Materials and Procedures for Repair of Joint Seals in Portland Cement Concrete Pavements—Manual of Practice

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shrp

FOREWORD

This manual (FHWA-RD-99-146) is an update of the Strategic Highway Research Program (SHRP) manual of practice (SHRP-H-349) on concrete pavement repair. The Federal Highway Administration, Long-Term Pavement Performance Program (LTPP) conducted five years of additional research on concrete pavement repair after the conclusion of SHRP. This research validated the repair procedures contained in the original SHRP manual. The manual presents updated guidelines and recommendations to assist highway maintenance agencies and other related organizations in planning, constructing, and monitoring the performance of concrete pavement joint resealing projects. Included in the manual are discussions pertaining to when joint resealing is appropriate, the types of sealant materials and construction methods that should be used, how each individual step in a joint resealing operation should be performed, and how the performance and cost-effectiveness of joint seals can be evaluated. This report will be of interest and benefit to various levels of agency maintenance personnel, from crew supervisors to the chief maintenance engineer.

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Director
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NOTICE

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16. Abstract

The Strategic Highway Research Program (SHRP) H-106 maintenance experiment and the Federal Highway Administration (FHWA) *Long-Term Monitoring (LTM) of Pavement Maintenance Materials Test Sites* project studied the resealing of joints in concrete pavements. Many different sealant materials and resealing methods were investigated between 1991 and 1998 through test sites installed at five locations in the United States. The findings of these combined studies have been merged with standard highway agency procedures to provide the most useful and up-to-date information on the practice of concrete joint resealing.

This Manual of Practice is an updated version of the 1993 SHRP Joint Seal Repair Manual. It contains the latest information pertaining to the performance of sealants and resealing methods, the availability and relative costs of sealant materials, and the proper ways of planning, designing, constructing, and monitoring the performance of joint resealing projects. It also provides an updated partial listing of material and equipment manufacturers.

This Manual is intended for field and office personnel within highway maintenance agencies and contracted maintenance firms. It contains valuable information for supervisors and foremen in charge of individual resealing operations, engineers in charge of planning and overseeing many joint resealing projects, and managers in charge of establishing resealing policies and standards.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3

NOTE: Volumes greater than 1000 l shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

Preface

This manual is intended for use by highway maintenance agencies and contracted maintenance firms in the field and in the office. It is a compendium of good practices for portland cement concrete (PCC) joint resealing operations, stemming from the Strategic Highway Research Program (SHRP) pavement maintenance studies and a follow-up study sponsored by the Federal Highway Administration (FHWA).

In SHRP project H-105, *Innovative Materials and Equipment for Pavement Surface Repair*, the researchers conducted a massive literature review and a nationwide survey of highway agencies to identify potentially cost-effective pavement repair and treatment options (Smith et al., 1991). The information and findings from that study were then used in the subsequent field experiments conducted under SHRP project H-106, *Innovative Materials Development and Testing*.

In project H-106, many different test sections were installed and evaluated to determine the cost-effectiveness of maintenance materials and procedures. Test sections were installed at 22 sites throughout the United States and Canada between March 1991 and February 1992, under the supervision of SHRP representatives. The researchers collected installation and productivity information at each site and periodically evaluated the experimental repairs and treatments through the end of 1992. The first version of this manual was prepared in October 1993 and was based on this work effort.

Following the conclusion of SHRP H-106 in 1993, the FHWA sponsored a study to continue monitoring the performance of the experimental repairs and treatments, beginning in October 1993. Under the *Long-Term Monitoring (LTM) of Pavement Maintenance Materials Test Sites* project, the repairs and treatments were evaluated annually through the end of 1997.

Pertinent long-term performance and cost-effectiveness information generated by the continued monitoring of the experimental joint resealing treatments has been included in this revised manual.

For the reader's convenience, potentially unfamiliar terms are italicized at their first occurrence in the manual and are defined in a glossary. Readers who want more information on topics included in this manual should refer to the reference list provided at the back. The final report for the H-106/*LTM* portland cement concrete (PCC) joint resealing study may be of particular interest to many readers (Evans et al., 1999). It details the installation procedures, laboratory testing of the materials, and field performance of each joint resealing treatment type investigated.

Acknowledgments

The research described herein was supported by the Strategic Highway Research Program and the Federal Highway Administration. SHRP was a unit of the National Research Council that was authorized by section 128 of the Surface Transportation and Uniform Relocation Assistance Act of 1987.

