0.50	0.14	7.41	3.52
225+00 - 231+00	Delastic V-687 (5)	-5.08	-1.81	-9.21	3.06	-3.70
194+00 - 200+00	Watson Bowman 687 (5)	-2.82	-1.52	-9.75	2.98	-3.95
154+00 - 160+00	Techstar W-050 (5)	4.65	0.41	0.69	6.83	3.51
219+00 - 225+00	No Sealant (2)	13.63	2.72	6.65	19.61	12.79
160+00 - 166+00	No Sealant (6)	-1.09	0.14	-5.28	3.94	-1.33
	AVG	2.18	0.29	-1.58	5.59	1.67
	MAX	14.40	2.72	12.50	19.61	13.56
	MIN	-5.56	-1.81	-9.75	-4.70	-5.96

Table 5.26 (continued)

(b) Eastbound driving lane

	MAYS	PSI	IRIlf	IRIrt	IRIbh
AVG	-2.91	-1.76	-0.67	-3.79	-2.18
MAX	-2.57	-1.16	-1.93	3.73	1.01
MIN	14.09	4.36	18.44	-5.26	9.33
STD	-6.80	16.95	-3.84	-3.38	-3.30
COV%	-3.76	19.05	-3.12	0.40	-1.08

Station	Material	MAYS	PSI	IRIlf	IRIrt	IRIbh
188+00 - 194+00	Crafco 903-SL (1)	3.06	-1.48	7.20	-2.68	2.57
206+00 - 213+00	Crafco 903-SL (4)	16.83	2.07	15.02	15.67	15.31
166+00 - 172+00	Dow 890-SL (3)	-12.64	-3.17	-7.45	-14.94	-11.06
213+00 - 219+00	Dow 890-SL (4)	12.72	1.35	9.76	14.10	11.88
266+00 - 272+00	Dow 890-SL (1)	-19.42	-4.34	-18.68	-17.95	-18.33
200+00 - 206+00	Crafco 902 (1)	-8.59	-2.25	-2.72	-10.66	-6.68
272+00 - 284+00	Dow 888 (1a)	-8.25	-2.73	-8.08	-6.27	-7.20
284+00 - 290+00	Dow 888 (1b)	-2.27	-1.59	-2.76	-2.36	-2.52
260+00 - 266+00	Crafco 444 (1)	-13.82	-4.79	-11.54	-9.49	-10.54
172+00 - 188+00	Crafco 221 (1)	3.36	-0.13	3.58	3.53	3.56
225+00 - 231+00	Delastic V-687 (5)	0.30	-0.41	1.49	0.58	1.01
194+00 - 200+00	Watson Bowman 687 (5)	-7.18	-1.72	-5.65	-6.37	-5.99
154+00 - 160+00	Techstar W-050 (5)	5.87	-0.06	6.43	4.99	5.68
219+00 - 225+00	No Sealant (2)	3.56	-0.74	4.47	1.20	2.90
160+00 - 166+00	No Sealant (6)	-6.31	-2.09	-1.60	-9.33	-5.38
	AVG	-2.19	-1.47	-0.70	-2.67	-1.65
	MAX	16.83	2.07	15.02	15.67	15.31
	MIN	-19.42	-4.79	-18.68	-17.95	-18.33

Table 5.27 Percent change in surface roughness for the eastbound lanes (PEBJN01 to PEBOC01)

(a) Eastbound passing lane

	MAYS	PSI	IRIlf	IRIrt	IRIbh
AVG	1.81	0.25	1.71	2.77	2.17
MAX	-0.29	2.29	4.32	4.47	-1.21
MIN	6.77	3.76	-4.17	-6.83	4.06
STD	-4.36	8.63	-4.50	-3.48	-4.13
COV%	-6.29	8.36	-6.31	-6.43	-6.44

Station	Material	MAYS	PSI	IRIlf	IRIrt	IRIbh
188+00 - 194+00	Crafco 903-SL (1)	3.54	0.01	1.65	6.24	3.63
206+00 - 213+00	Crafco 903-SL (4)	5.92	1.26	3.42	8.64	5.85
166+00 - 172+00	Dow 890-SL (3)	4.13	0.87	2.97	8.51	5.31
213+00 - 219+00	Dow 890-SL (4)	3.38	0.66	2.44	5.27	3.70
266+00 - 272+00	Dow 890-SL (1)	-4.96	-1.84	-4.48	-4.95	-4.69
200+00 - 206+00	Crafco 902 (1)	0.62	-0.20	3.08	-1.99	0.91
272+00 - 284+00	Dow 888 (1a)	2.25	0.28	1.83	3.26	2.45
284+00 - 290+00	Dow 888 (1b)	-3.81	-0.95	-3.11	-1.86	-2.57
260+00 - 266+00	Crafco 444 (1)	-0.22	0.20	0.95	-1.06	0.10
172+00 - 188+00	Crafco 221 (1)	1.50	0.39	0.69	2.83	1.64
225+00 - 231+00	Delastic V-687 (5)	4.76	1.06	4.73	3.59	4.25
194+00 - 200+00	Watson Bowman 687 (5)	1.89	0.13	3.22	1.13	2.33
154+00 - 160+00	Techstar W-050 (5)	4.07	0.38	4.43	4.73	4.56
219+00 - 225+00	No Sealant (2)	1.45	0.11	1.35	1.51	1.42
160+00 - 166+00	No Sealant (6)	3.59	0.43	4.30	6.16	5.06
	AVG	1.87	0.19	1.83	2.80	2.26
	MAX	5.92	1.26	4.73	8.64	5.85
	MIN	-4.96	-1.84	-4.48	-4.95	-4.69

Table 5.27 (continued)

(b) Eastbound driving lane

	MAYS	PSI	IRIlf	IRIrt	IRIbh
AVG	0.44	0.67	-3.10	4.18	0.48
MAX	1.69	0.33	3.98	0.00	2.16
MIN	-19.94	-14.63	-27.39	-3.00	-15.03
STD	5.20	-7.27	6.61	3.23	5.00
COV%	4.78	-7.88	9.42	-0.99	4.55

Station	Material	MAYS	PSI	IRIlf	IRIrt	IRIbh
188+00 - 194+00	Crafco 903-SL (1)	-2.00	1.22	-8.60	6.00	-1.38
206+00 - 213+00	Crafco 903-SL (4)	-10.29	-1.74	-15.75	-1.44	-9.03
166+00 - 172+00	Dow 890-SL (3)	3.87	1.48	1.29	6.45	3.87
213+00 - 219+00	Dow 890-SL (4)	-9.73	-1.18	-10.61	-7.98	-9.35
266+00 - 272+00	Dow 890-SL (1)	6.62	1.79	7.68	5.28	6.51
200+00 - 206+00	Crafco 902 (1)	1.52	0.70	-3.35	5.08	1.02
272+00 - 284+00	Dow 888 (1a)	5.56	2.06	3.30	7.36	5.28
284+00 - 290+00	Dow 888 (1b)	-0.37	0.20	-3.59	2.80	-0.37
260+00 - 266+00	Crafco 444 (1)	9.29	3.27	7.54	8.93	8.21
172+00 - 188+00	Crafco 221 (1)	-2.05	0.16	-6.62	3.02	-2.04
225+00 - 231+00	Delastic V-687 (5)	-0.26	0.25	-2.33	2.73	0.23
194+00 - 200+00	Watson Bowman 687 (5)	2.69	1.17	-2.77	8.45	2.71
154+00 - 160+00	Techstar W-050 (5)	-6.30	-1.01	-9.90	-0.67	-5.10
219+00 - 225+00	No Sealant (2)	-1.16	1.16	-5.23	4.39	-0.55
160+00 - 166+00	No Sealant (6)	-0.56	0.32	-6.76	4.91	-0.80
	AVG	-0.21	0.66	-3.71	3.69	-0.05
	MAX	9.29	3.27	7.68	8.93	8.21
	MIN	-10.29	-1.74	-15.75	-7.98	-9.35

Table 5.28 Percent change in surface roughness for the westbound lanes (PWBMR00 to PWBOC00)

(a) Westbound passing lane

	MAYS	PSI	IRIlf	IRIrt	IRIbh
AVG	-6.91	0.14	-11.08	-2.65	-6.73
MAX	-35.75	2.80	-24.42	-1.88	-31.03
MIN	15.23	-11.33	16.51	-5.99	0.73
STD	-29.60	10.69	-40.12	-4.63	-29.21
COV%	-21.30	10.49	-25.93	-1.94	-21.05

Station	Material	MAYS	PSI	IRIlf	IRIrt	IRIbh
188+00 - 194+00	Crafco 903-SL (1a)	10.66	2.13	8.65	13.05	10.94
194+00 - 200+00	Crafco 903-SL (1b)	2.98	3.52	0.05	7.77	4.04
266+00 - 272+00	Crafco 903-SL (4)	6.03	-0.12	2.64	8.20	5.51
166+00 - 172+00	Dow 890-SL (3)	-10.83	1.69	-11.00	-6.37	-8.59
200+00 - 206+00	Dow 890-SL (1)	-4.22	1.66	-7.20	1.13	-2.85
272+00 - 284+00	Dow 890-SL (4)	-14.72	-2.54	-14.41	-11.85	-13.11
213+00 - 219+00	Dow 888 (1a)	-14.15	-1.92	-22.01	-6.25	-13.57
260+00 - 266+00	Dow 888 (1b)	-5.74	5.67	4.97	-11.52	-2.71
172+00 - 188+00	Crafco 221 (1)	8.22	0.21	2.53	13.58	8.36
206+00 - 213+00	Crafco 444 (1)	-5.44	0.68	-16.05	3.29	-5.45
219+00 - 225+00	Delastic V-687 (5)	-8.74	-1.60	-10.60	-3.37	-6.90
225+00 - 231+00	Watson Bowman 812 (5)	-12.22	0.51	-17.21	-2.32	-9.13
133+60 - 139+60	Techstar W-050 (5)	-15.33	1.58	-8.19	-13.53	-10.72
139+60 - 166+00	No Sealant (2)	-9.25	1.18	-12.27	-2.16	-7.01
284+00 - 290+00	No Sealant (6)	-5.42	-2.75	-36.04	-4.49	-19.89
	AVG	-5.21	0.66	-9.08	-0.99	-4.74
	MAX	10.66	5.67	8.65	13.58	10.94
	MIN	-15.33	-2.75	-36.04	-13.53	-19.89

Table 5.28 (continued)

(b) Westbound driving lane

	MAYS	PSI	IRIlf	IRIrt	IRIbh
AVG	-15.30	-1.46	-21.59	-7.50	-14.25
MAX	-7.04	-4.21	-9.60	4.52	-6.24
MIN	-29.95	-0.98	-37.55	-8.48	-23.10
STD	-1.79	-16.96	-4.95	4.10	-0.64
COV%	11.72	-15.73	13.70	10.80	11.92

Station	Material	MAYS	PSI	IRIlf	IRIrt	IRIbh
188+00 - 194+00	Crafco 903-SL (1a)	1.40	2.73	-3.87	8.96	2.75
194+00 - 200+00	Crafco 903-SL (1b)	-5.41	3.59	-16.48	7.97	-3.14
266+00 - 272+00	Crafco 903-SL (4)	-2.60	1.32	-4.07	-1.63	-2.88
166+00 - 172+00	Dow 890-SL (3)	-11.49	-0.37	-26.99	2.93	-10.85
200+00 - 206+00	Dow 890-SL (1)	-18.15	-0.24	-24.24	-3.36	-13.15
272+00 - 284+00	Dow 890-SL (4)	-26.81	-4.15	-33.41	-20.83	-26.92
213+00 - 219+00	Dow 888 (1a)	-9.54	-2.64	-16.87	-5.33	-10.89
260+00 - 266+00	Dow 888 (1b)	-12.96	7.63	-22.44	-2.44	-11.73
172+00 - 188+00	Crafco 221 (1)	3.00	-5.48	-6.32	8.28	1.28
206+00 - 213+00	Crafco 444 (1)	-11.64	0.04	-14.98	-6.91	-10.92
219+00 - 225+00	Delastic V-687 (5)	-16.51	-5.60	-13.26	-17.29	-15.30
225+00 - 231+00	Watson Bowman 812 (5)	-5.75	-0.53	-18.46	3.94	-6.61
133+60 - 139+60	Techstar W-050 (5)	-29.33	-2.26	-37.25	-11.59	-23.43
139+60 - 166+00	No Sealant (2)	-15.55	-0.60	-21.13	-6.01	-13.28
284+00 - 290+00	No Sealant (6)	-31.44	-6.80	-33.26	-32.63	-32.95
	AVG	-12.85	-0.89	-19.54	-5.06	-11.87
	MAX	3.00	7.63	-3.87	8.96	2.75
	MIN	-31.44	-6.80	-37.25	-32.63	-32.95

Table 5.29 Percent change in surface roughness for the westbound lanes (PWBOC00 to PWBJN01)

(a) Westbound passing lane

	MAYS	PSI	IRIlf	IRIrt	IRIbh
AVG	7.64	1.44	6.39	6.57	6.48
MAX	49.99	3.87	67.48	-16.43	51.35
MIN	15.90	108.63	-11.36	33.75	0.37
STD	25.65	-23.82	49.83	-0.96	31.10
COV%	19.55	-24.86	46.31	-8.04	26.31

Station	Material	MAYS	PSI	IRIlf	IRIrt	IRIbh
188+00 - 194+00	Crafco 903-SL (1a)	2.76	0.52	2.68	1.88	2.26
194+00 - 200+00	Crafco 903-SL (1b)	6.89	0.32	7.30	1.97	4.64
266+00 - 272+00	Crafco 903-SL (4)	2.79	-0.72	3.59	1.56	2.55
166+00 - 172+00	Dow 890-SL (3)	6.28	2.37	-5.50	2.87	-1.23
200+00 - 206+00	Dow 890-SL (1)	2.91	0.35	2.96	3.93	3.44
272+00 - 284+00	Dow 890-SL (4)	7.68	0.84	7.69	6.43	7.06
213+00 - 219+00	Dow 888 (1a)	1.89	1.21	-4.41	4.75	0.15
260+00 - 266+00	Dow 888 (1b)	8.15	1.07	7.66	5.69	6.67
172+00 - 188+00	Crafco 221 (1)	0.67	0.78	-6.14	-2.97	-4.57
206+00 - 213+00	Crafco 444 (1)	0.94	1.00	1.29	5.05	3.18
219+00 - 225+00	Delastic V-687 (5)	-0.88	0.16	-7.76	4.37	-1.71
225+00 - 231+00	Watson Bowman 812 (5)	0.03	-0.28	2.86	-3.53	-0.39
133+60 - 139+60	Techstar W-050 (5)	29.32	6.28	17.71	24.17	20.86
139+60 - 166+00	No Sealant (2)	19.11	4.15	4.96	17.33	11.10
284+00 - 290+00	No Sealant (6)	7.75	2.20	28.31	5.13	17.96
	AVG	6.42	1.35	4.21	5.24	4.80
	MAX	29.32	6.28	28.31	24.17	20.86
	MIN	-0.88	-0.72	-7.76	-3.53	-4.57

Table 5.29 (continued)

(b) Westbound driving lane

	MAYS	PSI	IRIlf	IRIrt	IRIbh
AVG	13.98	1.88	15.03	13.31	14.19
MAX	-2.58	3.72	2.67	-2.84	-2.74
MIN	28.73	-6.27	32.10	22.68	27.29
STD	-2.59	24.08	-3.27	-2.14	-4.58
COV%	-19.27	21.79	-21.57	-17.82	-21.89

Station	Material	MAYS	PSI	IRIlf	IRIrt	IRIbh
188+00 - 194+00	Crafco 903-SL (1a)	10.51	0.39	10.52	9.84	10.20
194+00 - 200+00	Crafco 903-SL (1b)	19.67	2.86	18.26	19.99	19.12
266+00 - 272+00	Crafco 903-SL (4)	14.19	0.99	16.80	13.30	15.10
166+00 - 172+00	Dow 890-SL (3)	-1.01	-0.26	1.87	-0.80	0.61
200+00 - 206+00	Dow 890-SL (1)	13.97	1.72	13.84	14.00	13.92
272+00 - 284+00	Dow 890-SL (4)	16.49	2.19	19.83	13.95	16.95
213+00 - 219+00	Dow 888 (1a)	6.08	1.52	8.16	7.16	7.68
260+00 - 266+00	Dow 888 (1b)	12.85	1.76	14.46	11.03	12.77
172+00 - 188+00	Crafco 221 (1)	2.45	-0.54	6.22	2.53	4.44
206+00 - 213+00	Crafco 444 (1)	8.08	0.40	7.34	10.26	8.76
219+00 - 225+00	Delastic V-687 (5)	8.35	1.65	6.95	7.99	7.50
225+00 - 231+00	Watson Bowman 812 (5)	-0.35	-0.91	-0.64	2.75	1.00
133+60 - 139+60	Techstar W-050 (5)	31.18	6.24	30.97	29.13	30.08
139+60 - 166+00	No Sealant (2)	20.86	3.19	21.93	18.24	20.14
284+00 - 290+00	No Sealant (6)	19.97	4.56	17.48	22.65	20.13
	AVG	12.22	1.72	12.93	12.13	12.56
	MAX	31.18	6.24	30.97	29.13	30.08
	MIN	-1.01	-0.91	-0.64	-0.80	0.61

Table 5.30 Percent change in surface roughness for the westbound lanes (PWBJN01 to PWBOC01)

(a) Westbound passing lane

	MAYS	PSI	IRIlf	IRIrt	IRIbh
AVG	-2.64	-0.50	-2.15	1.03	-0.57
MAX	0.61	-5.89	8.26	20.72	3.48
MIN	-38.53	2.86	-4.61	-34.40	4.43
STD	1.91	-17.50	-2.90	4.93	-2.71
COV%	4.44	-17.08	-0.73	3.93	-2.13

Station	Material	MAYS	PSI	IRIlf	IRIrt	IRIbh
188+00 - 194+00	Crafco 903-SL (1a)	3.67	0.88	0.84	6.73	3.84
194+00 - 200+00	Crafco 903-SL (1b)	0.32	0.24	-2.88	5.54	1.41
266+00 - 272+00	Crafco 903-SL (4)	2.13	0.39	-1.36	5.99	2.37
166+00 - 172+00	Dow 890-SL (3)	-5.85	-2.67	2.45	0.01	1.26
200+00 - 206+00	Dow 890-SL (1)	3.08	0.59	2.88	3.26	3.06
272+00 - 284+00	Dow 890-SL (4)	-1.46	0.07	-4.21	1.57	-1.29
213+00 - 219+00	Dow 888 (1a)	-0.11	-0.03	-0.63	1.67	0.50
260+00 - 266+00	Dow 888 (1b)	-2.86	-0.17	-4.89	0.87	-1.95
172+00 - 188+00	Crafco 221 (1)	-3.80	-1.73	0.25	3.31	1.75
206+00 - 213+00	Crafco 444 (1)	1.52	-0.12	2.11	-0.90	0.63
219+00 - 225+00	Delastic V-687 (5)	-3.84	-0.71	-4.79	0.27	-2.44
225+00 - 231+00	Watson Bowman 812 (5)	0.41	0.23	-5.72	4.40	-0.40
133+60 - 139+60	Techstar W-050 (5)	-16.20	-2.06	-2.44	-7.95	-5.02
139+60 - 166+00	No Sealant (2)	-12.34	-2.54	-0.61	-6.11	-3.16
284+00 - 290+00	No Sealant (6)	-2.03	-0.26	-3.14	0.73	-1.15
	AVG	-2.49	-0.53	-1.48	1.29	-0.04
	MAX	3.67	0.88	2.88	6.73	3.84
	MIN	-16.20	-2.67	-5.72	-7.95	-5.02

Table 5.30 (continued)

(b) Westbound driving lane

	MAYS	PSI	IRIlf	IRIrt	IRIbh
AVG	-9.45	-2.22	-14.06	-5.31	-9.73
MAX	-11.90	-2.28	-105.10	-7.27	-19.19
MIN	-23.26	-41.89	-23.69	0.30	-13.78
STD	-14.80	49.06	-47.55	-6.84	-17.69
COV%	-4.88	52.44	-29.36	-1.45	-7.26

Station	Material	MAYS	PSI	IRIlf	IRIrt	IRIbh
188+00 - 194+00	Crafco 903-SL (1a)	-6.70	-4.05	-17.86	2.81	-7.84
194+00 - 200+00	Crafco 903-SL (1b)	-13.70	-5.01	-22.46	-6.19	-14.63
266+00 - 272+00	Crafco 903-SL (4)	-11.57	-1.85	-12.54	-10.18	-11.36
166+00 - 172+00	Dow 890-SL (3)	3.49	0.72	0.91	6.46	3.57
200+00 - 206+00	Dow 890-SL (1)	-6.36	-0.60	-8.89	-4.81	-6.89
272+00 - 284+00	Dow 890-SL (4)	-14.56	-4.49	-23.90	-7.47	-15.56
213+00 - 219+00	Dow 888 (1a)	-6.68	-2.61	-9.82	-5.05	-7.46
260+00 - 266+00	Dow 888 (1b)	-9.44	-1.18	-10.46	-7.36	-8.90
172+00 - 188+00	Crafco 221 (1)	-0.02	0.04	-1.27	0.13	-0.58
206+00 - 213+00	Crafco 444 (1)	-1.58	-0.57	-4.88	-0.39	-2.71
219+00 - 225+00	Delastic V-687 (5)	-3.41	-1.04	-7.43	0.81	-3.21
225+00 - 231+00	Watson Bowman 812 (5)	2.67	0.68	0.31	3.89	1.96
133+60 - 139+60	Techstar W-050 (5)	-24.95	-3.28	-27.75	-18.91	-23.40
139+60 - 166+00	No Sealant (2)	-17.40	-2.08	-20.59	-12.47	-16.56
284+00 - 290+00	No Sealant (6)	-12.45	-2.65	-19.48	-6.73	-13.12
	AVG	-8.18	-1.87	-12.41	-4.36	-8.45
	MAX	3.49	0.72	0.91	6.46	3.57
	MIN	-24.95	-5.01	-27.75	-18.91	-23.40

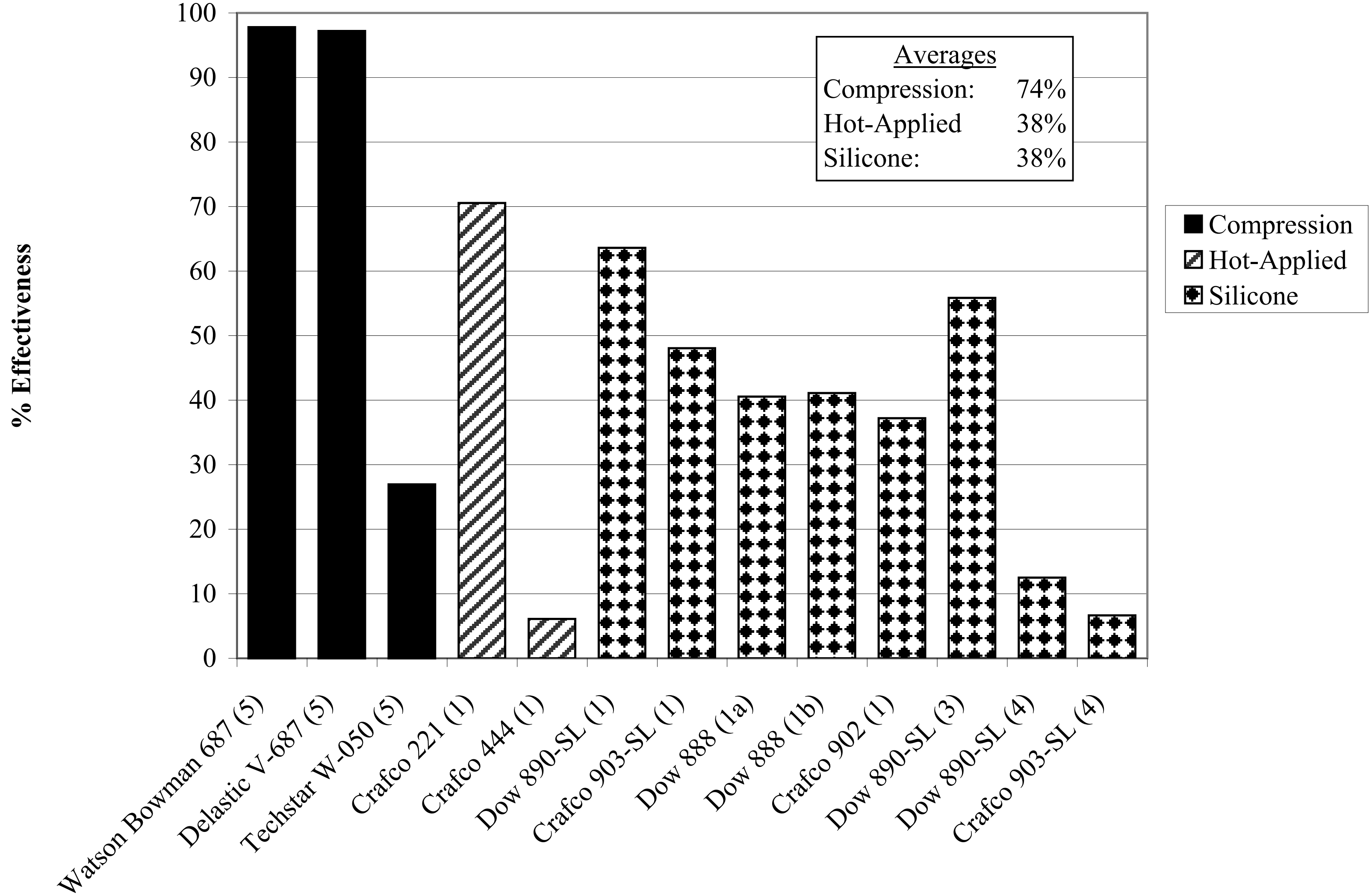


Figure 5.1 Comparison between silicone, hot-applied, and compression sealants during EBOC00

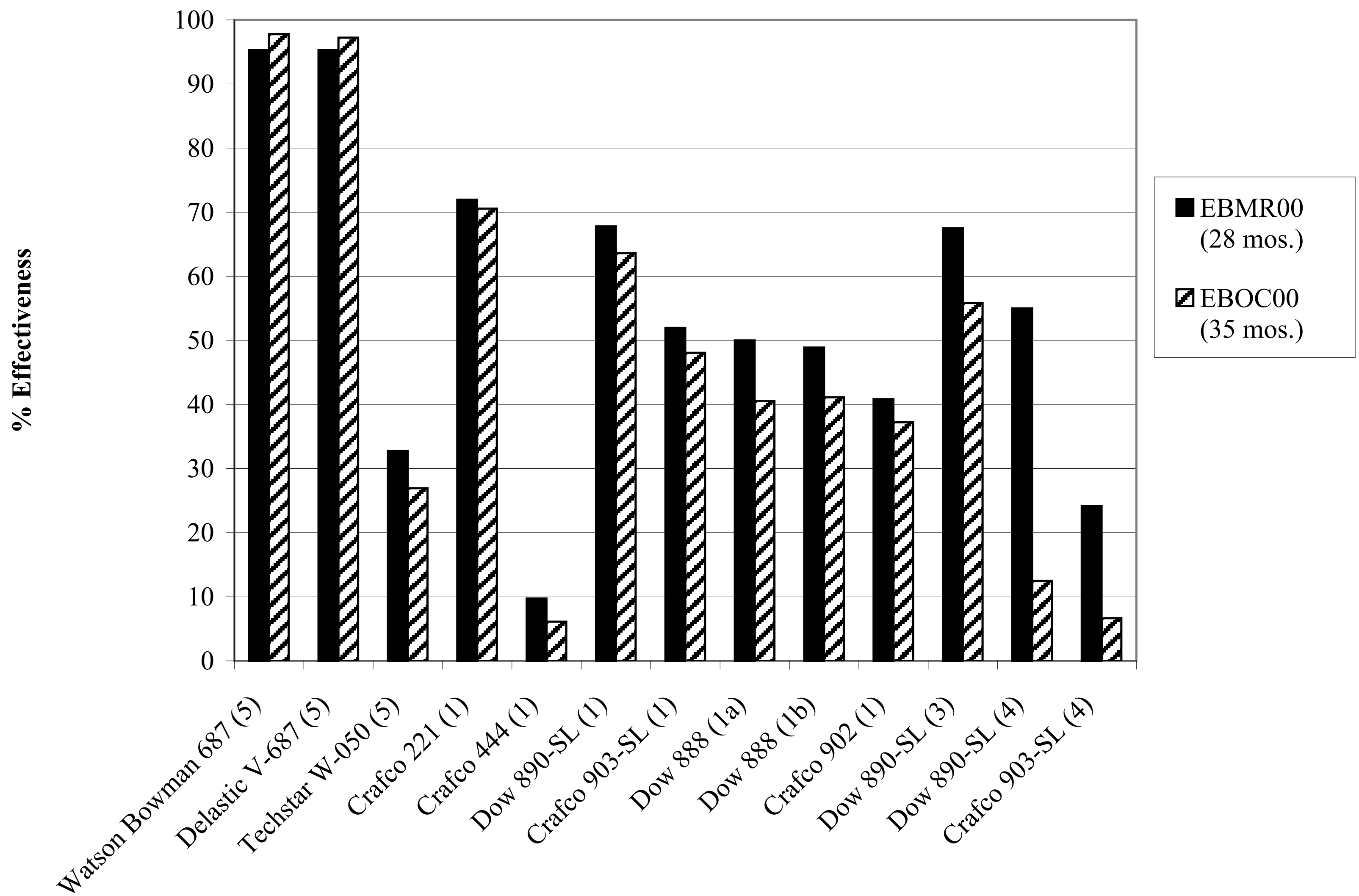


Figure 5.2 Deterioration of sealants from EBMR00 to EBOC00

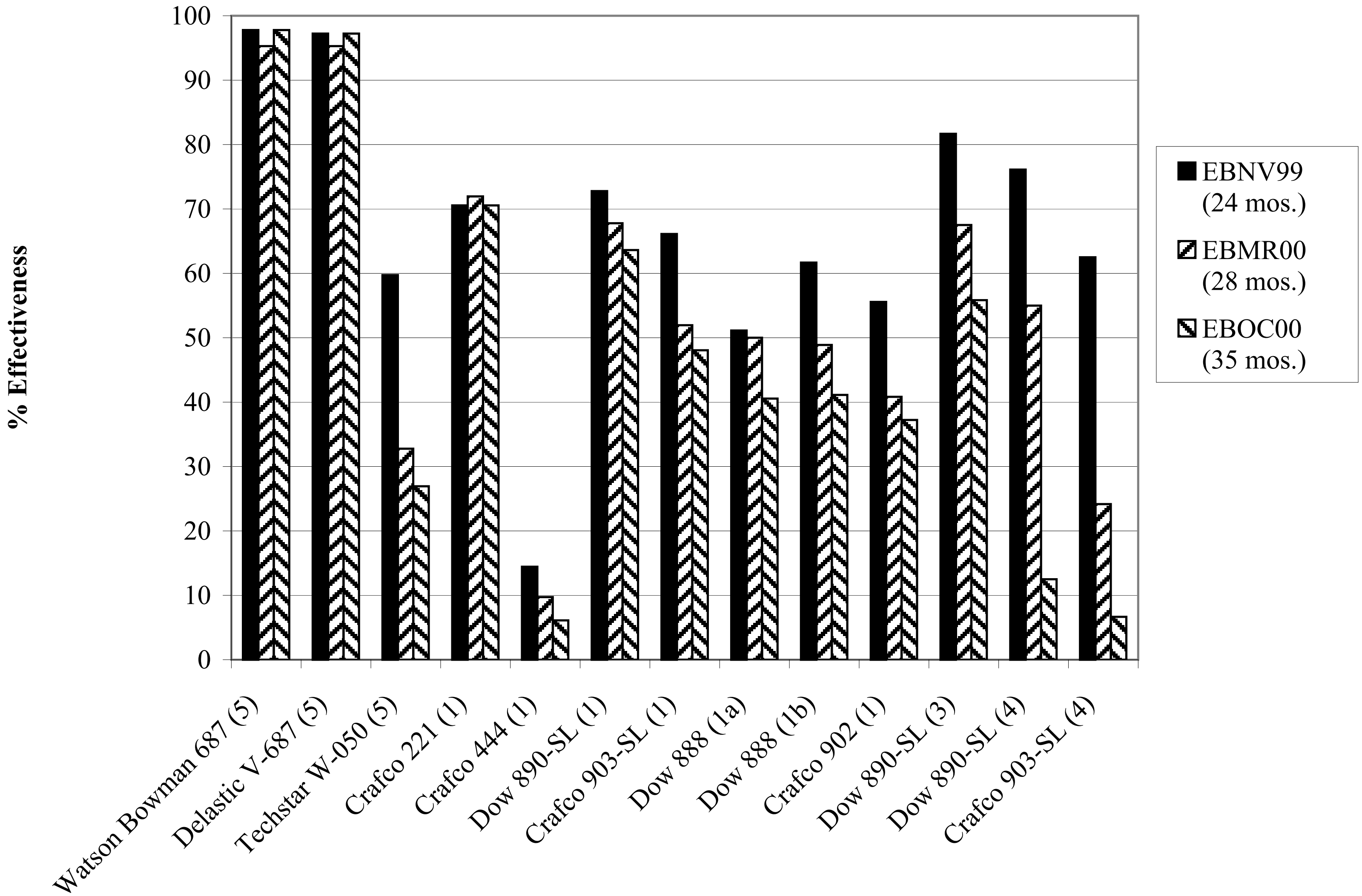


Figure 5.3 Deterioration of sealants from EBNV99 to EBOC00

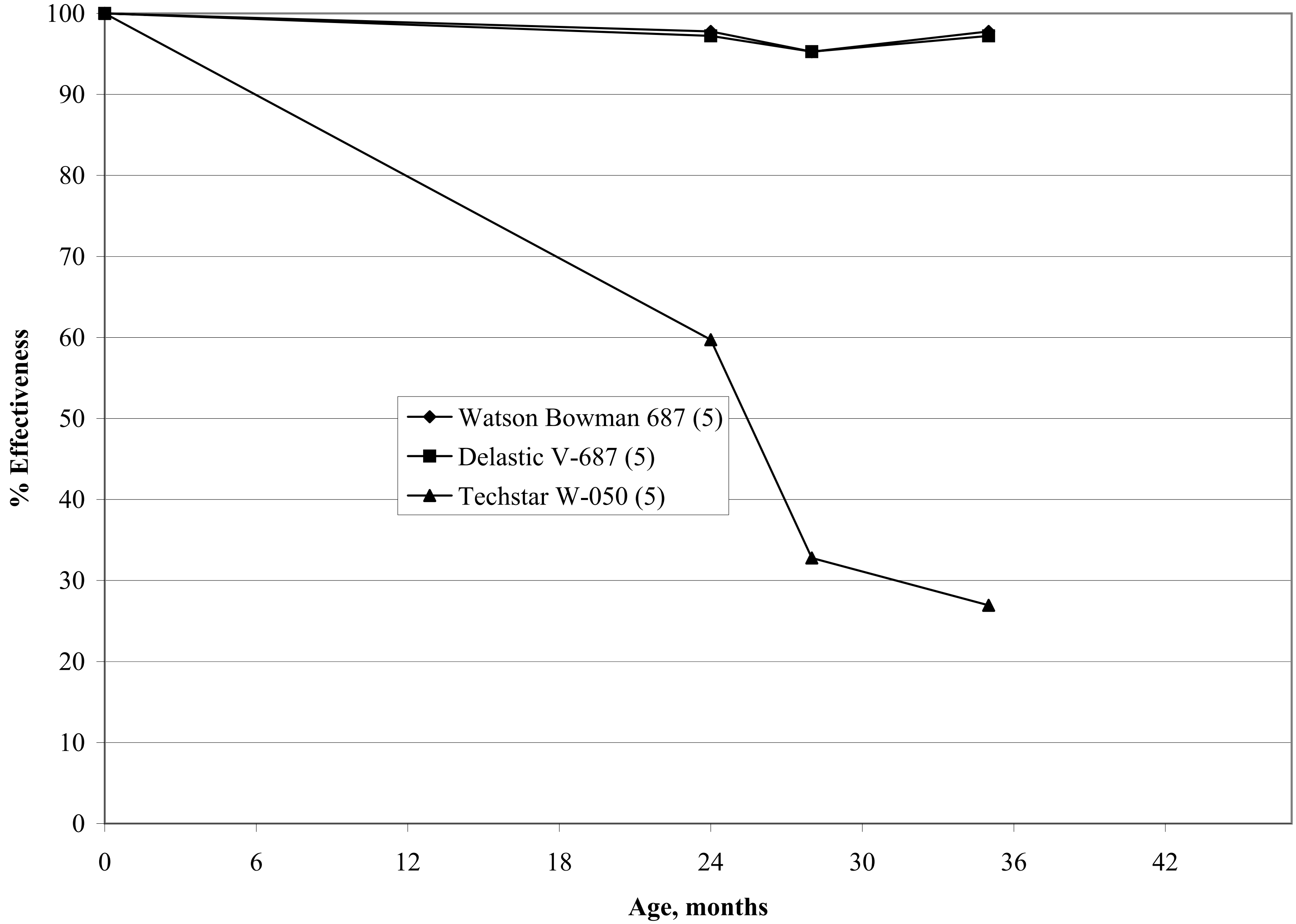


Figure 5.4 Deterioration of compression seals in the eastbound lanes as of EBOC00

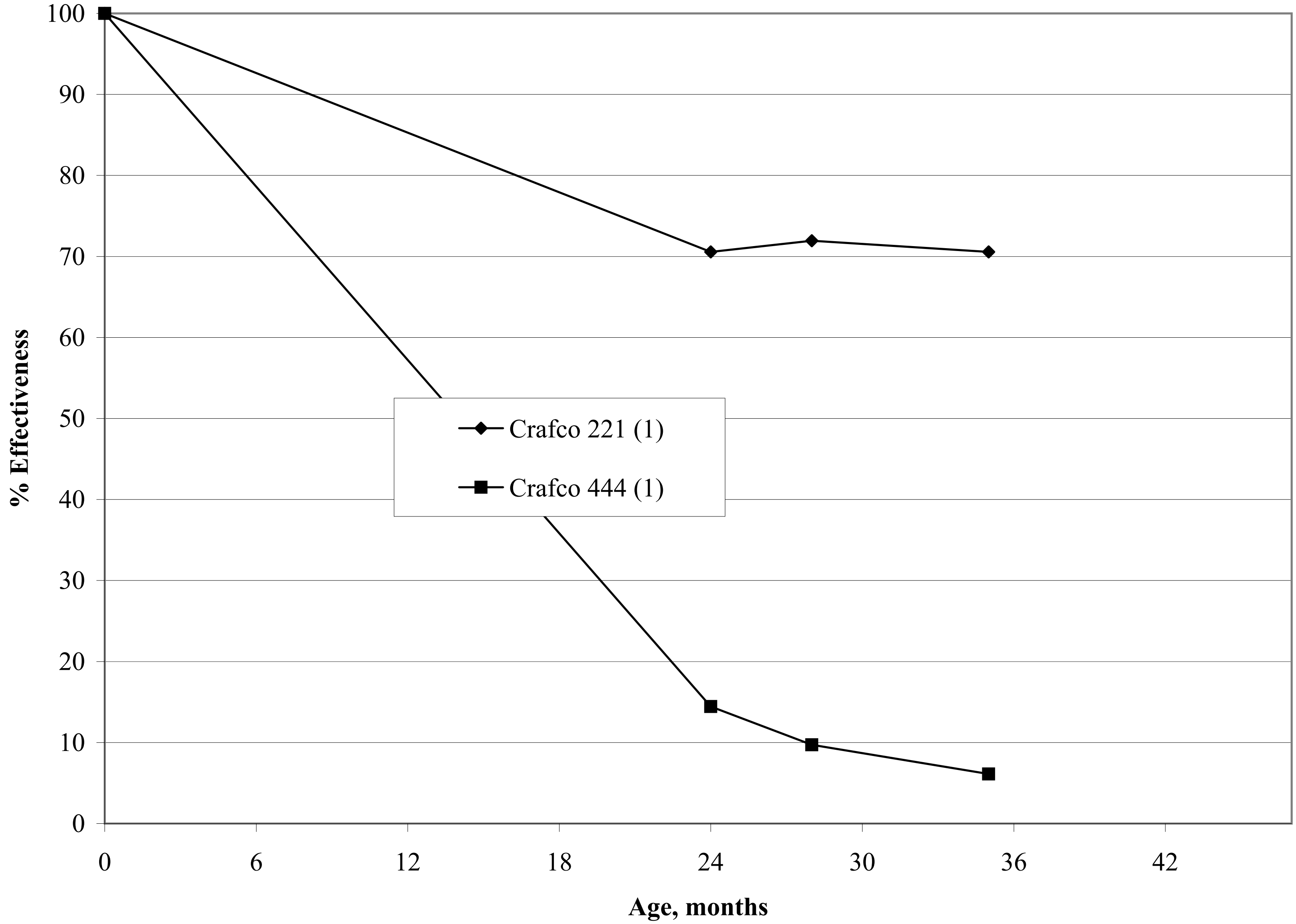


Figure 5.5 Deterioration of hot-applied sealants in the eastbound lanes as of EBOC00

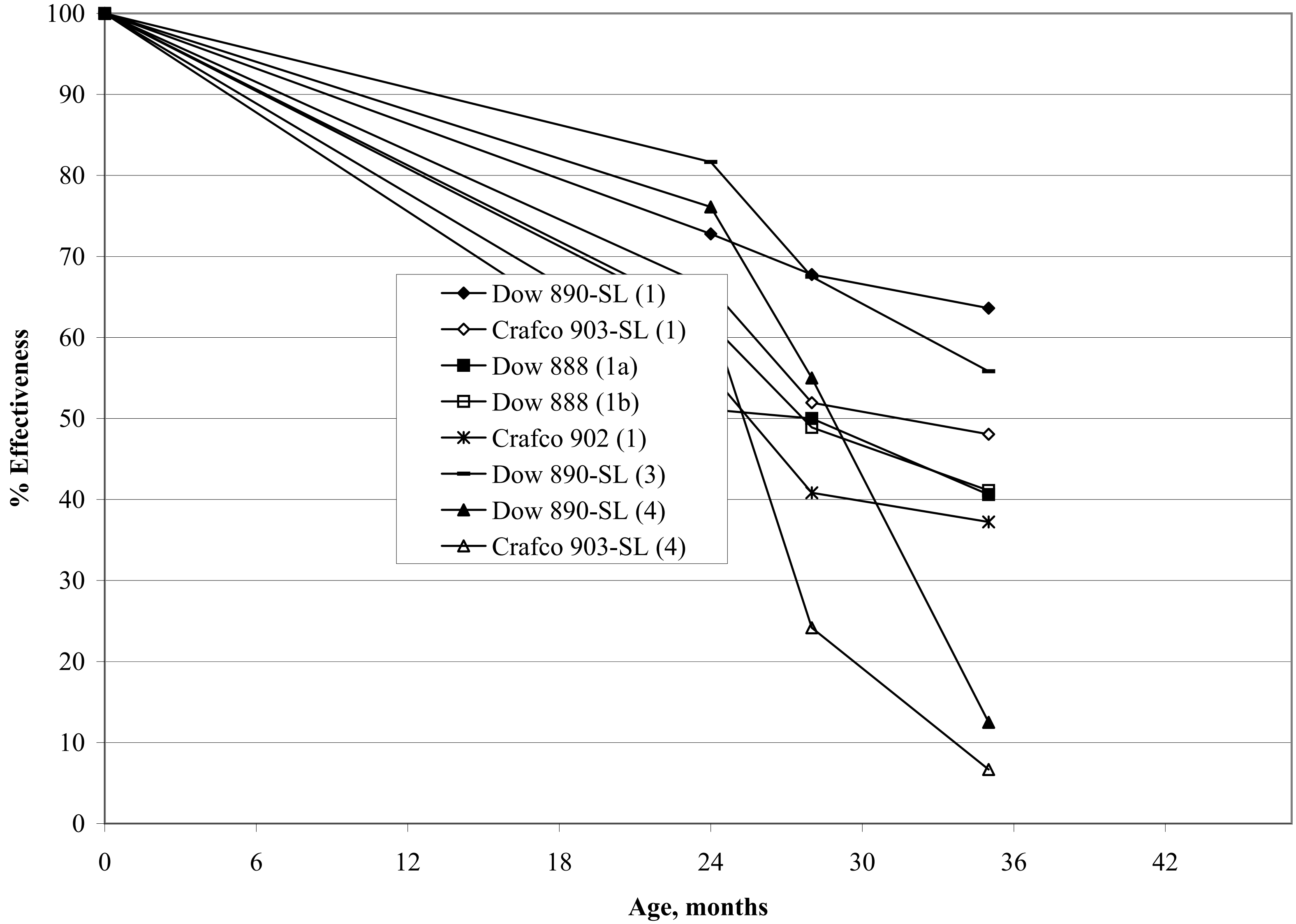


Figure 5.6 Deterioration of silicone sealants in the eastbound lanes as of EBOC00

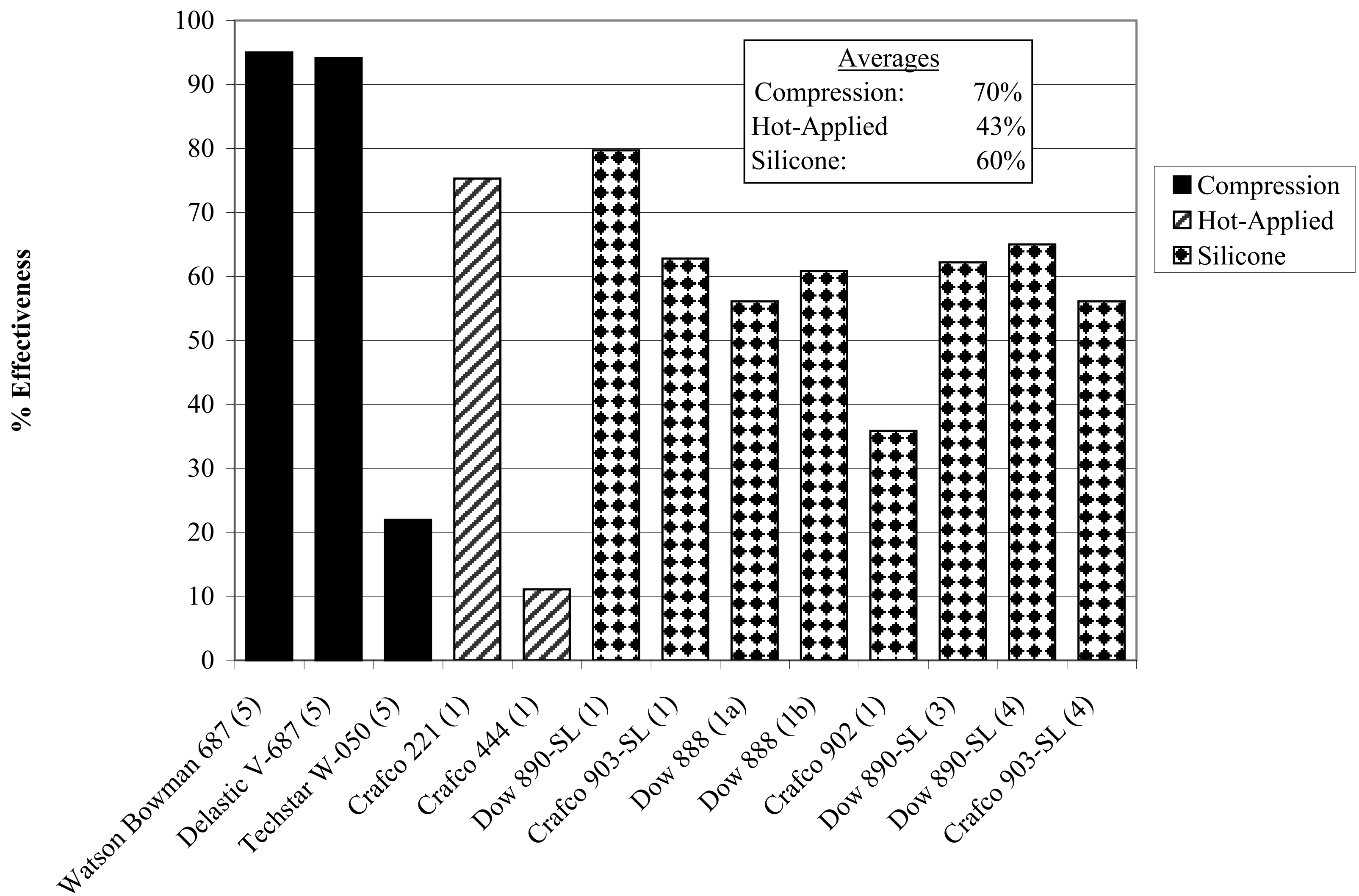


Figure 5.7 Comparison between silicone, hot-applied, and compression sealants during EBJN01

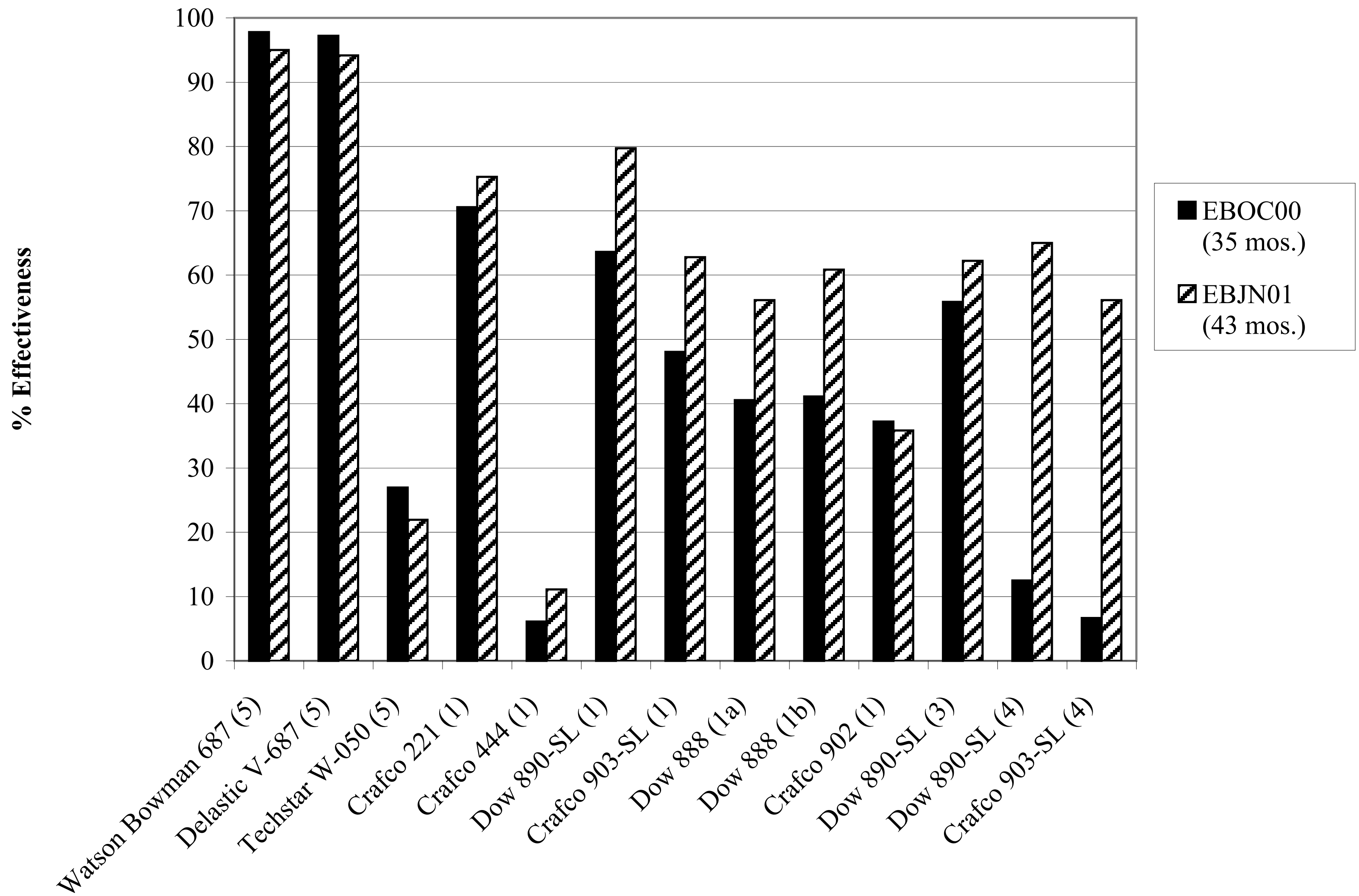
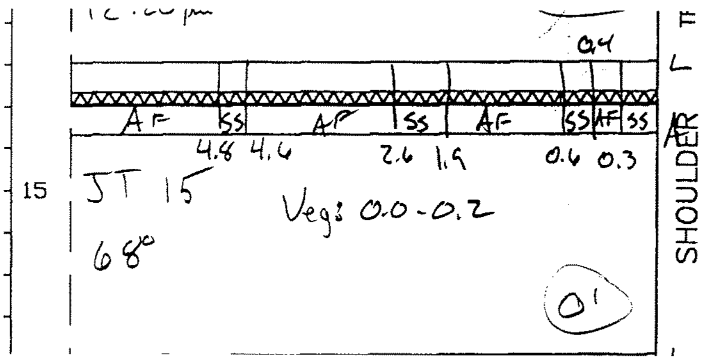
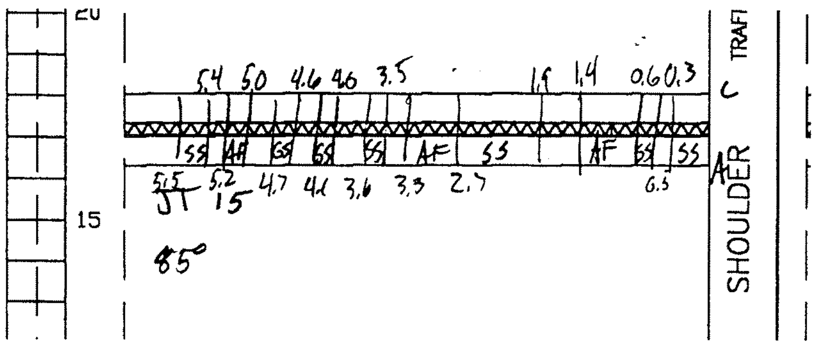


Figure 5.8 Deterioration of sealants from EBOC00 to EBJN01



(a) From Survey EBOC00



(b) From Survey EBJN01

Figure 5.9 Comparison between field logs from EBOC00 and EBJN01 for Joint 15 in the Crafco 903-SL (4) section.

