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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Ohio Route 50 Joint Sealant Experiment

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Abstract

This research project entailed the construction and evaluation 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.
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April 2002

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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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<tr>
<td>°C</td>
<td>Degrees Celsius</td>
</tr>
<tr>
<td>°F</td>
<td>Degrees Fahrenheit</td>
</tr>
<tr>
<td>AASHTO</td>
<td>American Association of State Highway and Transportation Officials</td>
</tr>
<tr>
<td>AC</td>
<td>Asphalt Concrete</td>
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<tr>
<td>ADT</td>
<td>Average Daily Traffic</td>
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<tr>
<td>BSG</td>
<td>Bulk Specific Gravity</td>
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<tr>
<td>C</td>
<td>Drainage Coefficient</td>
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<tr>
<td>COV</td>
<td>Coefficient of Variation</td>
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<td>EB</td>
<td>Eastbound</td>
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<td>EBNV99</td>
<td>November 1999 sealant evaluation in the eastbound lanes</td>
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<td>March 2000 sealant evaluation in the eastbound lanes</td>
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<td>June 2001 sealant evaluation in the eastbound lanes</td>
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<tr>
<td>EBOC01</td>
<td>October 2001 sealant evaluation in the eastbound lanes</td>
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<tr>
<td>Ec</td>
<td>Modulus of Elasticity</td>
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<tr>
<td>ESAL</td>
<td>Equivalent Single Axle Load</td>
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<tr>
<td>F</td>
<td>Fair</td>
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<tr>
<td>FDB</td>
<td>Free Draining Base</td>
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<td>FHWA</td>
<td>Federal Highway Administration</td>
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<td>ft</td>
<td>feet</td>
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<td>Abbreviation</td>
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<tr>
<td>G</td>
<td>Good</td>
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<tr>
<td>GGBFS</td>
<td>Ground Granulated Blast Furnace Slag</td>
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<tr>
<td>HPCP</td>
<td>High Performance Concrete Pavements</td>
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<td>in.</td>
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<td>IRI</td>
<td>International Roughness Index</td>
</tr>
<tr>
<td>IRIbh</td>
<td>International Roughness Index, both wheel tracks</td>
</tr>
<tr>
<td>IRIlf</td>
<td>International Roughness Index, left wheel tracks</td>
</tr>
<tr>
<td>IRIrt</td>
<td>International Roughness Index, right wheel tracks</td>
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<tr>
<td>J</td>
<td>Load transfer Coefficient</td>
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<td>JPCP</td>
<td>Jointed Plain Concrete Pavements</td>
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<td>JRCP</td>
<td>Jointed Reinforced Concrete Pavement</td>
</tr>
<tr>
<td>k</td>
<td>Modulus of Subgrade Reaction</td>
</tr>
<tr>
<td>km</td>
<td>kilometers</td>
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<tr>
<td>l</td>
<td>Radius of Relative Stiffness</td>
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<td>L</td>
<td>Slab Length</td>
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<tr>
<td>m</td>
<td>meters</td>
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<tr>
<td>MAX</td>
<td>Maximum Value</td>
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<td>MAYS</td>
<td>Mays Number</td>
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<tr>
<td>MIN</td>
<td>Minimum Value</td>
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<td>mm</td>
<td>millimeters</td>
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<tr>
<td>Mr</td>
<td>Modulus of Rupture</td>
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<td>NCDC</td>
<td>National Climatic Data Center</td>
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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 \(0^\circ C\) (\(32^\circ F\))
and the average daily minimum temperature is \(-6^\circ C\) (\(21^\circ F\)). The average summer
temperature is \(22^\circ C\) (\(71^\circ F\)), with an average daily maximum temperature of \(29^\circ C\)
(\(85^\circ F\)). The mean monthly average temperature is \(12^\circ C\) (\(53^\circ F\)). The low average
monthly temperature is \(0^\circ C\) (\(32^\circ F\)), whereas the high average monthly temperature is
\(24^\circ C\) (\(75^\circ F\)). 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 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 4°C (40°F) 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 \( \frac{L}{l} \), of the slab length, \( L \), to the radius of relative stiffness, \( l \), of the slab-subgrade system, and recommended joint spacings corresponding to an \( \frac{L}{l} \) ratio ranging between 4 and 6 (with 5 being “a promising alternative”). Subsequently, on the basis of extensive field investigations, Smith, \textit{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, \( k_r \), of 27 MN/m³ (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.