Special thanks are due the project management teams at SHRP and the FHWA, and to the following State highway agencies:

- Arizona Department of Transportation
- Colorado Department of Highways
- Iowa Department of Transportation
- Kentucky Transportation Cabinet
- South Carolina Department of Highways and Public Transportation

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Contents

1.0 Introduction 1
- 1.1 Scope of Manual 1
- 1.2 Overview 2

2.0 Need for Joint Resealing 3
- 2.1 Seal Condition 3
- 2.2 Pavement Condition 9
- 2.3 Environmental Conditions 11
- 2.4 Traffic Conditions 12
- 2.5 Determining the Need to Reseal 13

3.0 Planning and Design 15
- 3.1 Primary Considerations 15
- 3.2 Objective of Resealing 15
- 3.3 Accounting for Existing Conditions 16
- 3.4 Selecting a Sealant Material Type 17
- 3.5 Selecting Backer Materials 20
- 3.6 Selecting Primer Materials 21
- 3.7 Selecting Joint Reservoir Dimensions 22
- 3.8 Selecting Preparation and Installation Procedures 26
- 3.9 Selecting Equipment 29
  - 3.9.1 Joint Plows 29
  - 3.9.2 Concrete Saws 32
  - 3.9.3 Abrasive Blasting Equipment 33
  - 3.9.4 Airblasting Equipment 34
  - 3.9.5 Hot Airblasting Equipment 36
  - 3.9.6 Backer Rod Installation Tools 36
  - 3.9.7 Hot-Applied Sealant Installation Equipment 37
  - 3.9.8 Silicone Sealant Applicators 38
  - 3.9.9 Other Equipment 39
- 3.10 Estimating Material, Labor, and Equipment Requirements 39

Preceding Page Blank

3.11 Determining Cost-Effectiveness 41
3.11.1 Material and Shipping Costs 41
3.11.2 Labor Costs 43
3.11.3 Equipment Costs 43
3.11.4 User Delay Costs 43
3.11.5 Cost-Effectiveness Comparisons 45

4.0 Construction 47
4.1 Traffic Control 47
4.2 Safety Precautions 47
4.3 Preparing the Joint 48
4.3.1 Removing the Old Sealant 48
4.3.2 Refacing the Joint Sidewalls 51
4.3.3 Abrasive Blasting the Joint Sidewalls 53
4.3.4 Airblasting the Joint Reservoir 56
4.3.5 Installing Primer 59
4.4 Material Preparation and Installation 59
4.4.1 Installing Backer Rod 60
4.4.2 Sealant Installation 63

5.0 Evaluation of Joint Seal Performance 77

Appendix A Material Testing Specifications 79

Appendix B Sample Cost-Effectiveness Calculations 83

Appendix C Material and Equipment Safety Precautions . . 89
C.1. Materials 89
C.1.1. Hot-Applied Sealants 89
C.1.2. Cold-Applied Sealants 90

Appendix D Inspection Checklists for Construction 91
D.1 Preconstruction Plans and Specifications 91
D.2. Equipment Inspection 93
D.3. Field Installation Inspection 94
D.3.1. Inspection of Joint Preparation 94
D.3.2. Inspection of Joint Sealant Installation 98
D.4. Final Inspection 101

Appendix E Partial List of Material and Equipment Sources 103
E.1. Sealant Material 103
E.1.1. Manufacturers of Hot-Applied Rubberized Asphalt Sealant 103
E.1.2. Manufacturers of Self-Leveling and Non-Self-Leveling Silicone Sealant . . 104
E.2. Backer Rod Material 104
E.2.1. Manufacturers of Expanded Closed-Cell Foam Rod 104
E.3. Sealant Installation Equipment 105
E.3.1. Manufacturers of Melter–Applicators For Hot-Applied Sealants 105
E.3.2. Manufacturers of Pump Applicators For Cold-Applied Sealants 105

Glossary 107

References 111

Figures

Figure 1. Concrete pavement/joint survey form 4
Figure 2. Sealant adhesion failure 7
Figure 3. Full-depth cohesion failure 7
Figure 4. Typical joint cross section 23
Figure 5. Rear-mounted joint plow 31
Figure 6. Undercarriage-mounted joint plow 31
Figure 7. Concrete joint saw 32
Figure 8. Abrasive blasting equipment 34
Figure 9. Airblasting operation 35
Figure 10. Hand-operated backer rod installation tool 36
Figure 11. Automated backer rod installation tool 37
Figure 12. Joint plowing operation 50
Figure 13. Joint resawing operation 52
Figure 14. Abrasive blasting operation 55
Figure 15. Airblasting operation 57
Figure 16. Backer rod installation 62
Figure 17. Hot-applied sealant installation 67
Figure 18. Silicone sealant installation 72
Figure 19. Example joint seal deterioration chart 78