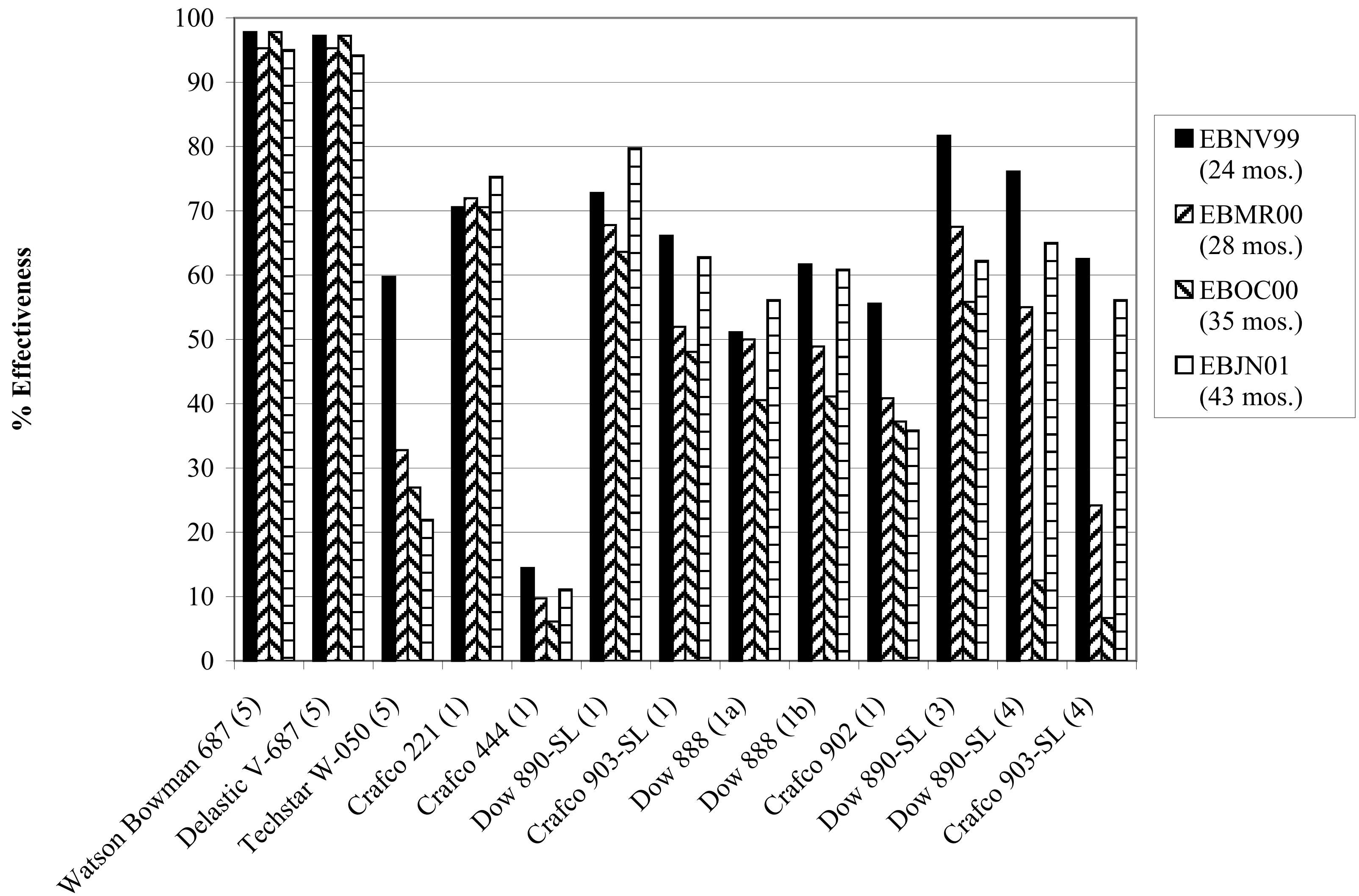


Figure 5.10 Deterioration of sealants from EBNV99 to EBJN01

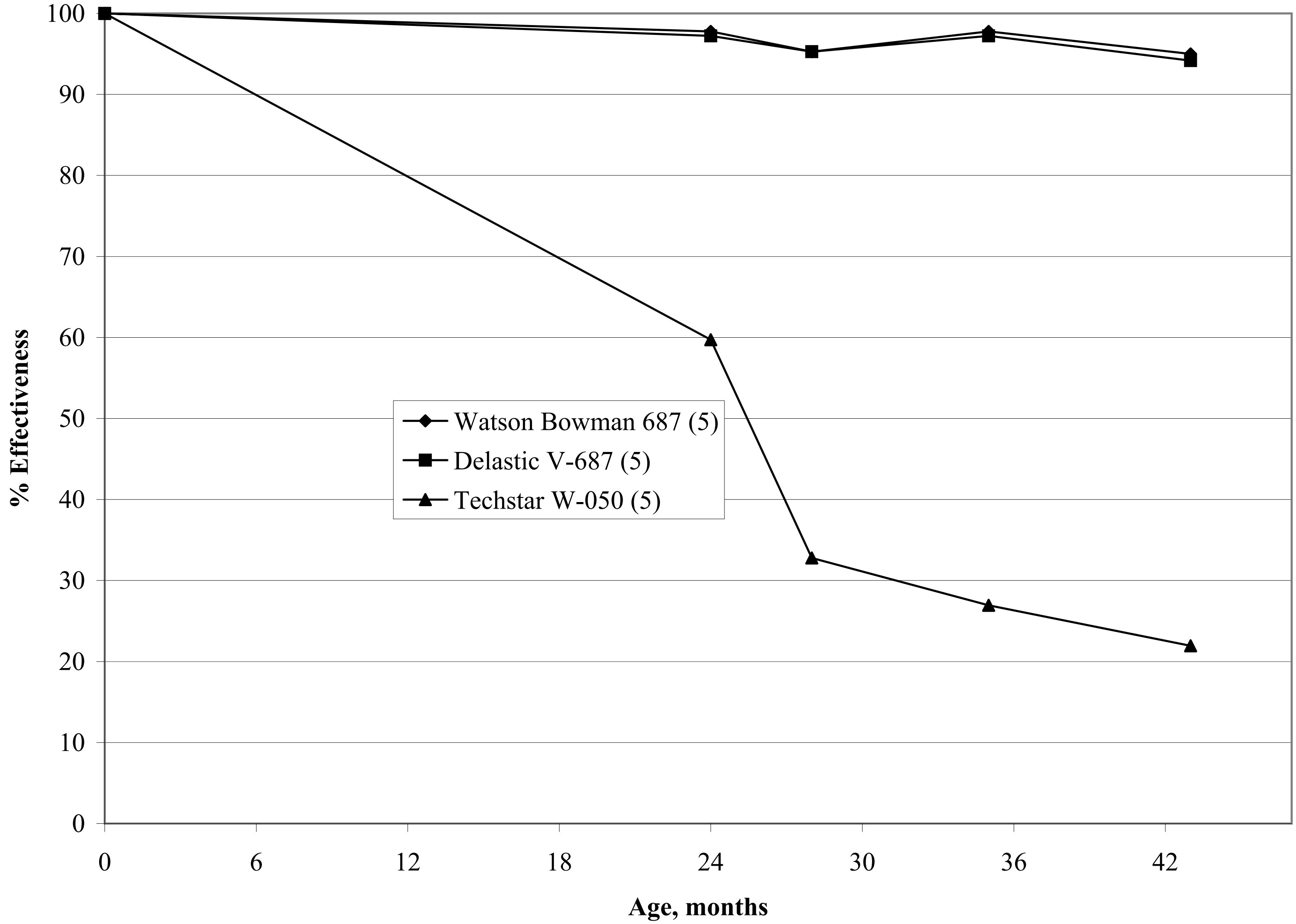


Figure 5.11 Deterioration of compression seals in the eastbound lanes as of EBJN01

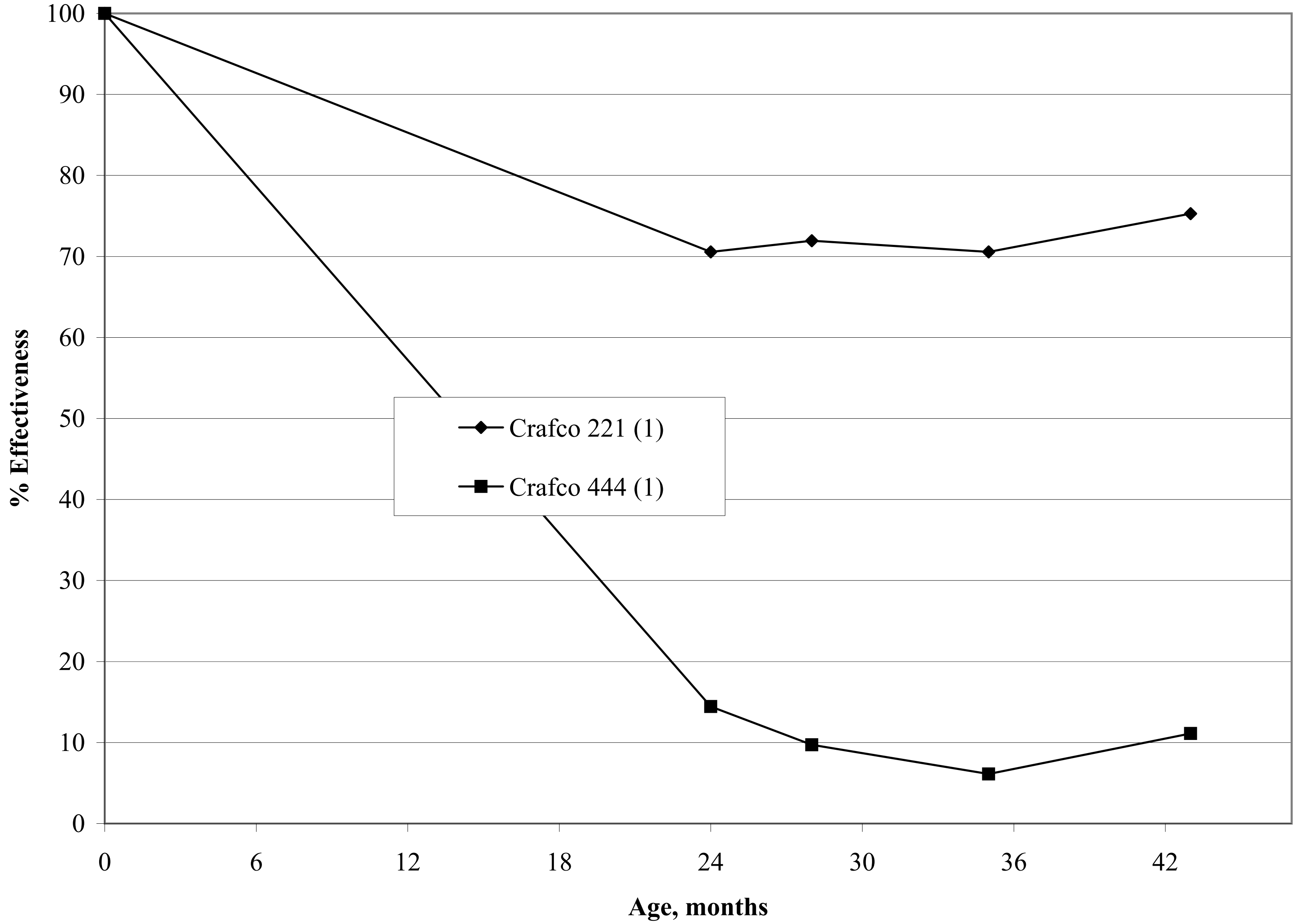


Figure 5.12 Deterioration of hot-applied sealants in the eastbound lanes as of EBJN01

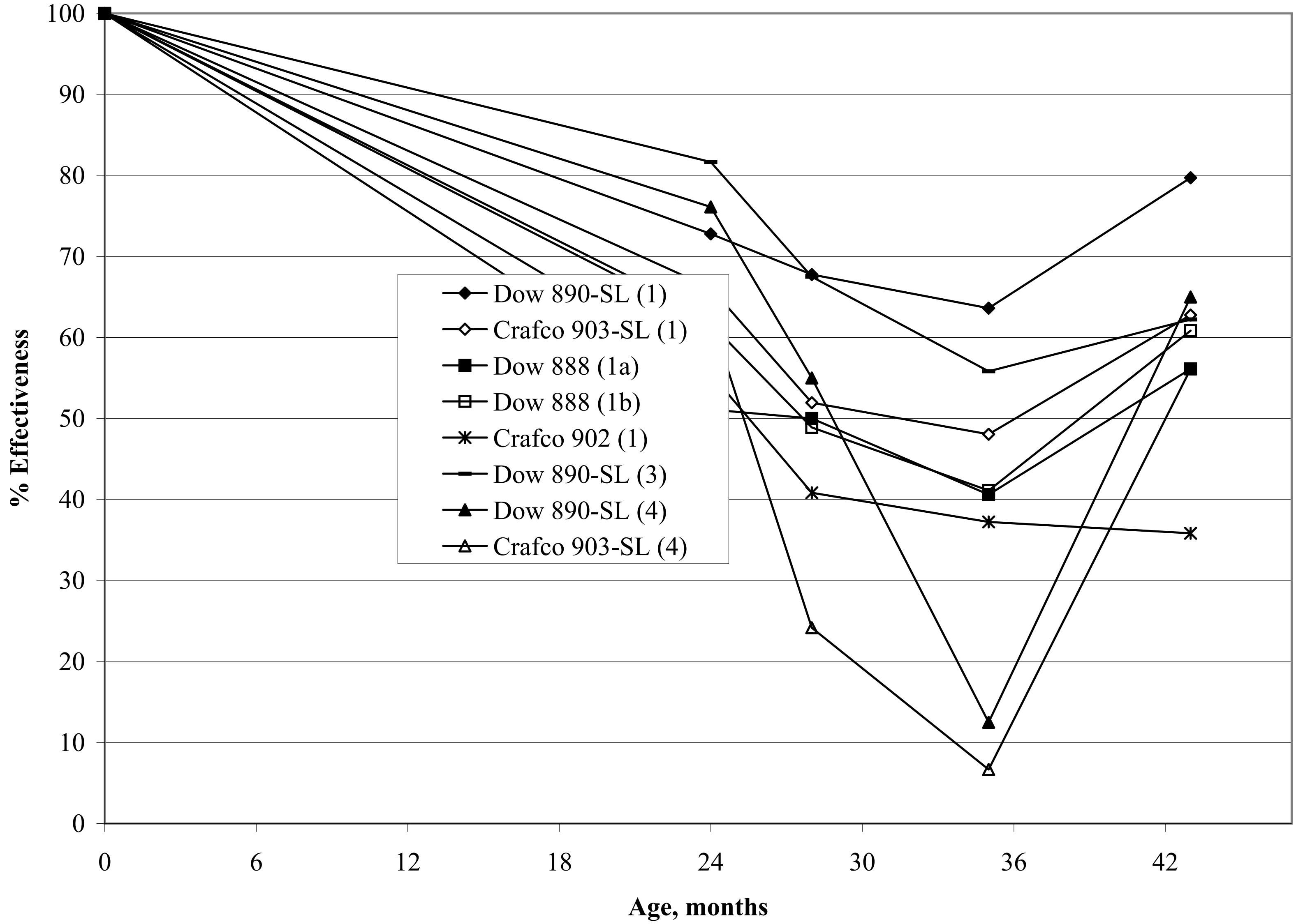


Figure 5.13 Deterioration of silicone sealants in the eastbound lanes as of EBJN01

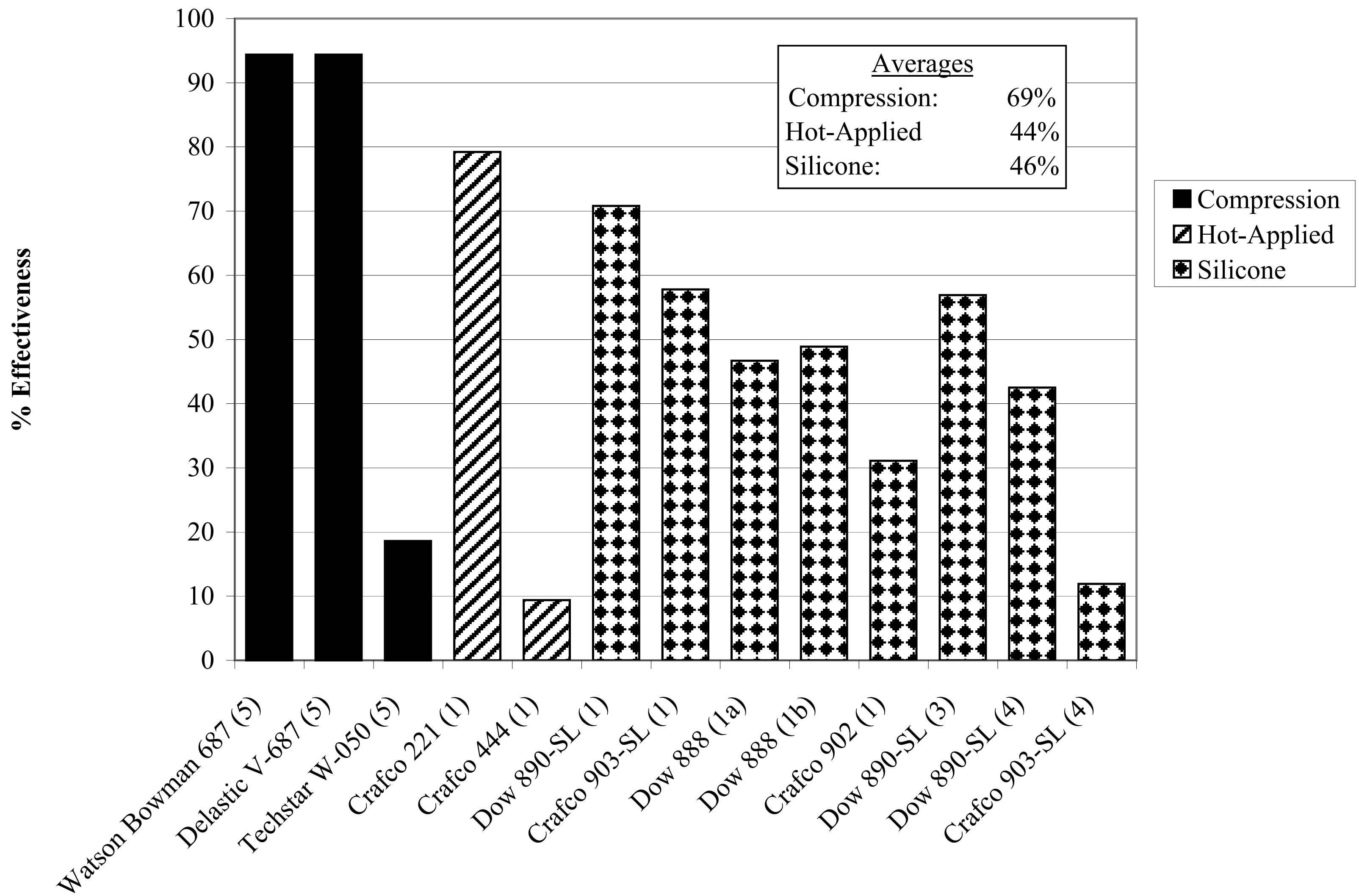


Figure 5.14 Comparison between silicone, hot-applied, and compression sealants during EBOC01

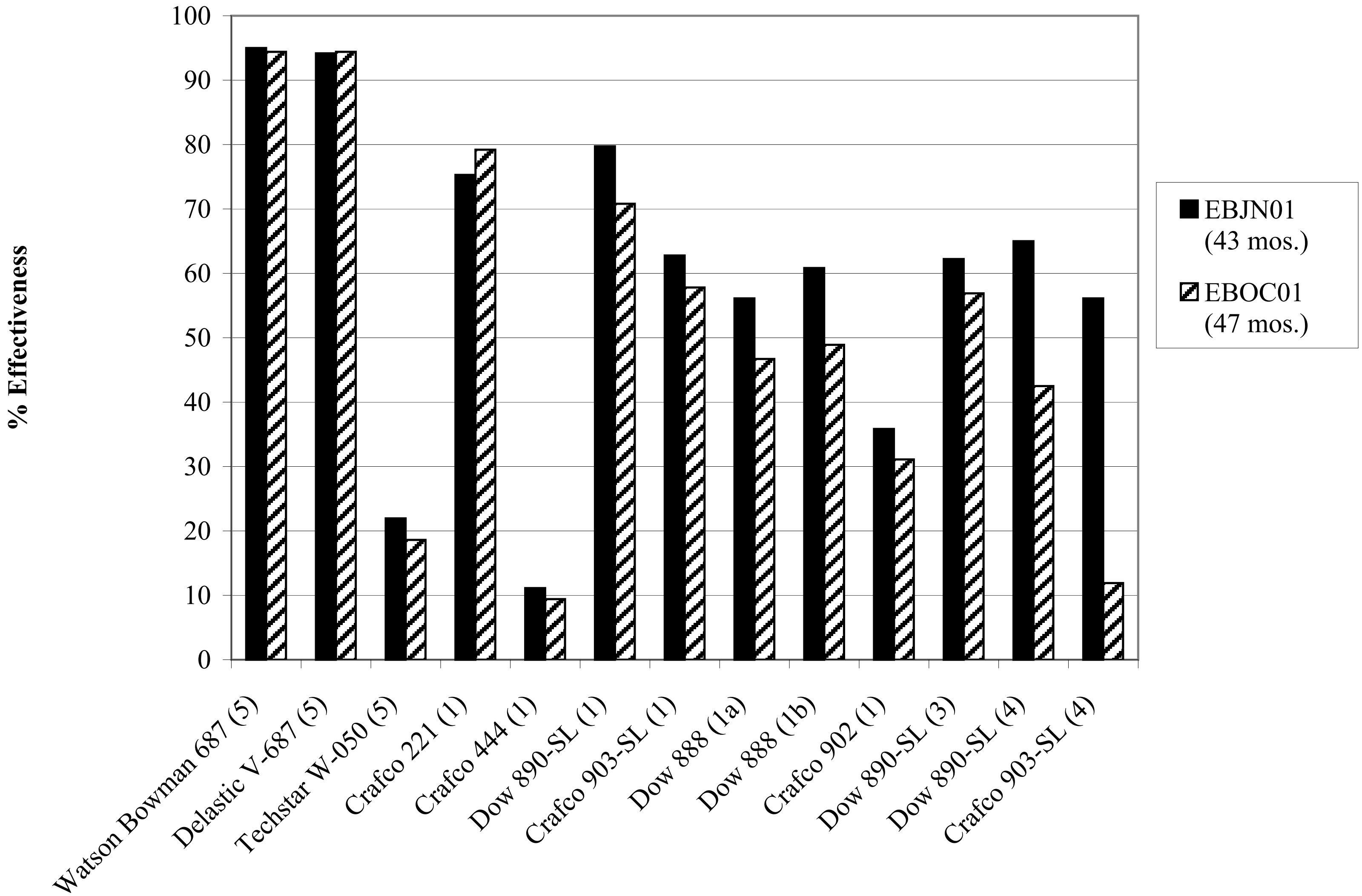


Figure 5.15 Deterioration of sealants from EBJN01 to EBOC01

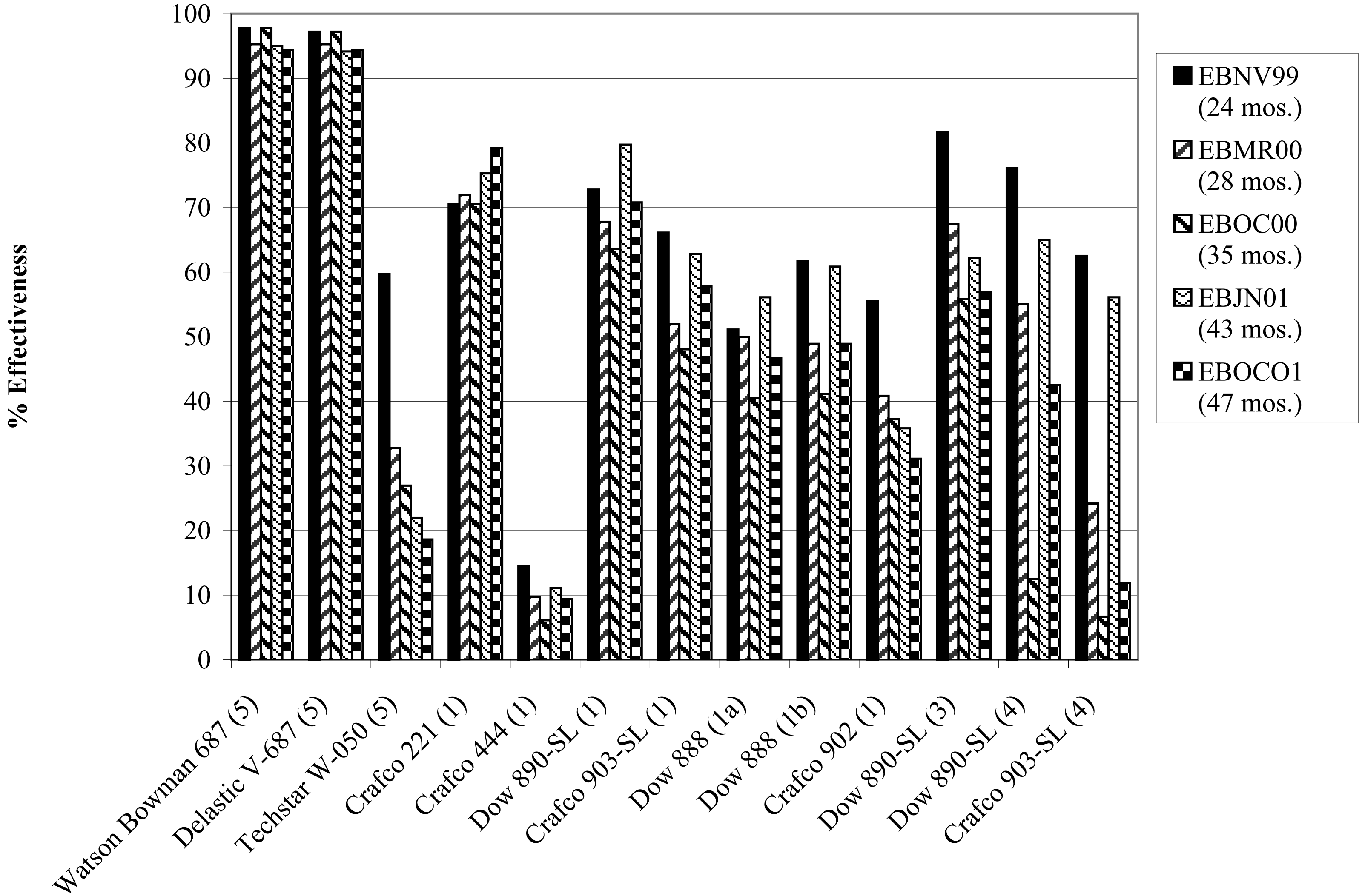


Figure 5.16 Deterioration of sealants from EBNV99 to EBOC01

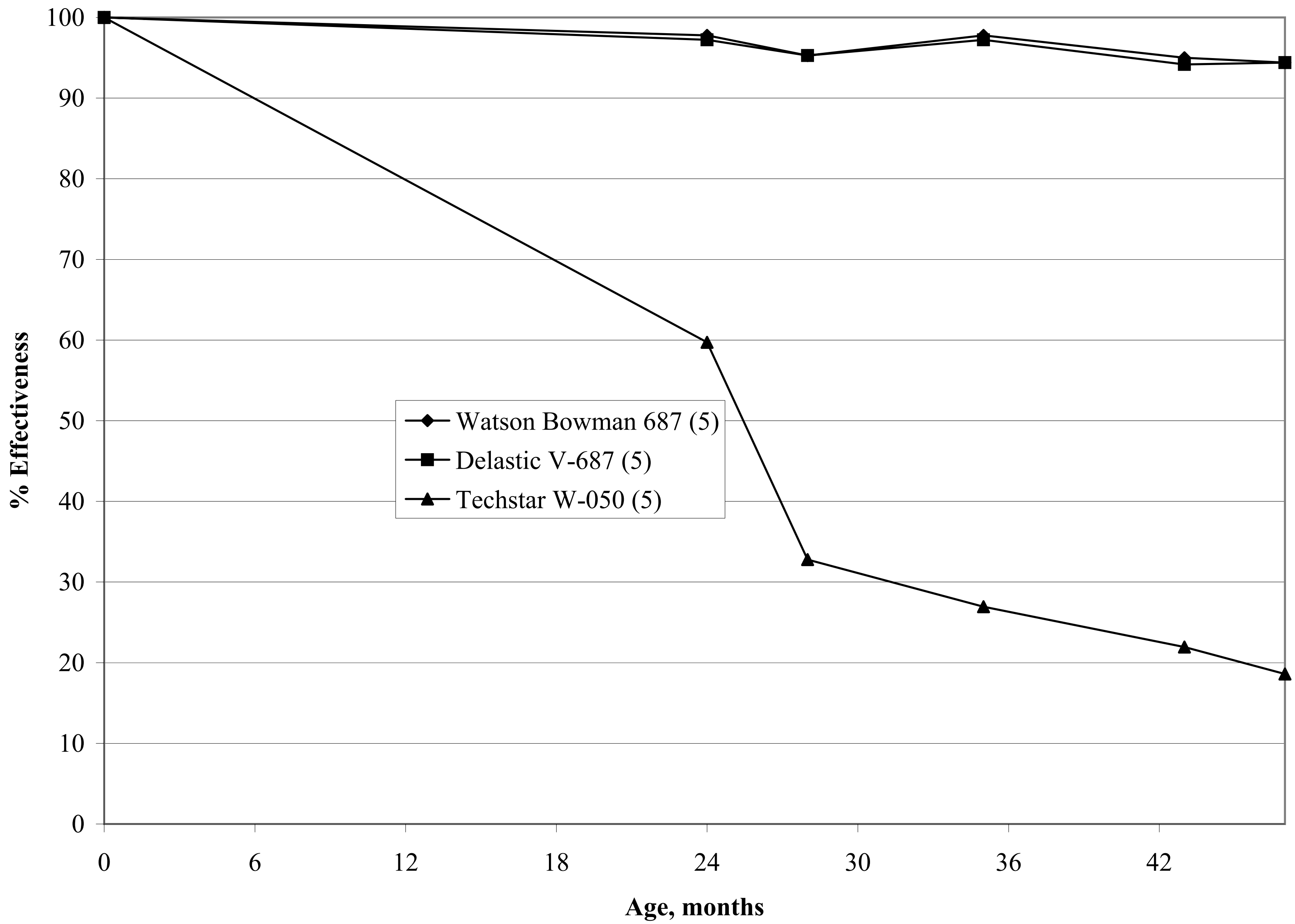


Figure 5.17 Deterioration of compression seals in the eastbound lanes as of EBOC01

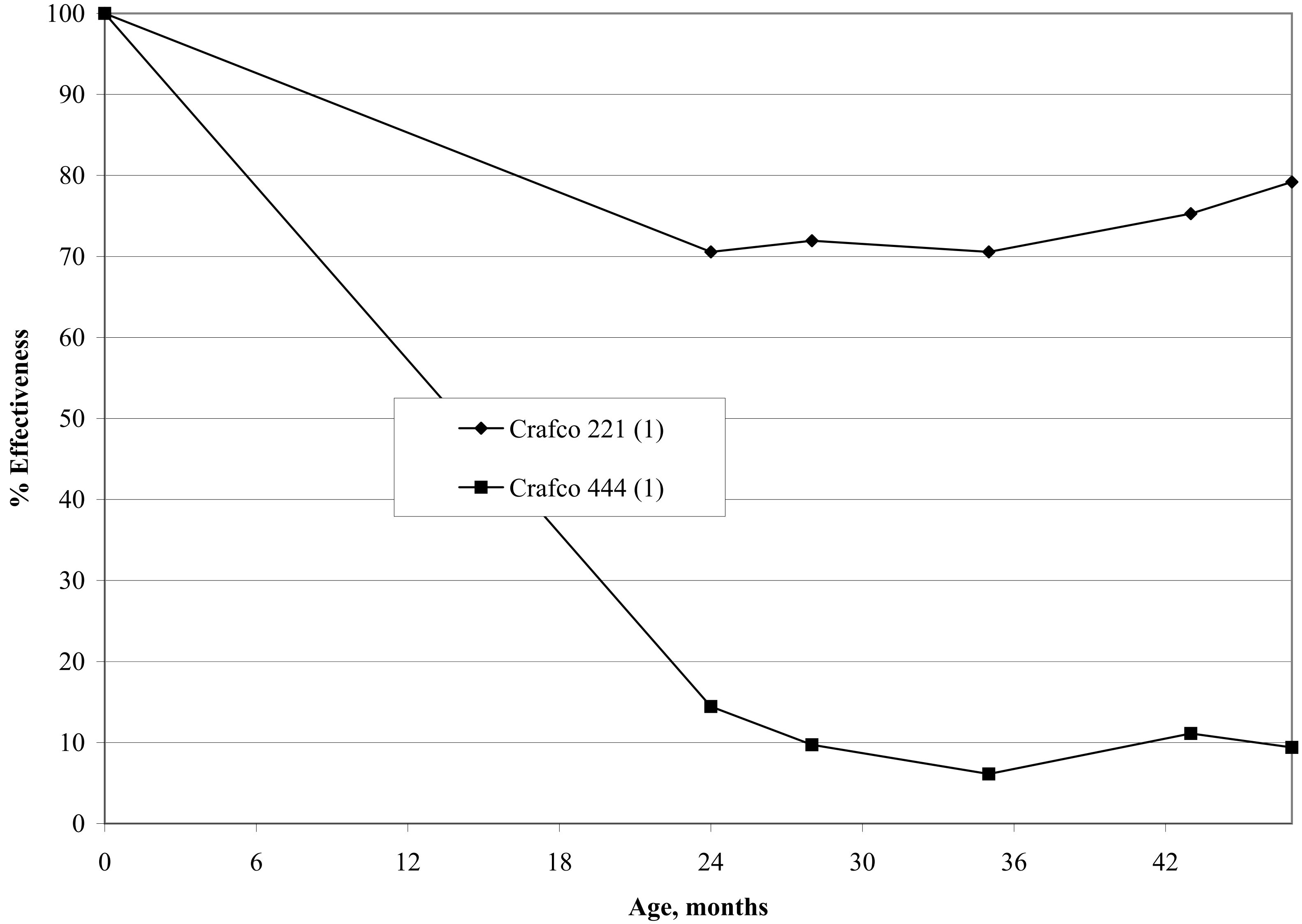


Figure 5.18 Deterioration of hot-applied sealants in the eastbound lanes as of EBOC01

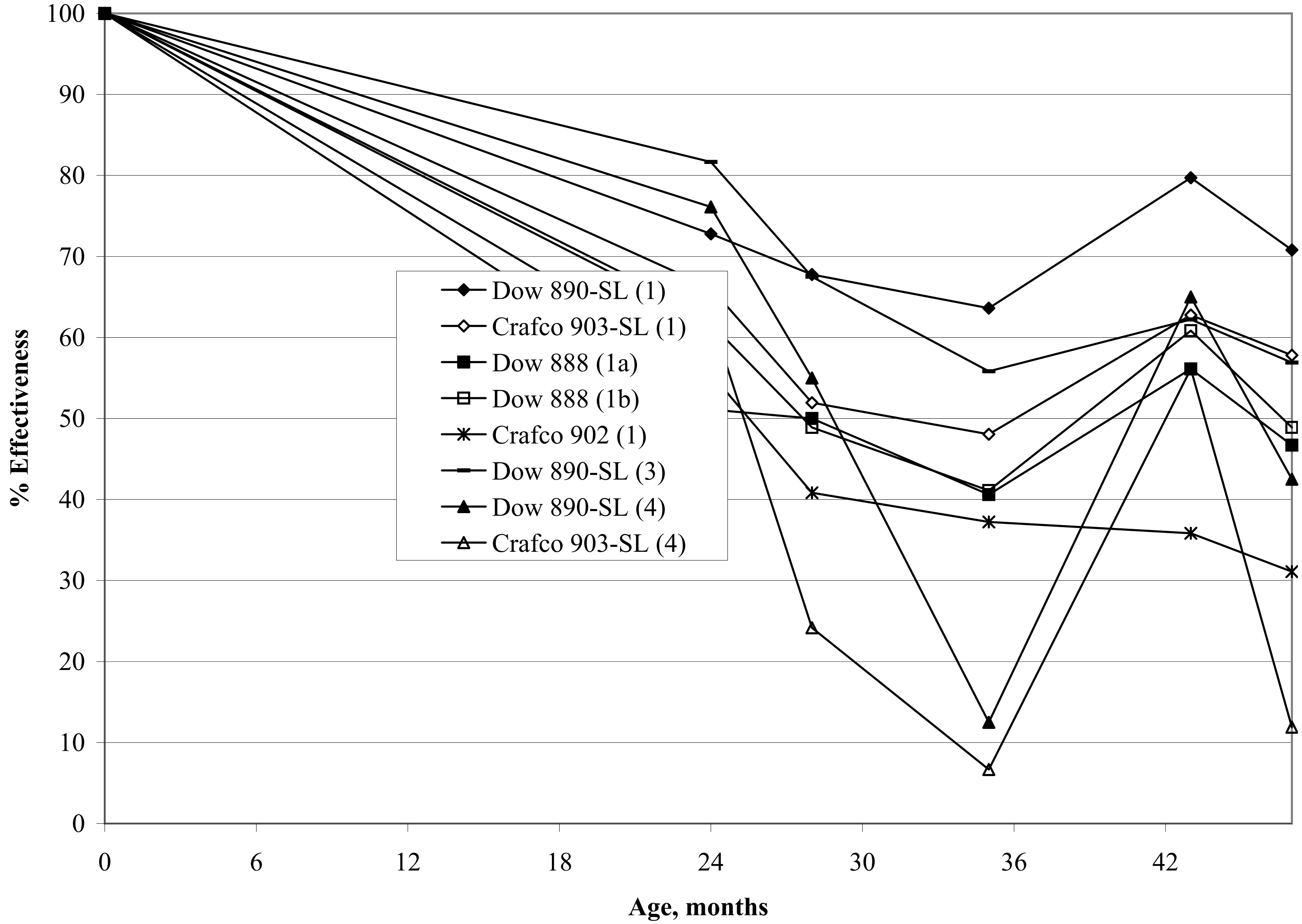


Figure 5.19 Deterioration of silicone sealants in the eastbound lanes as of EBOC01

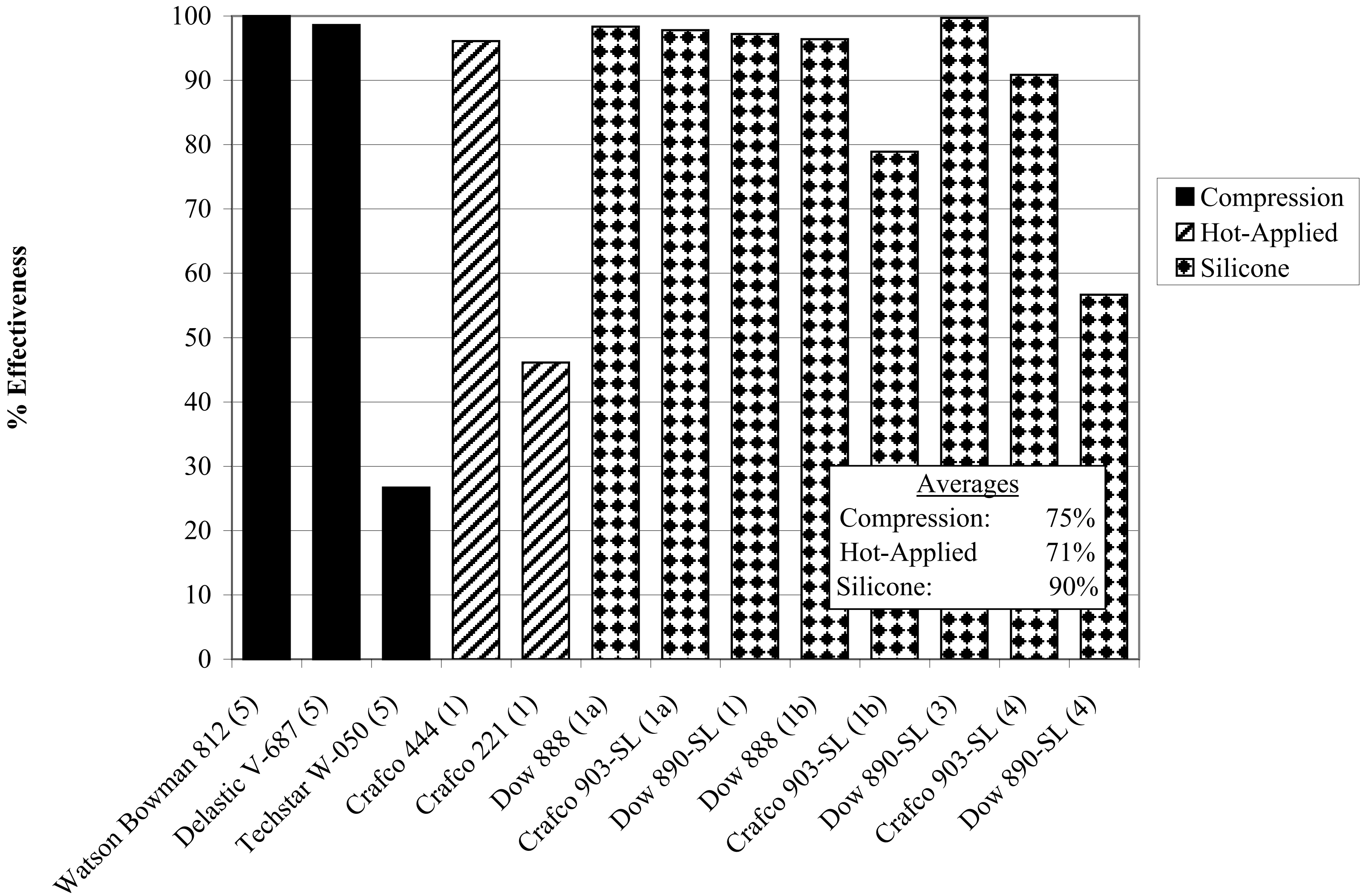


Figure 5.20 Comparison between silicone, hot-applied and compression sealants during WBOC00