Construciton 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°C (25 and
66°F), respectively. In the westbound lanes, the minimum and maximum air
temperatures recorded between 9/30 and 10/7/98 were 1 and 28°C (34 and 83°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 sheepfoot 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/m³ (412 lb/yd³) of Type I cement; 82 kg/m³ (138 lb/yd³) of ground granulated blast furnace slag; 847 kg/m³ (1428 lb/yd³) of river sand with a bulk specific gravity (BSG) of 2.61; and, 810 kg/m³ (1365 lb/yd³) 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/m³ (600 lb/yd³) of cement; 762 kg/m³ (1285 lb/yd³) of fine
aggregate; 967 kg/m³ (1630 lb/yd³) of coarse aggregate; and 178 kg/m³ (300 lb/yd³) 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 132°C (270°F) and 143°C (290°F) 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 193°C (380°F) and 210°C (410°F) 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

<table>
<thead>
<tr>
<th>Type</th>
<th>Sealant</th>
<th>Joint Config.</th>
<th>Stations</th>
<th>No. of Joints</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-leveling silicone</td>
<td>Crafco 903-SL</td>
<td>1</td>
<td>188+00 to 194+00</td>
<td>29</td>
</tr>
<tr>
<td>Self-leveling silicone</td>
<td>Crafco 903-SL</td>
<td>4</td>
<td>206+00 to 213+00</td>
<td>33</td>
</tr>
<tr>
<td>Self-leveling silicone</td>
<td>Dow 890-SL</td>
<td>3</td>
<td>166+00 to 172+00</td>
<td>29</td>
</tr>
<tr>
<td>Self-leveling silicone</td>
<td>Dow 890-SL</td>
<td>4</td>
<td>213+00 to 219+00</td>
<td>29</td>
</tr>
<tr>
<td>Self-leveling silicone</td>
<td>Dow 890-SL</td>
<td>1</td>
<td>266+00 to 272+00</td>
<td>28</td>
</tr>
<tr>
<td>Non-sag silicone</td>
<td>Crafco 902</td>
<td>1</td>
<td>200+00 to 206+00</td>
<td>29</td>
</tr>
<tr>
<td>Non-sag silicone</td>
<td>Dow 888</td>
<td>1a</td>
<td>272+00 to 284+00</td>
<td>57</td>
</tr>
<tr>
<td>Non-sag silicone</td>
<td>Dow 888</td>
<td>1b</td>
<td>284+00 to 290+00</td>
<td>29</td>
</tr>
<tr>
<td>Hot-pour</td>
<td>Crafco 221</td>
<td>1</td>
<td>260+00 to 266+00</td>
<td>29</td>
</tr>
<tr>
<td>Hot-pour</td>
<td>Crafco 444</td>
<td>1</td>
<td>172+00 to 188+00</td>
<td>76</td>
</tr>
<tr>
<td>Compression Seal</td>
<td>Delastic V-687</td>
<td>5</td>
<td>225+00 to 231+00</td>
<td>29</td>
</tr>
<tr>
<td>Compression Seal</td>
<td>Watson Bowman WB-687</td>
<td>5</td>
<td>194+00 to 200+00</td>
<td>27</td>
</tr>
<tr>
<td>Compression Seal</td>
<td>Techstar W-050</td>
<td>5</td>
<td>154+00 to 160+00</td>
<td>29</td>
</tr>
<tr>
<td>Unsealed</td>
<td>No Sealant</td>
<td>6</td>
<td>160+00 to 166+00</td>
<td>29</td>
</tr>
<tr>
<td>Unsealed</td>
<td>No Sealant</td>
<td>2</td>
<td>219+00 to 225+00</td>
<td>28</td>
</tr>
</tbody>
</table>
Table 2.1 (continued)

(b) Westbound test sections

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

<table>
<thead>
<tr>
<th>Sieve No.</th>
<th>Allowable % Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 in.</td>
<td>100</td>
</tr>
<tr>
<td>1 in.</td>
<td>70 - 100</td>
</tr>
<tr>
<td>0.75 in.</td>
<td>50 - 90</td>
</tr>
<tr>
<td>No. 4</td>
<td>30 - 60</td>
</tr>
<tr>
<td>No. 30</td>
<td>9 - 33</td>
</tr>
<tr>
<td>No. 200</td>
<td>0 - 13</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Sieve No.</th>
<th>NJ Type % Passing</th>
<th>NJ Type (Eastbound Lanes) Specified Gradation</th>
<th>IA Type % Passing</th>
<th>IA Type (Westbound Lanes) Specified Gradation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 in.</td>
<td>100</td>
<td>100</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1 in.</td>
<td>100</td>
<td>95 - 100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>0.5 in.</td>
<td>65</td>
<td>60 - 80</td>
<td>56</td>
<td>50 - 80</td>
</tr>
<tr>
<td>No. 4</td>
<td>42</td>
<td>40 - 55</td>
<td>31</td>
<td>-</td>
</tr>
<tr>
<td>No. 8</td>
<td>14</td>
<td>5 - 25</td>
<td>25</td>
<td>10 - 35</td>
</tr>
<tr>
<td>No. 16</td>
<td>4</td>
<td>0 - 8</td>
<td>14</td>
<td>-</td>
</tr>
<tr>
<td>No. 50</td>
<td>1</td>
<td>0 - 5</td>
<td>3</td>
<td>0 - 15</td>
</tr>
<tr>
<td>No. 200</td>
<td>-</td>
<td>-</td>
<td>1.3</td>
<td>0 - 6</td>
</tr>
</tbody>
</table>
Table 2.3  Portland cement concrete mix design used for the U.S. 50 High Performance Concrete pavement slab (Sargand, 2000)