Tables

Table 1. Decision table for resealing PCC joints 5

Table 2. Climatic region parameters 12

Table 3. Traffic-level rating 13

Table 4. Relationship between pavement condition and sealing objectives 16

Table 5. Factors affecting sealant conditions 18

Table 6. Summary of sealant materials 19

Table 7. Backer rod materials 21

Table 8. Typical recommended shape factors 23

Table 9. Typical joint design dimensions 25

Table 10. Joint preparation/installation procedures 27

Table 11. Joint resealing equipment requirements 30

Table 12. Production rates, costs, and amounts 40

Table 13. Material and shipping costs 42

Table 14. Labor costs 44

Table 15. Equipment costs 44

Table 16. Cost-effectiveness worksheet 46

Table 17. Troubleshooting procedures for plowing 50

Table 18. Troubleshooting procedures for resawing 53

Preceding Page Blank

Table 19. Troubleshooting procedures for sandblasting 56

Table 20. Troubleshooting procedures for airblasting 58

Table 21. Troubleshooting procedures for backer rod installation 63

Table 22. Troubleshooting procedures for hot-applied sealant installation 69

Table 23. Troubleshooting procedures for cold-applied sealant installation 74

Table A-1. Rubberized asphalt specifications 80

Table A-2. ASTM D 5893 silicone sealant specifications . . 81

Table B-1. Example material and shipping costs 84

Table B-2. Example labor costs 85

Table B-3. Example equipment costs 86

Table B-4. Example cost-effectiveness calculations 87

1.0 Introduction

This manual has been prepared for use by maintenance engineers, maintenance field supervisors, crew persons, maintenance contractors, and inspectors as an easy reference for *resealing** transverse and longitudinal joints in portland cement concrete (PCC) pavements.

1.1 Scope of Manual

Included in this manual are descriptions of procedures and materials recommended for resealing joints in PCC pavements. Guidelines for planning a resealing project and steps for installing joint seals and inspecting the process are presented. The resealing of concrete-asphalt shoulder joints and sealing cracks in PCC pavements are not addressed.

The information contained in this manual is based on the most recent research, obtained through reviews of literature and of current practice, as well as from the field results of a 7-year study (Smith et al., 1991; Evans et al., 1999). This study investigated the performance in PCC joints of various hot- and cold-applied sealants using several methods of installation.

* Italicized words are defined in the glossary.

1.2 Overview

Several steps are required for successful resealing of joints in PCC pavements. The first is determining the need for resealing. Chapter 2 of this manual contains a general procedure that can be easily modified to meet the needs of any highway agency.

Once the need for resealing is determined, the next step is planning the operation. Chapter 3 leads the maintenance planner through the steps for selecting sealant and accessory materials, choosing preparation and installation procedures, specifying equipment, and estimating material and labor requirements.

The construction phase of joint resealing is described in chapter 4. Details of each step of the preparation and installation operations are listed, along with troubleshooting procedures for each operation.

The appendixes provide material testing specifications, sample cost-effectiveness calculations, safety precautions, and inspection checklists to help ensure good resealing practices and high-quality results.

2.0 Need for Joint Resealing

Excessive delay in replacing a failing *sealant system* in concrete pavement joints can result in more rapid deterioration of the pavement. However, if sealant is replaced too early, precious maintenance funds may not have been used in the most cost-effective manner. How, then, can those responsible for maintenance determine when is the best time to reseal joints in concrete pavements? Some States specify that joints be resealed when a specified amount of sealant material (25 to 50 percent) has failed, allowing moisture or *incompressible materials* to progress past the sealant to the underlying layers. Other agencies base their decision on pavement type, pavement and sealant condition, and available funding.

A more complete method for determining whether a pavement needs to be resealed is to calculate rating numbers based on the sealant and pavement condition, traffic levels, and climatic conditions. Figure 1 presents a worksheet that can be used to estimate these properties, and table 1 gives recommendations about the need to reseal based on these properties. The following sections assist in determining the necessary ratings and conditions.