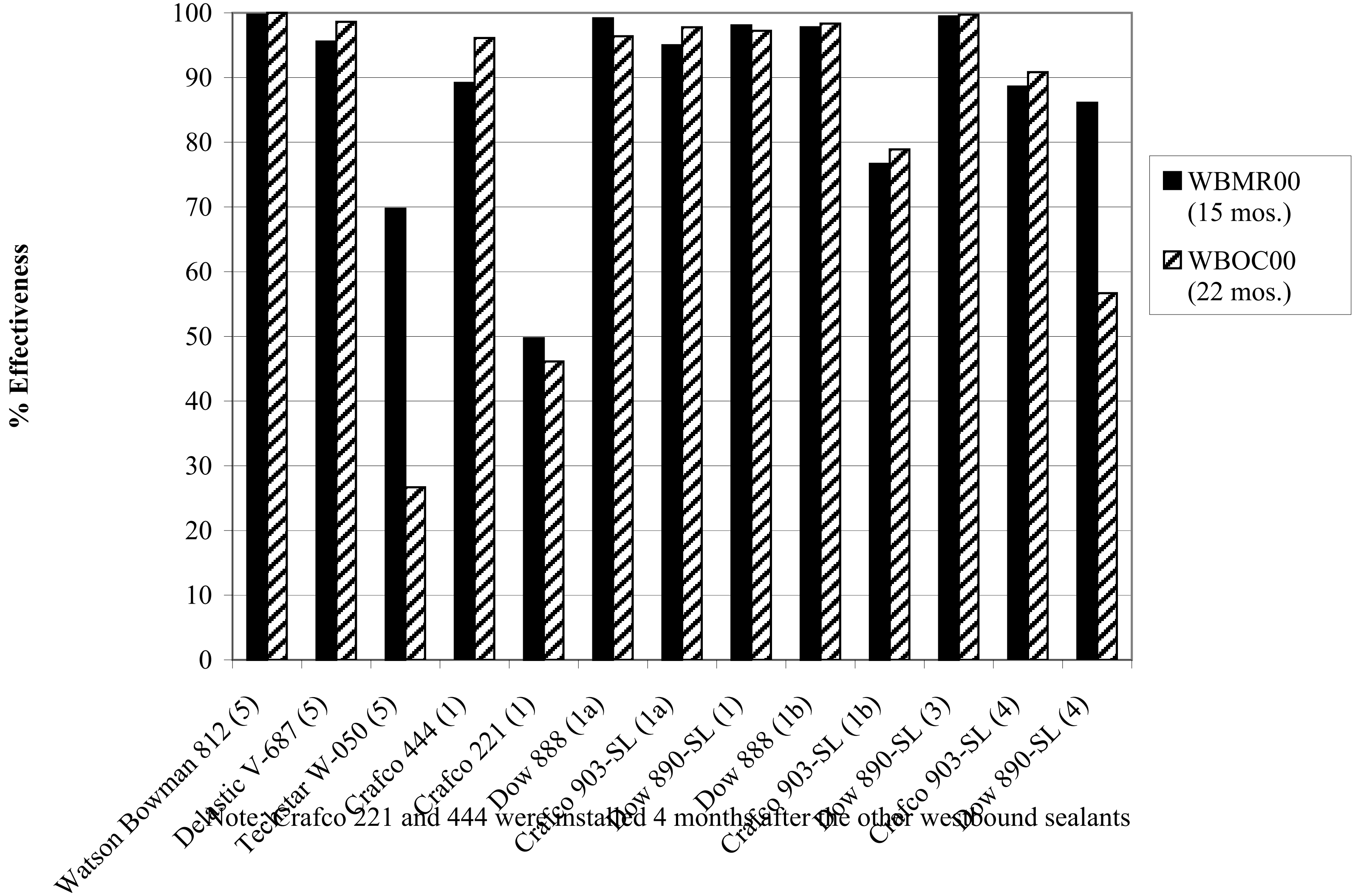


Figure 5.21 Deterioration of sealants from WBMR00 to WBOC00

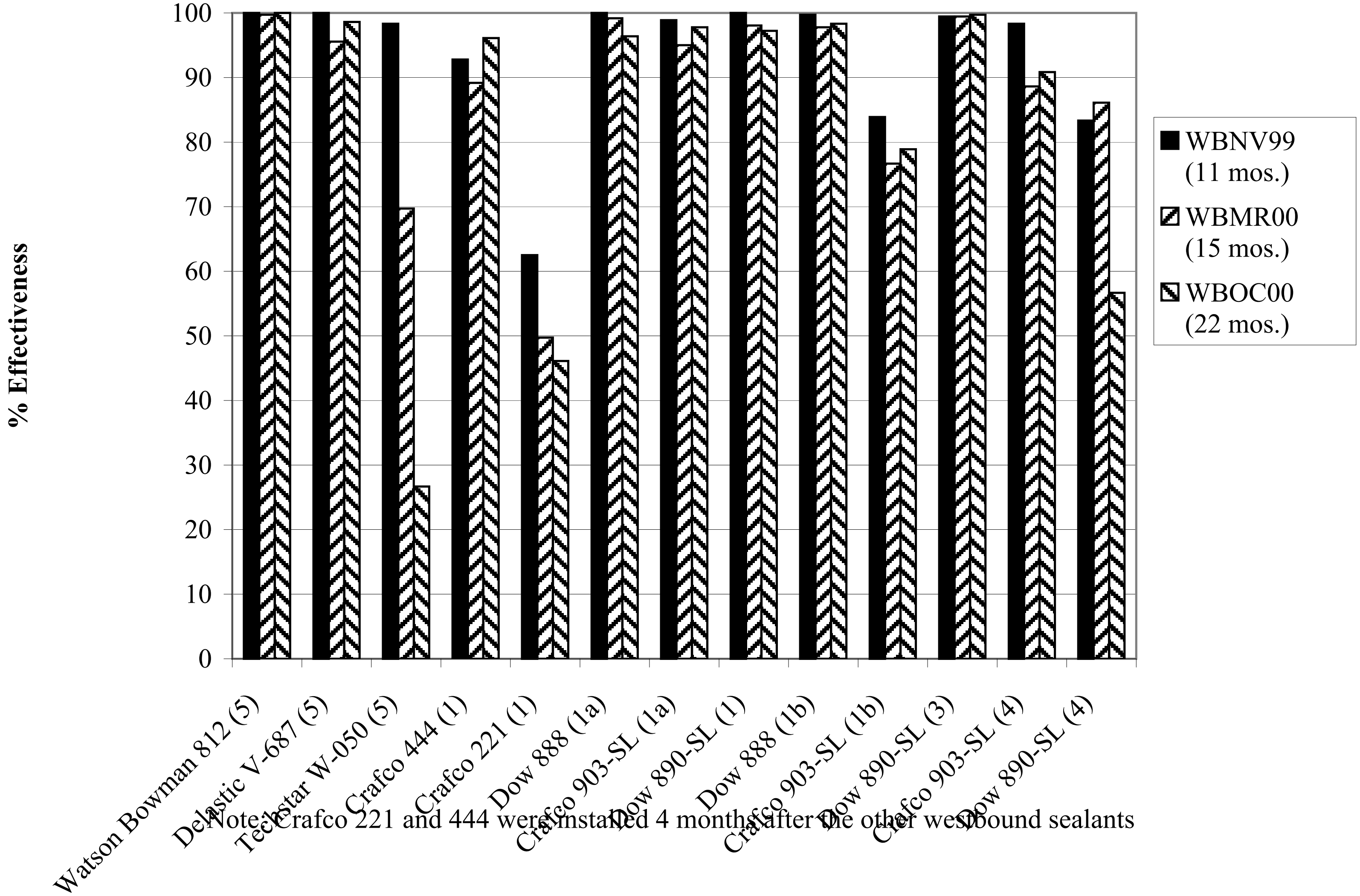


Figure 5.22 Deterioration of sealants from WBNV99 to WBOC00

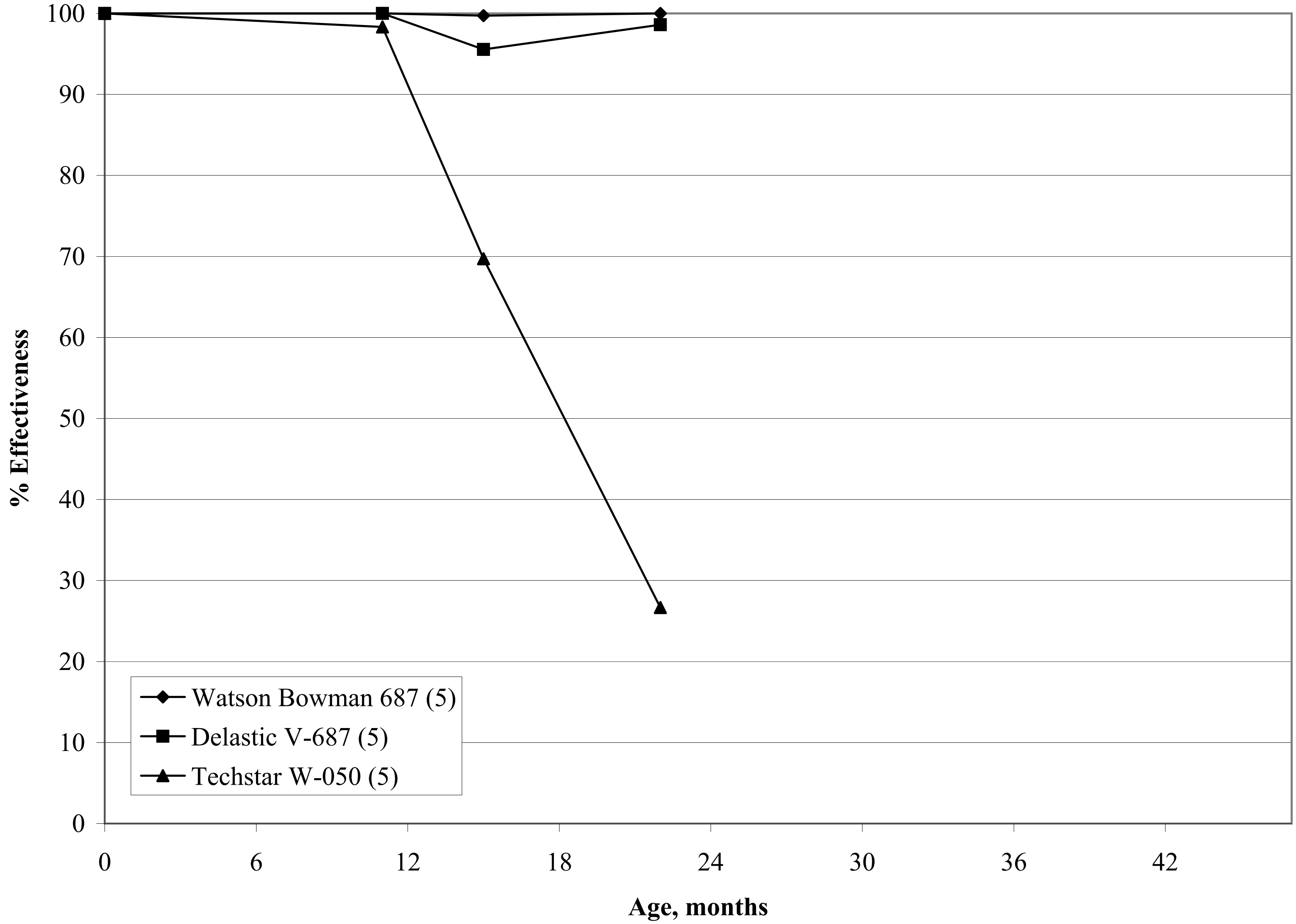


Figure 5.23 Deterioration of compression seals in the westbound lanes as of WBOC00

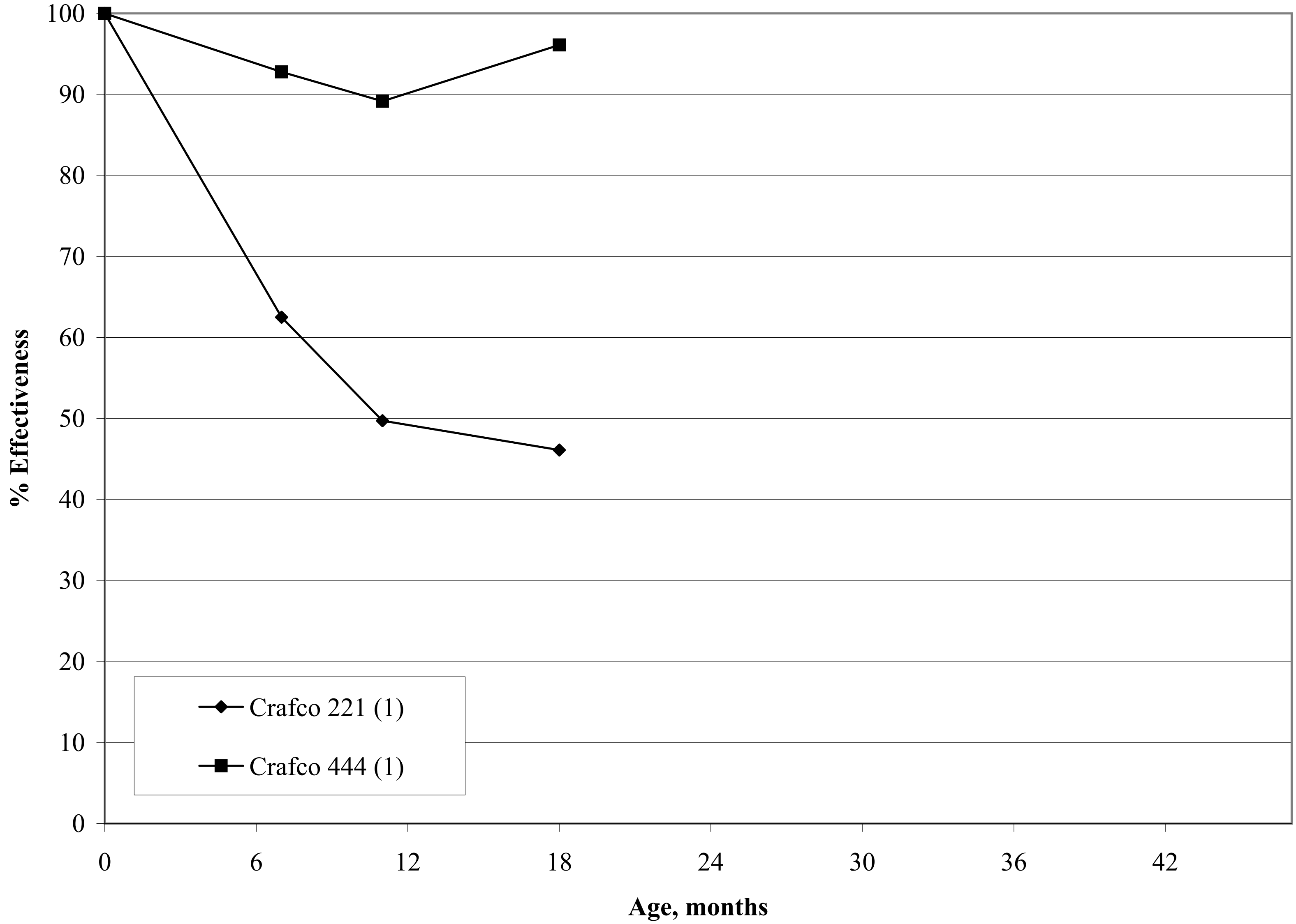


Figure 5.24 Deterioration of hot-applied sealants in the westbound lanes as of WBOC00

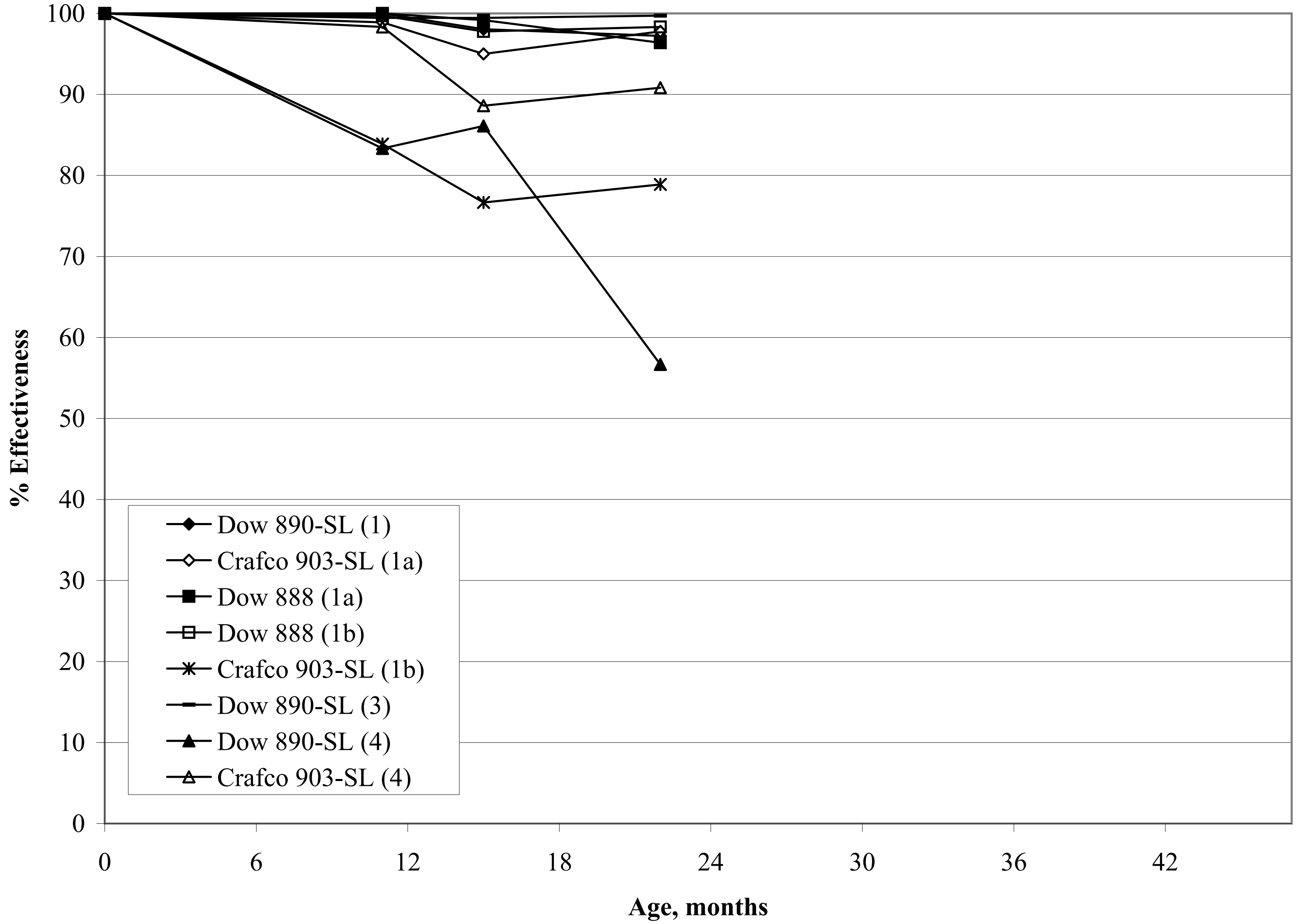


Figure 5.25 Deterioration of silicone sealants in the westbound lanes as of WBOC00

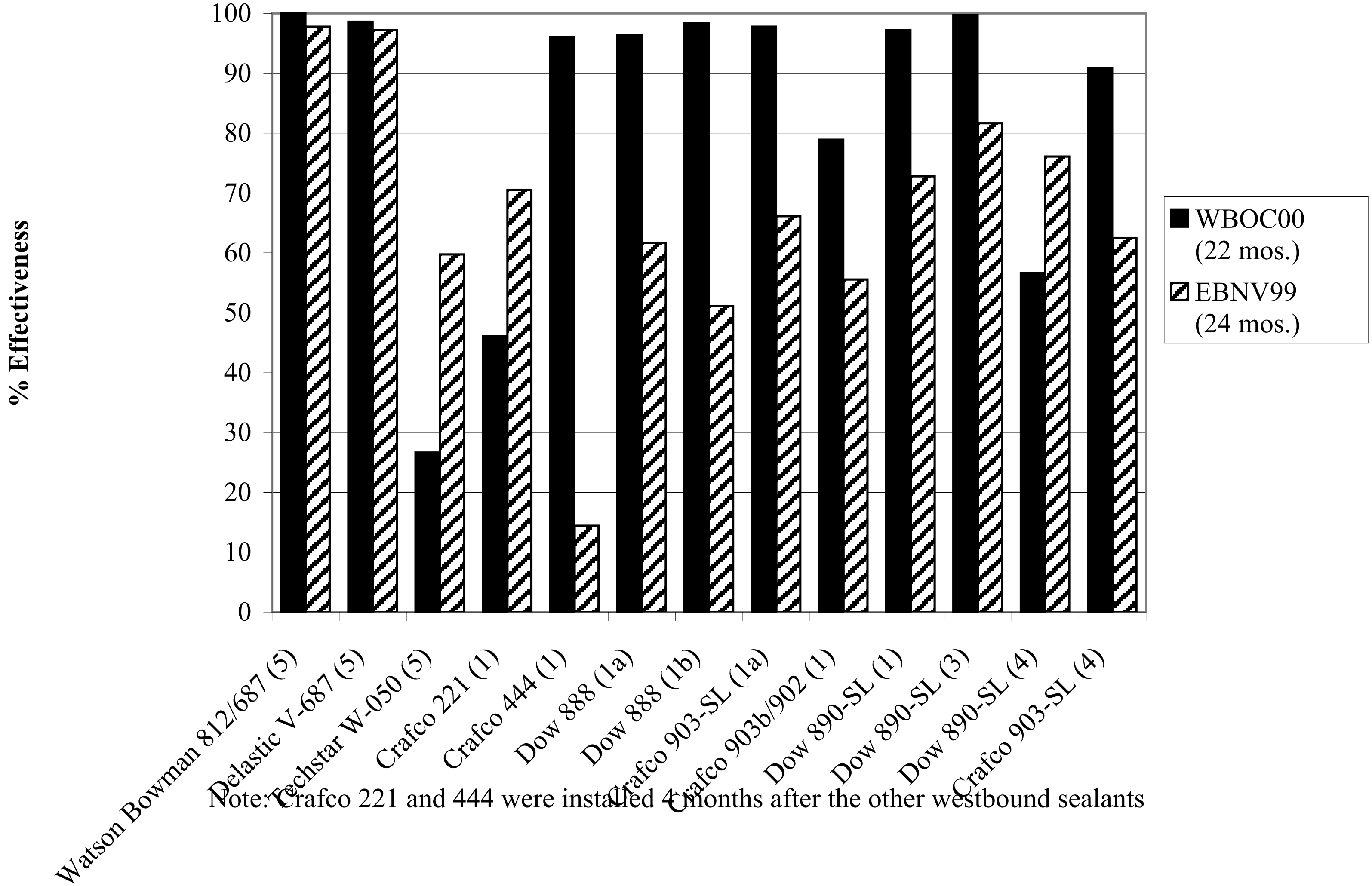


Figure 5.26 Comparison of eastbound and westbound lane sealants after 2 years in service

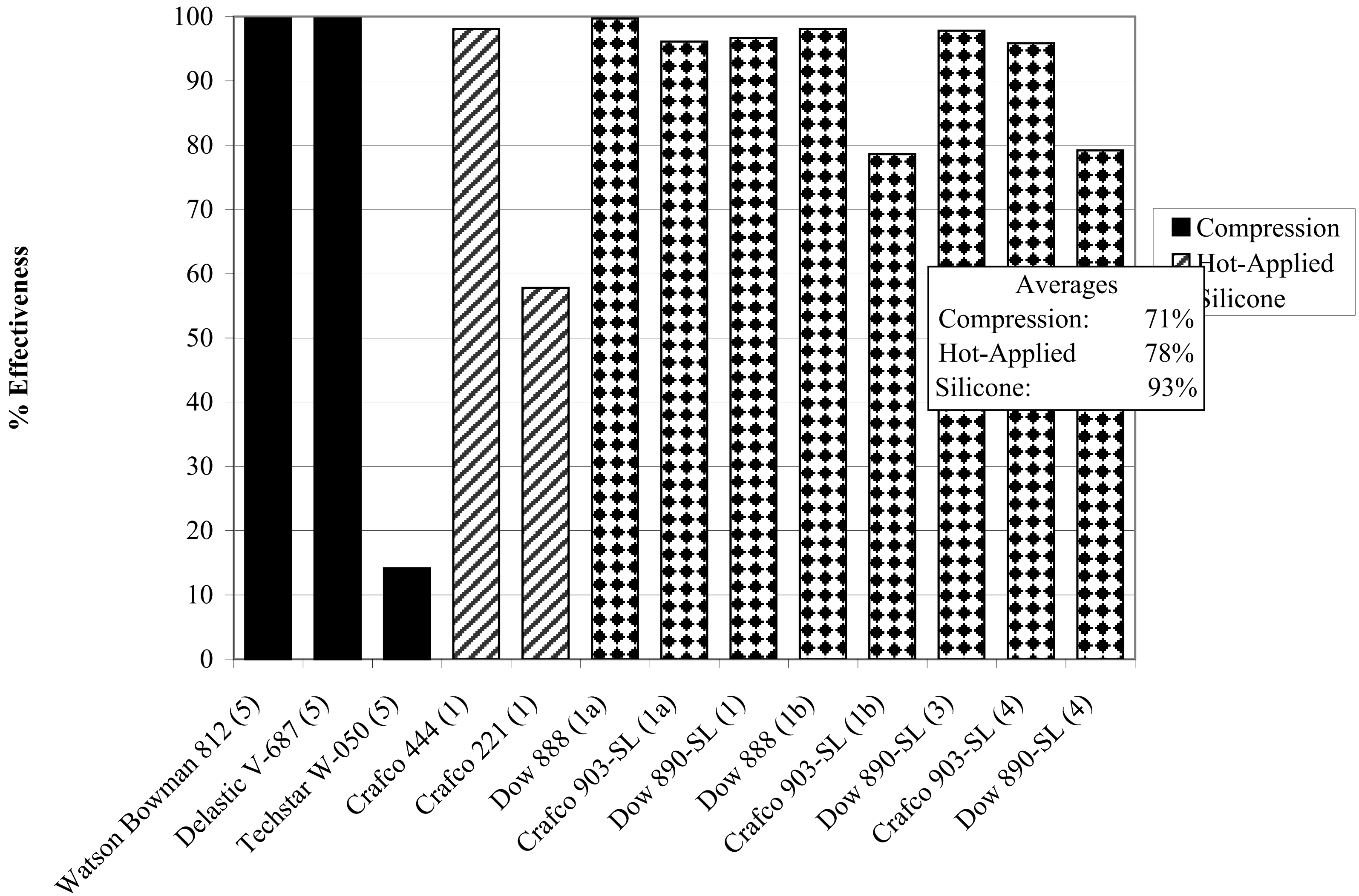


Figure 5.27 Comparison between silicone, hot-applied and compression sealants during WBJN01

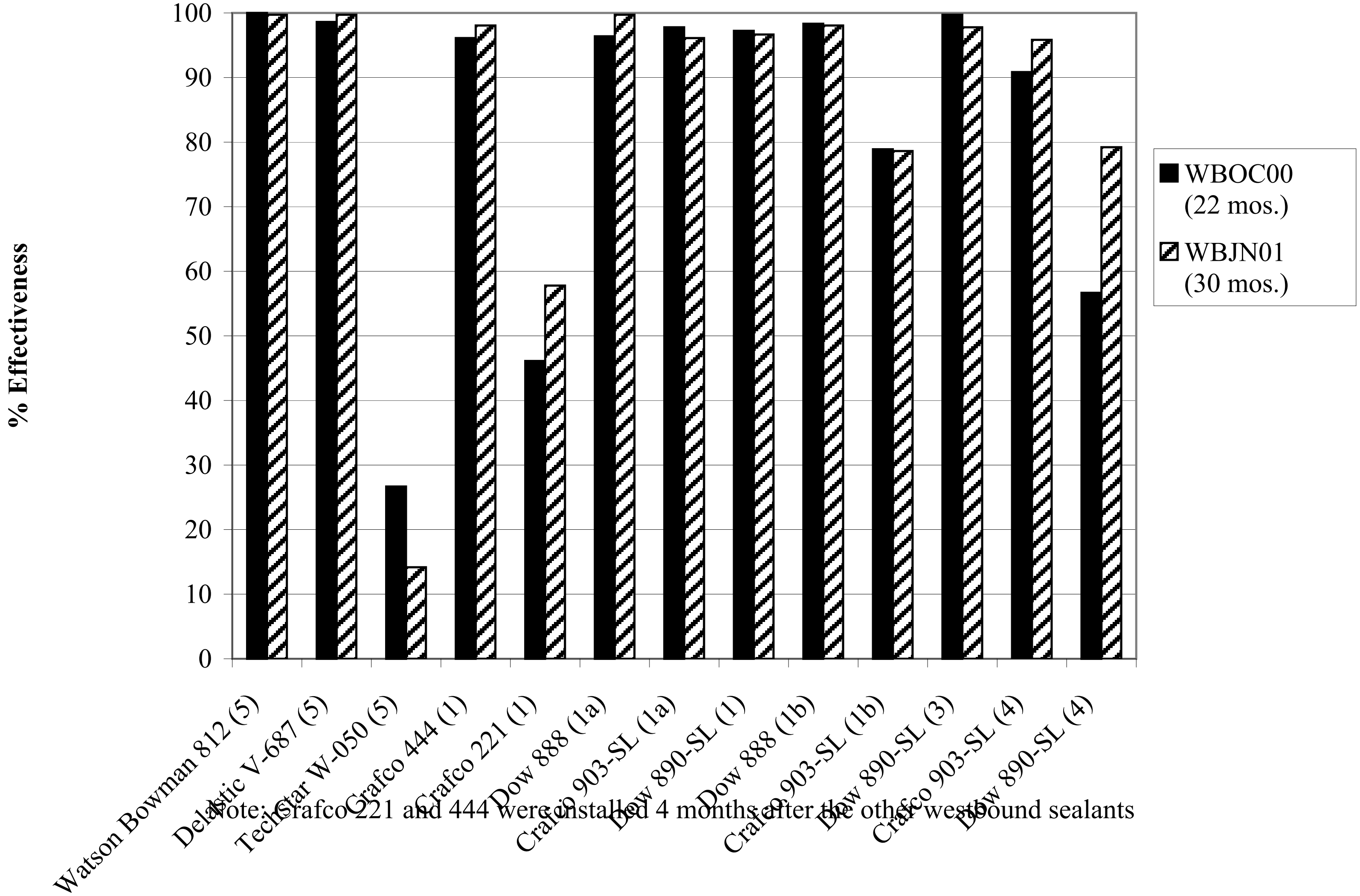
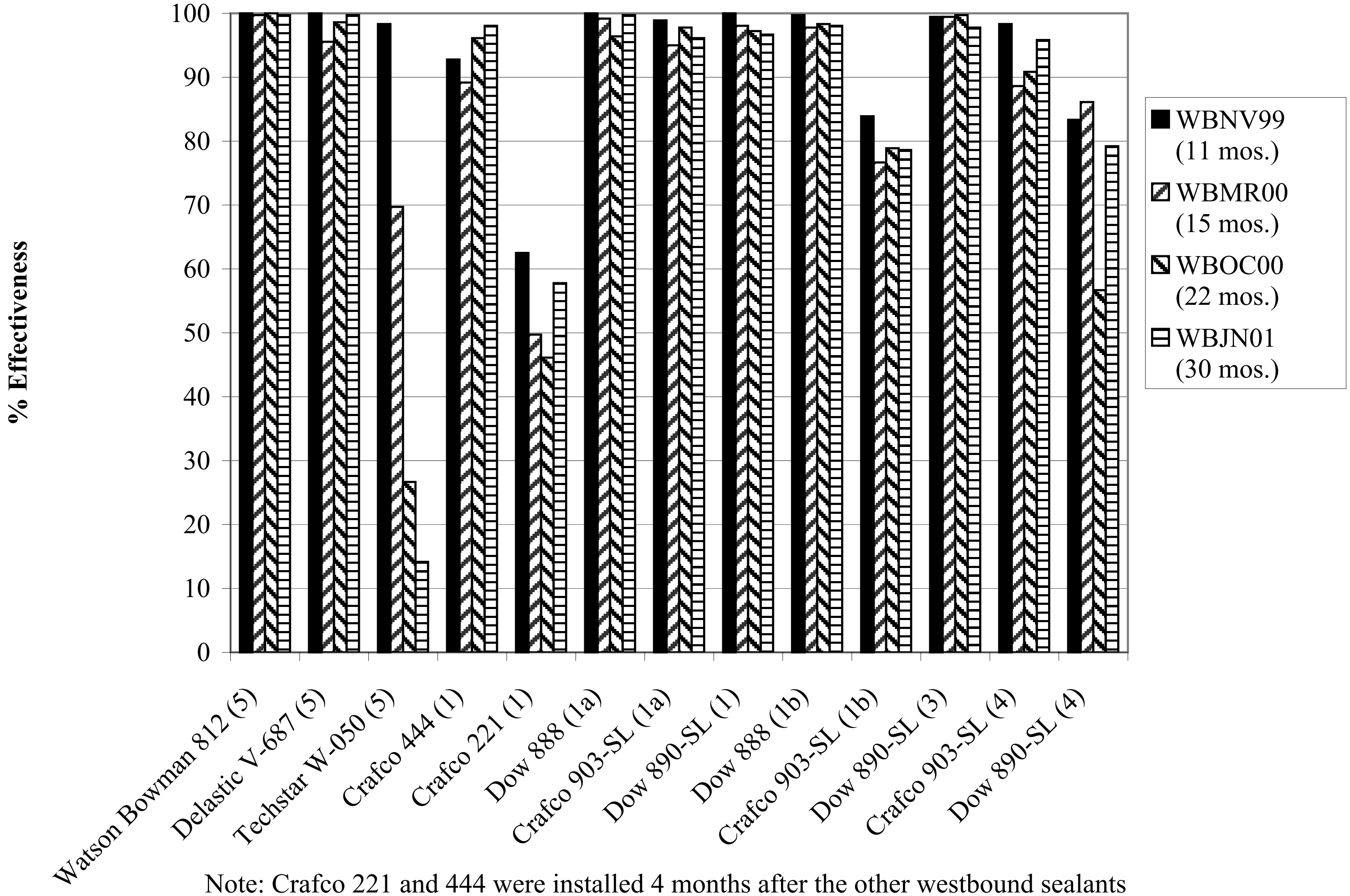


Figure 5.28 Deterioration of sealants from WBOC00 to WBJN01



Note: Crafco 221 and 444 were installed 4 months after the other westbound sealants

Figure 5.29 Deterioration of sealants from WBNV99 to WBJN01

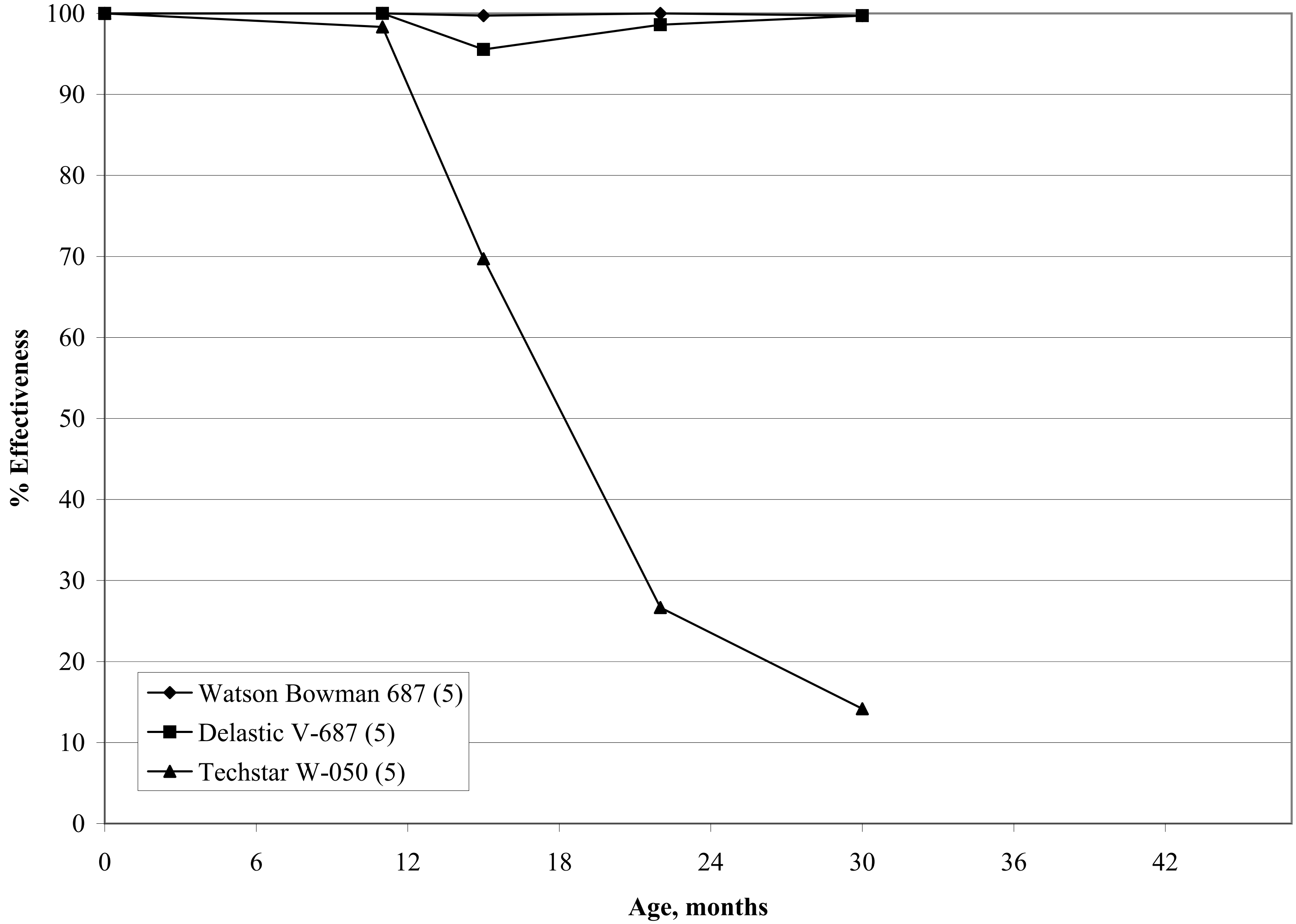


Figure 5.30 Deterioration of compression seals in the westbound lanes as of WBJN01

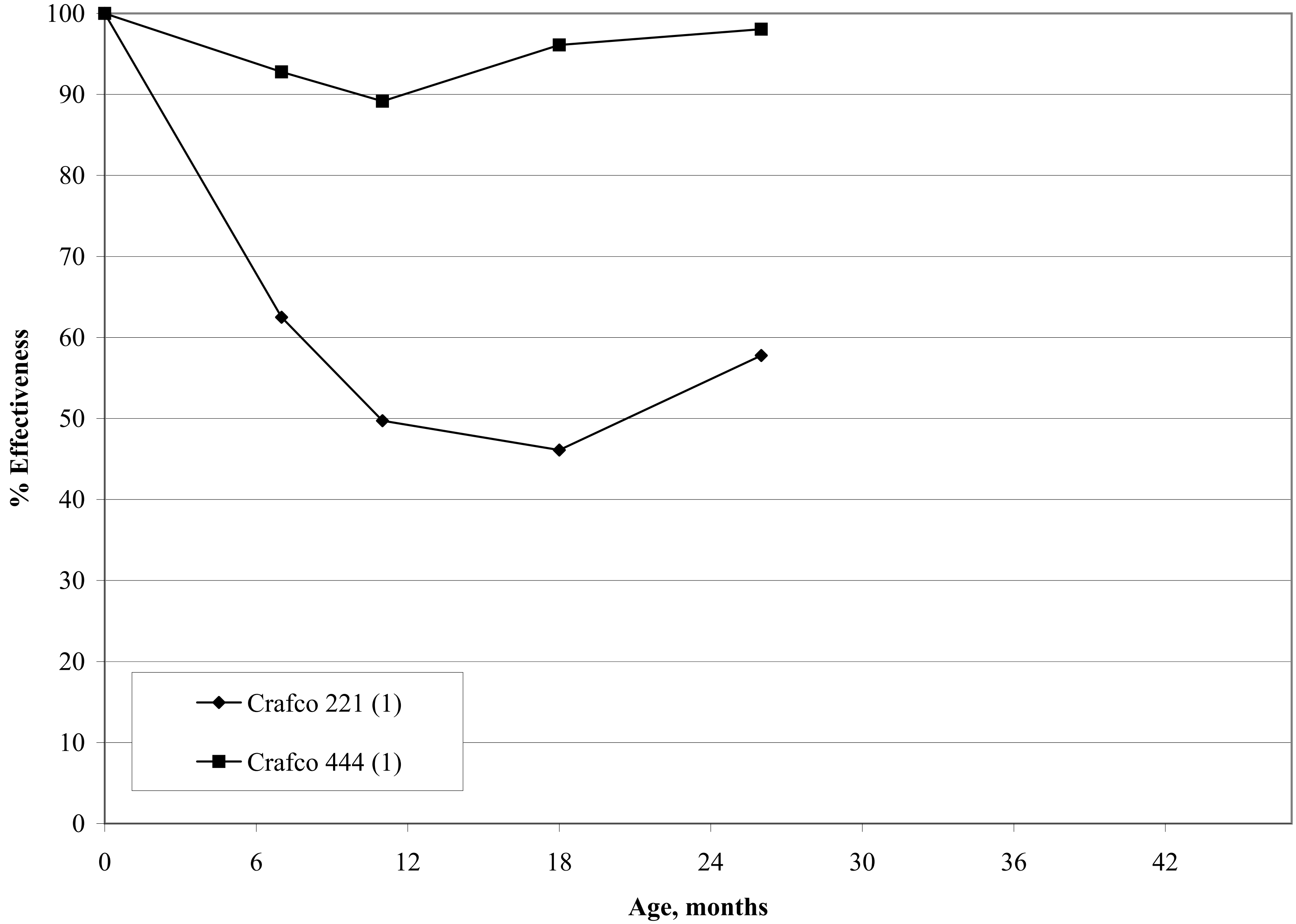


Figure 5.31 Deterioration of hot-applied sealants in the westbound lanes as of WBJN01

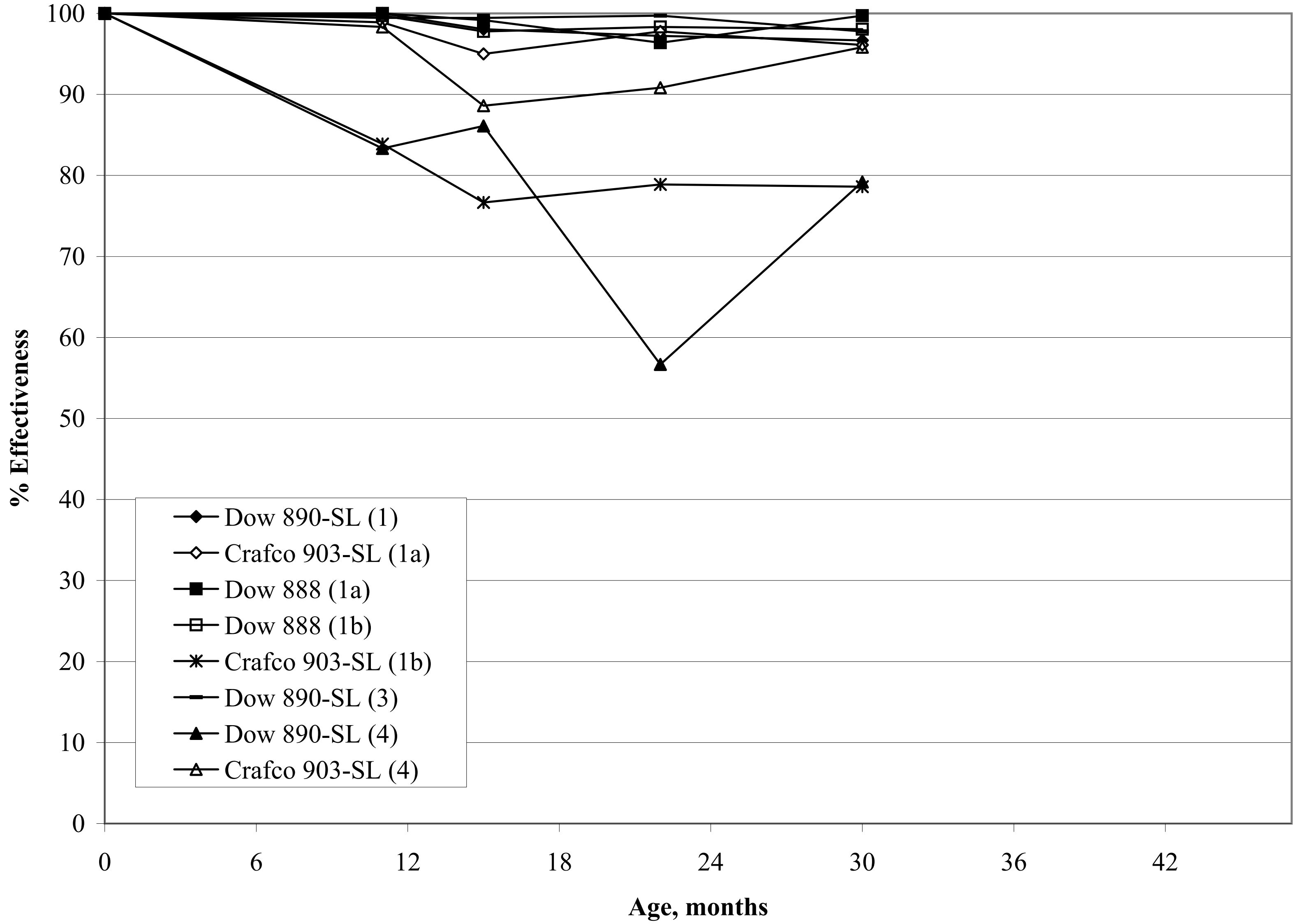


Figure 5.32 Deterioration of silicone sealants in the westbound lanes as of WBJN01

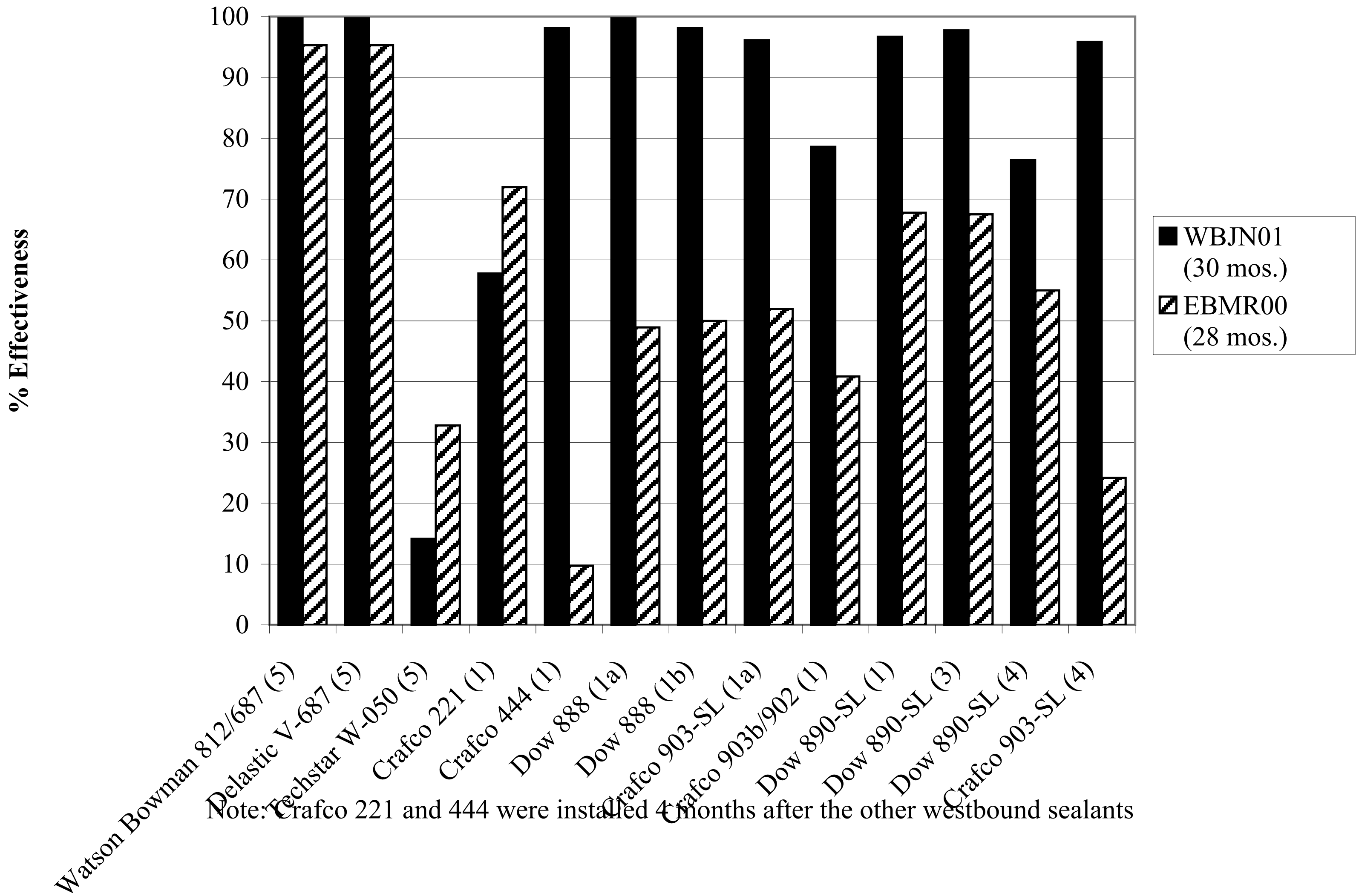


Figure 5.33 Comparison of eastbound and westbound lane sealants after 2 1/2 years in service