<table>
<thead>
<tr>
<th>PCC Mix Component</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine Aggregate (dry)</td>
<td>1428 lb/yd³</td>
</tr>
<tr>
<td>- natural concrete sand -</td>
<td></td>
</tr>
<tr>
<td>Coarse Aggregate (dry)</td>
<td>1365 lb/yd³</td>
</tr>
<tr>
<td>- #8 gravel -</td>
<td></td>
</tr>
<tr>
<td>Cement</td>
<td>412 lb/yd³</td>
</tr>
<tr>
<td>Water</td>
<td>316 lb/yd³</td>
</tr>
<tr>
<td>GGBFS</td>
<td>138 lb/yd³</td>
</tr>
<tr>
<td>Water Reducer</td>
<td>2 oz/cwt</td>
</tr>
<tr>
<td>Air Entrainer</td>
<td>4.2 oz/cwt</td>
</tr>
</tbody>
</table>
Deta

De a 3

Detail

Detail 4

Compression Seal

1 1/8 in

1/4 in

3 3/4 in

1/4 - 3/16 in

1/4 - 1/8 in

1/4 in

1 1/8 in

1/4 in

3 3/4 in

1/4 - 3/16 in

1/4 - 1/8 in

1/4 in

1/16 - 1/16 in

1/4 in

1/16 in

Backer Rod

Backer Rod

Backer Rod

Backer Rod

Figu 2. omnt configuration details sed the U. 50 experiment math, 2000
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)

### Field-Molded Sealants

<table>
<thead>
<tr>
<th>Distresses</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partial Depth Adhesion Loss</td>
<td>Separation of the sealant from one or both edges of the joint, but the separation does not extend through the entire sealant depth.</td>
</tr>
<tr>
<td>Partial Depth Spalling</td>
<td>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.</td>
</tr>
<tr>
<td>Partial Depth Cohesion Loss</td>
<td>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.</td>
</tr>
<tr>
<td>Stone Intrusion</td>
<td>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.</td>
</tr>
</tbody>
</table>

### Preformed Compression Seals

<table>
<thead>
<tr>
<th>Distresses</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partial Depth Adhesion Loss</td>
<td>Separation of the sealant from one or both edges of the joint, but the separation does not extend through the entire sealant depth.</td>
</tr>
<tr>
<td>Partial Depth Spalling</td>
<td>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.</td>
</tr>
<tr>
<td>Stone Intrusion</td>
<td>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.</td>
</tr>
<tr>
<td>Surface Extrusion</td>
<td>The neoprene seal distends above the pavement surface as a result of twisting or high placement.</td>
</tr>
<tr>
<td>Failures</td>
<td>Description</td>
</tr>
<tr>
<td>------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Field-Molded Sealants</strong></td>
<td></td>
</tr>
<tr>
<td>Full Depth Adhesion Loss</td>
<td>The sealant has separated completely from one or both edges of the joint, allowing infiltration of moisture and incompressibles.</td>
</tr>
<tr>
<td>Full Depth Spalling</td>
<td>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.</td>
</tr>
<tr>
<td>Full Depth Cohesion Loss</td>
<td>The sealant has split vertically through its entire depth allowing infiltration of moisture and incompressibles.</td>
</tr>
<tr>
<td>Sunken Seal</td>
<td>Sealant has completely separated from both edges and sunken into the joint leaving a low area that is not watertight.</td>
</tr>
<tr>
<td><strong>Preformed Compression Seals</strong></td>
<td></td>
</tr>
<tr>
<td>Full Depth Adhesion Loss</td>
<td>Compression seal has separated completely from one or both walls of the joint, allowing infiltration of moisture and/or incompressibles.</td>
</tr>
<tr>
<td>Full Depth Spalling</td>
<td>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.</td>
</tr>
<tr>
<td>Twisted/rolled Seal</td>
<td>Condition in which the neoprene seal is twisted, rolled, or turned in the joint leaving the surface edges of the seal at different elevations.</td>
</tr>
<tr>
<td>Compression Set</td>
<td>When the neoprene web structure loses its ability to exert outward pressure as a result of being in compression for a very long duration.</td>
</tr>
<tr>
<td>Gap</td>
<td>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.</td>
</tr>
<tr>
<td>Sunken Seal</td>
<td>Seal has sunken into the joint leaving a low area that is not watertight.</td>
</tr>
</tbody>
</table>
Figure 3.1 Joint sealant evaluation form used during field inspections