2.1 Seal Condition

Joint sealant system effectiveness is judged by the sealant's ability to resist *embedment* of incompressible materials and the sealant system's success in preventing entry of water and incompressible materials into the joint. To evaluate pavement seal condition, the following steps should be completed and results recorded on the pavement survey form:

Figure 1. Concrete pavement/joint survey form.

Seal Condition	Low	Med	High
Water entering, % length	< 10	10-30	> 30
Stone intrusion	L	M	H
Seal Rating	Good	Fair	Poor

Environmental Conditions	
Avg annual precip., mm	
Days $\leq$ 0°C	
Avg low / high temp, °C	
Climatic Region [a]	WF WNF DF DNF

Traffic Conditions		
ADT (vpd); % Trucks		
Traffic Level [b]	Low	Med	High

Pavement Condition	Low	Med	High
Expected Pavement Life, yrs.	> 10	5-10	< 5
Average faulting, mm	<1.5	1.5-3.0	>3.0
Corner breaks, % slabs	< 1	1-5	> 5
Pumping, % joints	< 1	1-5	> 5
Spalls >25 mm, % slabs	< 5	5-10	>10
Pavement Rating	Good	Fair	Poor

Current Joint Design	
Sealant age, yrs	
Avg. sealant depth, mm	
Avg. joint width, mm	
Avg. joint depth, mm	
Max. joint spacing, m	

[a] See table 2.
[b] See table 3.

Table 1. Decision table for resealing PCC joints.

Sealant Rating[a]	Pvmt. Rating	Traffic Rating	Climatic Region: Freeze, Wet	Climatic Region: Freeze, Dry	Climatic Region: Nonfreeze, Wet	Climatic Region: Nonfreeze, Dry
Fair	Good	Low	Possibly	Possibly	Possibly	Possibly
Fair	Good	Med	**Yes**	Possibly	Possibly	Possibly
Fair	Good	High	**Yes**	**Yes**	**Yes**	Possibly
Fair	Fair	Low	**Yes**	Possibly	Possibly	Possibly
Fair	Fair	Med	**Yes**	**Yes**	**Yes**	Possibly
Fair	Fair	High	**Yes**	**Yes**	**Yes**	Possibly
Fair	Poor	Low	Possibly	Possibly	Possibly	Possibly
Fair	Poor	Med	**Yes**	**Yes**	**Yes**	Possibly
Fair	Poor	High	**Yes**	**Yes**	**Yes**	**Yes**
Poor	Good	Low	**Yes**	Possibly	Possibly	Possibly
Poor	Good	Med	**Yes**	**Yes**	**Yes**	Possibly
Poor	Good	High	**Yes**	**Yes**	**Yes**	**Yes**
Poor	Fair	Low	**Yes**	**Yes**	**Yes**	Possibly
Poor	Fair	Med	**Yes**	**Yes**	**Yes**	**Yes**
Poor	Fair	High	**Yes**	**Yes**	**Yes**	**Yes**
Poor	Poor	Low	**Yes**	**Yes**	**Yes**	Possibly
Poor	Poor	Med	**Yes**	**Yes**	**Yes**	**Yes**
Poor	Poor	High	**Yes**	**Yes**	**Yes**	**Yes**

[a] Sealants rated in "Good" condition do not require replacement.

1. Choose 10 or more joints whose sealant condition is representative of the entire site. If large variations in condition are evident, subdivide the site into sections having similar seal condition and evaluate 5 to 10 joints from each section.
2. Cut 50-mm samples of sealant from a few joints and measure the joint width, depth, and sealant thickness.
3. Determine from the construction records the type and age of the sealant, the design joint width, and sealant thickness.
4. Record the maximum spacing between joints.

Carefully inspect each of the chosen joints, recording the following items on the pavement survey form:

- Water Resistance—The percentage of overall joint length where water can bypass the sealant and enter the joint.
- Stone Intrusion—The amount of stones, sand, and debris embedded in the sealant.