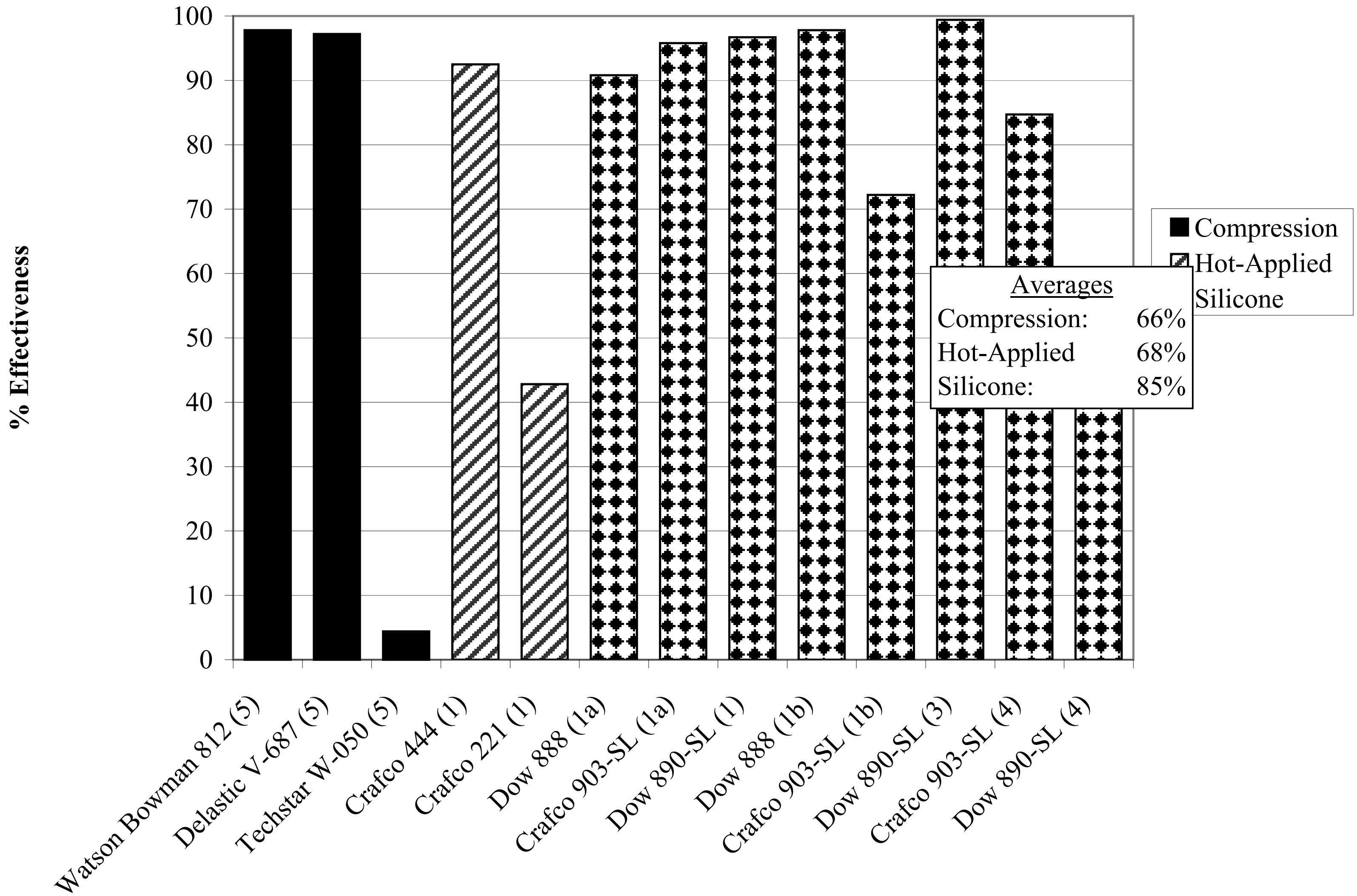
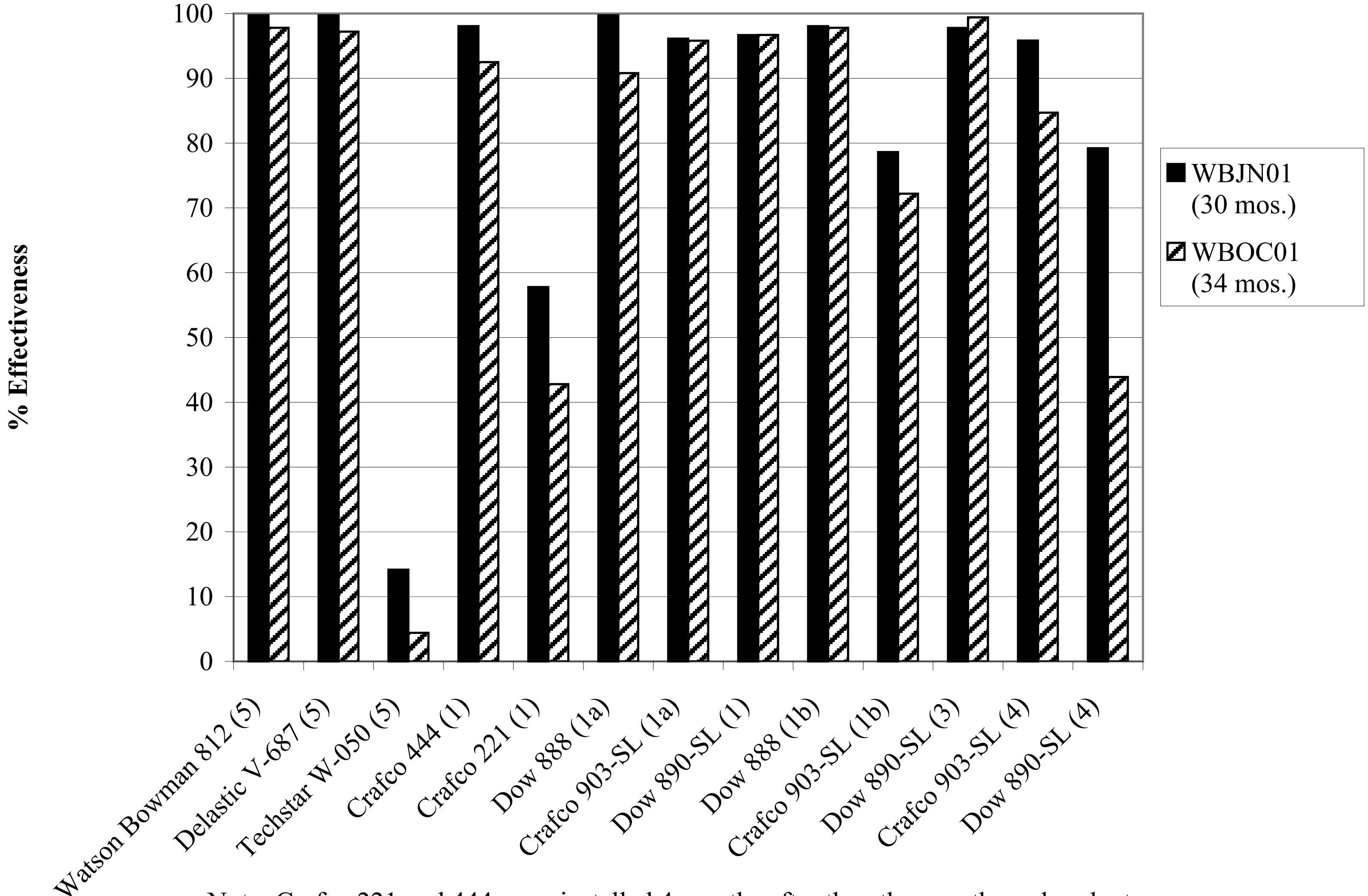


Figure 5.34 Comparison between silicone, hot-applied and compression sealants during WBOC01



Note: Crafco 221 and 444 were installed 4 months after the other westbound sealants

Figure 5.35 Deterioration of sealants from WBJN01 to WBOC01

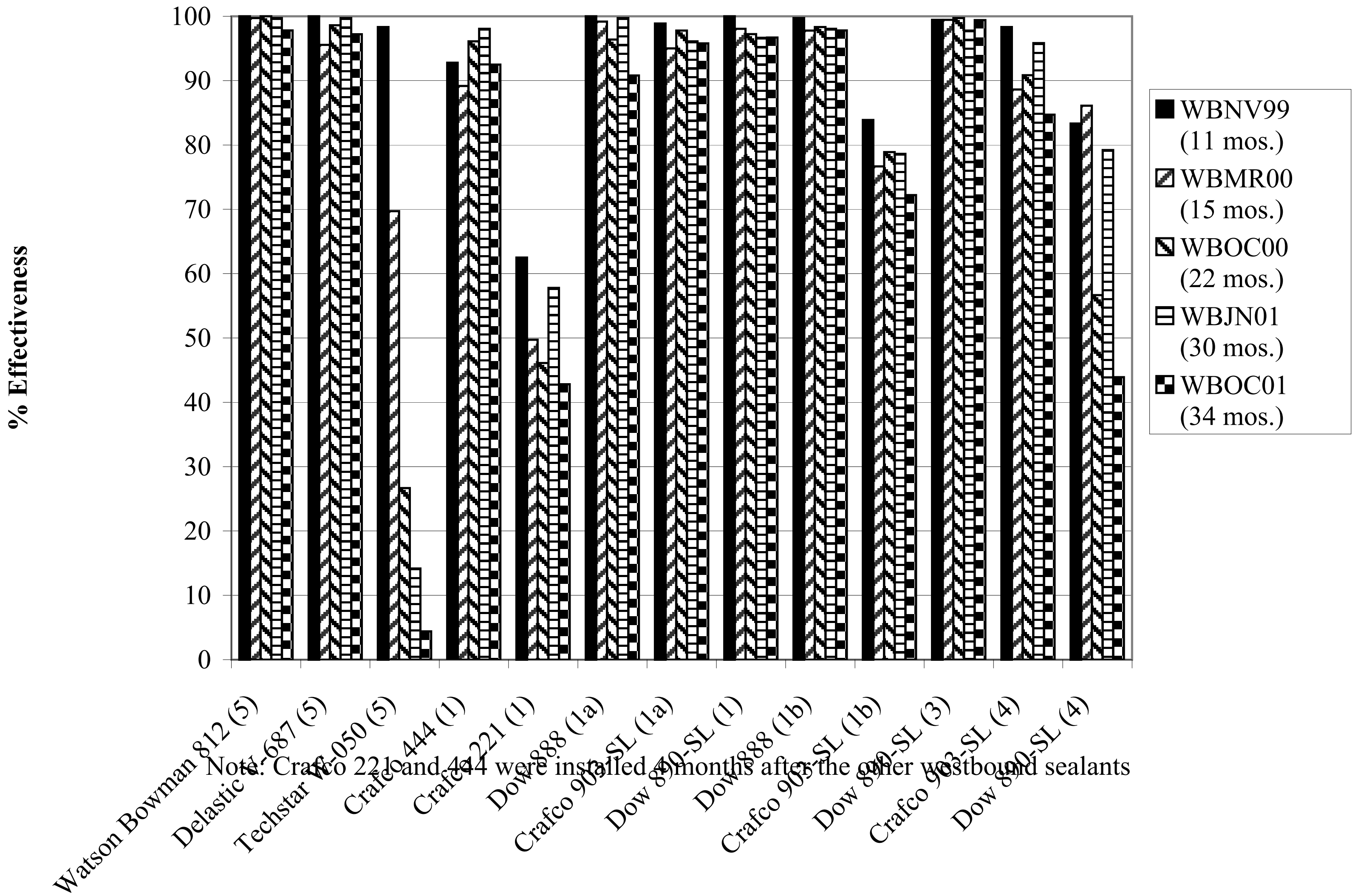


Figure 5.36 Deterioration of sealants from WBNV99 to WBOC01

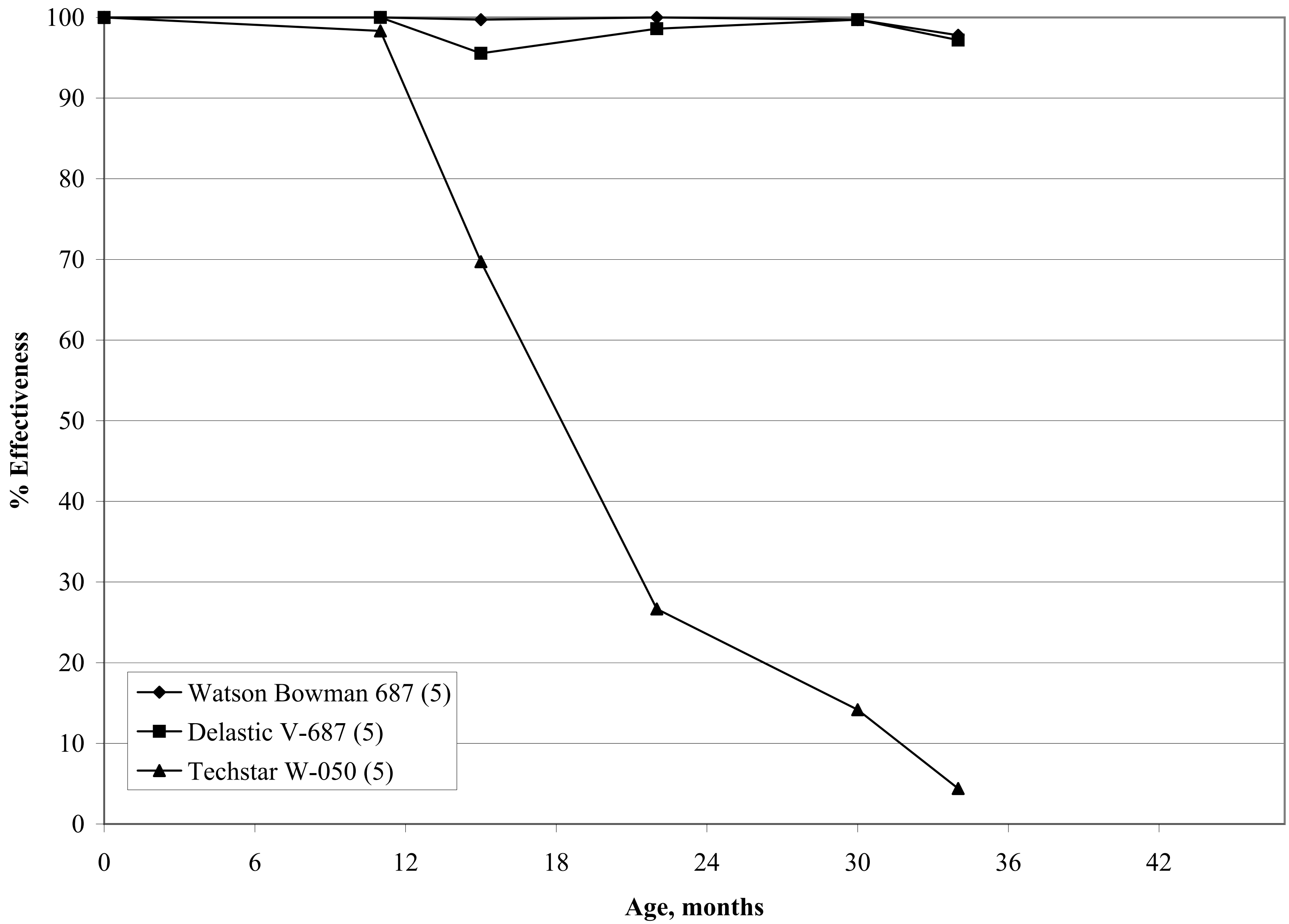


Figure 5.37 Deterioration of compression seals in the westbound lanes as of WBOC01

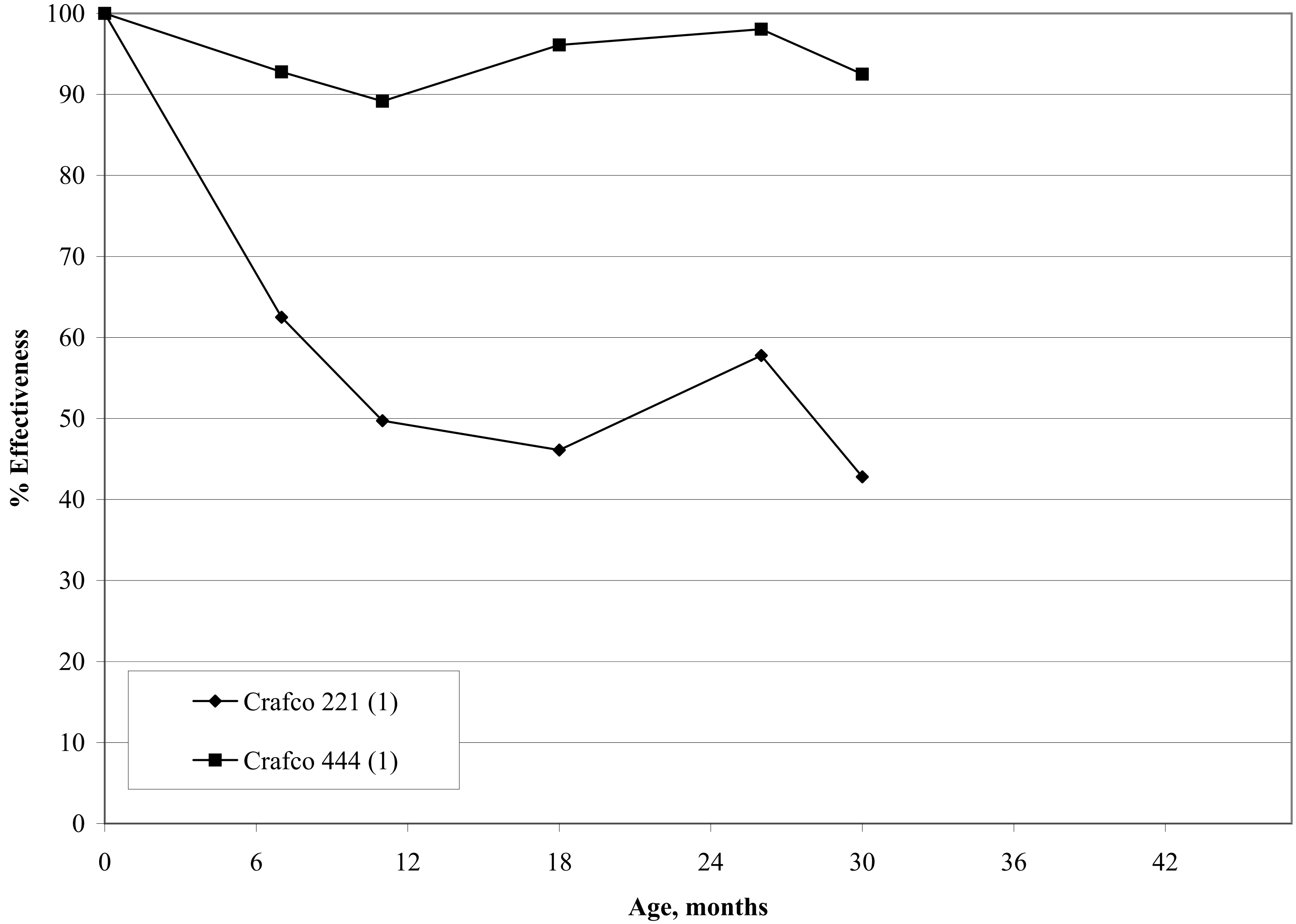


Figure 5.38 Deterioration of hot-applied sealants in the westbound lanes as of WBOC01

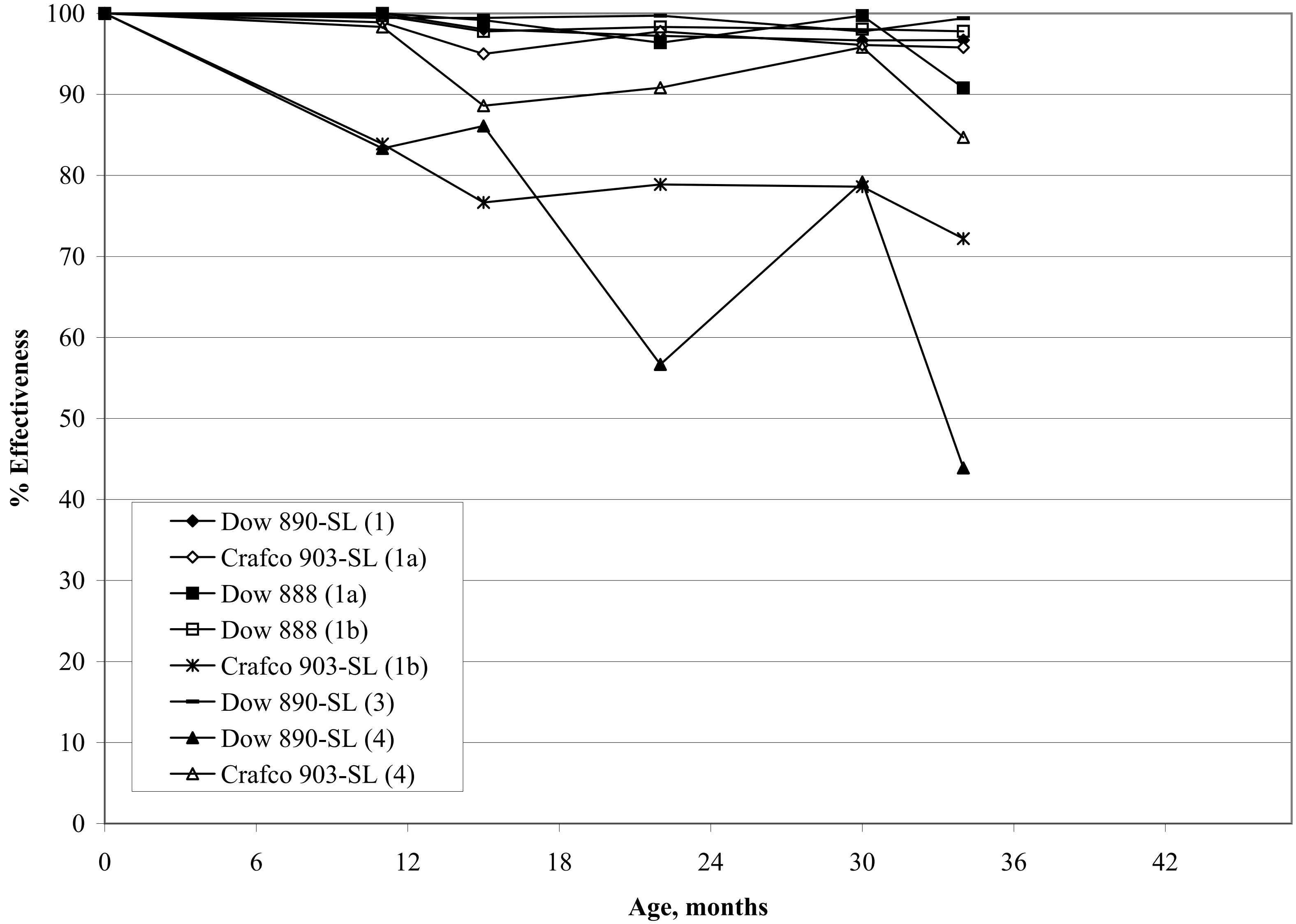
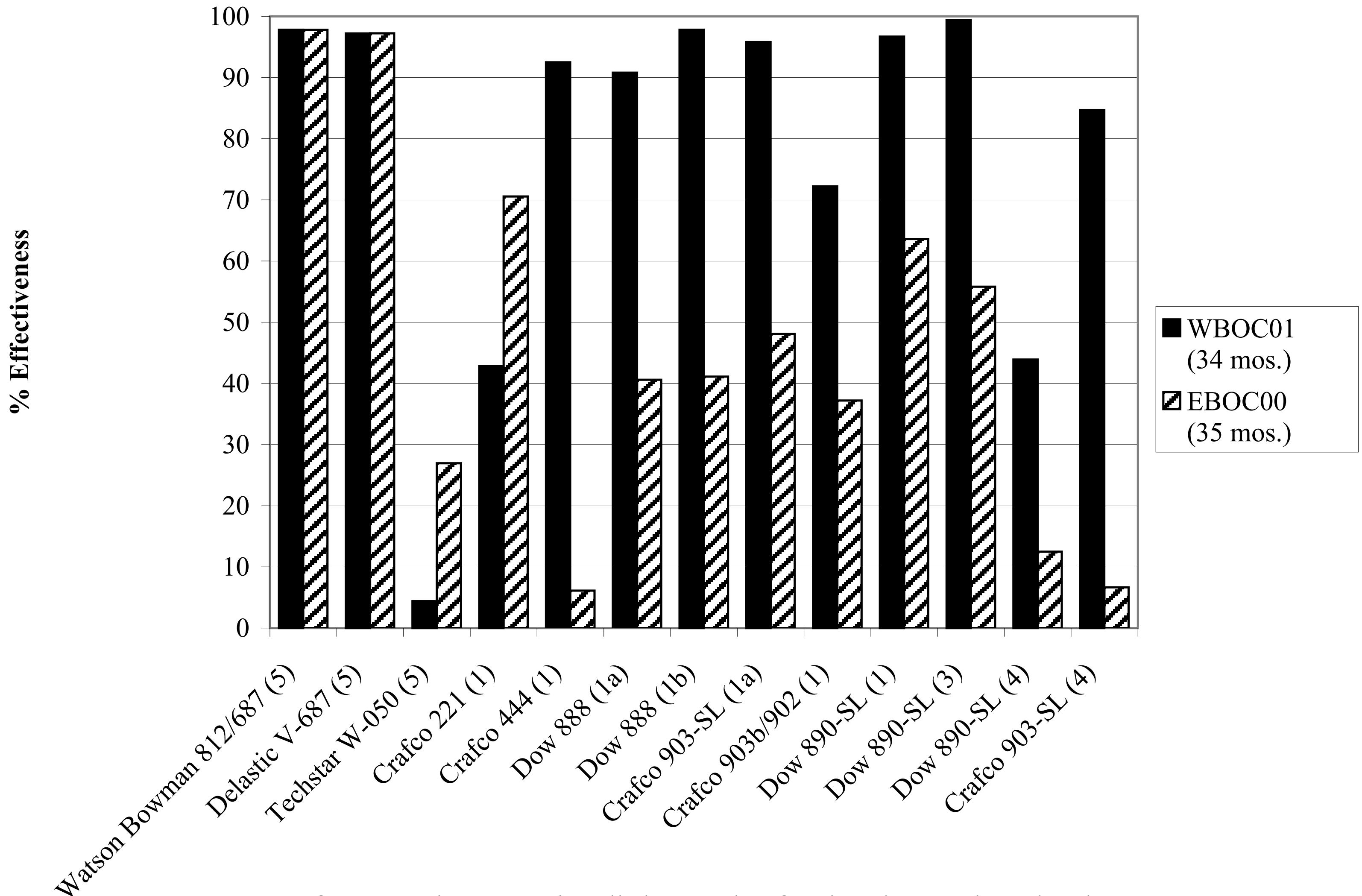


Figure 5.39 Deterioration of silicone sealants in the westbound lanes as of WBOC01



Note: Crafco 221 and 444 were installed 4 months after the other westbound sealants

Figure 5.40 Comparison of eastbound and westbound lane sealants after 3 years in service

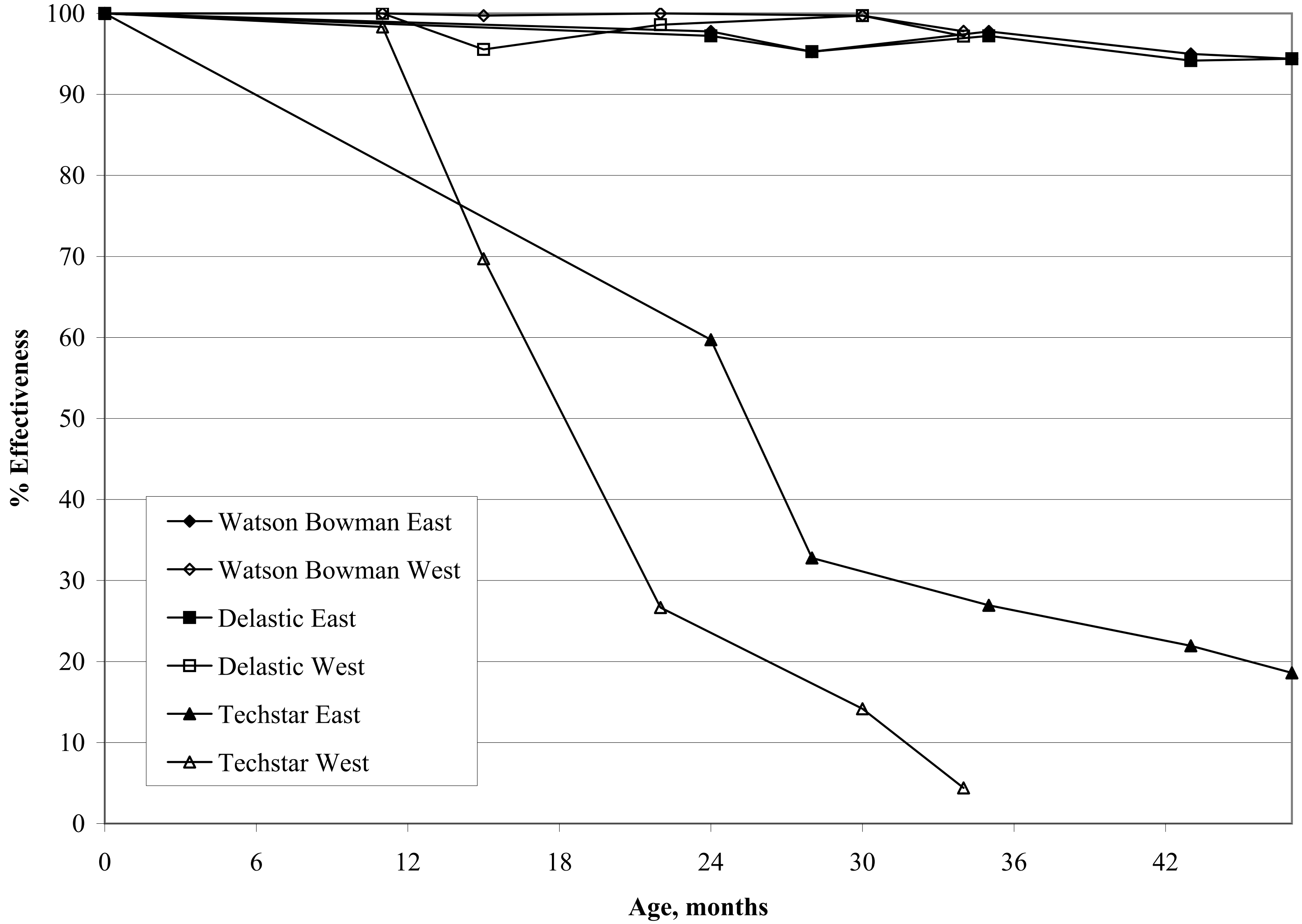


Figure 5.41 Deterioration of compression seals in the eastbound and westbound lanes

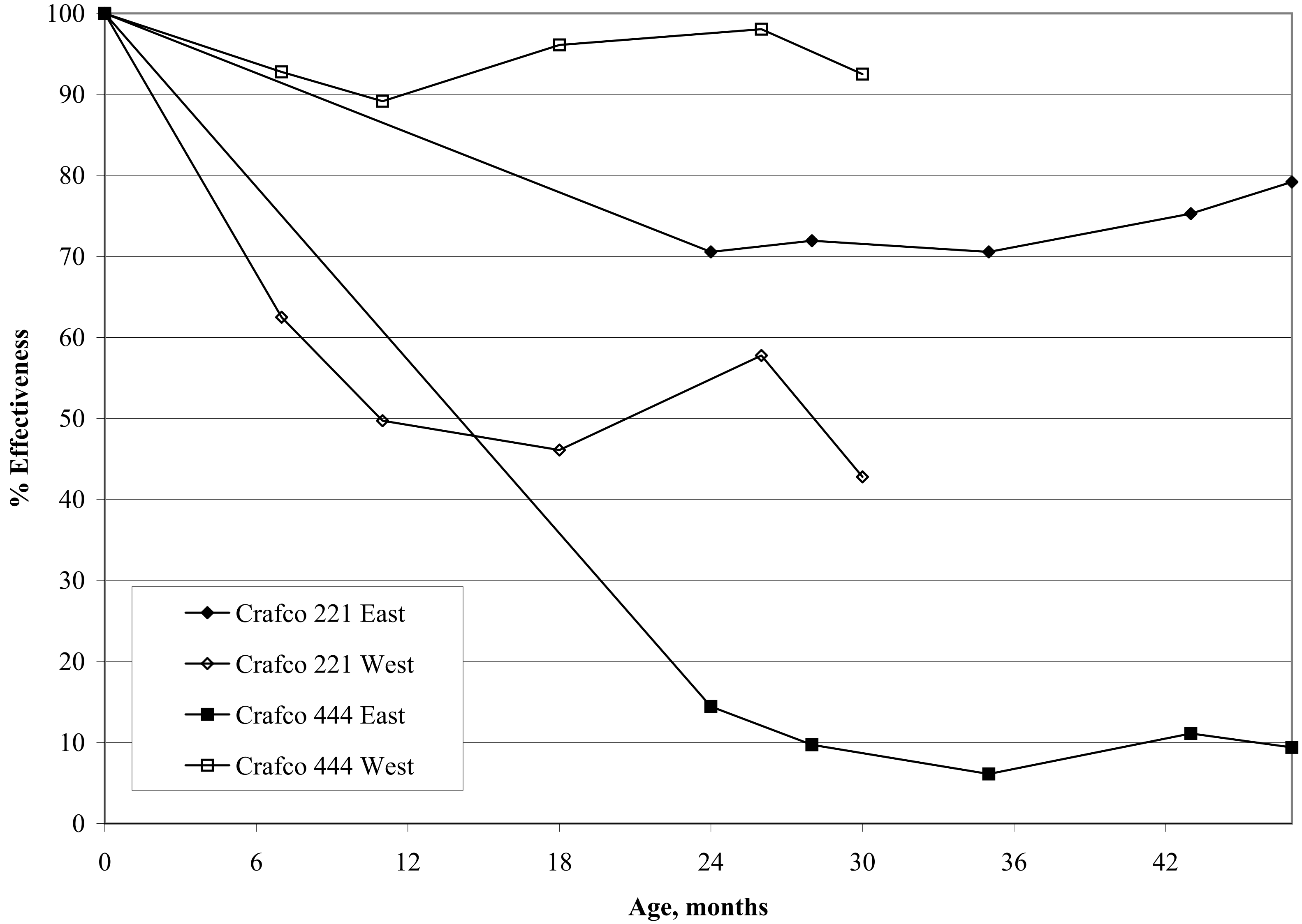


Figure 5.42 Deterioration of hot-applied sealants in the eastbound and westbound lanes

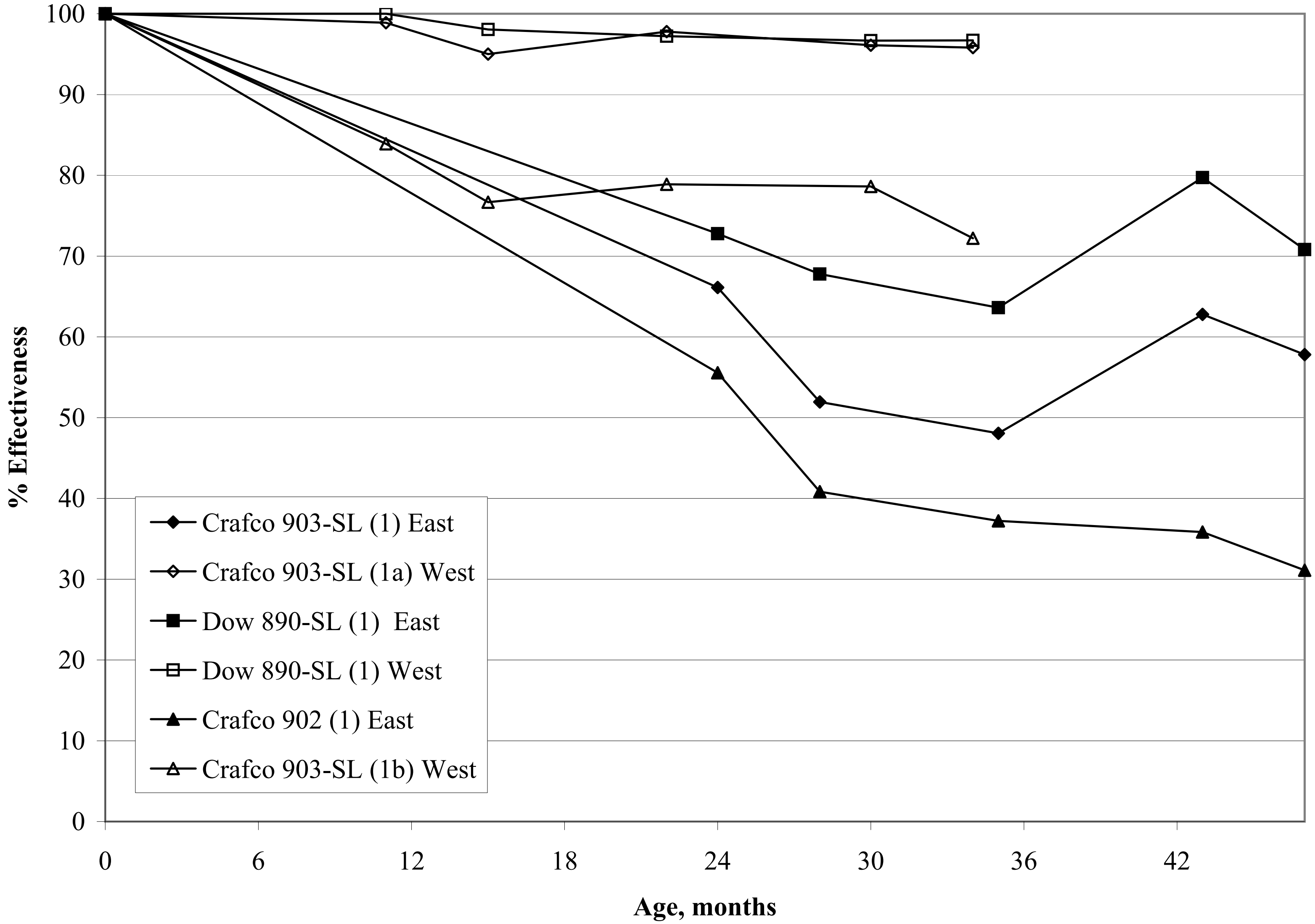


Figure 5.43 Deterioration of self-leveling silicone sealants with Joint Configuration 1 in the eastbound and westbound lanes

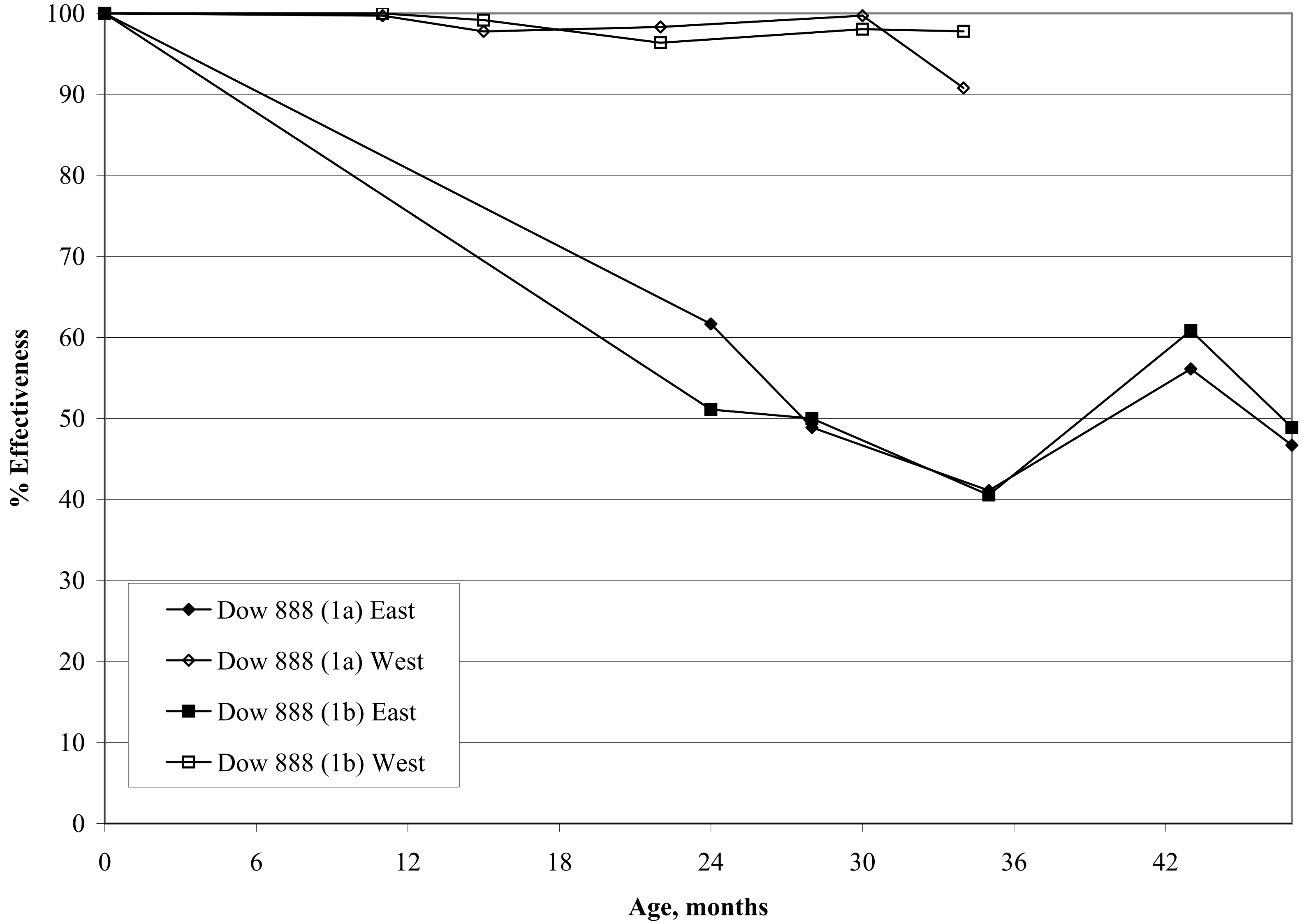


Figure 5.44 Deterioration of non-sag silicone sealants in the eastbound and westbound lanes

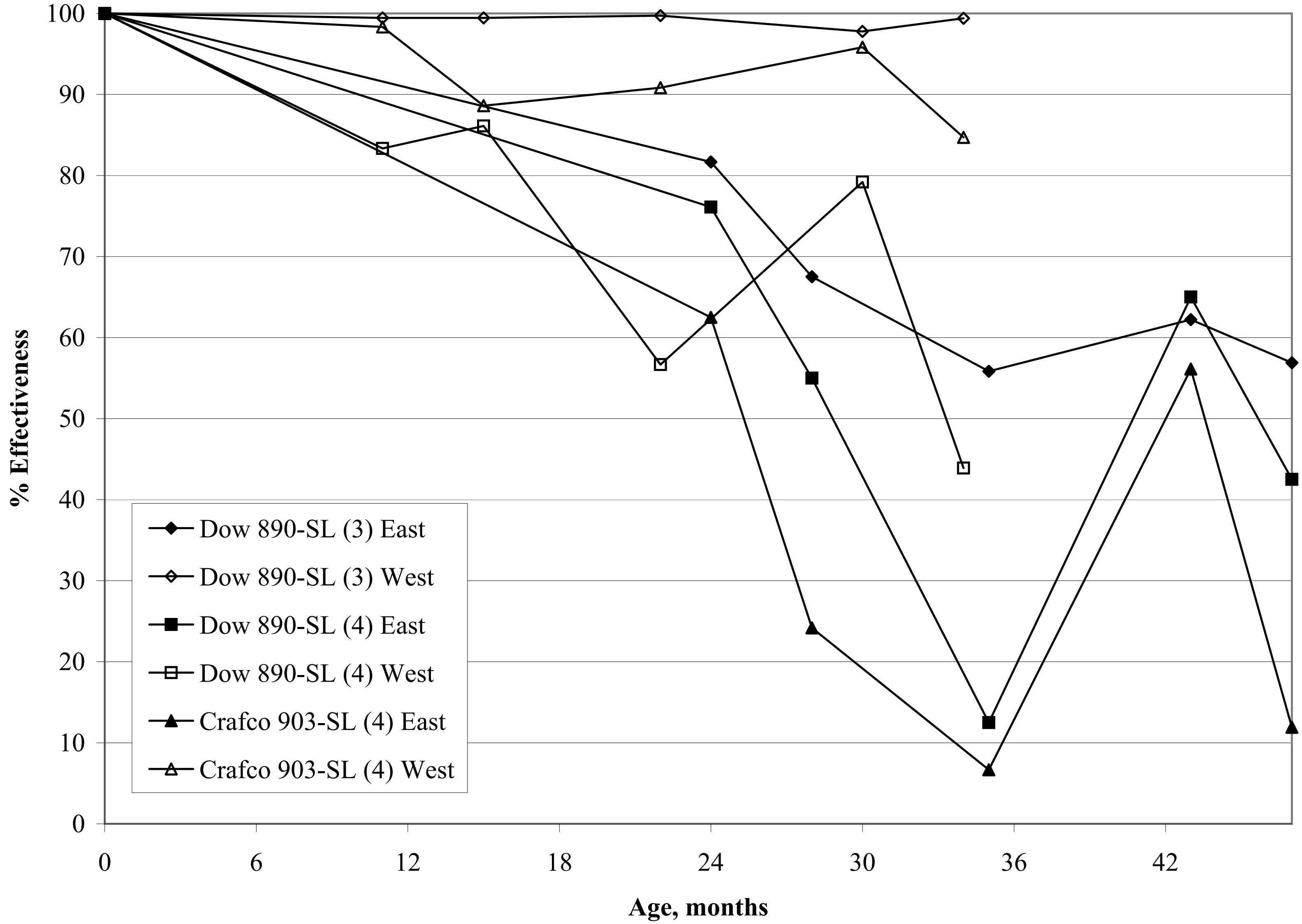


Figure 5.45 Deterioration of self-leveling silicone sealants with Joint Configurations 3 and 4 in the eastbound and westbound lanes

Figure 5.46 Examples of transverse cracks

Figure 5.47 Examples of corner breaks

Figure 5.48 Examples of spalling failures

[Top: Joint 7 of WB Dow 890 (4); Bottom: Joint 40 of WB Crafco 221 (1); both appear to been created at the time of joint sawing]