Common joint seal distresses include loss of bonding to the concrete sidewall (figure 2), cohesive failure (figure 3), spalls, and torn or missing sealant. They reduce water resistance and allow moisture, sand, and dirt to enter the joint. Bond failure can be determined by pulling the sealant away from the joint edge and inspecting for *adhesion failure*. Full-depth spalls can be identified by gently inserting a dull knife into the spall and observing if the knife tip can pass below the sealant. Another method for locating areas of bond failure is with the Iowa vacuum (IA-VAC) tester, developed by the Iowa Department of Transportation (DOT). The percentage of water resistance loss can be computed using equation 1.

$$\% L = \left[\frac{L_f}{L_{tot}} \right] x \ 100 \qquad \text{Eq. 1}$$

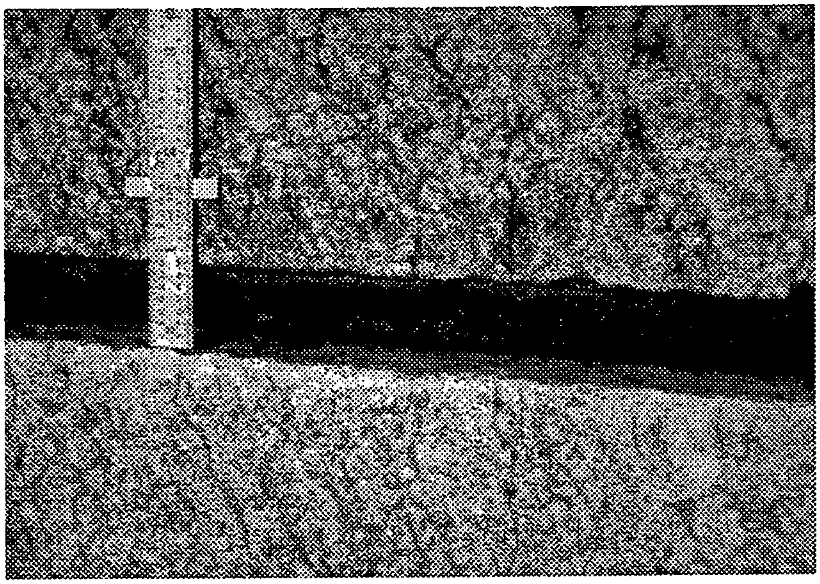

Figure 2. Sealant adhesion failure.

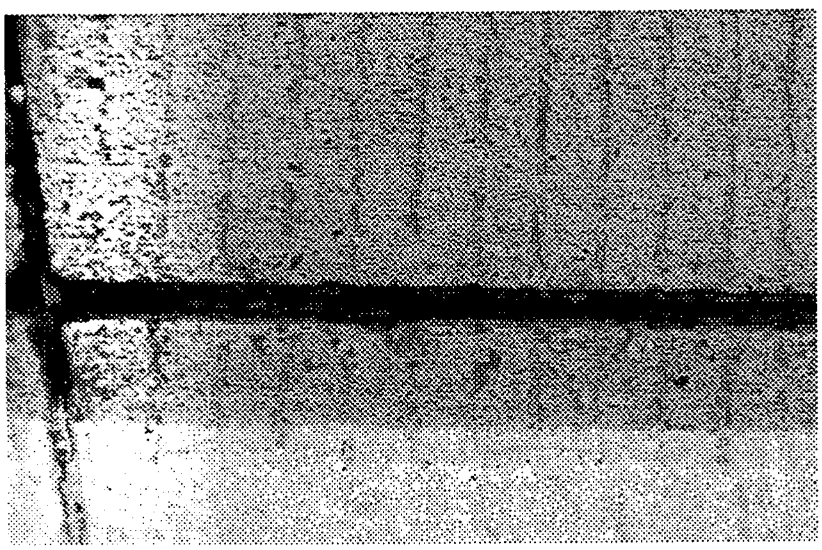

Figure 3. Full-depth cohesion failure.

where: $\%L$ = Percent length allowing water to enter joint.

L_f = Total length of joint sections allowing the entrance of water, m.

L_{tot} = Total joint section length evaluated, m.

Stone intrusion can be rated using the following criteria, and the rating should be recorded on the pavement survey form:

Low = Occasional stones or sand stuck to the top of the sealant (or material embedded on the surface of the *sealant/channel interface*).

Medium = Sand or debris stuck to sealant and some debris deeply embedded in the sealant.

High = Much sand and debris stuck to and deeply embedded in the sealant or filling the joint.

Next, determine the sealant rating by calculating the seal condition number (*SCN*). This number can be computed using the following equation:

$$SCN = 1(L) + 2(M) + 3(H) \qquad \text{Eq. 2}$$

where: SCN = Seal condition number.

L = The number of low-severity seal conditions recorded on the pavement survey form.

M = The number of medium-severity seal conditions.

H = The number of high-severity seal conditions.

Use the *SCN* and the following rating to determine whether the existing joint seal is in good, fair, or poor condition, and circle the correct seal rating on the pavement survey form.

Seal Rating	***SCN***
Good	0 - 1
Fair	2 - 3
Poor	4 - 6

Results of a seal condition rating can also be used to monitor the performance of joint seals and to assist in follow-up rehabilitation planning.

2.2 Pavement Condition

Pavement condition is the next item to identify. A pavement will provide several indicators that the joint seal is not performing adequately and is allowing too much water to reach the underlying layers. These indicators include the following:

- Surface staining or the accumulation of fine material on the surface close to joints or cracks indicates *pumping* of the base or subbase. This results, in part, from excess moisture, and it contributes to formation of voids beneath the pavement, cracks, and corner breaks.
- *Faulting*, or drop-off between adjacent slabs, can indicate that excess moisture is reaching a water-susceptible base or subgrade, and that voids are forming beneath one side of the pavement as a result of continual traffic.
- *D-cracking* can result from excess moisture beneath a pavement.

A pavement system can also manifest the effects of the entrance of stones and other incompressible materials into pavement joints by the following:

- Compression-related spalling of the walls of joints that are filled with sand and stones.
- *Blowups* and shattering of slab edges, as well as permanent increases in joint width causing closure of nearby expansion joints.

To evaluate the condition of a pavement considered for resealing, record the following items in the pavement condition section of the concrete pavement/joint survey form (figure 1). These items should be based on field inspection and the maintenance schedule.

- The estimated number of years before the pavement requires major rehabilitation.
- The average vertical faulting movement.
- The percentage of slabs containing corner breaks.
- The percentage of joints visibly indicating pumping.
- The percentage of slabs containing full-depth spalls extending greater than 25 mm from the face of the joint.

To determine a pavement condition number (*PCN*), use figure 1 and equation 3.

$$PCN = 1(L) + 2(M) + 3(H) \qquad \text{Eq. 3}$$

where: PCN = Pavement condition number.
L = The number of low-severity pavement condition indicators from the pavement survey form.
M = The number of medium-severity pavement condition indicators.
H = The number of high-severity pavement condition indicators.

Use the *PCN* and the following ratings to determine the condition of the existing pavement and circle the correct pavement rating on the pavement survey form:

Pavement Rating	***PCN***
Good	0 - 3
Fair	4 - 5
Poor	6 - 15

2.3 Environmental Conditions

The effects of extreme temperatures and precipitation on joint seal and pavement performance cannot be minimized. In extremely cold temperatures, sealants are stretched the most as pavements shrink and joints widen. Extremely hot temperatures can compress improperly placed sealant, forcing it above the pavement surface where it may be pulled out by vehicle tires.

Wet climatic regions need highly effective seals (approaching 100 percent effectiveness) to prevent water damage to susceptible base and pavement structures. Dry climates also may require highly effective seals to prevent the intrusion of incompressible material into the joint, which can result in *joint growth*, blowups, and structural damage.

When evaluating the climatic conditions that a pavement will experience, determine the following information and enter it in the environmental condition section of the concrete pavement/joint survey form:

Table 2. Climatic region parameters

Climatic Region	Mean annual days $\leq 0°C$	Average annual precipitation
Wet-Freeze	> 100	≥ 635 mm
Wet-Nonfreeze	< 100	≥ 635 mm
Dry-Freeze	> 100	≤ 635 mm
Dry-Nonfreeze	< 100	≤ 635 mm

- The normal annual total precipitation for the location.
- The mean number of days in a year with a minimum temperature of 0°C or below.
- The highest and lowest recorded temperatures.

This information is available from the National Climatic Data Center in Asheville, North Carolina, or from local weather recording stations. Then, using the information from figure 1 and table 2, identify the climatic region in which the pavement is located. Circle the correct climatic region on the pavement survey form.

2.4 Traffic Conditions

To identify traffic conditions, obtain the *average daily traffic* (ADT) level and the percent truck traffic. Determine the traffic level rating from table 3. If the percent trucks is greater than 10 percent or the expected growth rate is greater than 5 percent, use the next higher traffic level rating.

Table 3. Traffic-level rating.