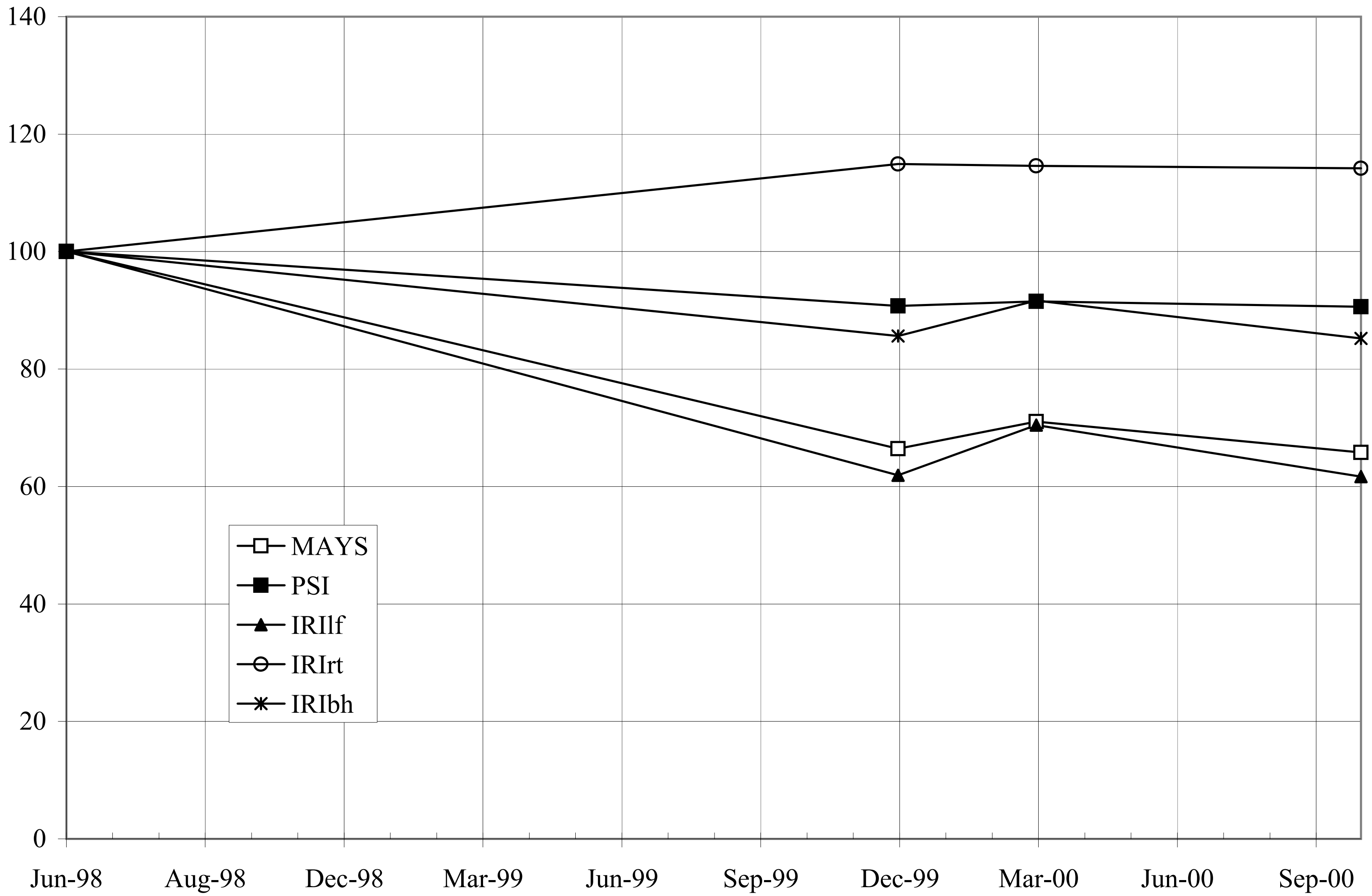


Figure 5.49 Trendlines for the Eastbound Passing Lane through October 2000

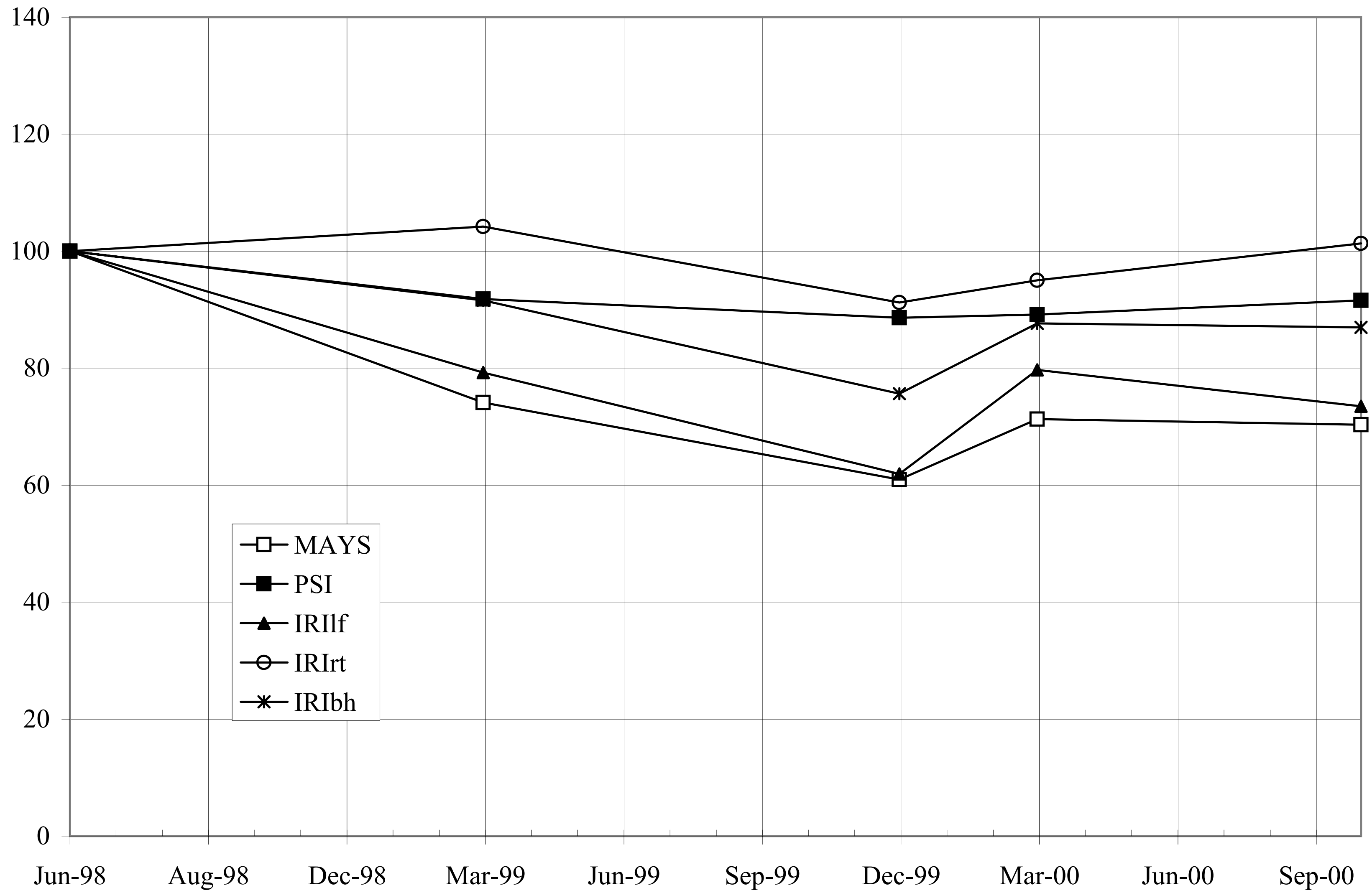


Figure 5.50 Trendlines for the Eastbound Driving Lane through October 2000

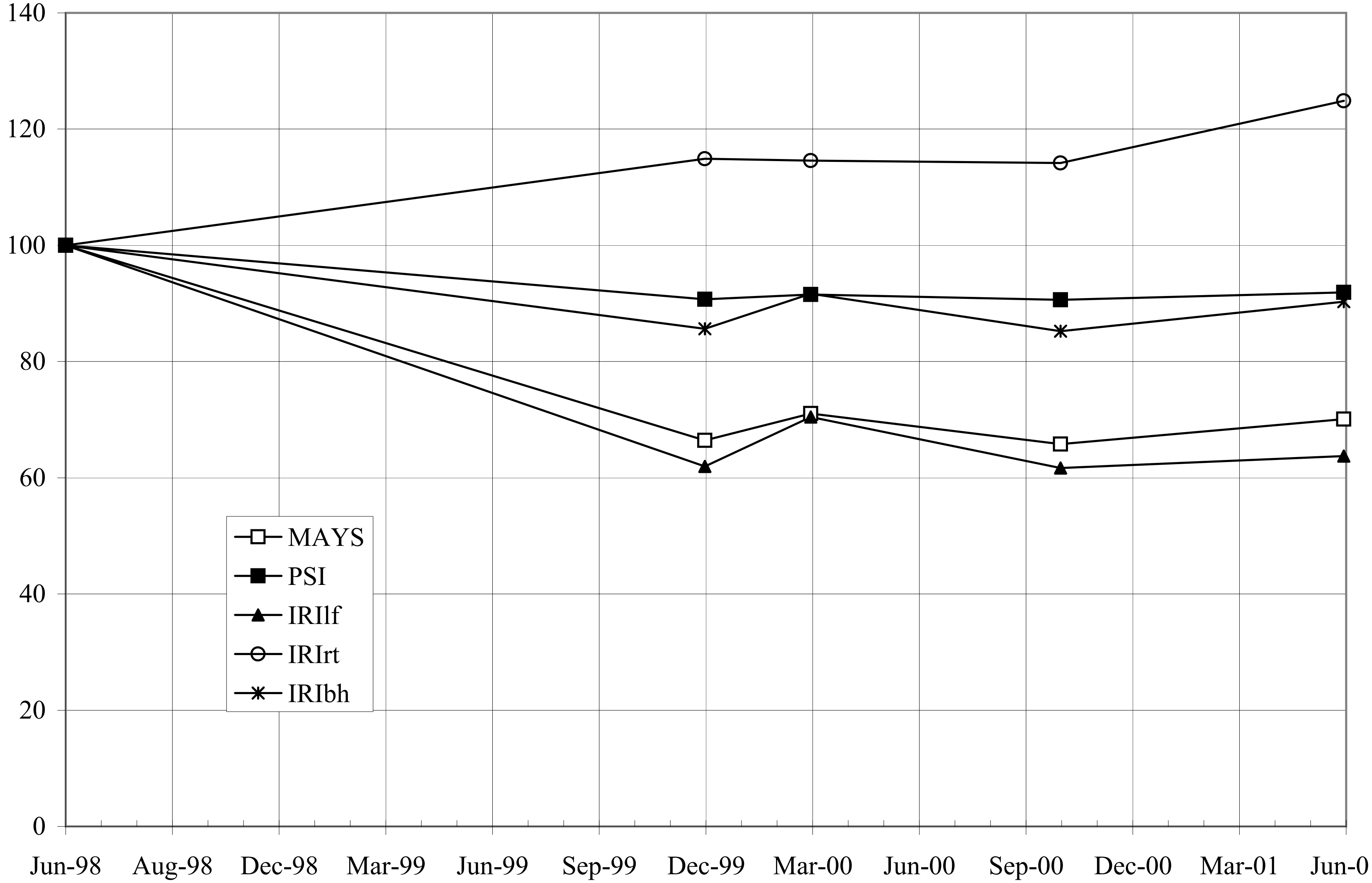


Figure 5.51 Trendlines for the Eastbound Passing Lane through June 2001

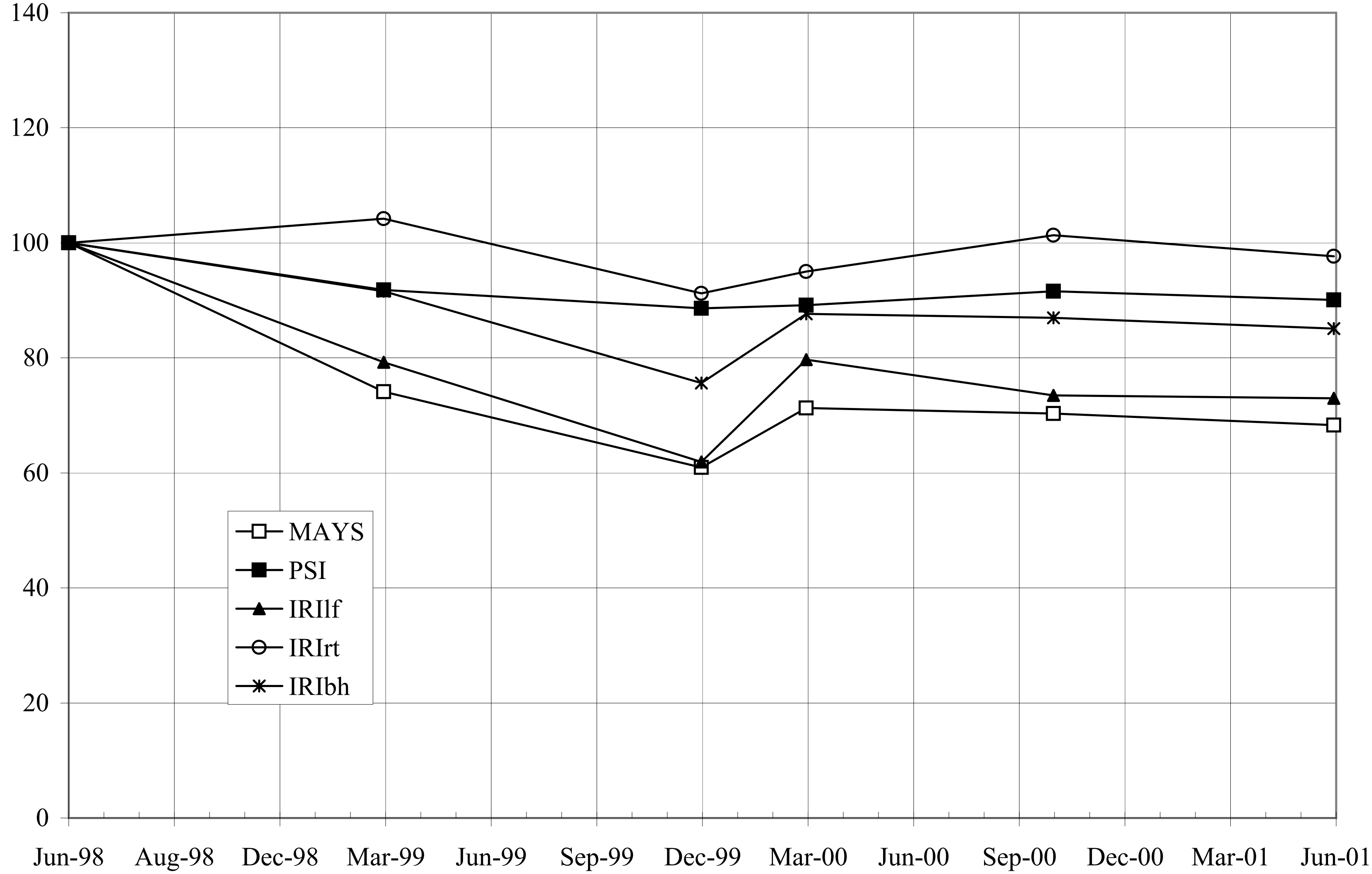


Figure 5.52 Trendlines for the Eastbound Driving Lane through June 2001

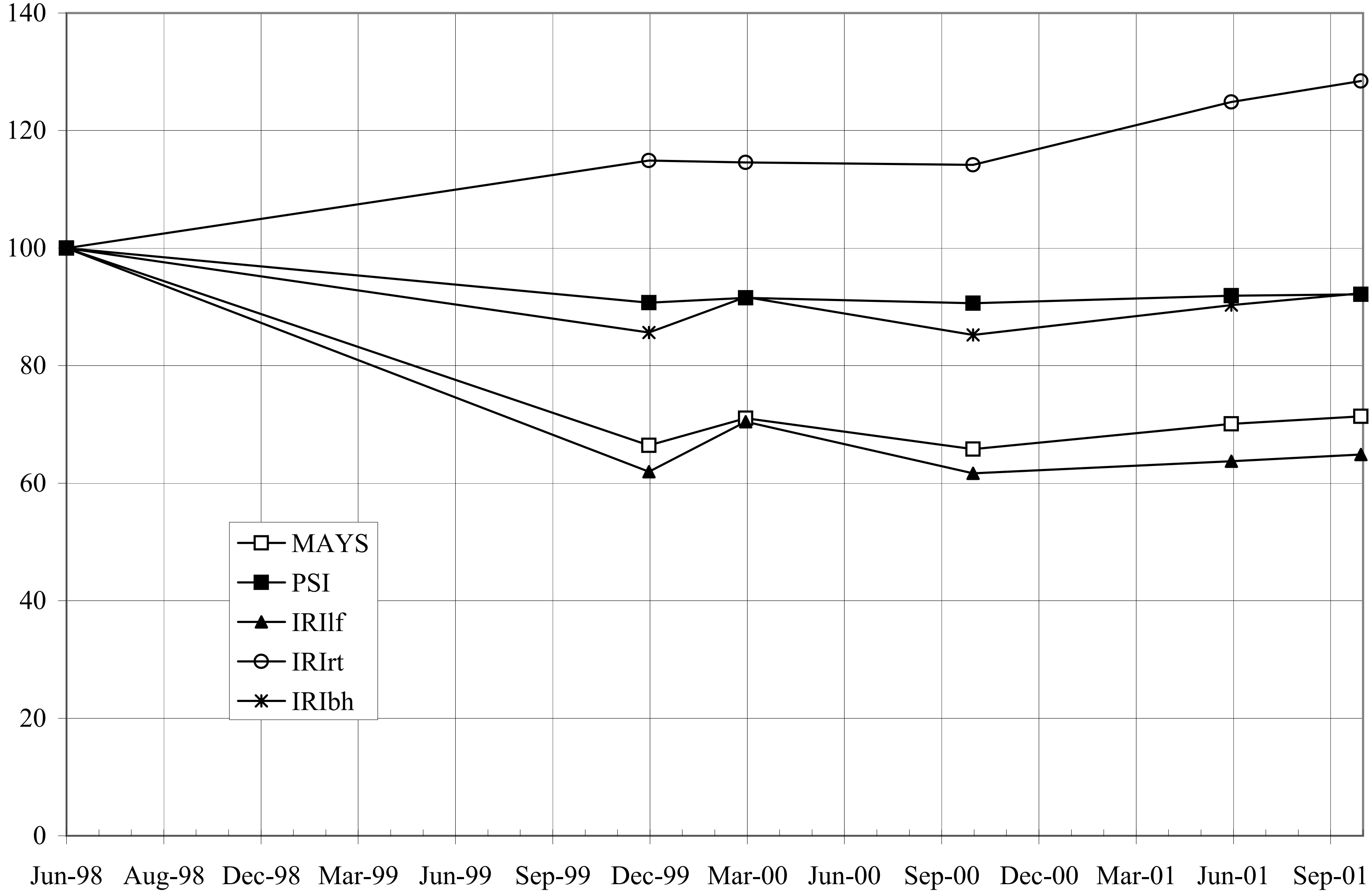


Figure 5.53 Trendlines for the Eastbound Passing Lane through October 2001

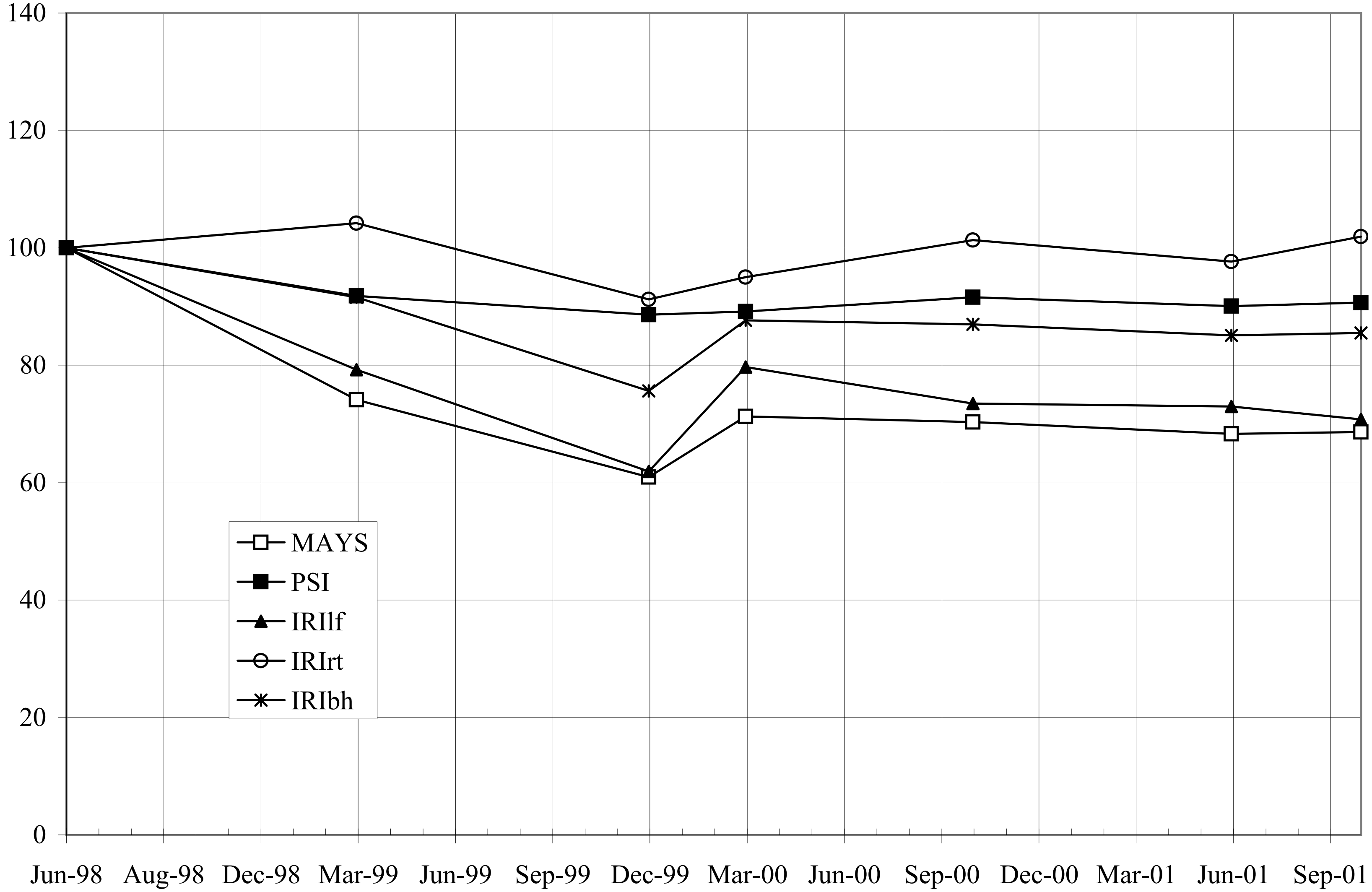


Figure 5.54 Trendlines for the Eastbound Driving Lane through October 2001

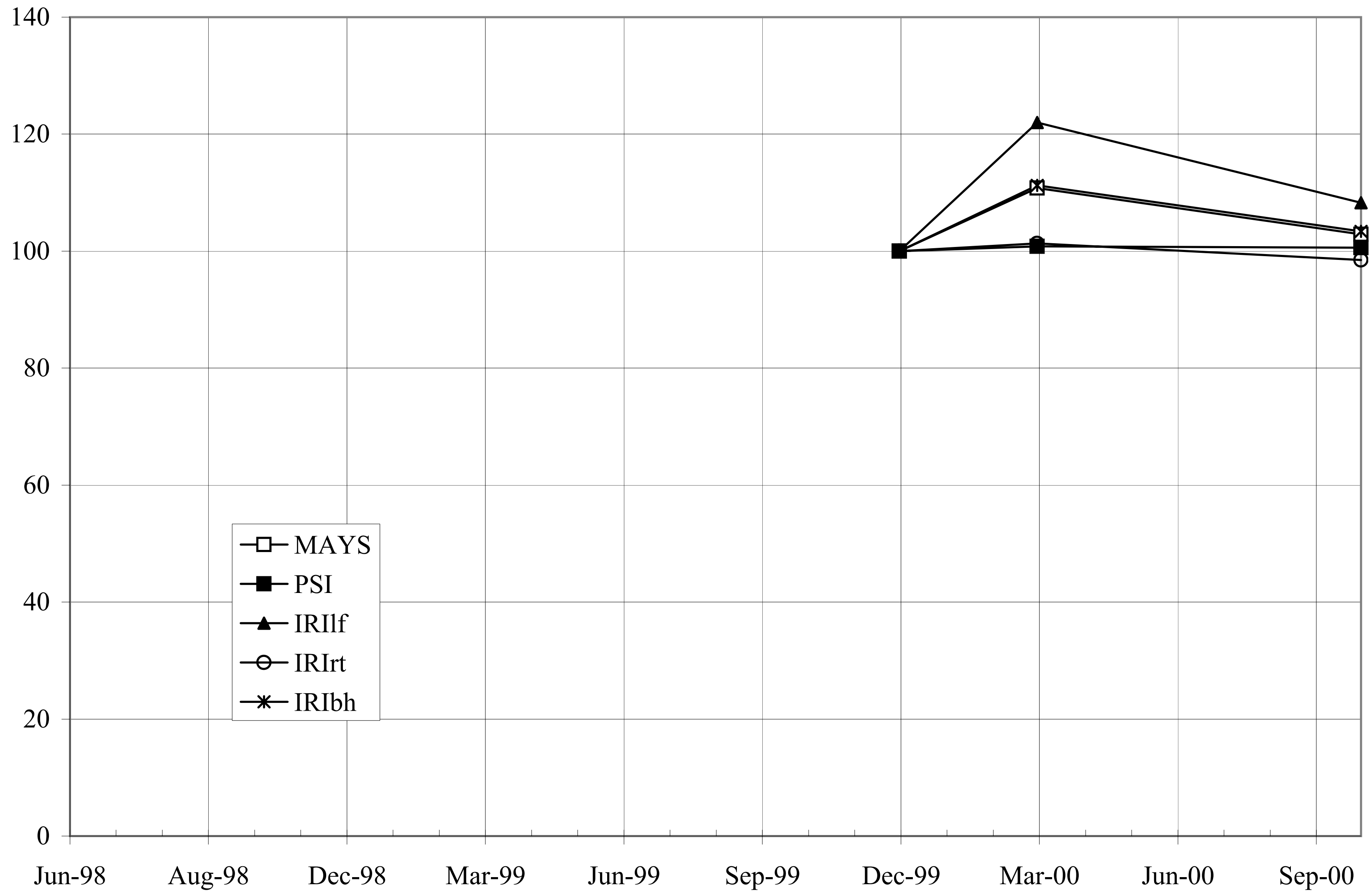


Figure 5.55 Trendlines for the Westbound Passing Lane through October 2000

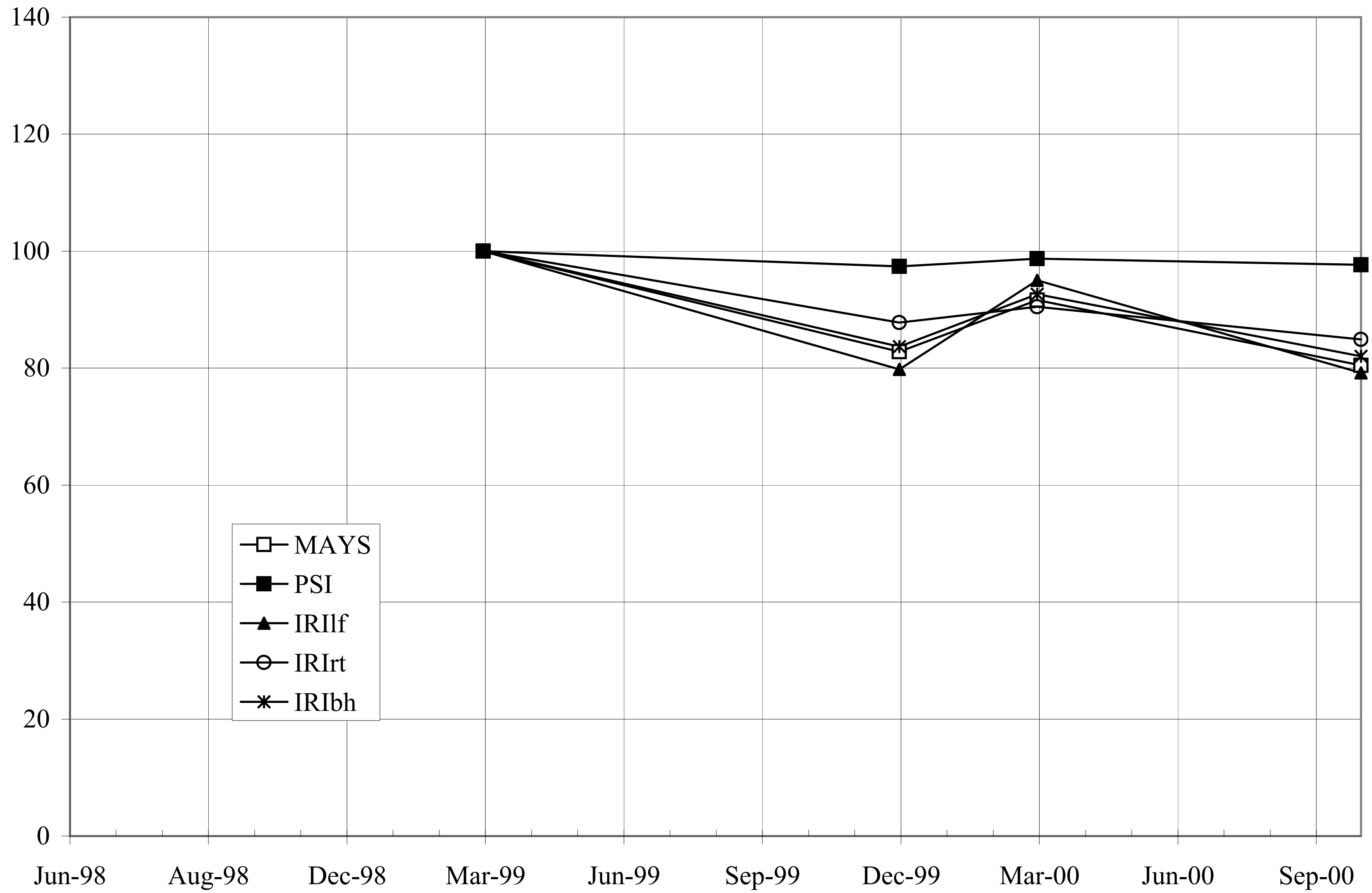


Figure 5.56 Trendlines for the Westbound Driving Lane through October 2000

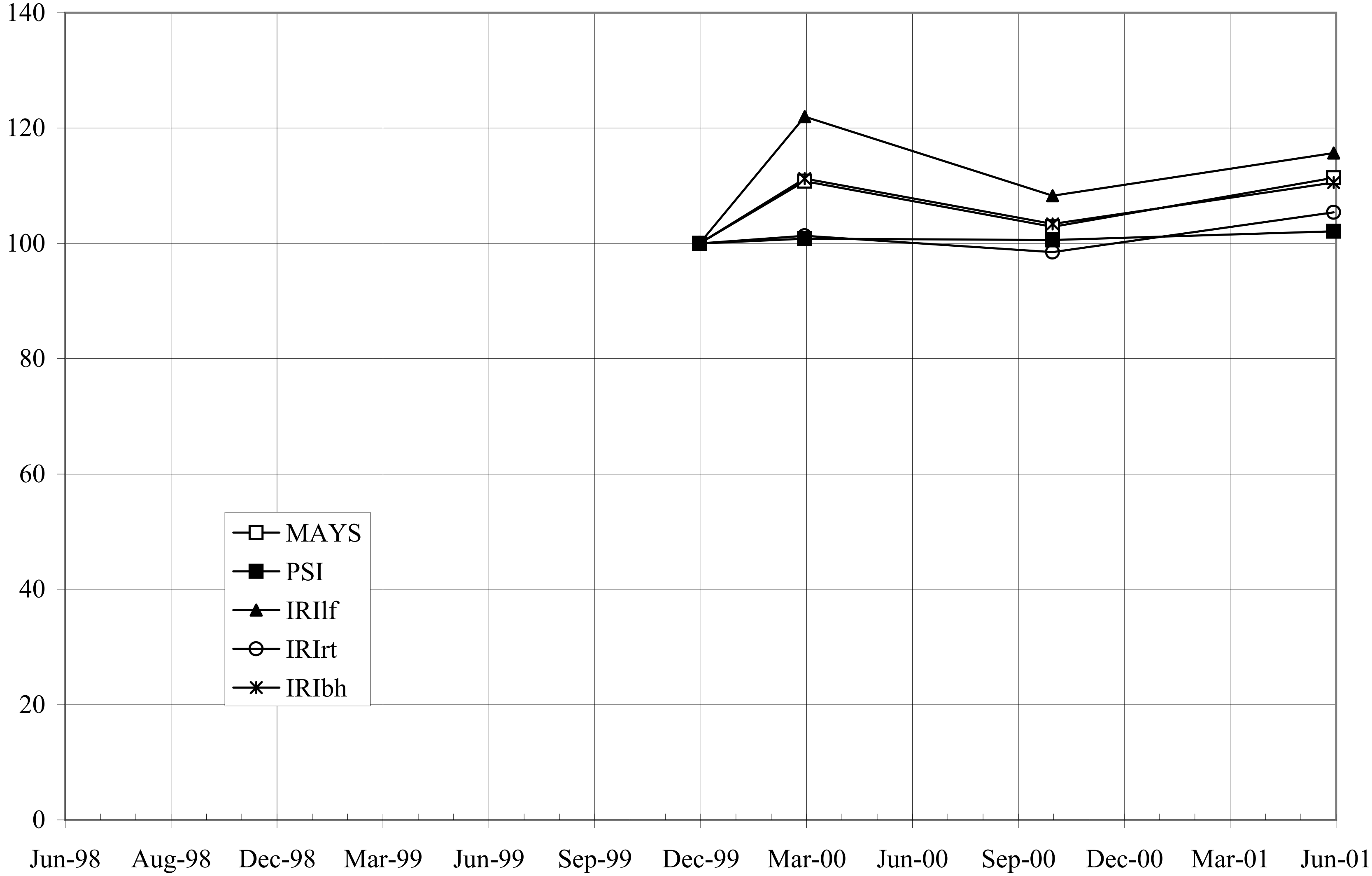


Figure 5.57 Trendlines for the Westbound Passing Lane through June 2001

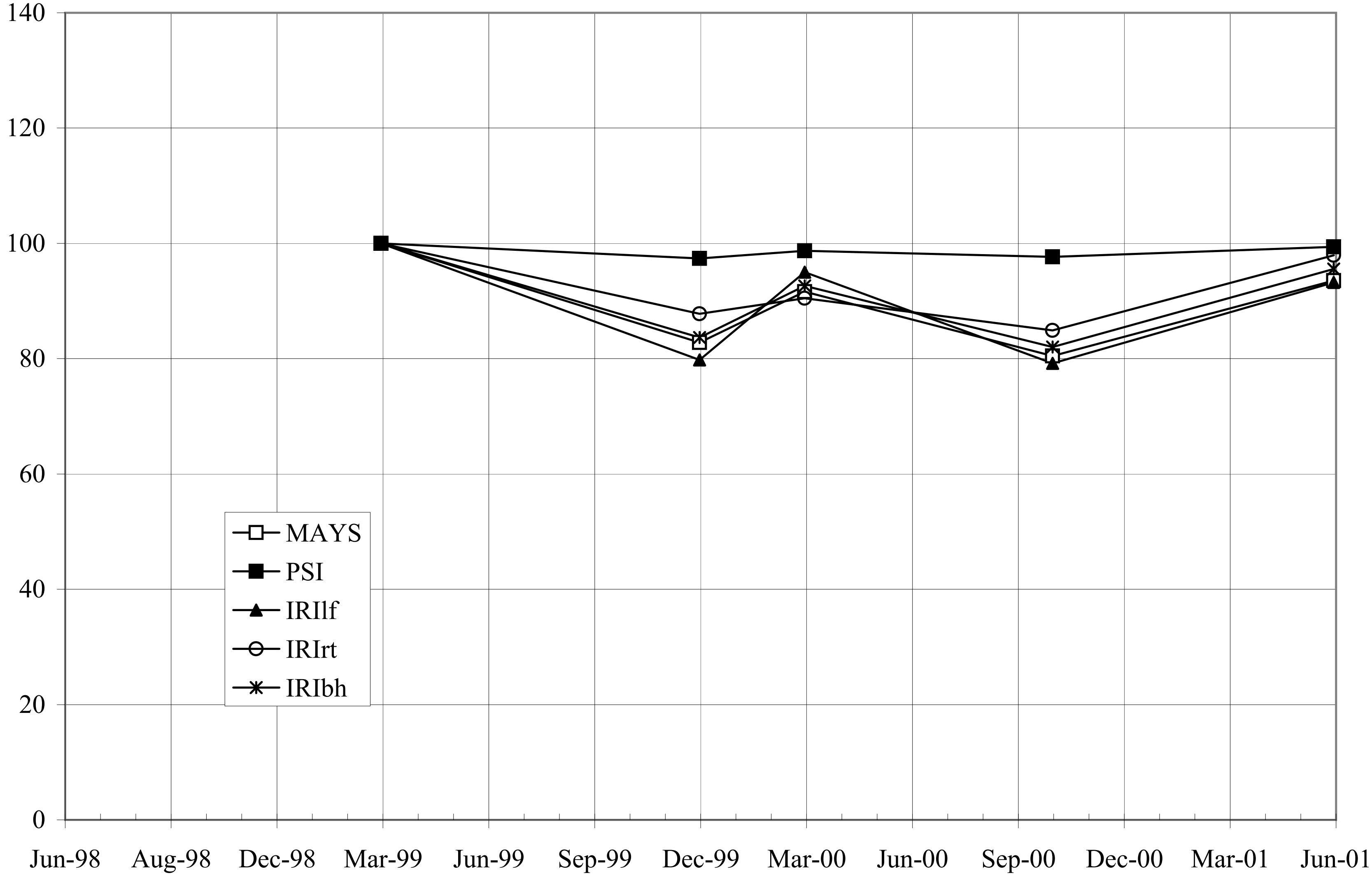


Figure 5.58 Trendlines for the Westbound Driving Lane through June 2001

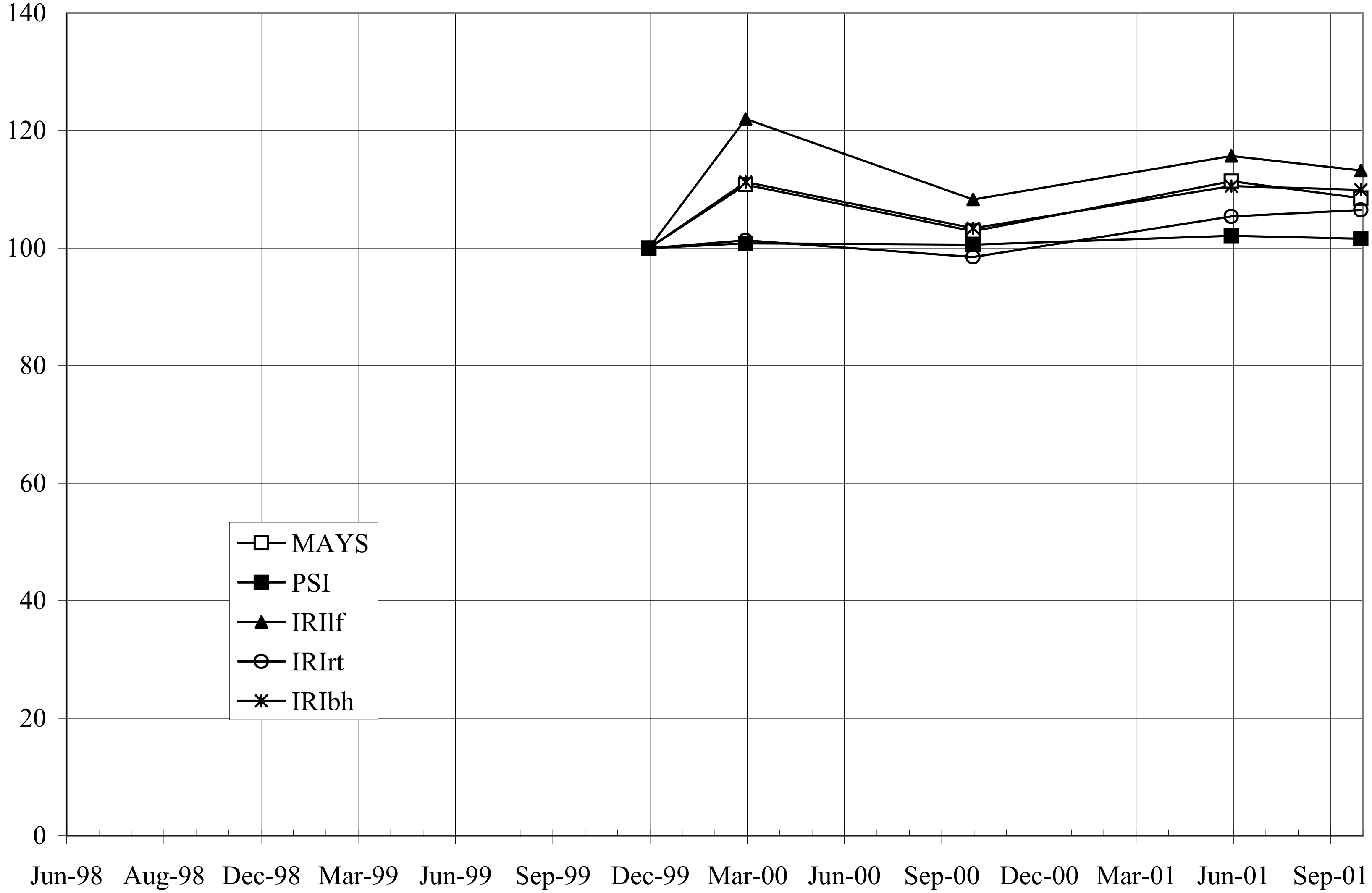


Figure 5.59 Trendlines for the Westbound Passing Lane through October 2001

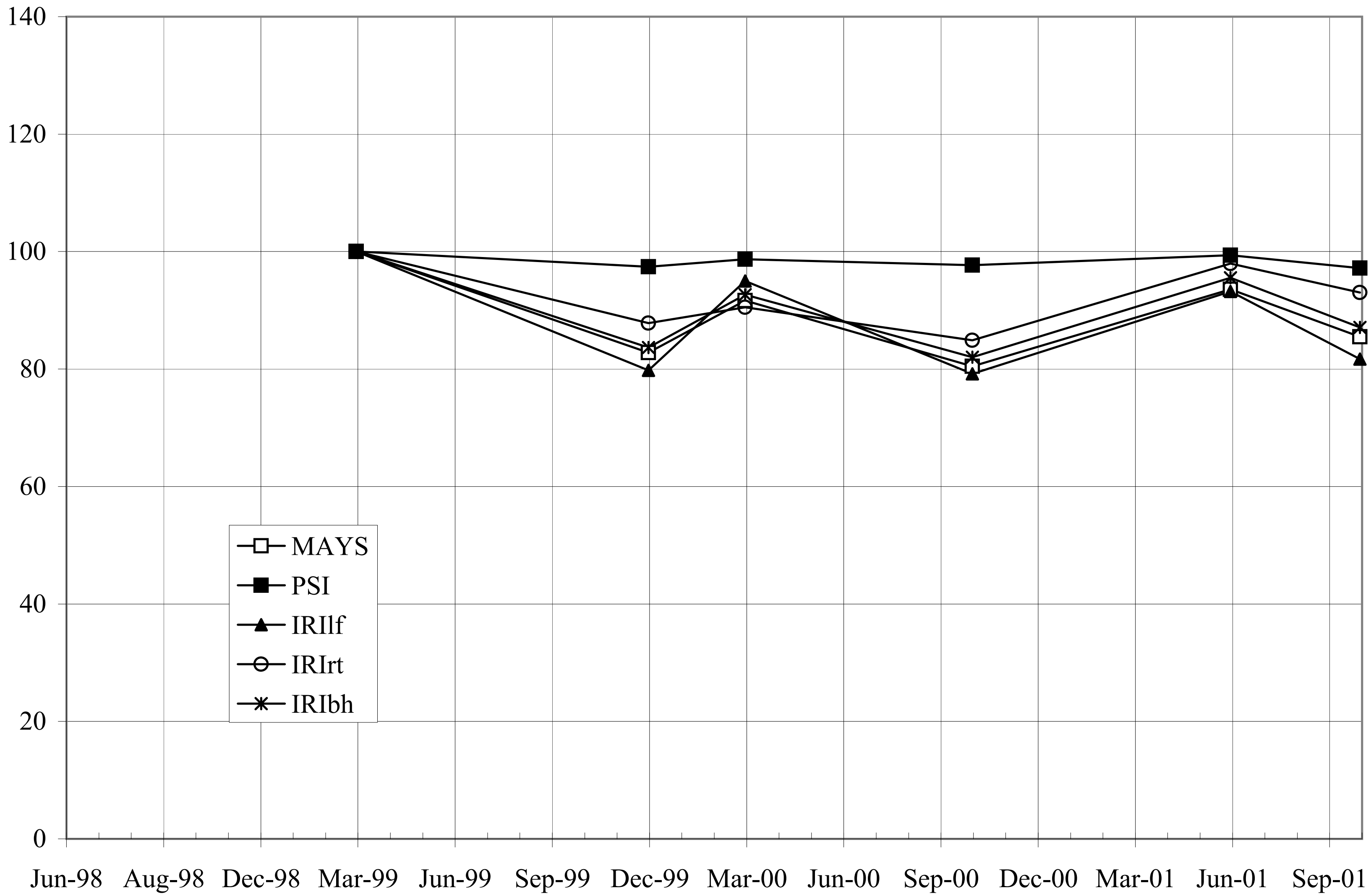


Figure 5.60 Trendlines for the Westbound Driving Lane through October 2001

6 DRAINAGE EVALUATION

6.1 General Information

Along with the sealant materials examined, the U.S. 50 Athens test site contains an experimental free draining base (FDB), which is designed to allow water to discharge away from the pavement quickly. This non-stabilized 100 mm (4 in.)-thick layer consists of granular materials of the New Jersey type in the eastbound lanes, and of the Iowa type in the westbound lanes (Hawkins, 1999). The infiltrating water is transferred to roadside drainage ditches via longitudinal and transverse collector pipes.

The University of Cincinnati (UC) research team, concerned with the drainage aspects of the project site, undertook to investigate the concrete outlets. The initial evaluation was planned for Wednesday, June 6, 2001, i.e., the day after the survey code-named WBJN01. The investigators were able to work for a short period of time before inclement weather caused this effort to be interrupted, after only one outlet had been examined. All of the outlets were subsequently inspected on Wednesday, October 17, 2001, following the Fall 2001 sealant evaluation, and the researchers' findings are described in the following sections.

6.1.1 Collector Pipes

It is impossible to view the collector pipes without the aid of special equipment, namely a borehole camera. This device can be fed through the system of collector pipes and relay a visual output to a monitor. The camera, along with the necessary accessories, can cost as much as $60,000 (Steffes, et al., 1991). An expenditure of this magnitude could not be justified on the current project, and such devices were not used. Consequently, collector pipes could be viewed only near the outlet, with the help of a flashlight (Figure 6.1). At one of the outlets, a video camera was placed near the end of the collector pipe and using the infrared feature, a picture of the inside of the pipe was obtained (Figure 6.2). Large amounts of silt and debris, which impede the flow of water, are observed. If the collector pipes cannot discharge the infiltrating water quickly, the base may become saturated and significantly weaker, which may explain some of the observed transverse cracking.

6.1.2 Outlets

Table 6.1 lists the location of outlets between Stations 133+60 and 291+00, not including the stretch that corresponds to the location of the batch plant and of the headquarters of the project contractor (*Kokosing Construction Company, Inc.*), an area of intense and heavy truck traffic (Stations 231+00 to 260+00). Although the sealant experiment reaches only up to Station 290+00 in the easternly direction, the drainage evaluation is extended to Station 291+00 to allow for the inspection of two additional outlets, one on each of the northern and southern shoulders. Outlet No. 209, at Station 257+00, was also included. The Table also records if the outlet was actually found, if the rodent screen was in place, the amount of silt and vegetation present, and the presence of standing or flowing water.

Some of the outlets that listed on the Ohio Department of Transportation (ODOT) specifications and plans (ODOT, 1995) were not found. Of the 26 outlets listed in the project span, 19 were found (73%). Many of the outlets were engulfed by tall vegetation growth (Figure 6.3), which had to be cleared before they could be examined (Figure 6.4). The area adjacent to the shoulder had been mowed, but the region further back, where the outlets are located, had not been (Figure 6.5). Such regions are intentionally left unmowed for environmental conservation reasons (Bob McQuiston, 2001: personal communication). It is believed that some of the outlets were not found because of the thick vegetation, even after the area had been thoroughly searched. Other locations, however, did not have large amounts of vegetation, yet some outlets were not found there either. These outlets were probably never constructed in accordance with the ODOT (1995) plans. The experience of the UC research team is not untypical. Baldwin and Long (1987) conducted a similar evaluation in the mid-1980s, inspecting drain outlets once a year for three years. During their inspections, they never found more than 60% of the total 533 possible outlets. Compared to their efforts, the number of outlets discovered at the Athens project site may be considered remarkable.

Most of the outlets that were found had large amounts of silt, moss, and weeds in them, and at times this combination was several inches thick (Figure 6.6). One outlet even had a large weed growing out of its rodent screen (Figure 6.7). All outlets were checked for standing or flowing water, which is a telltale sign as to whether the collector pipes are functioning properly. If water is found flowing out of the outlet, the drain is obviously working (Figure 6.8), but if the water is standing, the drain is probably not capable of removing the water quickly enough (Figure 6.9). Some drains are found completely dry, which may indicate that the pipe is broken or clogged and that water is not reaching the outlet. It is unlikely that the water had already drained away leaving the pipe dry, since there was rainfall during the day prior to the inspection.

Upon observing several of the outlets, the UC research team noticed that those that had a considerable gradient were relatively free of silt and free flowing; the ODOT (1995) specifications call for a 1% slope of the outlet drains. It is difficult to ascertain precisely if the drains are at the required gradient, but there is an obvious correlation between steeper slopes and freely draining outlets.

None of the outlets in the eastbound lanes have rodent screens, whereas all but one of the outlets in the westbound lanes have them. The investigators found that the absence of a screen may actually be beneficial. At the outlets with the rodent screens, moss, weeds, and eventually silt is allowed to gather on them (Figure 6.10), transforming them in some cases into small dams that prevent any drainage water from flowing out. When the screen was temporarily removed during the survey, water was able to flow out. The rodent screen did not appear capable of serving its intended purpose: several of the screens had been bent, creating a gap large enough for small rodents to fit through (Figure 6.11). It is unclear why these screens had been bent, but two hypotheses emerge: (a) The screens had been bent on purpose during construction, possibly to provide a snugger fit with the concrete outlet, even though this is not a method endorsed by ODOT; and (b) they had been bent accidentally during construction or subsequent periodic mowing operations.

Once the outlet was visually inspected and recorded, the vegetation and sediments were removed. In most outlets, this permitted the trapped water to flow fast and freely (Figure 6.12). Figure 6.13 displays the difference cleaning an outlet makes. Figure 6.13 (a) shows a clogged outlet before cleaning, whereas in Figure 6.13 (b) the water is observed flowing freely once the silt and weeds are removed. Such observations reaffirm the need for regular maintenance of the outlets. If the outlets are kept free of obstructions, water from the base layer will be free to escape preventing prolonged exposure of the material to saturation levels. The underdrains should be periodically cleaned or flushed, and this process can be aided by the placement of clean-out boxes (Moulton, 1980). No such clean-out boxes are located on the U.S. 50 project site, and, therefore, flushing may be more difficult and not as effective.

The precast reinforced concrete outlets are generally in good condition, with only few distresses observed. Outlet No. 209 appears to be recycled from another roadway (Figure 6.14). It is noticeably older as evidenced by the discoloration and deterioration of the concrete. This concrete outlet has been improperly placed and does not provide adequate protection to the conduit. Consequently, the pipe has been crushed and its lip forms a "V" at the tip, impeding water flow. Standing water is found inside the pipe. Outlet No. 143 has slipped down the hillside, leaving the underdrain pipe completely exposed (Figure 6.15). The pipe seems to be in good condition, but it was not inspected very closely because of the presence of a snake, which was sunbathing on the concrete outlet (Figure 6.16). The UC research team felt it was better to leave the pipe uninspected rather than disturb the reptile!

6.1.3 Markers

An outlet marker is a posted sign that clearly shows the location of an outlet. It should be on a protective post tall enough to be seen over the vegetation growth. There are no outlet markers of any kind found at the Athens project site. The researchers had difficulty finding the outlets due to the extensive overgrowth. Some of the outlets are not located as specified in the ODOT specifications and plans (ODOT, 1995), but are often found within about 15 m (45 ft). Outlet markers would be most beneficial in locating such outlets.

6.2 Drainage Recommendations

The inclusion of open-graded bases in the design of Portland Cement Concrete (PCC) pavements seeks to ensure adequate drainage, but such layers must be properly maintained. If silt, moss, and other debris are allowed to accumulate in the drains, the water will not be able to escape and the base will become saturated. To keep the drains draining freely, a routine maintenance program must be implemented. Maintenance should consist of cleaning the outlets of any vegetation overgrowth that may hamper future efforts to locate the outlet. Once the outlet is found, a marker should be installed that clearly identifies its location, so that it may be found easily in the future. All silt, moss, and debris should be removed at the outlet and from the rodent screen. Flushing is suggested by Moulton (1980), but without the aid of clean-out boxes it may be rather difficult to perform. The use of a device similar to a plumber's snake may be enough to clear the drains of any debris. The rodent screens should be inspected for damage, such as bending. A redesign of the rodent screen may also be necessary to ensure that it will fit snugly into the head wall without any gaps. The present design allows small rodents to pass through between the head wall and screen. The gradient of the transverse collector pipes should be increased to produce a higher exit velocity, so that silt and debris cannot gather in the pipe. Nonperforated metal or smooth, rigid pipes may resist clogging more effectively.

Table 6.1 Location and condition of underdrains

Figure 6.1 Inspecting the inside of a drain

Figure 6.2 View of inside of collector pipe using the infrared device

Figure 6.3 Tall vegetation made finding the outlets difficult

Figure 6.4 Clearing the growth so that the outlet can be observed

Figure 6.5 Mowed and unmowed areas

Figure 6.6 Combination of silt, moss, and weeds that has collected in the outlet

Figure 6.7 A large weed growing out of one of the outlets

Figure 6.8 Water flowing out of the outlet

Figure 6.9 Standing water, approximately 1" deep, unable to flow out

Figure 6.10 Moss and silt that has gathered on the rodent screen

Figure 6.11 The rodent screen has been bent back, creating a gap for small rodents

Figure 6.12 A large amount of water is able to drain after removing sediments

(a)

(b)

Figure 6.13 (a) Outlet as found, (b) outlet after sediments removed

Figure 6.14 An older concrete outlet, which appears to have been recycled

Figure 6.15 A concrete outlet that has slipped down the hillside, exposing the drain

Figure 6.16 A snake sunbathing on the concrete outlet

Table 6.1 Location and condition of underdrains

	Underdrain No.	Station	Offset	Found	Screen	Silt	Vegetation	Water
EASTBOUND	84	155+00	95' RT	YES	NO	LOW	HIGH	STANDING
	92	152+68	122' RT	YES	NO	LOW	HIGH	NONE
	109	170+00	98' RT	YES	NO	HIGH	HIGH	NONE
	115	174+50	103' RT	YES	NO	HIGH	HIGH	STANDING
	121	178+97	104' RT	YES	NO	LOW	HIGH	-
	136	184+00	106' RT	YES	NO	NONE	HIGH	FLOWING
	143	199+00	84' RT	YES	NO	N/A	HIGH	N/A
	149	202+97	81' RT	YES	-	HIGH	HIGH	NONE
	155	206+74	72' RT	YES	NO	HIGH	HIGH	STANDING
	166	213+00	62' RT	YES	NO	LOW	HIGH	FLOWING
	171	218+00	70' RT	YES	NO	HIGH	-	NONE
	209	257+00	81' RT	YES	NO	HIGH	HIGH	STANDING
	226	272+75	86' RT	NO	-	-	-	-
	232	279+97	100' RT	NO	-	-	-	-
	238	280+03	100'RT	NO	-	-	-	-
	244	291+00	93' RT	NO	-	-	-	-
WESTBOUND	82	148+50	95' LT	YES	YES	HIGH	HIGH	STANDING
	89	155+00	93' LT	YES	YES	NONE	LOW	FLOWING
	94	152+00	105' LT	YES	NO	NONE	HIGH	STANDING
	114	170+00	90' LT	YES	YES	NONE	LOW	NONE
	120	174+50	95' LT	NO	-	-	-	-
	132	184+50	95' LT	YES	YES	NONE	LOW	FLOWING
	221	261+00	82' LT	NO	-	-	-	-
	237	276+00	98' LT	YES	YES	NONE	HIGH	STANDING
	243	280+00	98' LT	NO	-	-	-	-
	249	291+00	81' LT	YES	YES	NONE	LOW	FLOWING

Figure 6.1 Inspecting the inside of a drain

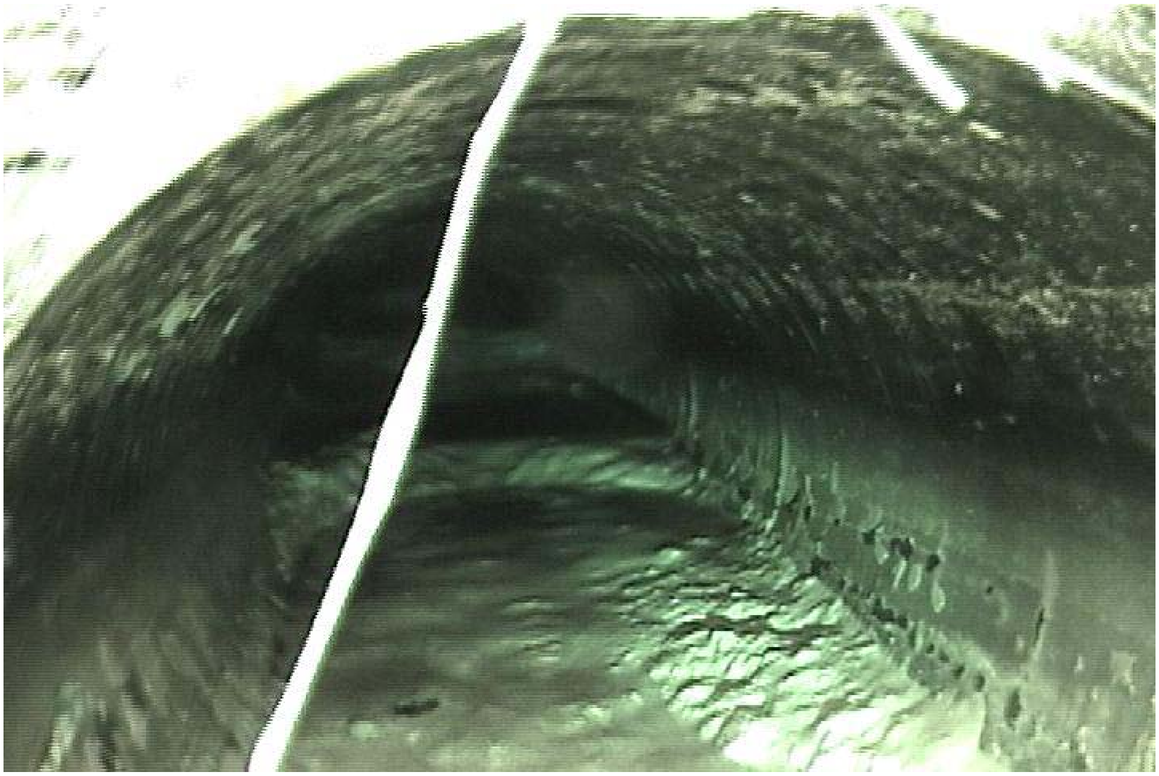


Figure 6.2 View of inside of collector pipe using the infrared device

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Figure 6.9 Standing water, approximately 1” deep, unable to flow out

Figure 6.10 Moss and silt that has gathered on the rodent screen

Figure 6.11 The rodent screen has been bent back, creating a gap for small rodents

Figure 6.12 A large amount of water is able to drain after removing sediments

(a)

(b)

Figure 6.13 Typical outlet, as found and after sediments were removed

Figure 6.14 An older concrete outlet, which appears to have been recycled

Figure 6.15 A concrete outlet that has slipped down the hillside, exposing the drain

Figure 6.16 A snake sunbathing on the concrete outlet

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary

The project described in this Final Report entails the construction and evaluation to date of a joint sealant experiment near Athens, Ohio in the Wet-Freeze climatic zone. The experimental design, performance evaluation methodology and data analysis for this project conform to guidelines established by previous studies, particularly those under the Strategic Highway Research Program (SHRP) Specific Pavement Studies (SPS)-4 sealing effectiveness initiative. Ten different joint sealant materials and fifteen material-joint configurations are used in the new eastbound and westbound lanes of a stretch of U.S. Route 50, constructed between 1997 and 1999. The eastbound lanes were constructed first and have been open to traffic since the Spring of 1998, whereas the westbound lanes have been serving traffic only since the Spring of 1999.

Evaluations to date include two profile surveys and two visual inspections of the eastbound lanes, as well as a single profile survey and visual inspection of the westbound lanes, conducted prior to Fall 1999 and reported by Hawkins (1999); two profile surveys and two visual inspections of the both sides of the test pavement conducted in Fall 1999 and Spring 2000 and discussed by Sander (2002), who also presented an initial data set pertaining to the development of structural distresses in the pavement slab, notably transverse and corner cracking; and three profile surveys and three visual inspections in accordance to the same evaluation plan first implemented in Fall 1999, conducted in Fall 2000, Spring 2001 and Fall 2001. The latter three evaluations are examined in detail in this Final Report. In addition, additional structural distress data are analyzed in order to determine whether any correlation exists between sealant performance and pavement slab condition. Finally, this Report presents the results of an evaluation of the drainage features of the highway, since these are related in various ways to both the sealant effectiveness and structural response of the pavement system.

7.2 Conclusions

The deteriorating condition of the sealants in the eastbound lanes was first reported by Hawkins (1999), when that stretch of the pavement had been open to traffic for a little longer than a year. The following is excerpted from the Conclusions Chapter of Hawkins (1999), since the observations made then are still valid three years later for both the eastbound and westbound lanes:

"Consider, for example, the condition of the silicone and hot-pour sealants in the eastbound lanes. After only one year of service, these sealants are in very poor condition. The majority of these sections have already experienced significant full-depth adhesion failure, with the sealant either sinking completely into the joint or being pulled away by traffic. In this condition, the sealants might as well not be present, thus rendering the unsealed sections significantly more cost effective. In fact, joints in which the sealant becomes ineffective over a significant length may be considered as partially sealed joints, and may exhibit worse performance than unsealed joints of the same configuration (Shober, 1986).

"Since the sealants have remained effective for less than one year, serious consideration needs to be given to the joint cleaning and sealant placing operations currently employed. The worst of the sealed sections were obviously those with a narrow joint width of 3 mm (1/8 in.). In most joints with such a configuration, the sealant material had overflowed and run onto the pavement surface, thereby being exposed to tire traffic. Oversight and inspection provided were ineffective in averting the use of equipment and procedures that were obviously inadequate. Special nozzles or applicators need to be used, so that the sealant will be placed from the bottom up at a slow rate, ensuring that the joints are not overfilled.

"Moreover, since even some of the wider joints also exhibited overfilling, more than just the equipment employed needs to be reconsidered. The placement of the backer rod should be performed with care, subject to stringent inspection, so that the proper depth and continuity are maintained. Another extremely important consideration is that of joint cleaning, and joint condition at the time of placement. The joints in this experiment were cleaned only by water- and air-blasting, even though the manufacturers' recommendations usually called for sandblasting. [The *Plan Notes* from the Ohio Department of Transportation (ODOT), reproduced in Figure 2.2, stipulate that sealants "shall be installed in accordance with the manufacturer's recommendations".] It is possible that the extensive adhesion loss already noted is related to the joint cleaning procedures. Sandblasting provides a rougher surface for the sealant to bond to, but even this may not be enough. The surfaces of the joints need to be subjected to inspection before sealing, to ensure that they are clean and free of moisture, as this is an important detail in obtaining effective, long-lasting sealed joints. If the equipment and procedures employed in placing silicone and hot-pour sealants during this experiment represent the conditions on a typical highway construction site, it is apparent that not sealing would have been a preferable alternative, in terms of convenience as well as cost.

"With the exception of the TechStar W-050, the preformed compression seals have exhibited significantly better performance to date than liquid sealants. Both the Watson Bowman and Delastic seals are performing very well, with no visible signs of adhesion loss or other distress at the time of the second visual analysis. It appears that the adhesive used with these seals results in a more durable bond between the seal and joint walls.

"The TechStar seal has not performed as had been anticipated if only by its much higher cost, and had developed significant adhesive failure by the time of the second visual inspection. The seal had simply broken free of the proprietary adhesive and had sunk into the joint, leaving the dried-out adhesive visible on the joint walls near the pavement surface. Although it is not possible to verify the causes of such widespread adhesion failure at this time, incompatibility between the adhesive and the seal cannot be ruled out, either.

"The unsealed sections are also performing very well, exhibiting no visible signs at this time of distress at the joints (e.g., spalling) or in the pavement slabs. Small-size debris has entered the shoulder joints, but the traffic lane joints are still fairly open and clean. No blowups or loss of subbase support have occurred. In fact, the surface profile of the unsealed sections shows them to be performing as well, if not better, than most of the sealed sections. Interestingly, no mention is made of any distresses or problems with the unsealed sections in the Strategic Highway Research Program (SHRP) Specific Pavement Studies (SPS)-4 supplemental joint seal experiment (Smith, et al., 1999), either. It will be interesting to continue monitoring unsealed sections and comparing their performance to that of sealed sections. If no significant differences in performance can be found, leaving Portland cement concrete (PCC) pavement joints unsealed should be considered a cost-effective design feature.

"It is reiterated that as this project will undergo several more years of evaluation, conclusions reached thus far are based only on relatively early observations. It is hoped that future evaluation of both the westbound and eastbound lanes will provide significant feedback regarding the effectiveness of current joint sealing procedures. It is also noted that the performance of the pavement to date as indicated by the profile surveys does not appear to be related directly to the effectiveness of the joint seals. Rather, the roughness indices recorded provide a measure of the driver response to the overall pavement surface, in a manner that probably reflects most immediately the overall condition of the concrete slab. Whether the latter will deteriorate with time on account of ineffective sealants can only be ascertained after long-term evaluation. The provision of several drainage features (e.g., underdrain in subgrade, drainable base layer) and the tightly controlled pavement construction procedures followed on this site may well counterbalance any deficiencies in joint sealants, ensuring satisfactory service of the highway for many years to come."

Early evaluations of sealant performance reported by Hawkins (1999) were hampered by the continuing construction operations on the test site. Consequently, research team members were obliged to observe the joints standing at the pavement shoulder, and were unable to make measurements of the extents of developing distresses. To provide consistent and comparable performance evaluations during subsequent visual inspections of sealant and pavement condition, a performance evaluation plan was developed, as described by Sander (2002). The data collected according to the performance plan, which was first implemented during the Fall 1999 evaluation of joint sealants at the U.S. 50 project, are analyzed to determine the average effectiveness of a sealed joint treatment, which is the combination of a particular joint configuration and sealant material. The rating scheme developed by Belangie and Anderson (1985) is used to assign the treatment to a particular category, i.e., very good, good, fair, etc. The thirteen joint sealant treatments are also ranked according to their level of effectiveness, as well as the percentage point deterioration, <u>%</u>, of each treatment in the time period between each pair of successive performance evaluations.

In addition to the visual inspections, results from four profile surveys of pavement surface roughness performed in the eastbound and westbound traffic lanes are analyzed, in an attempt to establish general trends in pavement surface condition based on measured roughness.

Sander (2002) examined in detail the data collected during the performance evaluations of Fall 1999 and Spring 2000. At the time of the latter, the pavement had served traffic for two and one years along the eastbound and westbound lanes, respectively. Commenting on these data, Sander (2002) stated:

"Regarding sealant performance, the general indications are that joint seals installed in the westbound lanes appear to be exhibiting higher effectiveness levels compared to those in the eastbound lanes. The weighted average effectiveness of sealed treatments installed in the westbound lanes is 84%, compared to only 50% total average effectiveness of the sealed treatments in the eastbound lanes. The difference in effectiveness levels is certainly to be attributed to age; the sealants in the westbound lanes are approximately eleven months 'younger' than those installed in the eastbound directions of traffic, and, therefore, have not been subjected to traffic and environmental stressors for quite as long a time period.

"After two years of service in the eastbound lanes, compression seals, with the exception of the TechStar W-050, significantly outperform the other two sealant classes, i.e., silicone and hot-pour types, retaining an average effectiveness of 75%, or 95% without the inclusion of the TechStar W-050 seals. Silicone and hot-pour sealants exhibit average effectiveness values of 50 and 40%, respectively. It appears likely that these general trends will be replicated in the westbound lanes as time goes by. Of the fifteen treatments, the Watson Bowman WB-687 (5) and WB-812 (5), as well as the Delastic V-687 (5) treatments, exhibit the least deterioration (fewer than 5 percentage points) between the Fall 1999 and Spring 2000 inspections. The Watson Bowman treatments in the eastbound lanes retained the No. 1 rank, with an average effectiveness of 98% and 95% at the time of the Fall 1999 and Spring 2000 performance evaluations, respectively.

Delastic V-687 (5) was a close second in this ranking system. In both the eastbound and westbound lanes, the TechStar W-050 material has failed to maintain an effective seal between the joint walls.

“Among the four silicone sealants installed in the eastbound lanes, the Dow 890-SL treatments exhibit better performance than the other three silicone sealants, having an average effectiveness of 63%. The Crafco 903-SL, Crafco 902 and Dow 888 treatments show combined average effectiveness levels of 38, 41 and 49%, respectively. The three treatments of Dow 890-SL self-leveling silicone sealant captured the rankings of 4, 5 and 6 during the Spring 2000 inspection of the eastbound lanes. In the westbound lanes, the Dow 888 non-sag treatments outperform the Dow 890-SL and Crafco 903-SL joint sealant treatments, retaining an average effectiveness of 99%.

“The hot-pour sealants were found to show the worst performance of the three sealant types with an average effectiveness of 40% in the eastbound lanes and 69% in the ‘younger’ westbound lanes. Hot-pour sealants showed the fastest rate of deterioration up to the age of twenty months. In contrast, their performance between twenty and twenty-four months was relatively constant, showing very little joint seal deterioration over that time period. Variations are noted in the performance of the Crafco 444 treatment; in the westbound lanes the joint seal was about 89% effective, whereas in the eastbound lanes the average effectiveness is only 10%. The hot-pour sealants appear to have aged prematurely, as the surface of the sealants exhibit signs of hairline cracking, and the sealant material is brittle in the joint.

“The sections containing unsealed joints are performing very well. In fact, the unsealed sections are continuing to perform better than most of the test sections with sealed joints, however, such a comparison between sealed and unsealed joints is limited and can only be based on the presence of structural distresses at the joint. The only visible distress in unsealed test sections at the time of the Fall 1999 and Spring 2000 inspections is spalling of the lips in several isolated joints. It is likely that most of the joint lip spalls observed may have been caused at the time of initial sawing. Debris in the form of small stones and sand had entered and accumulated on the bottom of many of the unsealed joints, however, this has not affected their performance. For the most part, the joints remain free of incompressibles lodged between the joint walls. Moreover, no blowups or signs of pumping are evident in the unsealed test sections, and there is no evidence that any of the observed corner breaks or transverse cracks formed as a result of unsealed contraction joints, as might be expected.

"Results from the four profiles of surface roughness conducted in the eastbound and westbound lanes are used to draw general inferences pertaining to pavement performance. The profile measures indicate that after approximately one and a half years of a deteriorating pavement condition, or decreasing serviceability, the surface has exhibited increased smoothness and serviceability. This observation of increasing roughness is observed between the Fall 1999 profiles of surface roughness and the Spring 2000 roughness assessments in both the eastbound and westbound lanes. Comparisons are made between the various profile roughness measures and the average treatment effectiveness recorded in each test section. The tabulated and graphical results presented indicate that a correlation does not exist between the two performance categories; the average treatment effectiveness, i.e., sealant performance, cannot be confidently estimated from the values of pavement surface roughness.

“The sealant inspection plan calls for the recording of distresses occurring in the immediate vicinity of joints which may be indicative of joint seal inefficiency or failure. The first signs of such pavement distress are in the form of mid-slab transverse cracks revealed in several of the test sections in the eastbound lanes as the wet pavement surface began to dry. The frequency and widespread distribution of these transverse cracks, does not suggest that their occurrence is necessarily related to joint seal failure.

“A pilot study into the frequency and distribution of transverse cracks in the westbound driving lane shows that mid-slab cracks occur in ten of the fifteen test sections, whereas corner cracks were observed in seven test sections. The test section displaying the greatest frequency of mid-slab cracks and the top percentage of slabs cracked is the Dow 890-SL (1) treatment, with a total of 9 transverse cracks, accounting for 33.3% slabs cracked. The section sealed with the Watson Bowman WB-812 (5) treatment has the second highest percentage of cracked slabs, with 18.5% slabs cracked. No transverse cracks are evident in the No Sealant (6) section, as well as Crafco 903-SL (1a), Dow 888 (1a), Crafco 903-SL (4), and Dow 890-SL (4) treatments.

“There are no visible signs of corner breaks at any of the transverse joints in eight test sections in the westbound driving lane, including one that has unsealed joints. The other unsealed section in the westbound direction exhibits a single corner crack in one of its 125 slabs, accounting for 0.8% slabs cracked. The section with the Dow 890-SL (3) treatment had developed the highest percentage of slabs with corner cracks: four corner breaks were observed in its 28 slabs, accounting for 14.3% slabs cracked.

"Mid-slab cracking of significant extent was first observed in both the eastbound and westbound lanes in the Spring of 2000, following an extreme flooding event, which inundated a extensive area on both sides of the highway embankment. Neither the drainage provisions in the pavement, nor the nearby Hocking River appeared to be able to handle the amount of precipitation received during this event."

Sander (2002) also examined a number of features associated with sound pavement design. The features analyzed apply to the U.S. 50 experimental joint sealant test site and include drainage provisions, load transfer, tied shoulders and transverse joint spacing. Their influence at the U.S. 50 test site was determined through a series of mechanistic computations using a variety of existing pavement engineering software. The concept behind the mechanistic evaluations is to investigate whether the PCC pavement could maintain a high performance level even if joint sealants were to deteriorate, or whether the pavement might deteriorate rapidly even if all sealants continued to function properly. The following is a summary of these efforts, excerpted from Sander (2002):

"The mechanistic analyses focused primarily on the effects of subgrade support, load transfer, transverse joint spacing and tied PCC shoulders. Values representative of those at the U.S. 50 test pavement were chosen for the soil, concrete and dowel properties used in the analyses. The effects of complete saturation and corresponding softening of the subgrade due to poor drainage were modeled, and it was found that weakening the subgrade soil due to prolonged flooding led to increases in maximum bending stress,

σ_{max}, of 19, 23 and 17% at the interior, edge and corner of the slab, respectively. The effect on the maximum slab deflection, δ_{max}, is considerably more pronounced, leading increases of 144, 159 and 164% under interior, edge and corner loads, respectively. In contrast, the maximum subgrade stress, q_{max}, decreases by 58, 57 and 55%, at the slab interior, edge and corner, respectively.

"In a separate investigation concerning saturation and subsequent weakening of the base and subbase layers, it was found that the effects of strength loss in the base and subbase layers were insignificant. As the base and subbase layer stiffnesses are reduced by about 90%, the interior bending stress increases only by 1%. The subgrade stress and subgrade deflection are reduced by less than 4%. In contrast, slab deflections exhibit an increase of 4.2% over the range of parameters considered. These results indicate that softening of the base and subbase layers can result in significant plastic and permanent deformations which produces non-uniform support conditions.

"Shoulder ties and transverse load transfer provisions were also investigated for this Report. Through analysis, it was noted that load transfer devices installed significantly reduced the level of edge stress and deflection at the transverse and shoulder joints. Adopting typical and reasonable values for the joint opening and the modulus of dowel reaction, calculated values of deflection load transfer efficiency range from 81 to 93%, while those for stress load transfer efficiency vary between 40 and 60%. It is shown that σ_{max} and q_{max} at doweled joints are reduced by about 30 to 60%, respectively, compared to the free edge responses. The corresponding value of δ_{max} is reduced by 60%. Bearing stress values as high as 8 MPa (1150 psi) are obtained, the highest values being associated with improved load transfer efficiencies. A mechanistic analysis using *ILSL2* indicates that shoulder ties lower the free edge bending stress by about 11 to 20%. Reductions in free edge deflection range from 27 to 33%, whereas the free edge subgrade stress is decreased by 26 to 33%.

"Several popular fatigue models were utilized to examine the benefits of load transfer in terms of pavement longevity. The results showed that by effectively reducing bending stress levels at the joint, the pavement was capable of withstanding a significantly increased number of load repetitions until failure. The *Austin Research Engineers, Inc.* (ARE) fatigue model shows that the number of load repetitions to failure with transverse load transfer devices increases from 1.56 to 3.76 times to that for a free edge condition. Similarly, N_f increases by 2.51 to 7.04 times according to the *Resource International, Inc.* (RISC) equation. The effect of providing shoulder ties in the pavement is similar; according to the ARE formula, the bending stress reduction leads to an increase in the number of load repetitions to failure by about 1.5 to 2.1 times compared to free edge conditions. Similar trends are observed when applying the RISC model; the allowable number of repetitions to failure increases by about 1.7 to 2.7 times.

"The factor having the most pronounced affect on pavement performance was transverse joint spacing. The ratio of the slab length, L, to the radius of relative stiffness, *l*, and referred to as the (L/*l*) concept, was utilized to determine the theoretical maximum joint spacing. The results clearly showed that the 6.4-m (21-ft) joint spacing in the U.S. 50 pavement, and corresponding (L/*l*) of about 6.1, exceeded the maximum recommended (L/*l*) ratio of 4.5 for jointed plain concrete pavements (Smith, et al., 1997). Based on an (L/*l*) of 4.5, transverse joints should have been provided at spacings no greater than 4.6 m (15 ft) in order to prevent or minimize slab cracking. This unfortunate discrepancy may lead to premature pavement distress in the form of transverse cracking throughout the concrete slab.

"Computations were performed to study the effect of the selected reliability level on pavement slab thickness. Using input values identical to those used in the original pavement design for the U.S. 50 pavement, and varying the reliability from 85% to 99%, it was shown that selecting a higher level of reliability (>95%) requires a slab thickness greater than 250 mm (10 in.).

"Several construction issues were suggested as possible contributors to mid-slab transverse cracks observed in the eastbound and westbound lanes of the experimental pavement. The two primary concerns are the low curing temperatures of the PCC pavement slab and the use of ground granulated blast furnace slag (GGBFS) cement as a replacement for some of the Portland cement in the mix design. These factors along with several others led to a delay in the time to initial set, as a result, promoting drying shrinkage, which would add to the concave upward distortion of the slab.

The three latest visits to the test site by the University of Cincinnati research team are detailed in this Final Report; these visits occurred in October 2000, June 2001, and October 2001 . During each of these visits, the team conducted a visual evaluation of the condition of the sealants and of the structural performance of the pavement slab, collecting numerical data for subsequent analysis. Moreover, the ODOT profilometer crew performed surveys of the highway profile in each of the two directions, on each of the driving and passing lanes. The profilometer surveys occurred within a few days of the visual inspections, depending on the practicality of scheduling them in the framework of the ODOT crew's other assignments.

The following is a summary of the observations regarding the sealants in the eastbound and westbound lanes, respectively, following the most recent of the three evaluations discussed in this Final Report.

Performance of Eastbound Lane Seals as of EBOC01

The compression seals are the superior sealant material in the eastbound lanes, averaging 69% effectiveness, even when including the TechStar W-050 (5) section, which is only 19% effective. If this section is excluded, the compression seals' average becomes 94%, which is the effectiveness value for both Watson Bowman 687 (5) and Delastic V-687 (5). The two hot-applied sealants differ quite dramatically from one another. Crafco 221 (1) has the third highest effectiveness value (79%), yet Crafco 444 (1) has the lowest value (9%). These two sections average 44% effectiveness, the lowest among the three sealant types. The silicone sealants average 46% effectiveness, which is only slightly better than the hot-applied. The two self-leveling sealants with the No. 1 joint configuration are the best performing silicone sections to date. Dow 890-SL (1) and Crafco 903-SL (1) have effectiveness values of 71 and 58%, respectively. Only one other silicone section is above 50%, namely Dow 890-SL (3), which is 57% effective. The remaining five sections are below 50% effectiveness, including Crafco 903-SL (4), which is only 12% effective.

Performance of Westbound Lane Seals as of WBOC01

Partially due to their 'younger' age, the westbound sealants are performing much better than those in the eastbound lanes. The westbound compression seals, with the exception of TechStar W-050 (5), continue to perform exceptionally well. Watson Bowman 812 (5) and Delastic V-687 (5) are 98 and 97% effective, respectively. The average of the compression seals (66%) is depressed due to the ineffectiveness of the TechStar W-050 (5) section. Excluding this section yields an average of 98%, which is best amongst all the sealants. The difference in effectiveness between the two superior compression seal sections and TechStar W-050 (5) could not be greater. The latter is only 4% effective, and its ability to keep any water out of the joint is extremely questionable. The difference between the two hot-applied sections continues to increase: Crafco 444 (1) is 93% effective, yet Crafco 221 (1) is only 43% effective making the difference 50%. The silicone sealants average 85% effectiveness, which is the best for the westbound lanes (when TechStar W-050 is included for the compression seals). All silicone sealants with the No. 1 configuration, with the exception of Crafco 903-SL (1b), are in very good condition ($\geq$ 90%). The only No. 3 configured section, Dow-SL 890 (3), has the highest effectiveness value (99%) out of all the westbound sections. The two No. 4 configured silicone sections, Crafco 903-SL (4) and Dow 890-SL (4), have effectiveness values of 85 and 44%, respectively. It is apparent that the No. 4 joint configuration continues to produce poor effectiveness values.

It is interesting to examine the performance of the sealants over the entire length of the project, and to compare the observations made in each of the two directions of the highway, accounting for the difference in age between the eastbound and westbound lanes. The following is a summary of this information.

Performance of Eastbound Lane Seals Over Entire Project

Over the course of the Project, the nearly identical excellent performance of the two compression seal sections, Watson Bowman 687 (5) and Delastic V-687 (5), is most noteworthy. The effectiveness values of these two seals never differ by more than 1% from one another. Their long-term performance looks promising, whereas the third compression seal, TechStar W-050 (5), seems doomed for a quick ultimate failure; the performance of the latter has fallen precipitously well below that of the other two compression seals. It is apparent that from the beginning Crafco 444 (1) began deteriorating at a faster rate than the other hot-applied section, Crafco 221 (1). The former appears to be at a terminal effectiveness level since it does not have much more effectiveness to lose, whereas the latter is maintaining its mediocre effectiveness. Generally, the silicone sealants have steadily declined in effectiveness since their installation. No section is currently above 75%, and five of the eight are below 50%, including Crafco 903-SL (4), which is only 12% effective. These sealants do not show much promise for the long-term.

Performance of Westbound Lane Seals Over Entire Project

A review of the westbound sealants' effectiveness values for all surveys indicates that two of the compression seals, Watson Bowman 812 (5) and Delastic V-687 (5), have maintained nearly all of their original effectiveness, which promises excellent performance in the future, as well. In contrast, the third compression seal, TechStar W-

050 (5), may have at one time been 100% effective, but deteriorated quickly soon after its installation. It is clear that this section has been steadily declining in effectiveness over the past three years. The hot-applied sealants were not installed until April 1999, whereas all other seals in the westbound lanes had been installed in December 1998. Unlike the eastbound lanes, where Crafco 444 (1) began deteriorating very rapidly and dramatically, the corresponding westbound section has lost very little effectiveness. It has generally maintained effectiveness values above 90% for its lifetime to date. Crafco 221 (1) deteriorated rapidly early on, but more recently it has maintained a steady effectiveness value. Most of the silicone sealants have maintained much of their original effectiveness throughout their lifetime. Four sections, Dow 890-SL (3), Dow 888 (1b), Dow 890-SL (1), and Crafco 903-SL (1a), have never dropped below 95% effectiveness. Dow 888 (1a) recently dropped to 91%, but it had been above 95% in all previous surveys. Crafco 903-SL (4) and Crafco 903-SL (1b) had deteriorated to 89% and 77%, respectively, during WBMR00, but they have essentially maintained those values since then. The two identical Crafco 903-SL (1) sections are performing quite differently. Crafco 903-SL (1a), which is between Stations 188+00 and 194+00, is outperforming its twin by approximately 20% throughout the time span considered. The Dow 890-SL (4) section is very hard to survey due to the very narrow joint width, which makes it difficult to determine adhesion failure.

Comparison of Performance of Eastbound and Westbound Lane Seals Over Entire Project

It is impossible to make a direct comparison between the eastbound and westbound sealants during any single survey. Consequently, the data from each survey must be expressed in terms of time elapsed since the highway was opened to traffic in each of the two directions, so that sealants of a similar age can be compared. Even when compared to the eastbound sealants at the same age, the westbound lane seals are performing much better than the those in the eastbound lanes. Only the compression seals are performing similarly to their opposite lane direction counterparts. The westbound silicone sealants are outperforming the eastbound sealants at the same age by 47%. The same comparison for the hot-applied sealants yields an average difference of 29% in favor of the westbound sealants. The U.S. 50 sealant experiment includes many sealant materials and joint configurations not normally utilized in Ohio. It is reasonable to expect that the sealant installation crew was less familiar with some treatments than with others. Because the westbound sealants were installed a year after those in the eastbound lanes, the crew may have benefitted from their first year experience, making the installation process more effective in the second. The similarity in the behavior of the eastbound and westbound lane compression seals that are commonly used in Ohio, corroborates this assertion.

The Watson Bowman and Delastic seals in both the eastbound and westbound lanes are performing extremely well. The eastbound TechStar section is outperforming its westbound counterpart, but effectiveness trends are pitifully poor. In both directions, this material exhibits less than 20% effectiveness, and continues to deteriorate. It is believed that these sealants are not designed to adhere to PCC since they are manufactured specifically for bridge decks. A large discrepancy between the two Crafco

444 (1) sections is evident. The eastbound section never performed as well as the westbound, which hints at possible deficiencies in the installation of the former. It is possible that the construction crew gained experience with the installation of the eastbound section, and used this effectively during the installation of the westbound. Moreover, it is possible that delaying the westbound installation until the following Spring was very beneficial. The Crafco 221 (1) sections, however, do not support these postulates. Just the opposite is observed in these sections, albeit to a much lesser degree: the eastbound are outperforming the westbound. The effectiveness difference between the two lane directions is about 25% for the Crafco 221 (1), whereas for the Crafco 444 (1) sections this difference is about 80%. All of the westbound silicone sealant sections are outperforming their eastbound counterparts by a large margin over their lifespan to date. Every section currently has at least 25% more effectiveness than its counterpart. It is apparent that all eastbound sections never performed as well as their westbound counterparts. The westbound Dow 888 (1) sections former have never dropped below 90% effectiveness, whereas the eastbound deteriorated drastically very early on and are currently about 50% below the westbound lanes. This suggests that poor workmanship may be responsible for the dismal performance of the eastbound silicone sealants. Westbound Dow 890-SL (3) and Crafco 903-SL (4) have outperformed their eastbound counterparts over the entire time span considered. The Dow 890-SL (3) section has maintained an effectiveness of at least 95% in the westbound lanes, yet its counterpart in the eastbound direction has deteriorated steadily to below 60%. The westbound Crafco 903-SL (4) section has never dropped below 80%, yet the corresponding eastbound

section began deteriorating quickly and never came close to matching the westbound performance. The eastbound section of Dow 890-SL (4) had better effectiveness values than the westbound section in early life, yet at approximately 25 months, it began to lose effectiveness very quickly and has since dropped below the latter. Additional surveys are needed to decipher the performance of these sealants over an extended period of time.

Turning now to the observations regarding the structural performance of the pavement slab discussed in this Final Report, the following remarks may be useful in summarizing the results obtained by the research team.

Unlike sealant performance, in which the westbound lanes are superior to the eastbound, pavement structural performance in the eastbound lanes is higher than in the westbound lanes, judging by the corresponding frequencies of transverse cracking. As of the latest survey (October 2001), the westbound lanes have 44% of their slabs cracked, but the eastbound only have 39%. This is surprising since the eastbound lanes are approximately one year older than the westbound. The fact that the westbound lanes have superior sealants but more extensive transverse cracking suggests that no correlation exists between sealant effectiveness and transverse cracking; a closer inspection verifies this assumption. It is observed that many of the sealant sections that have high effectiveness values also exhibit high percentages of transverse cracking. In addition, many of the sections with low effectiveness values have very little transverse cracking. Finally, the distribution of cracking is generally random, corroborating the assertion that no correlation exists between sealant effectiveness and transverse cracking.

There are only three sections with corner breaks in the eastbound lanes accounting for five slabs. Two of these sections are sealed with a compression seal and a silicone, respectively, whereas the third is unsealed. Therefore, it can be inferred that corner breaking has no correlation with sealant effectiveness, either.

The structural performance of the eastbound lanes suggests that the mere presence of a sealant may prevent spalling at the joints. Excluding a poorly constructed joint in the hot-applied section of Crafco 222 (1), the two sections that contain the most amount of spalling are the two unsealed sections. Among the sealed sections, however, those containing the highly effective compression seals also exhibit the highest extents of spalling, suggesting that the effectiveness of a seal is not a guarantee against this type of distress. Yet, to complicate matters, the westbound lanes do not always exhibit the same pavement distress trends as the eastbound lanes.

The extent of transverse cracking in the westbound lanes is surprisingly high: almost half of the slabs are cracked. Obviously, the highly effective sealants did not prevent such cracking. The compression sealed sections, which generally are the best performing seals, have the top three rankings in terms of transverse cracking. The unsealed sections, on the other hand, have some of the lowest percentages of slabs cracked. It is apparent that excellent sealant performance does not promote good pavement performance in the westbound lanes any more than it did in the eastbound direction.

There are more than twice the number of corner breaks in the westbound lanes as there are in the eastbound lanes. Corner breaks in the westbound lanes are distributed evenly among the sealant sections, which suggests that no correlation exists between sealant effectiveness and corner breaking. The degree of spalling in the westbound lanes may suggest a faint correlation with sealant effectiveness: the top four sealant sections in terms of sealant effectiveness have a total of only 51 mm (2 in.) of spalling.

The profilometer surveys for all four lanes follow similar, if not identical, trends. Since December 1999, all four lanes have been surveyed at the same time. With few exceptions, all indices in all lanes follow the same trend. Between the December 1999 and March 2000 surveys, nearly every index demonstrates a significant increase in smoothness, followed by an equivalent decrease during the following survey (October 2000). After the latter survey, the profile surface for the eastbound lanes is fairly constant, while the westbound lanes increase and decrease during the last two surveys. The remarkable similarity in the trendlines between all four lanes suggests that climatic factors, e.g., curling and warping, may be responsible for the fluctuations in the pavement profile, rather than pavement deterioration. If true, this would make it difficult to rely on future profilometer data to show deterioration in the pavement. Also, while analyzing the profilometer data on a section by section basis, it is apparent that no correlation exists between sealant effectiveness and pavement surface deterioration. Many of the superior sealant sections exhibit decreases in pavement surface smoothness, while many of the inferior sealant sections show increases in smoothness. Additional insights may be obtained by reviewing the profile data directly as recorded by the computer on board the profilometer van, but these are no longer available.

Along with the sealant and pavement inspections, the University of Cincinnati research team conducted an evaluation of the underdrain outlets since they too play a pivotal role in the performance of the pavement. The outlets and outlet pipes were viewed without the assistance of any special borehole video equipment. By viewing the outside of the outlets, however, substantial evidence could be gathered to determine the condition of the outlet pipes in that area. Many of the outlets (27%) could not be found either due to high vegetation growth or simply because the outlet was not located per ODOT specifications (1995). Many of the outlets contained large amounts of silt and debris, so that water from the underdrains could not flow out. Some of the clogged debris is due to the presence of rodent screens, which allowed moss to grow and trapped silt, creating a dam. None of the eastbound outlets contain rodent screens, but nearly all the westbound outlets do. Some of the outlets are completely dry, and due to the large amounts of rainfall from the previous day it can be assumed that the pipe is either completely blocked further inside or it has been broken inside and water is traveling a different route. A correlation between steeper outlet pipe gradients and lack of silt and debris is apparent. The steeper slope causes the water to discharge at a higher velocity allowing the silt and debris to be carried with it.

7.3 Recommendations

The following recommendations can be made at this time:

(a) Remove and replace all sealants having an average effectiveness below 75%, and thus are ineffective at preventing water and incompressibles into the joint. This recommendation is based on the statements made by Shober (1997) warning of the dangers of partially sealed joints. Based on the results presented earlier in this

Report, all sealants in the eastbound lanes, except for two of the compression seals, should be removed. The TechStar W-050 seals should be replaced with another compression seal such as Watson Bowman WB-687 or WB-812. Alternatively, the deteriorated sealants may be replaced only in the eastbound lanes, leaving the westbound lanes unchanged, for the purpose of a less expensive yet useful comparison, so as to possibly verify conclusions from studies elsewhere, notably in Wisconsin.

(b) Monitoring of joint sealant and pavement performance should continue for at least another five years to collect long-term performance data. The performance evaluation plan developed by the University of Cincinnati research team and implemented in the five evaluations since Fall 1999 should be used for all future evaluations of joint seal condition. This will provide consistent evaluations and will generate information that is reliable and comparable to that collected during future inspections. Performance monitoring of the sealed and unsealed test sections should continue under the established survey routine.

(c) Monitoring of pavement surface roughness via profile surveys should continue for the purpose of affirming or clarifying the trends revealed to date regarding the comparative performance of sections in the eastbound and westbound lanes, and providing a record of the progressive deterioration of each section. Attempts should be made to establish general roughness trends of the pavement, as well as to correlate seasonal curling and warping with roughness trends. The possibility of equipment malfunctions should be considered. There were several instances where data collected during the profile assessment was inconsistent and error plagued.

(d) Implement a drainage outlet maintenance program, according to which the outlets will be cleaned of silt and debris on an annual basis. This will allow the outlets to drain more freely, as was the case when the research team performed such cleaning during their inspection of the drainage features. The maintenance program would be aided by the presence of outlet markers, which would clearly show the location of the outlet so that maintenance personnel could find the outlet without much delay. During the Spring 2000 evaluation, large areas of ponded water were noted in the drainage swales alongside both directions of the highway, with water levels appearing to be almost at the elevation of the pavement subgrade surface. Additional investigations into the effectiveness of the open graded base material and the elevations and pitch of the drainage ditches should also be conducted.

(e) Transverse contraction joint spacing in PCC pavements should be determined using the (L/*l*) concept of the ratio of the slab length to the radius of relative stiffness of the slab-subgrade system. Although this concept was originally formulated with reference to plain jointed PCC pavements, its applicability to jointed reinforced slabs such as those at the U.S. 50 test site appears to be warranted, as well.

(f) Pending the results of additional investigations into the effectiveness of sealants in the Wet-Freeze climatic zone, the use of compression seals, e.g., Watson

Bowman and Delastic should continue. The use of TechStar W-050 should be discouraged as this material has been proven to be unsuitable for pavement applications.

8 REFERENCES

Baldwin, J. S. and Long, D. C. (1987), "Design, Construction and Evaluation of West Virginia's First Free-Draining Pavement System," Transportation Research Record 1159, Transportation Research Board, National Research Council, Washington D.C., pp. 1-6.

Belangie, M. C. and Anderson, D. I. (1985), "Crack Sealing Methods and Materials for Flexible Pavements-Final Report," Utah Department of Transportation, Report No. FHWA/UT-85/1, Salt Lake City, Utah.

Bradbury, R. D. (1938), "Reinforced Concrete Pavements," Wire Reinforcement Institute, Washington, D.C.

Evans, L. D., Pozsgay, M. A., Smith, K. L., and Romine, A. R. (1999), "Long-Term Monitoring of SHRP H-106 Pavement Maintenance Materials Test Sites, PCC Joint Reseal Experiment Final Report," Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.

Hawkins, B. K., Ioannides, A. M., and Minkarah, I. A. (2001), "To Seal Or Not To Seal– Construction of a Field Experiment to Resolve An Age-Old Dilemma," Transportation Research Record 1749, Transportation Research Board, National

Research Council, Washington, D.C., pp. 38-45.

Hawkins, B. K. (1999), "To Seal or Not to Seal? Construction of a Field Experiment to Resolve an Age-Old Dilemma," Thesis submitted in partial fulfillment of the requirements for the degree of Master of Science (A.M. Ioannides: Advisor), Department of Civil and Environmental Engineering, University of Cincinnati, Cincinnati, OH.

Ioannides, A. M., and Khazanovich, L. (1994), "Structural Analysis of Unbonded Concrete Overlays under Wheel and Environmental Loads," Transportation Research Record 1449, Transportation Research Board, National Research Council, Washington, D.C., pp. 174-181.

Ioannides, A. M., and Salsilli-Murua, R. A. (1989), "Temperature Curling in Rigid Pavements: An Application of Dimensional Analysis," Transportation Research Record 1227, Transportation Research Board, National Research Council, Washington, D.C., pp. 1-11.

Ioannides, A. M., Sander, J.A., and Minkarah, I.A. (2001), "The Ohio HPCP Joint Sealant Experiment," Proceedings, Seventh International Conference on Concrete Pavement Design and Rehabilitation, International Society for Concrete Pavements, Orlando, FL (Sept., 9-13), Vol. 2, pp. 1045-1059.

McGhee, K. H. (1995), “Design, Construction, and Maintenance of PCC Pavement Joints,” Synthesis of Highway Practice 211, National Cooperative Highway Research Program, Transportation Research Board, National Research Council, Washington, D.C.

Moulton, L. K. (1980), “Highway Subdrainage Design,” Federal Highway Administration, U. S. Department of Transportation, Washington, D.C.

ODOT (1995), “Project 180/97 Plans and Construction Drawings (US Route 50, Athens, OH),” Ohio Department of Transportation, Columbus, OH.

Ray, G. K. (1980), “Effect of Defective Joint Seals on Pavement Performance,” Transportation Research Record 752, Transportation Research Board, National Research Council, Washington D.C., pp. 1-3.

Sander, J. A. (2002), “Mechanistic-Empirical Performance of U.S. 50 Joint Sealant Test Pavement,” Thesis submitted in partial fulfillment of the requirements for the degree of Master of Science (A.M. Ioannides: Advisor), Department of Civil and Environmental Engineering, University of Cincinnati, Cincinnati, OH.

Sargand, S. M. (2002), “Application of High Performance Concrete in the Pavement System: Structural Response of High Performance Concrete,” Final Report No.

FHWA/OH-2001/15;16, Ohio Department of Transportation, March, Columbus, OH.

Sargand, S. M. (2000), "Performance of Dowel Bars and Rigid Pavement," Draft Final Report, Ohio Department of Transportation, Columbus, OH.

Shober, S. F. (1986), "Portland Cement Concrete Pavement Performance as Influenced by Sealed and Unsealed Contraction Joints," Transportation Research Record 1083, Transportation Research Board, National Research Council, Washington D.C., pp. 7-12.

Shober, S. F. (1997), "The Great Unsealing: A Perspective on Portland Cement Concrete Joint Sealing," Transportation Research Record 1597, Transportation Research Board, National Research Council, Washington D.C., pp. 22-30.

Smith, K. D. (2000), "Status of High Performance Concrete Pavements," Draft Final Report DTFH61-00-P-00254, November, U.S. Department of Transportation, Federal Highway Administration, November, Washington D.C.

Smith, K. L., Pozsgay, M. A., Evans, L. D., and Romine, A. R. (1999), "Long-Term Monitoring of SHRP SPS-4 Pavement Maintenance Materials Test Sites, SPS-4 Supplemental Joint Seal Experiment Final Report," Federal Highway

Administration, U.S. Department of Transportation, Washington, D.C.

Steffes, R. F., Marks, V. J., and Dirks, K. L., (1991), "Video Evaluation of Highway Drainage Systems", Transportation Research Record 1329, Transportation Research Board, National Research Council, Washington D.C., pp. 27-35.

Voigt, G. F. (1997), "Summary of State Highway Agency Use of Joint Sealant for Transverse Contraction Joints in Highway Pavements," Proceedings, Pavement Crack and Joint Sealants for Rigid and Flexible Pavements Conference, USAE Waterways Experiment Station, Vicksburg, MS, May 20-21, pp. 70-86.

Yoder, E. J. and Witczak, M. W. (1975), "Principles of Pavement Design," Second Edition, John Wiley and Sons, Inc., New York, NY.

APPENDIX

Output from Profilometer Runs (Eastbound and Westbound Lanes)

October 2000 Profile Survey of Eastbound Lanes, Driving Lane (PEBOC00)
October 2000 Profile Survey of Eastbound Lanes, Passing Lane (PEBOC00)
October 2000 Profile Survey of Westbound Lanes, Driving Lane (PWBOC00)
October 2000 Profile Survey of Westbound Lanes, Passing Lane (PWBOC00)
June 2001 Profile Survey of Eastbound Lanes, Driving Lane (PEBJN01)
June 2001 Profile Survey of Eastbound Lanes, Passing Lane (PEBJN01)
June 2001 Profile Survey of Westbound Lanes, Driving Lane (PWBJN01)
June 2001 Profile Survey of Westbound Lanes, Passing Lane (PWBJN01)
October 2001 Profile Survey of Eastbound Lanes, Driving Lane (PEBOC01)
October 2001 Profile Survey of Eastbound Lanes, Passing Lane (PEBOC01)
October 2001 Profile Survey of Westbound Lanes, Driving Lane (PWBOC01)
October 2001 Profile Survey of Westbound Lanes, Passing Lane (PWBOC01)

Fifth Profile of Eastbound Lanes, Driving Lane (October, 2000)

ATHENS 050 - October 2000 Tests

LANE 1 PASS 1 UP
LOG NUMBERS ASCENDING

OUTPUT FILE VM:ATHUSM.013

STATION	MAYS	PSI	IRIlf	IRIrt	IRIbh
15400.0					
15452.8	61.7	3.858	61.6	65.6	63.6
15505.6	121.7	2.985	128.2	120.9	124.5
15558.4	75.0	3.630	69.6	83.4	76.5
15611.2	87.3	3.682	71.8	109.1	90.4
15664.0	95.0	3.527	94.9	101.3	98.1
15716.8	81.1	3.473	81.2	92.6	86.9
15769.6	63.3	3.858	62.9	67.9	65.4
15822.4	45.2	4.046	48.8	50.8	49.8
15875.2	37.8	4.159	48.0	38.2	43.1
15928.0	47.0	4.061	47.0	55.3	51.1
15980.8	55.4	4.017	61.0	54.5	57.8
16033.6	64.5	3.792	63.0	70.0	66.5
16086.4	60.5	3.924	67.1	63.5	65.3
16139.2	74.4	3.701	73.4	79.2	76.3
16192.0	43.6	4.174	51.2	46.5	48.9
16244.8	50.7	3.917	54.5	53.3	53.9
16297.6	60.2	4.027	67.4	57.6	62.5
16350.4	64.3	3.780	65.5	71.4	68.5
16403.2	52.7	4.075	59.7	50.6	55.1
16456.0	47.1	4.022	54.4	47.9	51.2
16508.8	44.1	4.253	49.4	44.9	47.2
16561.6	64.3	3.758	76.0	65.0	70.5
16614.4	58.3	4.035	65.4	57.7	61.6
16667.2	66.7	3.722	75.1	67.9	71.5
16720.0	50.2	4.001	59.9	60.2	60.0
16772.8	45.7	3.993	48.1	45.7	46.9
16825.6	47.5	3.978	51.7	51.9	51.8
16878.4	67.6	3.628	69.8	72.4	71.1
16931.2	73.0	3.804	85.7	62.5	74.1
16984.0	53.1	4.031	58.6	51.2	54.9
17036.8	70.0	3.948	77.2	67.7	72.4
17089.6	65.3	3.852	73.9	63.3	68.6
17142.4	71.6	4.084	82.5	66.3	74.4
17195.2	45.7	3.902	48.1	50.9	49.5
17248.0	76.4	3.895	88.7	68.7	78.7
17300.8	56.8	3.821	62.5	55.0	58.8
17353.6	60.8	3.834	72.0	53.2	62.6
17406.4	54.1	3.882	56.1	58.1	57.1
17459.2	97.3	3.515	107.3	91.1	99.2
17512.0	80.2	3.756	89.4	79.8	84.6
17564.8	71.4	3.949	78.1	70.3	74.2
17617.6	67.7	3.740	72.8	71.1	71.9

LANE 1 PASS 2 UP
LOG NUMBERS ASCENDING

OUTPUT FILE VM:ATHUSO.015

STATION	MAYS	PSI	IRIlf	IRIrt	IRIbh
15400.0					
15452.8	57.6	3.879	59.3	62.2	60.8
15505.6	125.4	2.849	127.6	129.9	128.7
15558.4	76.9	3.678	72.4	88.0	80.2
15611.2	94.0	3.476	94.5	96.7	95.6
15664.0	91.5	3.516	101.8	95.1	98.4
15716.8	79.2	3.496	87.9	85.7	86.8
15769.6	61.5	3.874	62.9	67.1	65.0
15822.4	42.1	4.067	47.7	41.9	44.8
15875.2	39.1	4.143	43.9	40.9	42.4
15928.0	45.5	4.043	46.5	49.8	48.1
15980.8	57.0	4.023	58.8	60.2	59.5
16033.6	59.1	3.818	61.4	60.5	60.9
16086.4	58.6	3.928	63.1	60.9	62.0
16139.2	69.1	3.753	67.7	76.7	72.2
16192.0	43.3	4.158	50.3	44.5	47.4
16244.8	50.5	3.931	53.5	56.3	54.9
16297.6	60.9	3.964	65.6	59.3	62.5
16350.4	59.2	3.765	65.5	60.7	63.1
16403.2	53.8	4.106	58.8	52.7	55.7
16456.0	47.7	4.036	56.2	53.3	54.8
16508.8	45.6	4.267	47.4	48.4	47.9
16561.6	62.9	3.795	75.7	59.5	67.6
16614.4	55.2	4.089	63.8	51.7	57.8
16667.2	67.5	3.716	67.6	75.4	71.5
16720.0	42.5	4.120	57.8	43.3	50.5
16772.8	47.8	4.086	53.7	45.1	49.4
16825.6	48.3	3.994	54.2	49.0	51.6
16878.4	71.9	3.633	69.6	80.5	75.1
16931.2	74.4	3.802	83.1	68.9	76.0
16984.0	53.4	3.964	53.6	57.4	55.5
17036.8	73.7	3.965	81.2	72.7	76.9
17089.6	62.2	3.974	69.8	61.9	65.9
17142.4	73.1	4.044	81.4	65.6	73.5
17195.2	42.5	3.927	46.9	44.1	45.5
17248.0	77.7	3.885	85.3	73.0	79.2
17300.8	55.2	3.812	60.1	58.5	59.3
17353.6	59.7	3.877	69.9	54.2	62.1
17406.4	51.1	3.902	57.7	57.4	57.5
17459.2	98.8	3.519	103.4	97.8	100.6
17512.0	79.9	3.770	88.6	78.0	83.3
17564.8	72.8	3.957	75.2	76.4	75.8
17617.6	69.2	3.692	67.5	77.5	72.5

LANE 1 PASS 3 UP
LOG NUMBERS ASCENDING

OUTPUT FILE VM:ATHUSQ.017

STATION	MAYS	PSI	IRIlf	IRIrt	IRIbh
15400.0					
15452.8	58.6	3.894	55.8	65.4	60.6
15505.6	121.7	3.006	119.7	128.4	124.0
15558.4	69.8	3.752	63.8	81.1	72.5
15611.2	77.4	3.757	64.6	97.7	81.2
15664.0	89.8	3.526	83.8	100.1	91.9
15716.8	79.6	3.530	81.5	87.8	84.7
15769.6	59.6	3.879	58.1	68.6	63.4
15822.4	41.4	4.080	48.3	41.0	44.7
15875.2	40.2	4.124	48.2	43.2	45.7
15928.0	45.0	4.109	48.2	48.0	48.1
15980.8	56.2	3.919	62.6	56.6	59.6
16033.6	64.6	3.804	63.6	70.2	66.9
16086.4	57.0	3.948	59.8	65.3	62.5
16139.2	70.0	3.725	71.4	77.0	74.2
16192.0	44.2	4.123	52.7	44.1	48.4
16244.8	49.8	3.933	46.9	55.4	51.1
16297.6	59.5	3.970	62.5	59.1	60.8
16350.4	63.0	3.779	64.0	68.5	66.3
16403.2	48.8	4.142	54.9	46.2	50.6
16456.0	48.5	4.048	50.6	53.7	52.2
16508.8	43.6	4.275	46.8	48.8	47.8
16561.6	65.1	3.812	77.8	58.3	68.1
16614.4	55.6	4.075	58.9	59.1	59.0
16667.2	62.1	3.824	62.4	65.8	64.1
16720.0	47.7	4.026	52.9	51.9	52.4
16772.8	40.8	4.124	45.2	40.6	42.9
16825.6	44.5	4.046	50.0	44.6	47.3
16878.4	74.8	3.512	74.1	84.9	79.5
16931.2	75.1	3.696	79.3	77.6	78.4
16984.0	54.7	3.922	58.3	58.1	58.2
17036.8	70.2	3.841	81.1	65.3	73.2
17089.6	67.2	3.796	76.1	64.5	70.3
17142.4	68.8	4.043	81.3	63.3	72.3
17195.2	43.8	3.844	48.8	47.2	48.0
17248.0	72.3	3.955	83.3	65.1	74.2
17300.8	51.5	3.892	59.0	49.1	54.0
17353.6	59.6	3.929	70.3	51.8	61.1
17406.4	50.8	3.896	59.7	48.2	54.0
17459.2	94.9	3.534	96.9	100.7	98.8
17512.0	75.7	3.834	86.6	73.8	80.2
17564.8	71.8	3.946	74.5	74.0	74.2
17617.6	66.5	3.786	69.4	71.6	70.5

17670.4	68.7	3.785	73.5	80.4	77.0	17670.4	64.5	3.808	71.6	67.6	69.6	17670.4	67.4	3.806	77.6	65.7	71.6
17723.2	81.1	3.695	92.9	74.5	83.7	17723.2	76.1	3.775	87.7	70.5	79.1	17723.2	75.0	3.782	84.8	73.3	79.1
17776.0	63.6	4.096	68.1	61.3	64.7	17776.0	62.8	4.101	64.2	63.0	63.6	17776.0	60.3	4.144	65.0	57.0	61.0
17828.8	43.4	4.179	51.3	46.0	48.6	17828.8	41.8	4.207	47.2	48.0	47.6	17828.8	44.2	4.197	46.2	51.5	48.9
17881.6	62.4	3.953	73.2	57.9	65.6	17881.6	64.6	3.997	72.9	58.7	65.8	17881.6	61.3	3.991	67.1	58.7	62.9
17934.4	53.3	4.059	61.6	49.5	55.5	17934.4	48.3	4.101	55.2	45.9	50.5	17934.4	53.4	4.020	63.1	49.7	56.4
17987.2	76.1	3.912	87.8	68.6	78.2	17987.2	75.5	3.927	89.0	66.6	77.8	17987.2	70.0	3.929	81.1	65.4	73.2
18040.0	58.2	4.111	65.2	58.4	61.8	18040.0	54.9	4.116	66.5	50.5	58.5	18040.0	53.7	4.149	60.5	52.6	56.6
18092.8	65.2	3.893	66.0	71.4	68.7	18092.8	72.6	3.780	78.8	73.9	76.3	18092.8	67.8	3.864	71.6	70.8	71.2
18145.6	73.1	3.841	75.7	75.4	75.5	18145.6	70.5	3.824	81.3	67.1	74.2	18145.6	68.9	3.895	77.1	66.3	71.7
18198.4	79.7	4.063	80.5	83.2	81.8	18198.4	74.7	4.098	77.6	73.7	75.6	18198.4	75.8	4.069	77.1	77.9	77.5
18251.2	57.4	3.865	68.6	52.1	60.3	18251.2	54.8	3.874	65.6	50.5	58.1	18251.2	54.9	3.894	69.7	45.8	57.8
18304.0	59.7	4.159	65.3	57.7	61.5	18304.0	59.8	4.166	66.8	56.4	61.6	18304.0	57.6	4.169	64.1	55.6	59.8
18356.8	73.9	4.042	81.2	69.1	75.1	18356.8	70.6	4.070	76.8	67.8	72.3	18356.8	70.0	4.059	75.8	66.8	71.3
18409.6	54.5	4.124	62.2	51.8	57.0	18409.6	52.9	4.175	58.9	52.8	55.9	18409.6	53.4	4.152	57.1	53.7	55.4
18462.4	66.0	3.976	71.2	63.2	67.2	18462.4	66.8	3.990	71.2	64.1	67.6	18462.4	63.7	4.047	66.8	62.2	64.5
18515.2	59.5	3.977	67.0	57.3	62.1	18515.2	59.0	3.970	62.3	61.5	61.9	18515.2	63.4	3.921	64.3	64.4	64.3
18568.0	54.9	4.029	58.1	56.7	57.4	18568.0	59.7	4.002	66.4	60.1	63.2	18568.0	59.6	4.008	65.4	56.9	61.2
18620.8	113.4	3.730	113.3	114.6	113.9	18620.8	104.8	3.764	107.5	104.8	106.2	18620.8	120.6	3.229	149.1	98.8	124.0
18673.6	83.0	3.716	84.8	86.5	85.7	18673.6	79.9	3.800	86.0	86.1	86.1	18673.6	82.3	3.825	81.4	90.2	85.8
18726.4	67.1	3.908	72.7	79.7	76.2	18726.4	72.4	3.916	75.4	85.5	80.5	18726.4	70.4	3.921	74.0	83.9	78.9
18779.2	67.7	3.806	74.7	66.3	70.5	18779.2	63.9	3.885	67.1	63.5	65.3	18779.2	72.9	3.621	67.2	84.9	76.1
18832.0	57.0	4.117	60.0	60.1	60.0	18832.0	53.5	4.098	57.4	60.3	58.9	18832.0	52.4	4.152	54.5	61.5	58.0
18884.8	74.4	4.016	81.9	68.3	75.1	18884.8	72.6	3.985	76.7	72.8	74.7	18884.8	66.4	4.071	74.5	61.9	68.2
18937.6	53.5	4.075	58.7	49.9	54.3	18937.6	47.1	4.069	52.8	47.4	50.1	18937.6	49.8	4.071	54.2	54.9	54.5
18990.4	59.2	4.080	67.6	56.4	62.0	18990.4	54.3	4.192	63.4	50.6	57.0	18990.4	50.1	4.220	56.8	48.5	52.7
19043.2	59.0	4.184	62.5	63.6	63.0	19043.2	58.8	4.235	58.9	63.2	61.0	19043.2	58.9	4.250	58.6	62.5	60.5
19096.0	92.7	3.519	104.6	87.0	95.8	19096.0	84.4	3.605	96.5	77.2	86.9	19096.0	86.1	3.695	94.8	81.1	88.0
19148.8	79.3	3.866	82.1	78.9	80.5	19148.8	71.8	3.918	82.6	65.7	74.1	19148.8	72.3	3.955	76.8	69.8	73.3
19201.6	76.9	3.955	86.9	69.1	78.0	19201.6	72.7	3.839	86.9	62.0	74.5	19201.6	69.7	3.973	74.8	65.9	70.4
19254.4	90.8	3.754	95.2	88.7	91.9	19254.4	86.2	3.747	93.4	83.2	88.3	19254.4	85.6	3.830	91.3	86.3	88.8
19307.2	67.4	3.856	78.2	62.9	70.6	19307.2	70.7	3.773	81.4	64.1	72.7	19307.2	64.5	3.912	74.6	60.8	67.7
19360.0	69.5	3.711	75.1	70.5	72.8	19360.0	57.9	3.805	67.9	61.1	64.5	19360.0	66.3	3.737	71.4	70.2	70.8
19412.8	76.4	3.983	75.4	78.8	77.1	19412.8	72.1	3.904	74.5	74.2	74.3	19412.8	70.3	4.037	73.3	71.4	72.3
19465.6	74.6	3.736	78.4	80.4	79.4	19465.6	77.5	3.811	80.6	82.0	81.3	19465.6	74.4	3.837	75.1	79.6	77.4
19518.4	80.0	3.700	80.2	81.9	81.1	19518.4	66.0	3.857	75.4	69.2	72.3	19518.4	71.2	3.934	77.8	68.3	73.0
19571.2	69.8	3.741	72.5	71.5	72.0	19571.2	52.0	3.984	59.3	64.6	61.9	19571.2	55.1	3.893	60.8	60.6	60.7
19624.0	49.6	4.004	55.3	50.9	53.1	19624.0	43.1	4.044	46.8	48.0	47.4	19624.0	41.8	4.064	43.6	46.4	45.0
19676.8	51.3	4.048	54.5	56.6	55.6	19676.8	51.4	4.131	48.0	61.4	54.7	19676.8	47.3	4.087	54.8	52.5	53.6
19729.6	62.7	3.943	70.0	63.1	66.5	19729.6	61.1	3.983	63.3	60.2	61.7	19729.6	65.0	3.911	64.1	66.4	65.3
19782.4	55.1	3.808	62.4	63.5	63.0	19782.4	56.5	3.874	60.2	59.0	59.6	19782.4	55.5	3.911	61.8	58.3	60.1
19835.2	53.5	3.792	64.7	50.1	57.4	19835.2	54.2	3.887	56.7	55.6	56.2	19835.2	51.3	3.860	53.5	53.6	53.6
19888.0	60.2	3.915	71.1	55.7	63.4	19888.0	59.1	3.911	67.4	61.2	64.3	19888.0	57.1	3.897	68.8	56.2	62.5
19940.8	101.5	3.993	114.2	91.4	102.8	19940.8	104.0	3.994	113.4	95.8	104.6	19940.8	105.7	3.979	117.1	100.2	108.6
19993.6	77.9	3.865	84.8	72.6	78.7	19993.6	73.8	4.065	77.1	74.2	75.6	19993.6	74.6	4.052	79.5	73.0	76.3
20046.4	55.4	4.140	57.7	59.2	58.4	20046.4	59.0	4.010	52.8	73.0	62.9	20046.4	53.7	4.112	56.8	54.1	55.4
20099.2	76.1	3.592	88.6	71.0	79.8	20099.2	72.2	3.616	80.4	75.8	78.1	20099.2	85.9	3.585	85.0	91.9	88.5
20152.0	66.3	3.823	70.0	69.6	69.8	20152.0	61.6	3.813	62.7	71.3	67.0	20152.0	60.4	3.859	68.8	60.6	64.7
20204.8	81.2	3.563	91.6	85.8	88.7	20204.8	86.3	3.523	93.9	98.2	96.0	20204.8	83.1	3.695	89.7	92.1	90.9
20257.6	58.6	3.881	65.5	62.6	64.0	20257.6	54.5	3.929	62.5	58.3	60.4	20257.6	58.9	3.883	58.1	69.8	64.0
20310.4	56.5	4.080	56.8	65.4	61.1	20310.4	56.9	4.053	53.7	63.1	58.4	20310.4	63.9	3.908	59.1	70.9	65.0
20363.2	72.3	3.836	79.2	69.5	74.3	20363.2	74.0	3.792	76.4	77.8	77.1	20363.2	80.0	3.628	79.3	83.9	81.6
20416.0	54.8	4.084	60.4	59.9	60.2	20416.0	54.4	4.099	58.8	59.0	58.9	20416.0	51.4	4.130	57.7	54.2	56.0
20468.8	50.6	3.952	61.1	47.2	54.2	20468.8	46.3	4.005	54.2	47.0	50.6	20468.8	50.9	4.009	58.9	49.4	54.2
20521.6	61.5	3.955	69.0	60.0	64.5	20521.6	59.3	3.891	62.8	60.3	61.6	20521.6	62.0	3.917	63.1	66.6	64.8
20574.4	53.4	3.880	54.1	59.2	56.7	20574.4	54.8	3.847	53.7	62.5	58.1	20574.4	50.2	3.877	52.4	55.6	54.0

20627.2	55.8	4.141	64.6	51.9	58.2	20627.2	56.0	4.124	65.9	53.1	59.5	20627.2	56.2	4.139	64.1	52.6	58.4
20680.0	52.7	4.066	59.5	50.5	55.0	20680.0	49.0	4.089	57.4	45.9	51.6	20680.0	48.8	4.083	55.8	48.6	52.2
20732.8	70.2	4.076	72.6	70.4	71.5	20732.8	71.2	4.110	75.3	70.2	72.7	20732.8	70.9	4.053	71.6	74.6	73.1
20785.6	81.2	3.955	89.7	76.2	83.0	20785.6	79.3	3.952	89.1	73.8	81.5	20785.6	83.6	3.846	97.8	72.7	85.3
20838.4	67.2	4.007	69.2	66.6	67.9	20838.4	70.1	3.981	73.1	70.7	71.9	20838.4	67.5	3.995	67.9	69.5	68.7
20891.2	75.0	3.726	84.8	71.0	77.9	20891.2	72.3	3.726	86.5	64.3	75.4	20891.2	73.2	3.743	85.3	66.0	75.7
20944.0	53.1	4.154	59.3	54.9	57.1	20944.0	51.5	4.183	57.0	50.9	54.0	20944.0	47.3	4.205	54.8	45.3	50.0
20996.8	81.5	3.905	88.6	77.3	82.9	20996.8	79.7	3.866	87.8	77.1	82.4	20996.8	79.0	3.910	87.9	74.2	81.0
21049.6	61.8	4.125	70.2	58.9	64.5	21049.6	61.5	4.102	69.7	59.7	64.7	21049.6	61.2	4.168	70.5	57.1	63.8
21102.4	58.2	3.983	65.1	59.0	62.0	21102.4	55.6	4.002	58.7	63.7	61.2	21102.4	53.6	3.984	58.2	56.5	57.3
21155.2	82.8	3.925	87.7	81.5	84.6	21155.2	84.6	3.903	93.0	81.9	87.4	21155.2	81.2	3.950	87.6	78.8	83.2
21208.0	82.0	3.861	93.7	73.4	83.6	21208.0	76.6	3.919	85.3	70.7	78.0	21208.0	75.5	3.941	84.6	67.9	76.3
21260.8	58.3	4.060	62.2	65.6	63.9	21260.8	60.1	4.064	60.8	67.8	64.3	21260.8	59.7	4.037	61.4	64.9	63.1
21313.6	67.8	4.105	70.8	68.6	69.7	21313.6	62.2	4.169	63.6	66.2	64.9	21313.6	56.1	4.141	53.9	61.3	57.6
21366.4	67.0	4.040	78.8	63.6	71.2	21366.4	66.1	4.068	76.9	63.3	70.1	21366.4	67.5	4.036	73.7	64.3	69.0
21419.2	61.5	4.041	62.0	67.2	64.6	21419.2	61.0	4.016	65.9	64.4	65.2	21419.2	62.9	3.985	69.5	60.8	65.1
21472.0	40.1	4.153	52.9	40.2	46.5	21472.0	41.9	4.200	52.9	41.8	47.3	21472.0	40.0	4.273	48.8	40.8	44.8
21524.8	60.5	4.002	66.1	59.2	62.7	21524.8	56.4	4.076	60.9	60.2	60.6	21524.8	55.1	4.033	58.5	56.6	57.6
21577.6	85.4	4.205	79.9	93.1	86.5	21577.6	86.2	4.184	80.7	94.1	87.4	21577.6	90.3	4.154	86.6	96.7	91.7
21630.4	53.2	4.036	58.4	55.1	56.7	21630.4	50.8	4.049	55.2	52.5	53.9	21630.4	47.6	4.071	52.0	48.9	50.5
21683.2	66.8	3.933	74.4	62.2	68.3	21683.2	66.6	3.950	70.8	66.2	68.5	21683.2	66.1	3.965	69.4	65.1	67.2
21736.0	65.3	3.960	73.8	61.1	67.4	21736.0	65.1	3.977	72.6	62.4	67.5	21736.0	67.5	3.693	63.7	80.6	72.2
21788.8	60.4	4.099	56.9	68.0	62.4	21788.8	57.8	4.169	51.3	68.4	59.8	21788.8	58.0	4.155	56.3	66.6	61.5
21841.6	76.0	3.848	85.4	72.7	79.1	21841.6	79.7	3.766	84.3	77.0	80.7	21841.6	75.9	3.785	82.9	75.0	78.9
21894.4	61.7	4.018	70.0	60.7	65.4	21894.4	59.8	4.057	72.1	55.8	63.9	21894.4	60.9	4.051	71.3	56.3	63.8
21947.2	52.4	3.954	56.3	60.2	58.3	21947.2	48.4	4.020	47.3	60.3	53.8	21947.2	46.8	4.097	43.0	60.0	51.5
22000.0	79.5	3.894	84.5	81.5	83.0	22000.0	80.1	3.865	84.3	84.4	84.4	22000.0	76.3	3.852	81.3	76.9	79.1
22052.8	54.6	3.834	56.0	61.6	58.8	22052.8	57.7	3.775	61.3	61.9	61.6	22052.8	55.1	3.841	62.9	56.9	59.9
22105.6	70.5	3.966	80.6	64.9	72.7	22105.6	75.7	3.831	83.3	72.4	77.8	22105.6	68.4	3.957	76.3	65.9	71.1
22158.4	68.0	3.747	75.4	66.9	71.2	22158.4	60.4	3.625	73.5	59.9	66.7	22158.4	64.8	3.745	74.4	60.1	67.2
22211.2	69.4	3.804	76.4	69.9	73.1	22211.2	70.2	3.687	86.5	66.8	76.7	22211.2	68.0	3.769	83.1	63.5	73.3
22264.0	63.7	3.886	68.2	63.5	65.8	22264.0	64.3	3.864	68.9	62.8	65.9	22264.0	60.8	3.903	65.2	62.0	63.6
22316.8	57.9	3.986	55.6	63.6	59.6	22316.8	54.9	4.044	54.0	58.5	56.3	22316.8	56.6	3.994	54.8	61.2	58.0
22369.6	57.8	3.943	71.1	51.1	61.1	22369.6	59.7	3.891	71.6	54.0	62.8	22369.6	56.6	3.985	68.0	51.1	59.5
22422.4	64.7	3.768	70.7	63.9	67.3	22422.4	64.8	3.806	69.6	68.0	68.8	22422.4	67.9	3.784	77.5	63.4	70.4
22475.2	94.3	3.762	101.8	87.6	94.7	22475.2	92.0	3.638	99.1	87.9	93.5	22475.2	85.1	3.837	91.5	80.6	86.0
22528.0	60.5	3.908	59.5	66.3	62.9	22528.0	72.0	3.689	66.1	83.1	74.6	22528.0	68.7	3.745	69.5	74.2	71.9
22580.8	59.7	3.972	60.0	63.8	61.9	22580.8	53.2	4.053	60.7	56.9	58.8	22580.8	53.2	4.087	56.1	56.8	56.4
22633.6	57.9	4.003	59.0	62.1	60.6	22633.6	65.2	3.878	64.7	69.5	67.1	22633.6	59.1	3.988	61.0	62.6	61.8
22686.4	52.4	3.969	54.6	52.6	53.6	22686.4	47.3	4.029	49.1	48.0	48.5	22686.4	45.5	4.118	46.8	46.9	46.8
22739.2	57.8	4.047	69.2	56.5	62.8	22739.2	58.6	4.031	69.2	54.1	61.6	22739.2	59.9	3.873	67.7	59.2	63.4
22792.0	58.9	3.969	64.2	58.3	61.2	22792.0	58.3	4.073	61.5	59.5	60.5	22792.0	61.5	4.066	64.4	63.0	63.7
22844.8	58.5	3.831	57.0	67.5	62.2	22844.8	60.4	3.765	61.8	67.3	64.5	22844.8	55.8	3.865	58.9	61.1	60.0
22897.6	72.1	3.744	76.4	77.3	76.8	22897.6	74.8	3.738	76.6	82.0	79.3	22897.6	70.8	3.873	78.3	72.9	75.6
22950.4	65.4	3.840	77.3	59.6	68.4	22950.4	64.1	3.743	69.0	67.8	68.4	22950.4	59.0	3.946	68.0	58.1	63.0
23003.2	88.3	4.066	92.4	93.7	93.1	23003.2	89.6	4.042	92.5	92.0	92.3	23003.2	87.4	4.113	92.7	89.2	90.9
23056.0	67.2	4.151	62.8	75.5	69.1	23056.0	65.8	4.110	63.7	73.7	68.7	23056.0	64.7	4.085	60.4	74.1	67.2
23108.8	37.8	4.130	45.2	44.0	44.6	23108.8	35.3	4.119	44.2	46.2	45.2	23108.8	35.8	4.104	42.6	43.5	43.1
23161.6	70.7	4.072	77.1	71.8	74.5	23161.6	67.2	4.041	74.3	70.9	72.6	23161.6	69.0	4.120	72.6	70.4	71.5
23214.4	72.6	3.964	77.4	73.2	75.3	23214.4	69.7	4.007	78.4	67.8	73.1	23214.4	72.4	3.918	78.7	73.3	76.0
23267.2	92.0	3.741	100.1	92.4	96.3	23267.2	91.4	3.712	102.5	90.1	96.3	23267.2	89.8	3.658	96.3	89.8	93.0
23320.0	69.8	4.012	81.7	66.1	73.9	23320.0	69.3	4.034	79.7	65.5	72.6	23320.0	74.1	3.962	82.5	72.8	77.7
23372.8	75.5	3.766	89.2	68.8	79.0	23372.8	74.9	3.789	88.2	70.1	79.1	23372.8	73.5	3.823	88.1	66.0	77.0
23425.6	61.1	4.146	73.8	50.5	62.1	23425.6	61.0	4.232	72.8	51.5	62.2	23425.6	61.2	4.246	76.7	48.0	62.3
23478.4	79.5	3.937	97.8	63.3	80.6	23478.4	77.7	3.957	94.7	62.2	78.5	23478.4	74.0	4.013	91.8	59.1	75.5
23531.2	57.7	4.109	68.9	60.8	64.9	23531.2	56.6	4.119	62.7	59.6	61.2	23531.2	62.0	4.013	70.7	67.2	68.9

23584.0	90.4	4.016	94.5	97.3	95.9	23584.0	88.8	3.982	97.9	95.0	96.4	23584.0	84.5	4.061	86.7	94.9	90.8
23636.8	119.4	3.442	120.3	126.7	123.5	23636.8	120.1	3.363	125.9	125.6	125.8	23636.8	116.9	3.310	116.1	132.6	124.4
23689.6	84.6	3.785	87.3	90.8	89.1	23689.6	80.4	3.883	85.8	83.3	84.6	23689.6	94.2	3.726	92.9	107.7	100.3
23742.4	61.9	3.828	75.1	61.5	68.3	23742.4	52.1	3.946	61.2	54.4	57.8	23742.4	55.2	3.856	68.8	58.2	63.5
23795.2	67.3	3.814	73.4	67.2	70.3	23795.2	59.0	4.010	69.4	52.8	61.1	23795.2	58.8	3.993	67.5	53.5	60.5
23848.0	63.0	3.922	74.9	55.7	65.3	23848.0	52.8	4.101	65.4	44.7	55.0	23848.0	53.9	4.005	65.0	46.8	55.9
23900.8	39.6	4.222	49.7	35.8	42.7	23900.8	37.2	4.183	47.2	35.5	41.3	23900.8	37.0	4.215	43.0	37.1	40.0
23953.6	53.3	4.025	59.9	48.5	54.2	23953.6	41.9	4.067	59.9	32.7	46.3	23953.6	49.3	3.983	58.7	44.0	51.4
24006.4	63.9	3.855	67.2	65.0	66.1	24006.4	50.4	3.941	69.1	48.6	58.9	24006.4	66.1	3.805	69.1	69.0	69.1
24059.2	56.2	3.904	57.5	62.0	59.7	24059.2	47.8	3.837	55.1	46.5	50.8	24059.2	58.5	3.923	60.0	61.4	60.7
24112.0	69.0	3.915	73.5	67.4	70.5	24112.0	66.2	3.965	72.6	65.7	69.2	24112.0	66.5	3.906	64.7	73.9	69.3
24164.8	46.1	4.088	40.5	55.4	48.0	24164.8	35.0	4.219	36.7	40.2	38.4	24164.8	40.2	4.187	38.3	47.5	42.9
24217.6	58.0	4.031	73.3	52.4	62.8	24217.6	39.5	4.174	61.2	38.7	49.9	24217.6	46.6	4.039	65.4	40.5	52.9
24270.4	46.7	4.137	54.2	46.6	50.4	24270.4	40.1	4.246	51.7	38.0	44.9	24270.4	40.9	4.285	49.8	39.9	44.8
24323.2	57.6	3.835	56.8	63.9	60.3	24323.2	39.1	3.973	50.9	47.9	49.4	24323.2	54.8	3.855	53.3	63.0	58.1
24376.0	53.6	4.145	64.0	53.4	58.7	24376.0	43.5	4.148	61.6	31.7	46.6	24376.0	54.3	4.158	65.4	45.9	55.7
24428.8	49.7	4.173	60.9	45.1	53.0	24428.8	38.0	4.237	47.9	37.6	42.8	24428.8	50.3	4.146	59.2	48.8	54.0
24481.6	71.3	4.230	70.4	76.4	73.4	24481.6	70.8	4.079	78.9	69.3	74.1	24481.6	67.3	4.236	70.2	72.3	71.3
24534.4	45.9	4.255	50.5	44.5	47.5	24534.4	43.9	4.295	49.5	44.9	47.2	24534.4	46.1	4.274	47.1	48.9	48.0
24587.2	45.2	4.116	48.3	48.5	48.4	24587.2	40.2	4.213	43.7	44.7	44.2	24587.2	46.2	4.151	51.1	47.8	49.4
24640.0	54.2	4.047	63.5	47.7	55.6	24640.0	45.7	4.090	59.3	42.0	50.6	24640.0	54.9	4.042	59.6	53.8	56.7
24692.8	64.7	3.956	70.2	62.2	66.2	24692.8	57.8	4.030	68.7	60.1	64.4	24692.8	61.8	4.010	71.5	64.6	68.1
24745.6	49.3	4.104	58.8	56.3	57.6	24745.6	50.7	4.134	56.4	56.6	56.5	24745.6	50.8	4.105	55.2	56.7	55.9
24798.4	56.1	4.026	68.9	52.8	60.9	24798.4	52.3	4.085	51.7	56.1	53.9	24798.4	51.7	4.069	57.1	50.2	53.7
24851.2	54.3	4.035	59.3	52.8	56.1	24851.2	56.7	3.968	64.6	53.7	59.2	24851.2	54.5	3.989	60.6	52.5	56.5
24904.0	54.8	3.959	62.9	56.4	59.6	24904.0	56.7	3.942	60.2	59.5	59.9	24904.0	56.0	3.904	61.2	59.3	60.3
24956.8	67.5	3.912	68.2	77.5	72.9	24956.8	77.5	3.802	64.8	95.0	79.9	24956.8	73.7	3.855	64.2	91.8	78.0
25009.6	74.4	3.812	80.5	69.4	75.0	25009.6	79.6	3.718	84.3	76.6	80.5	25009.6	78.7	3.763	82.6	77.2	79.9
25062.4	42.2	3.988	50.9	37.4	44.2	25062.4	43.3	4.046	48.4	44.6	46.5	25062.4	46.8	3.881	51.1	51.8	51.4
25115.2	76.3	3.891	85.0	72.0	78.5	25115.2	78.2	3.881	85.4	74.1	79.7	25115.2	74.2	3.856	80.9	73.5	77.2
25168.0	93.9	3.639	102.2	98.4	100.3	25168.0	95.0	3.642	104.6	100.1	102.3	25168.0	93.4	3.602	103.7	108.4	106.1
25220.8	82.7	3.963	107.2	68.0	87.6	25220.8	84.2	3.898	102.9	72.5	87.7	25220.8	76.8	3.972	96.9	63.5	80.2
25273.6	54.6	4.104	62.5	54.4	58.5	25273.6	57.5	4.069	68.4	55.5	62.0	25273.6	54.3	4.070	62.5	53.2	57.8
25326.4	46.4	3.917	57.8	40.3	49.0	25326.4	49.2	3.936	59.6	45.5	52.6	25326.4	50.7	3.945	57.4	46.9	52.1
25379.2	53.8	4.007	65.9	46.2	56.1	25379.2	52.3	4.026	59.4	52.3	55.9	25379.2	48.6	4.054	55.0	46.7	50.8
25432.0	48.9	4.192	58.6	43.4	51.0	25432.0	48.7	4.231	54.1	47.4	50.8	25432.0	48.2	4.261	55.2	45.9	50.5
25484.8	49.9	4.026	60.4	42.2	51.3	25484.8	53.2	4.024	62.5	48.3	55.4	25484.8	55.3	3.963	65.3	52.2	58.8
25537.6	52.7	4.253	58.0	55.3	56.6	25537.6	59.0	4.150	66.4	57.7	62.1	25537.6	56.9	4.171	62.5	58.7	60.6
25590.4	55.9	3.924	64.6	55.6	60.1	25590.4	61.8	3.798	57.6	70.2	63.9	25590.4	66.9	3.718	61.3	77.2	69.2
25643.2	63.5	4.102	69.1	60.2	64.7	25643.2	62.6	4.131	71.0	59.1	65.1	25643.2	63.6	4.074	70.1	62.7	66.4
25696.0	85.8	3.962	91.1	82.8	87.0	25696.0	86.4	4.010	94.3	80.9	87.6	25696.0	84.4	4.007	92.9	77.7	85.3
25748.8	63.2	3.955	79.1	55.1	67.1	25748.8	71.7	3.847	85.8	64.9	75.4	25748.8	70.5	3.933	79.5	67.6	73.6
25801.6	62.7	4.042	71.9	60.4	66.1	25801.6	64.2	3.993	71.5	60.2	65.8	25801.6	64.0	3.992	67.4	63.1	65.3
25854.4	59.6	4.038	58.5	65.2	61.8	25854.4	60.1	4.092	59.5	67.5	63.5	25854.4	61.9	4.062	62.5	68.8	65.6
25907.2	66.7	3.863	83.5	57.9	70.7	25907.2	74.9	3.807	92.5	65.9	79.2	25907.2	76.3	3.851	93.4	66.0	79.7
25960.0	65.6	4.055	70.9	65.9	68.4	25960.0	71.6	4.115	76.6	70.5	73.5	25960.0	69.2	4.183	69.0	72.3	70.7
26012.8	58.5	4.044	66.5	58.0	62.2	26012.8	59.1	4.050	64.0	59.6	61.8	26012.8	67.7	3.926	75.1	65.8	70.5
26065.6	57.5	4.004	60.4	61.3	60.9	26065.6	61.4	3.936	62.4	67.1	64.7	26065.6	62.6	3.940	62.8	66.1	64.5
26118.4	81.7	3.554	85.8	87.6	86.7	26118.4	83.7	3.556	83.6	93.7	88.7	26118.4	86.2	3.540	90.1	90.0	90.1
26171.2	64.3	3.878	73.4	58.5	65.9	26171.2	59.1	3.926	71.8	52.0	61.9	26171.2	69.2	3.802	79.8	60.8	70.3
26224.0	67.0	3.741	72.4	69.1	70.8	26224.0	69.3	3.775	78.1	65.5	71.8	26224.0	75.1	3.719	79.6	76.4	78.0
26276.8	57.9	3.985	65.5	59.6	62.5	26276.8	62.4	3.997	65.0	64.1	64.5	26276.8	66.9	3.895	66.9	73.0	69.9
26329.6	88.2	3.767	98.6	84.3	91.5	26329.6	96.9	3.727	104.0	95.2	99.6	26329.6	105.1	3.652	113.6	99.7	106.6
26382.4	113.2	3.757	116.8	118.0	117.4	26382.4	110.4	3.794	116.0	118.3	117.1	26382.4	107.3	3.760	117.0	108.9	112.9
26435.2	138.7	3.587	142.9	146.3	144.6	26435.2	140.2	3.493	143.9	151.7	147.8	26435.2	136.7	3.575	142.1	144.2	143.1
26488.0	95.8	3.916	107.7	103.3	105.5	26488.0	98.2	3.849	108.0	104.3	106.2	26488.0	95.9	3.928	108.1	103.4	105.7

26540.8	82.5	3.708	85.2	89.4	87.3	26540.8	78.9	3.762	80.8	86.2	83.5	26540.8	82.4	3.713	85.9	88.9	87.4
26593.6	57.7	3.964	70.8	53.3	62.1	26593.6	59.5	3.984	70.5	55.7	63.1	26593.6	58.7	4.036	72.8	54.5	63.6
26646.4	93.5	3.562	103.7	87.0	95.4	26646.4	88.4	3.600	98.6	82.2	90.4	26646.4	92.9	3.579	106.4	84.0	95.2
26699.2	63.7	3.911	71.4	66.3	68.9	26699.2	64.2	3.924	73.3	64.5	68.9	26699.2	65.2	3.853	71.4	67.6	69.5
26752.0	80.4	3.723	98.6	72.8	85.7	26752.0	82.5	3.704	93.3	76.6	84.9	26752.0	83.9	3.721	95.7	77.9	86.8
26804.8	55.8	4.000	48.0	66.4	57.2	26804.8	52.9	4.148	47.5	61.4	54.4	26804.8	55.0	4.063	49.3	64.6	56.9
26857.6	63.7	3.868	65.1	66.2	65.6	26857.6	66.3	3.827	59.3	74.8	67.0	26857.6	66.0	3.855	64.9	68.8	66.8
26910.4	61.6	3.902	67.7	59.6	63.7	26910.4	68.7	3.785	69.9	71.5	70.7	26910.4	62.8	3.912	68.4	60.6	64.5
26963.2	79.1	3.714	75.5	84.4	79.9	26963.2	74.2	3.692	74.2	76.0	75.1	26963.2	75.1	3.674	73.9	77.8	75.8
27016.0	50.5	3.984	56.5	56.7	56.6	27016.0	51.4	3.981	56.2	56.8	56.5	27016.0	54.7	3.831	56.4	60.0	58.2
27068.8	54.3	4.012	55.3	57.1	56.2	27068.8	56.7	4.013	58.9	58.8	58.9	27068.8	58.6	3.997	57.0	63.1	60.0
27121.6	59.8	4.067	62.1	61.3	61.7	27121.6	56.9	4.112	60.3	56.6	58.5	27121.6	59.0	4.094	58.2	62.7	60.5
27174.4	58.8	3.893	62.9	60.6	61.7	27174.4	58.8	3.952	62.5	58.9	60.7	27174.4	67.6	3.867	72.1	65.0	68.5
27227.2	64.8	4.070	74.6	65.7	70.1	27227.2	66.3	4.069	77.2	70.0	73.6	27227.2	65.5	4.074	75.3	65.7	70.5
27280.0	72.5	4.104	75.3	75.2	75.3	27280.0	76.9	4.006	80.1	82.8	81.4	27280.0	76.6	4.071	75.1	82.7	78.9
27332.8	56.1	4.091	53.4	63.8	58.6	27332.8	58.2	4.053	57.4	65.2	61.3	27332.8	66.1	3.952	63.9	71.3	67.6
27385.6	71.4	3.980	77.1	69.8	73.4	27385.6	73.2	3.945	82.3	70.3	76.3	27385.6	66.4	4.060	71.9	65.8	68.8
27438.4	52.2	4.025	54.7	55.5	55.1	27438.4	51.0	4.053	51.0	57.9	54.5	27438.4	48.4	4.096	54.0	51.8	52.9
27491.2	60.4	3.913	66.7	62.2	64.4	27491.2	66.8	3.870	75.3	64.8	70.1	27491.2	70.7	3.828	80.4	69.1	74.8
27544.0	56.2	3.986	67.1	52.4	59.8	27544.0	55.2	4.042	63.5	50.5	57.0	27544.0	54.3	4.044	63.7	50.0	56.9
27596.8	56.0	3.917	61.9	59.4	60.6	27596.8	47.7	4.078	52.9	50.8	51.9	27596.8	46.9	4.084	50.7	51.2	51.0
27649.6	72.1	3.889	79.8	69.4	74.6	27649.6	73.5	3.813	78.4	73.6	76.0	27649.6	76.5	3.815	80.2	77.7	79.0
27702.4	47.3	4.179	48.2	52.1	50.2	27702.4	41.1	4.353	43.4	44.2	43.8	27702.4	39.8	4.374	41.5	46.5	44.0
27755.2	76.6	3.948	84.0	72.2	78.1	27755.2	75.6	3.914	85.2	67.9	76.6	27755.2	72.4	3.982	81.4	67.8	74.6
27808.0	59.2	4.207	64.7	60.5	62.6	27808.0	57.6	4.261	63.7	57.3	60.5	27808.0	56.3	4.268	59.7	57.7	58.7
27860.8	67.9	4.030	75.6	69.3	72.4	27860.8	64.9	4.103	72.3	69.5	70.9	27860.8	68.2	4.004	73.9	70.8	72.4
27913.6	57.4	3.914	54.7	62.4	58.5	27913.6	62.6	3.905	65.5	62.7	64.1	27913.6	64.4	3.829	57.5	73.4	65.5
27966.4	57.6	3.976	63.3	53.9	58.6	27966.4	52.8	3.938	60.0	53.6	56.8	27966.4	49.5	4.037	54.5	47.6	51.0
28019.2	45.4	4.201	45.2	50.8	48.0	28019.2	47.9	4.166	47.5	51.8	49.6	28019.2	51.4	4.109	49.5	56.7	53.1
28072.0	70.3	3.904	68.7	74.8	71.7	28072.0	68.2	3.912	68.3	73.2	70.7	28072.0	67.6	3.962	66.2	71.3	68.7
28124.8	52.6	4.162	48.5	59.2	53.8	28124.8	48.7	4.200	46.9	53.7	50.3	28124.8	46.5	4.172	46.8	50.4	48.6
28177.6	49.8	4.078	52.5	53.7	53.1	28177.6	49.5	4.049	53.0	48.7	50.9	28177.6	50.2	4.027	55.0	49.9	52.5
28230.4	55.1	4.142	63.0	52.4	57.7	28230.4	60.5	4.060	64.5	57.7	61.1	28230.4	56.6	4.173	62.0	54.0	58.0
28283.2	46.2	4.114	53.5	47.1	50.3	28283.2	54.5	4.082	54.3	58.7	56.5	28283.2	48.4	4.114	54.0	49.3	51.6
28336.0	52.9	4.156	63.8	45.8	54.8	28336.0	50.7	4.163	61.4	46.0	53.7	28336.0	48.9	4.172	60.6	47.6	54.1
28388.8	58.0	3.847	57.4	65.5	61.4	28388.8	56.8	3.879	57.7	63.9	60.8	28388.8	57.5	3.913	55.5	65.8	60.7
28441.6	64.1	3.919	60.4	72.4	66.4	28441.6	70.7	3.809	66.8	76.5	71.6	28441.6	73.0	3.771	67.1	80.2	73.6
28494.4	43.0	4.078	47.7	41.1	44.4	28494.4	46.7	4.024	50.7	47.2	49.0	28494.4	49.8	4.067	56.1	47.6	51.9
28547.2	45.8	4.189	48.5	46.4	47.4	28547.2	47.5	4.042	47.0	52.2	49.6	28547.2	49.9	3.915	52.9	52.5	52.7
28600.0	55.2	3.995	58.0	55.1	56.6	28600.0	52.9	4.064	53.3	56.0	54.7	28600.0	55.1	4.044	54.6	58.8	56.7
28652.8	55.0	4.051	63.7	50.3	57.0	28652.8	55.8	4.058	64.5	49.4	57.0	28652.8	53.6	4.019	62.2	49.8	56.0
28705.6	68.5	4.018	71.3	71.2	71.3	28705.6	66.4	4.058	69.9	68.9	69.4	28705.6	67.9	4.017	75.8	66.1	71.0
28758.4	57.5	4.081	56.2	64.3	60.3	28758.4	51.8	4.204	55.6	56.5	56.0	28758.4	49.9	4.158	55.2	53.3	54.2
28811.2	58.3	3.992	60.1	61.5	60.8	28811.2	62.5	4.001	68.9	60.4	64.6	28811.2	60.1	3.925	62.2	63.8	63.0
28864.0	82.4	3.719	72.3	97.7	85.0	28864.0	85.8	3.760	80.8	101.2	91.0	28864.0	80.1	3.763	71.5	95.7	83.6
28916.8	61.2	3.949	57.5	76.6	67.1	28916.8	73.9	3.855	69.1	84.5	76.8	28916.8	68.8	3.821	59.8	83.1	71.4
28969.6	64.7	3.846	72.4	61.5	67.0	28969.6	68.3	3.843	74.2	65.1	69.7	28969.6	72.3	3.769	81.2	68.5	74.9
29022.4	58.1	4.069	57.7	62.1	59.9	29022.4	51.9	4.155	49.3	55.1	52.2	29022.4	55.8	4.125	51.3	61.8	56.5

Fourth Profile of Eastbound Lanes, Passing Lane (October, 2000)

ATHENS 050 - October 2000 Tests

LANE 2 PASS 1 UP
LOG NUMBERS ASCENDING

OUTPUT FILE VM:ATHUSF.006

STATION	MAYS	PSI	IRIlf	IRIrt	IRIbh
15400.0					
15452.8	60.1	3.940	58.3	64.2	61.2
15505.6	88.2	3.501	103.2	86.2	94.7
15558.4	52.8	3.809	53.2	56.4	54.8
15611.2	67.7	4.027	72.6	64.4	68.5
15664.0	76.9	3.779	80.6	79.6	80.1
15716.8	70.5	3.893	69.3	76.7	73.0
15769.6	66.4	3.798	73.2	63.7	68.4
15822.4	61.8	3.904	71.4	59.1	65.2
15875.2	69.4	3.769	83.0	68.6	75.8
15928.0	92.9	3.553	114.5	74.8	94.6
15980.8	57.6	3.936	70.7	52.8	61.7
16033.6	67.9	3.746	81.1	63.6	72.3
16086.4	65.1	3.872	63.9	71.6	67.8
16139.2	67.8	3.808	89.3	63.6	76.5
16192.0	63.3	3.975	85.9	50.7	68.3
16244.8	63.2	3.773	78.6	58.3	68.4
16297.6	67.4	3.815	73.4	67.6	70.5
16350.4	66.8	3.703	86.5	54.4	70.5
16403.2	76.9	3.839	94.0	68.3	81.2
16456.0	79.3	3.617	96.1	67.6	81.9
16508.8	69.3	3.744	79.2	62.4	70.8
16561.6	96.6	3.484	114.3	84.0	99.1
16614.4	61.9	4.030	80.9	54.8	67.8
16667.2	54.8	3.984	72.6	45.1	58.8
16720.0	45.0	4.170	49.3	48.5	48.9
16772.8	71.0	3.892	77.0	69.4	73.2
16825.6	64.3	3.794	72.0	59.4	65.7
16878.4	80.8	3.825	92.6	73.1	82.9
16931.2	61.1	3.941	73.9	54.0	64.0
16984.0	80.2	3.580	103.4	67.2	85.3
17036.8	93.5	3.830	97.6	92.5	95.0
17089.6	73.2	3.870	75.9	78.6	77.3
17142.4	77.5	3.874	89.5	71.6	80.6
17195.2	61.5	3.926	65.2	62.9	64.0
17248.0	75.9	3.834	75.7	78.8	77.3
17300.8	73.1	3.664	84.3	70.5	77.4
17353.6	64.8	3.834	66.6	67.9	67.3
17406.4	70.5	3.659	77.2	68.4	72.8
17459.2	131.3	3.049	145.8	133.1	139.4
17512.0	124.4	3.286	123.9	127.7	125.8
17564.8	74.3	3.816	75.4	78.4	76.9
17617.6	93.2	3.594	111.0	82.5	96.7

LANE 2 PASS 2 UP
LOG NUMBERS ASCENDING

OUTPUT FILE VM:ATHUSH.008

STATION	MAYS	PSI	IRIlf	IRIrt	IRIbh
15400.0					
15452.8	57.8	3.924	58.0	60.5	59.3
15505.6	80.8	3.615	99.5	73.7	86.6
15558.4	50.1	3.913	54.1	49.8	52.0
15611.2	66.7	4.040	77.4	60.1	68.7
15664.0	75.6	3.763	82.7	73.3	78.0
15716.8	70.2	3.807	70.5	77.2	73.9
15769.6	62.2	3.859	75.4	54.8	65.1
15822.4	60.8	3.878	73.0	55.6	64.3
15875.2	68.5	3.775	83.0	63.8	73.4
15928.0	82.5	3.656	104.8	63.7	84.3
15980.8	61.1	3.902	70.5	55.8	63.1
16033.6	68.4	3.757	76.0	68.2	72.1
16086.4	75.1	3.792	87.8	71.3	79.5
16139.2	78.4	3.768	95.9	69.6	82.7
16192.0	63.4	3.940	87.6	46.8	67.2
16244.8	62.8	3.768	78.8	56.1	67.4
16297.6	69.9	3.680	88.0	72.5	80.3
16350.4	64.1	3.698	84.0	55.7	69.9
16403.2	75.1	3.866	88.1	70.8	79.5
16456.0	80.4	3.630	98.7	67.7	83.2
16508.8	71.4	3.798	84.5	62.6	73.6
16561.6	94.2	3.505	120.7	76.9	98.8
16614.4	60.8	4.004	82.0	52.5	67.3
16667.2	54.6	3.941	75.3	45.5	60.4
16720.0	48.8	4.097	54.8	52.6	53.7
16772.8	67.1	3.957	76.4	63.4	69.9
16825.6	67.0	3.777	78.4	57.9	68.2
16878.4	76.0	3.869	89.6	66.8	78.2
16931.2	64.7	3.888	78.7	55.7	67.2
16984.0	79.7	3.593	106.9	60.0	83.5
17036.8	98.9	3.829	105.6	94.2	99.9
17089.6	65.1	3.985	75.2	65.7	70.5
17142.4	79.0	3.893	93.5	74.1	83.8
17195.2	55.9	4.015	61.7	54.0	57.9
17248.0	80.5	3.848	82.7	82.3	82.5
17300.8	67.4	3.716	80.5	64.0	72.3
17353.6	67.3	3.809	74.4	67.6	71.0
17406.4	62.6	3.717	67.2	60.5	63.9
17459.2	130.5	3.045	144.5	136.0	140.2
17512.0	128.5	3.284	137.5	121.3	129.4
17564.8	66.9	4.009	65.8	70.5	68.2
17617.6	87.2	3.678	106.1	76.0	91.1

LANE 2 PASS 3 UP
LOG NUMBERS ASCENDING

OUTPUT FILE VM:ATHUSJ.010

STATION	MAYS	PSI	IRIlf	IRIrt	IRIbh
15400.0					
15452.8	55.8	3.985	60.3	56.1	58.2
15505.6	78.9	3.602	96.0	73.9	85.0
15558.4	47.4	3.901	53.5	44.9	49.2
15611.2	66.9	4.008	74.7	61.3	68.0
15664.0	72.7	3.789	77.1	72.8	75.0
15716.8	64.7	3.944	62.4	70.8	66.6
15769.6	60.9	3.845	68.2	57.6	62.9
15822.4	59.6	3.850	70.1	56.9	63.5
15875.2	67.2	3.825	78.7	63.6	71.2
15928.0	82.1	3.636	97.3	70.2	83.8
15980.8	57.1	4.016	66.6	51.7	59.1
16033.6	67.6	3.776	73.6	71.3	72.5
16086.4	71.7	3.885	79.0	71.8	75.4
16139.2	77.7	3.765	84.6	74.9	79.8
16192.0	59.5	3.995	70.6	52.4	61.5
16244.8	58.9	3.799	73.1	52.0	62.6
16297.6	68.6	3.818	75.7	71.8	73.8
16350.4	65.5	3.753	84.0	52.8	68.4
16403.2	72.8	3.882	87.1	67.9	77.5
16456.0	86.3	3.510	110.9	65.5	88.2
16508.8	70.7	3.788	83.8	62.7	73.3
16561.6	94.6	3.512	120.0	77.8	98.9
16614.4	65.2	3.959	83.8	55.0	69.4
16667.2	55.1	3.955	72.0	46.7	59.4
16720.0	47.7	4.104	56.1	48.1	52.1
16772.8	67.0	3.924	78.6	59.4	69.0
16825.6	65.8	3.810	73.9	59.0	66.5
16878.4	76.4	3.882	90.3	69.4	79.8
16931.2	60.3	3.973	75.0	50.4	62.7
16984.0	74.6	3.618	100.0	58.9	79.4
17036.8	96.2	3.809	100.2	95.3	97.8
17089.6	69.5	3.924	78.2	68.5	73.4
17142.4	77.7	3.894	90.7	69.4	80.0
17195.2	54.1	4.004	58.6	51.5	55.1
17248.0	79.0	3.875	79.9	80.2	80.1
17300.8	67.8	3.704	80.7	64.9	72.8
17353.6	71.6	3.784	78.3	70.0	74.1
17406.4	68.7	3.672	73.7	67.3	70.5
17459.2	126.5	3.094	145.6	127.6	136.6
17512.0	119.4	3.359	121.0	119.5	120.3
17564.8	69.3	3.962	69.6	71.9	70.7
17617.6	86.5	3.684	104.9	75.8	90.4

17670.4	75.9	3.841	79.5	75.5	77.5	17670.4	71.7	3.922	78.9	67.3	73.1	17670.4	74.4	3.813	85.1	66.0	75.5
17723.2	90.4	3.704	91.6	92.9	92.3	17723.2	85.1	3.777	89.2	86.2	87.7	17723.2	85.0	3.761	89.4	84.4	86.9
17776.0	75.2	3.947	78.3	76.0	77.1	17776.0	69.9	4.038	72.5	71.4	71.9	17776.0	65.9	4.076	69.9	67.5	68.7
17828.8	46.0	4.127	56.3	43.9	50.1	17828.8	43.6	4.113	46.9	44.8	45.8	17828.8	41.9	4.140	46.1	43.0	44.5
17881.6	69.0	3.929	75.3	65.9	70.6	17881.6	68.4	3.866	79.2	61.3	70.2	17881.6	62.7	3.985	68.5	62.5	65.5
17934.4	64.3	3.847	72.5	65.2	68.8	17934.4	57.8	3.934	66.4	58.2	62.3	17934.4	57.0	3.986	67.9	56.4	62.2
17987.2	86.2	3.844	84.1	91.1	87.6	17987.2	92.0	3.760	95.7	92.6	94.1	17987.2	89.7	3.789	88.0	95.7	91.8
18040.0	75.4	3.909	84.1	71.1	77.6	18040.0	72.6	3.952	80.9	68.4	74.7	18040.0	68.1	4.016	76.9	63.6	70.2
18092.8	91.5	3.584	108.2	78.1	93.2	18092.8	91.5	3.604	113.8	71.4	92.6	18092.8	80.0	3.737	97.5	65.7	81.6
18145.6	75.2	3.821	75.0	80.6	77.8	18145.6	77.5	3.791	84.8	76.4	80.6	18145.6	71.5	3.793	74.5	78.1	76.3
18198.4	91.7	3.735	111.1	80.0	95.5	18198.4	88.1	3.783	110.1	72.5	91.3	18198.4	82.6	3.889	104.6	73.0	88.8
18251.2	59.9	3.867	68.5	56.2	62.4	18251.2	61.9	3.868	73.5	53.8	63.7	18251.2	60.0	3.898	71.8	54.6	63.2
18304.0	58.4	4.039	63.3	58.6	61.0	18304.0	58.1	4.052	64.4	58.8	61.6	18304.0	56.1	4.062	64.1	53.4	58.7
18356.8	59.3	3.967	66.8	59.3	63.1	18356.8	52.3	4.069	58.7	52.2	55.5	18356.8	52.9	4.054	61.2	52.4	56.8
18409.6	75.7	3.923	86.4	67.0	76.7	18409.6	73.8	4.023	81.7	67.3	74.5	18409.6	74.9	3.996	83.7	67.5	75.6
18462.4	68.9	3.898	75.2	65.8	70.5	18462.4	65.7	3.831	72.0	63.1	67.6	18462.4	65.0	3.902	70.7	62.5	66.6
18515.2	75.9	3.817	89.0	68.4	78.7	18515.2	67.1	3.942	72.9	65.6	69.2	18515.2	71.7	3.831	83.8	65.2	74.5
18568.0	55.3	4.083	64.5	51.0	57.7	18568.0	59.8	3.909	71.9	53.0	62.4	18568.0	60.5	3.910	70.7	55.4	63.0
18620.8	129.4	3.685	131.3	129.3	130.3	18620.8	118.9	3.837	118.3	121.9	120.1	18620.8	117.4	3.822	116.2	119.5	117.8
18673.6	62.4	3.949	68.0	64.1	66.1	18673.6	61.6	3.954	66.6	64.3	65.4	18673.6	66.1	3.824	74.7	62.2	68.4
18726.4	93.0	3.663	111.8	80.5	96.1	18726.4	92.6	3.678	113.6	78.4	96.0	18726.4	98.8	3.562	122.0	81.7	101.9
18779.2	79.1	3.658	88.8	73.8	81.3	18779.2	77.7	3.737	86.4	72.3	79.3	18779.2	78.3	3.700	94.8	65.4	80.1
18832.0	74.7	3.882	86.3	70.8	78.5	18832.0	67.5	3.993	79.5	61.7	70.6	18832.0	68.4	4.002	79.9	65.4	72.7
18884.8	92.0	3.679	105.8	83.5	94.6	18884.8	93.3	3.748	107.6	80.8	94.2	18884.8	90.7	3.741	106.2	80.6	93.4
18937.6	69.8	3.847	82.2	60.0	71.1	18937.6	64.9	3.854	76.5	57.6	67.0	18937.6	58.0	4.004	74.3	45.4	59.9
18990.4	69.2	3.908	76.5	66.5	71.5	18990.4	66.3	3.960	74.5	62.5	68.5	18990.4	64.2	3.976	68.5	65.7	67.1
19043.2	66.0	4.159	75.8	59.6	67.7	19043.2	63.1	4.093	71.1	61.6	66.3	19043.2	54.7	4.126	64.6	52.2	58.4
19096.0	78.0	3.791	79.1	82.8	81.0	19096.0	78.7	3.769	87.4	75.5	81.4	19096.0	79.2	3.734	85.0	79.1	82.1
19148.8	84.9	3.789	90.2	82.0	86.1	19148.8	82.3	3.850	91.6	75.9	83.8	19148.8	80.7	3.842	90.9	74.1	82.5
19201.6	71.5	3.953	70.0	74.5	72.3	19201.6	74.1	4.053	71.9	77.9	74.9	19201.6	71.8	3.999	73.9	72.9	73.4
19254.4	86.1	3.714	90.2	85.3	87.7	19254.4	79.7	3.705	84.8	77.2	81.0	19254.4	76.9	3.688	82.5	75.0	78.8
19307.2	67.2	4.060	71.1	64.7	67.9	19307.2	64.5	4.154	69.8	61.5	65.6	19307.2	65.9	4.073	70.8	63.9	67.4
19360.0	82.9	3.772	93.4	78.6	86.0	19360.0	78.5	3.880	90.1	69.7	79.9	19360.0	78.9	3.787	88.8	74.2	81.5
19412.8	66.6	4.053	68.8	67.6	68.2	19412.8	63.8	4.095	66.4	67.2	66.8	19412.8	63.4	4.125	65.1	63.8	64.5
19465.6	74.3	3.740	81.2	73.5	77.4	19465.6	72.6	3.767	78.4	71.2	74.8	19465.6	67.5	3.758	76.8	65.9	71.4
19518.4	57.6	3.928	60.4	59.9	60.1	19518.4	58.6	3.923	64.7	58.8	61.8	19518.4	57.2	3.904	64.5	56.1	60.3
19571.2	73.8	3.645	91.8	58.8	75.3	19571.2	66.7	3.724	84.5	53.4	68.9	19571.2	67.2	3.751	83.7	54.9	69.3
19624.0	67.1	3.858	71.9	65.6	68.8	19624.0	68.4	3.815	75.7	66.3	71.0	19624.0	67.7	3.854	74.9	65.4	70.1
19676.8	76.4	3.674	85.1	72.5	78.8	19676.8	69.2	3.740	81.2	63.5	72.3	19676.8	74.0	3.699	85.5	67.8	76.6
19729.6	92.1	3.556	107.2	86.2	96.7	19729.6	88.5	3.606	104.5	80.5	92.5	19729.6	86.7	3.618	104.1	77.6	90.8
19782.4	65.2	3.765	82.6	52.4	67.5	19782.4	66.4	3.793	89.7	48.8	69.2	19782.4	65.2	3.756	86.5	49.7	68.1
19835.2	71.9	3.809	80.2	67.5	73.9	19835.2	74.7	3.806	78.1	73.3	75.7	19835.2	73.2	3.833	80.9	69.4	75.2
19888.0	100.2	3.731	107.0	95.6	101.3	19888.0	101.1	3.677	109.9	94.6	102.3	19888.0	99.3	3.632	110.0	93.2	101.6
19940.8	119.9	3.817	119.4	126.1	122.7	19940.8	122.3	3.809	121.2	127.2	124.2	19940.8	121.1	3.805	125.7	124.6	125.1
19993.6	77.6	3.713	91.3	69.4	80.3	19993.6	69.1	3.788	80.5	64.8	72.6	19993.6	76.3	3.709	90.6	66.0	78.3
20046.4	66.8	3.892	81.2	54.9	68.1	20046.4	59.3	3.933	77.3	44.5	60.9	20046.4	60.7	3.959	77.3	48.1	62.7
20099.2	107.9	3.375	133.1	86.0	109.5	20099.2	94.3	3.503	113.5	79.2	96.4	20099.2	98.7	3.448	115.0	84.0	99.5
20152.0	86.1	3.547	94.7	81.3	88.0	20152.0	81.4	3.589	92.6	75.8	84.2	20152.0	81.1	3.630	88.7	78.0	83.4
20204.8	109.9	3.720	118.3	106.7	112.5	20204.8	106.4	3.644	118.1	99.6	108.8	20204.8	109.7	3.587	122.8	104.3	113.5
20257.6	80.3	3.718	86.6	83.5	85.1	20257.6	79.2	3.909	86.3	73.4	79.8	20257.6	83.6	3.839	90.3	80.2	85.3
20310.4	96.8	3.573	120.7	78.6	99.7	20310.4	78.7	3.745	97.9	67.5	82.7	20310.4	77.9	3.724	98.2	70.6	84.4
20363.2	78.6	3.656	98.7	63.4	81.0	20363.2	78.4	3.641	96.1	66.8	81.5	20363.2	74.3	3.662	87.3	65.7	76.5
20416.0	68.0	3.759	72.6	67.8	70.2	20416.0	63.0	3.857	66.4	64.5	65.5	20416.0	57.5	4.033	61.9	57.8	59.8
20468.8	61.9	3.919	70.4	59.4	64.9	20468.8	71.7	3.807	83.1	64.2	73.6	20468.8	66.7	3.917	76.1	61.7	68.9
20521.6	82.8	3.676	88.7	78.9	83.8	20521.6	84.8	3.688	92.0	78.7	85.3	20521.6	83.0	3.737	89.3	79.0	84.1
20574.4	62.9	3.753	72.8	58.3	65.5	20574.4	61.9	3.760	71.9	60.0	66.0	20574.4	61.0	3.786	73.7	56.2	65.0

20627.2	71.7	3.938	87.9	66.5	77.2	20627.2	67.9	3.994	79.1	64.9	72.0	20627.2	70.3	3.973	81.7	66.9	74.3
20680.0	67.0	4.103	71.2	67.9	69.6	20680.0	67.3	4.004	73.7	65.6	69.6	20680.0	66.3	4.021	71.6	67.3	69.5
20732.8	68.6	3.956	75.6	68.6	72.1	20732.8	66.2	4.071	71.8	66.7	69.3	20732.8	64.1	4.059	69.8	63.4	66.6
20785.6	94.3	3.751	99.6	90.8	95.2	20785.6	98.4	3.746	103.3	95.1	99.2	20785.6	97.0	3.761	100.5	96.4	98.4
20838.4	58.4	4.047	57.6	69.2	63.4	20838.4	53.2	4.121	52.2	62.0	57.1	20838.4	52.5	4.115	50.9	63.4	57.1
20891.2	83.7	3.752	91.9	78.5	85.2	20891.2	82.5	3.719	95.2	74.3	84.8	20891.2	82.6	3.740	90.3	79.2	84.7
20944.0	70.7	3.868	82.5	64.0	73.3	20944.0	64.8	3.894	77.4	57.0	67.2	20944.0	63.1	3.948	72.5	57.8	65.2
20996.8	93.4	3.649	103.9	87.3	95.6	20996.8	104.2	3.598	117.7	94.4	106.0	20996.8	99.4	3.620	110.0	90.8	100.4
21049.6	85.6	4.054	87.6	84.5	86.0	21049.6	77.1	4.049	82.0	73.8	77.9	21049.6	74.9	4.057	79.9	71.0	75.5
21102.4	53.1	4.063	58.3	49.8	54.1	21102.4	52.0	4.111	54.4	53.1	53.8	21102.4	48.3	4.137	53.5	45.7	49.6
21155.2	78.2	3.932	76.4	82.7	79.5	21155.2	79.1	3.921	87.2	75.1	81.2	21155.2	74.9	3.964	76.5	76.3	76.4
21208.0	93.1	3.768	92.4	96.1	94.3	21208.0	96.9	3.778	98.9	95.8	97.3	21208.0	94.4	3.780	95.1	97.5	96.3
21260.8	59.5	4.057	64.4	62.2	63.3	21260.8	59.3	4.052	65.4	59.9	62.6	21260.8	58.3	4.085	65.3	57.7	61.5
21313.6	62.1	4.034	65.8	63.9	64.9	21313.6	62.4	4.016	67.0	64.3	65.7	21313.6	61.2	4.055	65.3	61.7	63.5
21366.4	58.7	4.016	63.6	59.0	61.3	21366.4	58.4	3.995	57.5	67.8	62.7	21366.4	55.6	4.037	60.3	57.3	58.8
21419.2	70.9	3.915	81.0	65.6	73.3	21419.2	75.2	3.839	83.2	70.6	76.9	21419.2	71.8	3.971	76.7	69.4	73.1
21472.0	69.6	4.041	78.9	66.2	72.5	21472.0	67.4	4.078	79.5	62.8	71.2	21472.0	66.4	4.141	74.9	60.0	67.4
21524.8	56.0	4.089	63.7	52.7	58.2	21524.8	56.1	4.117	59.6	56.8	58.2	21524.8	51.9	4.134	50.0	59.2	54.6
21577.6	67.0	4.260	65.5	72.9	69.2	21577.6	64.6	4.235	64.5	66.7	65.6	21577.6	66.6	4.274	66.3	68.0	67.2
21630.4	67.9	3.825	81.7	57.1	69.4	21630.4	69.2	3.759	85.2	56.0	70.6	21630.4	65.3	3.782	74.3	61.4	67.8
21683.2	76.0	3.778	84.6	72.1	78.4	21683.2	67.9	3.964	76.2	66.5	71.4	21683.2	67.7	3.993	71.4	67.4	69.4
21736.0	65.7	3.941	71.0	66.5	68.8	21736.0	64.8	4.023	73.5	61.7	67.6	21736.0	62.9	4.037	72.2	58.3	65.3
21788.8	66.0	4.107	73.2	61.4	67.3	21788.8	68.2	4.132	77.7	60.3	69.0	21788.8	69.0	4.102	77.8	64.4	71.1
21841.6	82.4	3.741	95.5	74.3	84.9	21841.6	67.5	3.869	79.1	63.4	71.2	21841.6	64.1	3.933	77.4	58.3	67.9
21894.4	65.9	4.012	75.5	61.8	68.7	21894.4	63.2	4.100	68.1	61.6	64.8	21894.4	62.6	4.089	65.7	62.7	64.2
21947.2	78.5	3.851	81.3	80.3	80.8	21947.2	82.8	3.904	87.7	80.3	84.0	21947.2	80.6	3.932	83.6	81.9	82.7
22000.0	86.8	3.954	85.9	89.5	87.7	22000.0	77.0	3.975	81.5	76.0	78.8	22000.0	72.7	4.021	75.2	72.7	74.0
22052.8	70.7	3.946	74.9	70.0	72.5	22052.8	74.8	3.966	84.2	69.9	77.1	22052.8	66.0	3.982	70.8	62.9	66.8
22105.6	58.6	4.021	64.2	56.8	60.5	22105.6	61.1	4.040	72.6	55.1	63.8	22105.6	62.3	4.043	69.9	61.2	65.6
22158.4	77.5	3.844	85.7	78.3	82.0	22158.4	77.4	3.793	89.6	72.6	81.1	22158.4	72.1	3.846	82.0	67.5	74.7
22211.2	73.6	3.775	76.8	76.3	76.5	22211.2	73.0	3.744	72.5	78.2	75.4	22211.2	69.8	3.813	75.0	69.4	72.2
22264.0	73.6	3.833	85.0	72.4	78.7	22264.0	77.8	3.809	92.0	71.7	81.8	22264.0	76.3	3.841	92.1	67.9	80.0
22316.8	58.5	3.961	69.2	56.4	62.8	22316.8	55.5	4.036	65.6	52.4	59.0	22316.8	57.0	4.020	64.9	54.4	59.7
22369.6	79.1	3.782	83.6	76.6	80.1	22369.6	76.7	3.836	82.3	72.7	77.5	22369.6	72.0	3.915	80.9	66.6	73.7
22422.4	65.5	3.924	70.2	68.6	69.4	22422.4	61.3	3.957	64.0	67.1	65.6	22422.4	56.7	4.016	64.3	59.3	61.8
22475.2	87.4	3.656	93.8	84.3	89.0	22475.2	87.0	3.685	94.6	84.7	89.6	22475.2	85.4	3.713	91.5	82.6	87.1
22528.0	54.4	4.014	65.3	55.0	60.1	22528.0	57.1	4.060	67.1	54.1	60.6	22528.0	55.1	4.081	64.5	52.4	58.5
22580.8	46.2	4.267	48.0	46.5	47.3	22580.8	39.8	4.258	43.8	41.2	42.5	22580.8	35.3	4.346	37.1	39.4	38.3
22633.6	46.4	4.184	58.3	39.2	48.7	22633.6	47.0	4.156	58.1	39.5	48.8	22633.6	45.3	4.179	56.7	38.7	47.7
22686.4	66.7	3.854	82.0	58.3	70.2	22686.4	66.1	3.877	85.1	55.6	70.4	22686.4	64.5	3.916	79.5	57.7	68.6
22739.2	72.9	3.776	84.9	69.6	77.2	22739.2	73.8	3.856	89.8	66.4	78.1	22739.2	71.9	3.905	86.3	68.9	77.6
22792.0	64.6	3.929	74.9	62.9	68.9	22792.0	62.3	3.986	73.0	56.0	64.5	22792.0	57.0	4.051	74.4	49.0	61.7
22844.8	41.3	4.124	51.1	37.5	44.3	22844.8	42.6	4.106	52.4	37.0	44.7	22844.8	46.5	4.044	55.3	42.4	48.9
22897.6	52.1	3.980	61.8	48.4	55.1	22897.6	49.3	4.030	70.3	41.0	55.6	22897.6	47.2	4.118	60.4	41.3	50.9
22950.4	57.1	4.033	56.5	67.6	62.1	22950.4	57.2	4.001	64.2	60.8	62.5	22950.4	59.3	3.998	65.0	64.2	64.6
23003.2	73.1	3.994	73.0	77.2	75.1	23003.2	69.5	4.052	76.5	72.4	74.4	23003.2	66.1	4.129	70.2	70.9	70.6
23056.0	65.2	3.969	70.5	62.3	66.4	23056.0	64.2	3.982	67.9	61.7	64.8	23056.0	65.4	3.938	78.4	58.3	68.4
23108.8	49.4	3.974	55.5	46.0	50.8	23108.8	51.0	4.031	56.8	49.1	52.9	23108.8	47.1	4.066	56.4	41.2	48.8
23161.6	87.5	3.941	94.2	83.6	88.9	23161.6	80.4	3.981	84.1	80.8	82.5	23161.6	81.5	3.918	86.1	81.6	83.8
23214.4	85.6	3.704	87.3	88.2	87.8	23214.4	86.9	3.737	94.5	85.2	89.9	23214.4	91.6	3.710	97.1	91.8	94.5
23267.2	109.8	3.440	125.3	95.8	110.6	23267.2	107.1	3.452	122.6	93.4	108.0	23267.2	107.5	3.322	124.2	96.0	110.1
23320.0	93.9	3.672	109.2	84.8	97.0	23320.0	85.3	3.752	102.5	75.1	88.8	23320.0	87.4	3.707	96.5	83.6	90.0
23372.8	66.5	4.051	75.4	66.1	70.7	23372.8	87.2	3.579	96.4	84.7	90.6	23372.8	87.8	3.600	97.5	85.0	91.2
23425.6	89.9	3.475	90.8	92.0	91.4	23425.6	77.7	3.778	75.5	85.5	80.5	23425.6	74.2	3.936	78.3	76.5	77.4
23478.4	73.5	4.011	78.0	77.0	77.5	23478.4	75.6	3.800	85.5	71.6	78.5	23478.4	82.9	3.820	93.3	75.6	84.4
23531.2	96.0	3.468	113.3	89.9	101.6	23531.2	96.5	3.503	119.9	85.6	102.7	23531.2	93.9	3.513	107.1	87.5	97.3

23584.0	82.0	3.857	91.8	78.3	85.0	23584.0	82.6	3.833	86.8	81.8	84.3	23584.0	85.4	3.835	92.8	81.8	87.3
23636.8	91.7	3.498	98.0	93.7	95.9	23636.8	106.8	3.421	120.1	103.5	111.8	23636.8	106.7	3.416	115.9	104.7	110.3
23689.6	102.7	3.640	120.4	91.3	105.9	23689.6	89.3	3.572	109.4	75.2	92.3	23689.6	90.1	3.590	109.9	76.3	93.1
23742.4	87.2	3.458	100.7	78.1	89.4	23742.4	84.9	3.597	97.4	75.1	86.3	23742.4	84.4	3.605	98.6	72.1	85.4
23795.2	96.3	3.498	109.5	85.2	97.4	23795.2	94.8	3.445	109.4	81.5	95.5	23795.2	95.3	3.476	108.7	83.7	96.2
23848.0	96.3	3.641	107.1	86.3	96.7	23848.0	87.9	3.847	95.0	81.0	88.0	23848.0	85.5	3.819	100.0	81.2	90.6
23900.8	60.3	3.856	71.3	52.8	62.1	23900.8	65.1	3.722	81.1	51.1	66.1	23900.8	69.3	3.635	85.7	54.9	70.3
23953.6	93.7	3.624	115.0	75.9	95.5	23953.6	91.7	3.736	110.3	78.0	94.2	23953.6	90.6	3.726	111.7	73.2	92.4
24006.4	72.2	3.700	88.4	63.7	76.1	24006.4	83.7	3.542	104.0	68.2	86.1	24006.4	91.7	3.485	112.8	74.9	93.8
24059.2	94.6	3.512	114.4	82.4	98.4	24059.2	74.8	3.697	88.9	65.0	76.9	24059.2	84.3	3.628	98.7	78.0	88.3
24112.0	80.6	3.763	90.3	75.0	82.7	24112.0	86.1	3.682	101.1	74.5	87.8	24112.0	86.1	3.620	102.4	72.4	87.4
24164.8	59.0	3.861	81.7	47.0	64.3	24164.8	54.8	3.956	71.8	47.4	59.6	24164.8	56.4	3.900	78.0	44.8	61.4
24217.6	106.0	3.461	119.7	101.0	110.4	24217.6	117.9	3.379	138.3	104.3	121.3	24217.6	120.7	3.303	144.8	102.7	123.7
24270.4	85.5	3.568	100.1	78.3	89.2	24270.4	68.9	3.710	82.7	63.3	73.0	24270.4	72.3	3.717	86.6	63.8	75.2
24323.2	79.5	3.587	96.9	65.4	81.1	24323.2	84.8	3.592	109.5	61.0	85.2	24323.2	81.2	3.602	110.7	53.8	82.3
24376.0	89.4	3.602	115.3	66.4	90.8	24376.0	90.0	3.612	112.4	71.4	91.9	24376.0	90.3	3.552	111.5	70.5	91.0
24428.8	82.0	3.460	106.4	67.9	87.2	24428.8	80.8	3.334	113.4	61.2	87.3	24428.8	82.7	3.411	124.8	57.2	91.0
24481.6	65.3	3.922	89.3	60.6	74.9	24481.6	72.2	3.905	98.7	65.8	82.3	24481.6	73.5	3.832	97.1	64.9	81.0
24534.4	50.1	4.086	69.8	42.7	56.3	24534.4	53.0	4.090	76.6	48.5	62.6	24534.4	52.1	4.109	77.2	43.4	60.3
24587.2	61.8	3.932	73.4	53.6	63.5	24587.2	58.7	3.916	72.2	51.1	61.7	24587.2	55.0	3.960	70.3	46.2	58.3
24640.0	85.0	3.651	104.9	75.5	90.2	24640.0	88.9	3.646	114.7	67.3	91.0	24640.0	93.2	3.586	121.9	68.5	95.2
24692.8	65.3	4.032	74.9	61.7	68.3	24692.8	59.1	4.034	70.7	56.9	63.8	24692.8	59.9	3.987	71.9	56.7	64.3
24745.6	78.2	3.791	87.2	74.7	81.0	24745.6	75.9	3.858	85.0	71.1	78.1	24745.6	75.8	3.797	85.6	70.5	78.0
24798.4	83.4	3.580	98.2	75.2	86.7	24798.4	91.6	3.471	107.9	79.1	93.5	24798.4	94.0	3.443	101.9	88.2	95.1
24851.2	80.3	3.633	93.4	72.5	83.0	24851.2	81.9	3.515	101.1	72.9	87.0	24851.2	84.4	3.480	101.4	76.7	89.0
24904.0	90.5	3.524	112.0	79.4	95.7	24904.0	84.7	3.674	98.1	77.1	87.6	24904.0	85.5	3.643	103.4	74.4	88.9
24956.8	90.9	3.599	115.1	72.6	93.9	24956.8	97.4	3.618	120.1	83.7	101.9	24956.8	92.9	3.633	114.7	84.0	99.3
25009.6	89.0	3.617	97.0	85.1	91.1	25009.6	88.8	3.574	95.0	86.4	90.7	25009.6	92.2	3.559	102.1	84.4	93.3
25062.4	74.9	3.599	88.5	68.0	78.2	25062.4	74.2	3.515	93.4	66.2	79.8	25062.4	80.7	3.473	107.7	70.6	89.1
25115.2	116.5	3.562	127.2	107.1	117.1	25115.2	113.2	3.640	123.4	104.6	114.0	25115.2	112.4	3.611	125.8	100.8	113.3
25168.0	133.7	3.409	150.5	122.9	136.7	25168.0	150.8	3.282	167.9	140.0	153.9	25168.0	137.2	3.437	161.4	120.0	140.7
25220.8	157.9	3.629	179.2	141.7	160.5	25220.8	151.4	3.734	173.4	132.0	152.7	25220.8	153.9	3.628	185.7	126.1	155.9
25273.6	84.1	3.694	87.6	84.5	86.0	25273.6	81.5	3.797	85.6	80.3	82.9	25273.6	82.7	3.752	94.9	73.4	84.1
25326.4	71.9	3.670	87.7	59.5	73.6	25326.4	62.5	3.783	74.7	53.7	64.2	25326.4	72.2	3.700	85.4	63.3	74.3
25379.2	89.5	3.562	102.6	79.1	90.9	25379.2	82.3	3.716	97.3	71.0	84.2	25379.2	90.4	3.619	111.6	70.8	91.2
25432.0	80.9	3.746	98.6	67.7	83.1	25432.0	63.7	3.888	82.0	50.8	66.4	25432.0	69.3	3.756	89.6	52.9	71.3
25484.8	73.5	3.598	95.1	55.8	75.5	25484.8	63.1	3.653	80.7	55.0	67.9	25484.8	71.4	3.510	89.2	56.9	73.1
25537.6	76.1	3.666	95.8	64.6	80.2	25537.6	80.6	3.667	103.7	63.1	83.4	25537.6	77.4	3.692	96.2	65.0	80.6
25590.4	84.0	3.555	99.3	71.6	85.5	25590.4	82.2	3.592	93.4	74.4	83.9	25590.4	86.6	3.468	105.6	71.2	88.4
25643.2	75.5	3.750	86.5	69.6	78.0	25643.2	76.7	3.754	86.6	72.5	79.5	25643.2	78.9	3.720	88.4	73.3	80.9
25696.0	109.3	3.606	126.8	99.2	113.0	25696.0	110.4	3.620	127.7	102.6	115.1	25696.0	116.2	3.571	132.1	105.5	118.8
25748.8	104.0	3.522	114.4	98.0	106.2	25748.8	98.3	3.526	104.6	96.7	100.7	25748.8	97.0	3.495	106.9	93.2	100.0
25801.6	92.8	3.484	112.5	78.3	95.4	25801.6	92.6	3.454	111.6	83.4	97.5	25801.6	89.9	3.507	112.0	71.6	91.8
25854.4	83.7	3.754	104.3	68.7	86.5	25854.4	82.6	3.724	95.8	73.7	84.7	25854.4	84.7	3.677	102.0	74.0	88.0
25907.2	95.0	3.592	107.2	90.9	99.0	25907.2	100.3	3.583	119.6	87.5	103.5	25907.2	100.8	3.542	116.8	90.4	103.6
25960.0	65.8	3.953	76.7	58.4	67.5	25960.0	57.6	4.020	68.1	50.7	59.4	25960.0	62.1	3.912	72.7	54.3	63.5
26012.8	77.6	3.691	96.9	65.0	80.9	26012.8	96.6	3.614	114.8	85.5	100.1	26012.8	96.4	3.630	123.7	73.4	98.6
26065.6	107.0	3.616	129.7	89.1	109.4	26065.6	88.4	3.664	109.8	72.7	91.2	26065.6	89.3	3.627	108.9	74.8	91.9
26118.4	104.1	3.434	125.0	86.6	105.8	26118.4	116.5	3.272	140.8	96.3	118.5	26118.4	118.5	3.266	141.0	98.1	119.5
26171.2	88.0	3.500	102.1	83.9	93.0	26171.2	84.5	3.651	95.0	81.5	88.2	26171.2	83.1	3.643	97.4	73.4	85.4
26224.0	81.0	3.600	88.0	82.9	85.5	26224.0	90.0	3.478	100.8	88.5	94.7	26224.0	84.3	3.553	96.2	83.8	90.0
26276.8	64.9	3.735	78.8	60.3	69.5	26276.8	62.2	3.796	70.1	59.0	64.5	26276.8	64.2	3.776	70.6	62.3	66.5
26329.6	82.7	3.717	91.6	79.4	85.5	26329.6	92.6	3.733	99.5	88.5	94.0	26329.6	91.4	3.757	98.3	87.7	93.0
26382.4	108.8	3.656	112.3	108.8	110.6	26382.4	109.4	3.574	113.2	110.0	111.6	26382.4	107.8	3.669	110.9	106.9	108.9
26435.2	115.6	3.525	121.0	112.2	116.6	26435.2	101.3	3.597	111.8	99.2	105.5	26435.2	100.0	3.690	107.8	99.0	103.4
26488.0	111.5	3.712	126.7	102.8	114.7	26488.0	114.1	3.656	130.5	103.4	116.9	26488.0	114.8	3.676	129.0	104.8	116.9

26540.8	101.6	3.392	119.0	89.8	104.4	26540.8	88.2	3.546	105.0	76.4	90.7	26540.8	88.1	3.527	105.2	75.7	90.4
26593.6	89.2	3.606	96.2	86.1	91.1	26593.6	90.8	3.660	98.0	85.7	91.9	26593.6	95.0	3.583	100.3	90.9	95.6
26646.4	99.2	3.538	106.1	95.7	100.9	26646.4	89.3	3.615	96.2	86.3	91.2	26646.4	89.2	3.627	95.3	87.6	91.5
26699.2	76.6	3.610	87.0	71.5	79.2	26699.2	77.0	3.611	84.8	74.5	79.7	26699.2	82.6	3.581	93.9	73.9	83.9
26752.0	99.1	3.592	116.7	85.2	101.0	26752.0	95.9	3.632	111.3	84.9	98.1	26752.0	95.5	3.662	112.6	82.9	97.8
26804.8	50.3	4.047	65.0	42.3	53.7	26804.8	53.7	3.865	66.9	45.8	56.3	26804.8	53.5	3.955	72.2	39.3	55.8
26857.6	66.0	3.836	75.4	58.3	66.9	26857.6	71.9	3.777	84.7	60.4	72.6	26857.6	74.6	3.823	89.5	61.5	75.5
26910.4	61.3	3.929	68.0	56.8	62.4	26910.4	62.1	3.944	69.5	56.7	63.1	26910.4	59.0	3.889	67.5	51.6	59.5
26963.2	68.5	3.748	77.1	62.2	69.6	26963.2	67.7	3.802	79.0	60.7	69.9	26963.2	69.5	3.788	81.2	61.1	71.1
27016.0	69.5	3.980	81.6	61.7	71.6	27016.0	69.3	3.914	82.5	61.6	72.0	27016.0	68.4	3.916	80.5	62.6	71.5
27068.8	57.9	4.085	74.9	48.7	61.8	27068.8	61.4	4.093	77.3	53.5	65.4	27068.8	60.4	4.112	77.1	51.7	64.4
27121.6	64.3	4.063	71.2	62.5	66.8	27121.6	68.3	3.884	75.9	67.1	71.5	27121.6	68.0	3.881	78.8	61.1	69.9
27174.4	68.2	3.824	80.3	59.1	69.7	27174.4	69.8	3.813	79.7	63.6	71.7	27174.4	64.5	3.892	71.9	59.6	65.7
27227.2	85.4	3.901	90.3	86.4	88.4	27227.2	90.0	3.851	94.3	91.8	93.0	27227.2	89.6	3.839	92.2	92.8	92.5
27280.0	82.3	3.786	93.1	74.5	83.8	27280.0	82.9	3.832	96.7	72.3	84.5	27280.0	82.8	3.874	96.2	71.9	84.1
27332.8	66.7	3.889	78.0	57.6	67.8	27332.8	62.0	3.959	76.4	53.5	65.0	27332.8	63.6	3.893	75.8	55.6	65.7
27385.6	68.1	3.803	68.9	68.5	68.7	27385.6	69.5	3.789	73.5	68.6	71.0	27385.6	64.3	3.882	70.1	59.9	65.0
27438.4	65.6	3.839	70.4	63.3	66.8	27438.4	79.4	3.603	90.2	75.1	82.7	27438.4	70.1	3.755	81.2	61.4	71.3
27491.2	74.7	3.794	86.7	68.3	77.5	27491.2	72.6	3.882	84.5	66.8	75.7	27491.2	68.4	3.932	81.1	61.0	71.1
27544.0	56.9	3.916	71.4	46.6	59.0	27544.0	57.2	3.879	75.9	43.4	59.6	27544.0	54.3	3.878	70.5	43.2	56.8
27596.8	61.8	3.842	73.2	54.6	63.9	27596.8	61.9	3.848	70.6	57.8	64.2	27596.8	59.1	3.914	68.6	52.7	60.7
27649.6	90.9	3.720	111.1	74.9	93.0	27649.6	103.4	3.611	124.2	85.7	105.0	27649.6	104.7	3.643	125.9	87.5	106.7
27702.4	88.2	3.940	97.0	80.8	88.9	27702.4	68.4	4.206	80.4	61.9	71.2	27702.4	65.0	4.184	74.3	58.2	66.3
27755.2	64.6	4.066	68.2	65.8	67.0	27755.2	69.9	3.945	72.2	72.8	72.5	27755.2	67.2	3.906	71.8	67.5	69.6
27808.0	68.4	3.934	69.9	71.3	70.6	27808.0	65.1	4.037	74.1	60.8	67.4	27808.0	65.3	4.039	72.8	62.4	67.6
27860.8	70.7	3.919	87.7	60.3	74.0	27860.8	64.5	3.876	74.4	58.3	66.4	27860.8	69.5	3.909	89.6	55.9	72.7
27913.6	72.6	3.795	94.8	55.5	75.1	27913.6	62.9	3.859	79.8	52.5	66.1	27913.6	66.9	3.908	75.7	60.7	68.2
27966.4	48.2	4.082	56.3	42.3	49.3	27966.4	55.8	3.929	69.9	45.7	57.8	27966.4	60.5	3.883	69.8	55.1	62.4
28019.2	62.1	3.867	80.4	48.7	64.5	28019.2	56.9	4.014	70.1	49.3	59.7	28019.2	56.6	3.995	71.5	47.5	59.5
28072.0	62.2	3.913	57.2	68.8	63.0	28072.0	64.6	3.865	65.3	67.0	66.2	28072.0	60.4	3.959	64.2	58.8	61.5
28124.8	55.3	4.053	64.5	49.5	57.0	28124.8	54.1	4.054	63.9	47.6	55.8	28124.8	50.1	4.092	57.3	44.4	50.8
28177.6	59.3	3.966	67.4	53.9	60.6	28177.6	57.9	3.937	68.1	51.3	59.7	28177.6	50.6	4.014	60.5	45.2	52.9
28230.4	61.6	4.101	68.4	57.7	63.1	28230.4	68.4	4.022	76.8	62.4	69.6	28230.4	66.3	4.060	71.1	66.5	68.8
28283.2	72.1	3.880	81.4	65.8	73.6	28283.2	67.1	3.952	80.1	57.2	68.7	28283.2	63.7	3.947	71.6	59.5	65.5
28336.0	53.3	4.113	59.6	50.3	54.9	28336.0	62.5	4.003	72.9	55.3	64.1	28336.0	62.7	3.974	74.2	55.7	65.0
28388.8	57.8	3.933	64.8	56.7	60.7	28388.8	53.5	3.992	60.2	50.2	55.2	28388.8	55.1	4.024	67.2	49.8	58.5
28441.6	77.2	4.025	87.2	75.2	81.2	28441.6	76.7	3.952	87.4	68.0	77.7	28441.6	86.8	3.790	103.6	74.5	89.0
28494.4	77.6	3.647	93.5	67.9	80.7	28494.4	69.1	3.690	84.6	59.5	72.0	28494.4	70.6	3.707	93.2	53.7	73.5
28547.2	52.0	3.982	61.7	48.4	55.1	28547.2	52.4	4.012	63.4	49.3	56.4	28547.2	55.0	3.924	69.6	49.7	59.6
28600.0	65.7	4.007	70.8	62.3	66.5	28600.0	61.0	4.031	70.1	56.5	63.3	28600.0	60.5	4.073	70.8	54.1	62.5
28652.8	49.7	4.140	57.0	48.0	52.5	28652.8	51.8	4.088	57.9	50.6	54.3	28652.8	49.3	4.153	54.9	48.7	51.8
28705.6	71.5	3.929	78.7	67.0	72.9	28705.6	72.4	3.881	82.9	64.4	73.6	28705.6	69.5	3.949	77.6	62.7	70.2
28758.4	56.1	4.178	60.8	54.9	57.9	28758.4	52.6	4.150	62.5	47.8	55.1	28758.4	47.9	4.144	55.6	46.1	50.9
28811.2	64.7	3.772	73.5	61.8	67.7	28811.2	65.6	3.849	75.9	59.7	67.8	28811.2	58.8	3.894	66.5	56.8	61.7
28864.0	48.0	3.925	63.5	42.3	52.9	28864.0	60.3	3.826	73.5	52.0	62.7	28864.0	58.1	3.771	76.8	44.8	60.8
28916.8	57.6	3.838	71.9	51.8	61.8	28916.8	50.3	3.963	69.2	43.2	56.2	28916.8	49.4	4.045	69.7	37.3	53.5
28969.6	77.6	3.812	96.2	61.6	78.9	28969.6	95.7	3.534	113.5	79.5	96.5	28969.6	88.2	3.597	116.3	63.2	89.8
29022.4	56.2	3.899	71.3	50.5	60.9	29022.4	219.8	0.477	53.2	391.3	222.3	29022.4	48.8	4.059	60.4	45.9	53.1