Traffic Level	ADT, vpd all lanes
Low	< 5,000
Medium	5,000 to 35,000
High	>35,000

2.5 Determining the Need to Reseal

After completing the pavement evaluation worksheet, use table 1 and the calculated *SCN*, *PCN*, the traffic rating, and the climatic region to evaluate the need for resealing. The basis for this table is engineering experience; however, it can be adjusted to the needs and policies of individual State agencies. Choose the row with the combination of sealant, pavement, and traffic rating from the three left-hand columns that match the pavement being evaluated. Then find the intersection of that row with the appropriate climatic region to obtain the recommendation on the need for resealing.

If the recommendation is that sealing is "possibly" needed, then the case is borderline, and good judgment should be used in determining the need to reseal. If D-cracking is evident in the pavement surface, it may be more critical to completely seal the transverse and longitudinal pavement joints. When an overlay or rehabilitation is scheduled within 3 to 5 years, sealing could be delayed unless pavement or base damage would result. Agencies should use local experience for final determination of whether and how to reseal.

3.0 Planning and Design

3.1 Primary Considerations

After determining the need to reseal the joints in a concrete pavement section, it is important to plan the sealing operation to ensure that a proper resealing job is completed. Proper planning should take into account the following factors:

- The long- and short-term objectives for resealing.
- The current sealant and pavement condition and the place of the resealing effort in an overall maintenance plan.
- The applicability and documented performance of the sealant materials chosen.
- The effectiveness of the equipment and installation methods chosen.
- The level of strain placed on the sealant system as a result of the dimensions of the joint reservoir.
- The minimization of traffic disruption, increased worker safety, and efficient installation rates.

3.2 Objective of Resealing

When beginning, it is important to determine the objective of the resealing project. Possible objectives include the following:

- Temporarily seal the pavement joints for 1 to 2 years until the pavement is overlaid or replaced.
- Seal and maintain watertight joints for 3 to 5 years.
- Seal and maintain watertight joints for a period extending more than 5 years.

Table 4. Relationship between pavement condition and sealing objectives.

Condition	Objective
Pavement to be overlaid in 1 to 2 years.	Temporarily seal pavement.
Pavement in fair condition. Major rehabilitation scheduled in 5 years.	Maintain seal until rehabilitation.
Pavement in good condition and carries high level of traffic.	Maintain seal as long as possible.

Each of these objectives may be correct for a different situation, depending primarily on the pavement condition and the traffic level, as illustrated in table 4.

In dry climates, it is more important to keep sand and dirt out of the joints to prevent spalling and blowups. A sealant should then be chosen that does not allow sand to penetrate the sealant surface. In hot climates, some sealants *flow* down into the joint, or *track* on the surface, or allow stones to become embedded in the sealant. In some situations, a jet-fuel resistant (JFR) sealant material is required. In some pavements, only certain areas of sealant have failed and selective replacement is needed. Consequently, when choosing sealant materials and installation methods, the objectives must match the requirements of the situation.

3.3 Accounting for Existing Conditions

The condition of a pavement when it is resealed can greatly affect the performance of the seal. Corner breaks, large spalls, voids beneath the pavement, faulting, and poor *load transfer* can all reduce the effective life of resealed joints. Depending on existing conditions, some of these pavement distresses should be repaired before sealant is installed (Collins et al., 1986). Specifically, prior to resealing, the following repairs should be considered (Darter et al., 1985):

- Full-depth repair of corner breaks and deep spalls.
- Partial-depth repair of spalls that extend more than 25 mm from the face of the joint.
- Improving *subdrainage* or roadside drainage.
- Restoring load transfer at joints and cracks where poor load transfer exists.
- *Undersealing* the pavement where voids exist.
- Grinding the pavement surface to restore a smooth ride or to improve traction.

Each of these repairs, if needed, should be completed before resealing begins. The condition of the sealant in longitudinal joints and transverse cracks should also be evaluated to determine if resealing is appropriate (Carpenter et al., 1987). Studies have shown that extensive pavement damage can occur due to the large amount of water entering a pavement system through open transverse cracks and longitudinal joints.

The condition of the existing joints and sealant can reveal much about the conditions under which it failed. Several of these indicators are listed in table 5. When these or other conditions are evident, care should be taken to address and eliminate them for the resealing project.

3.4 Selecting a Sealant Material Type

Sealant materials are subjected to very harsh conditions. Selected sealants must have the following capabilities:

Table 5. Factors affecting sealant conditions.

Observed Sealant Condition	Possibly Indicates That...
Sealant pulled away from edges along majority of the site.	Large amount of joint movement. Poor sealant or placement methods.
Sealant pulled away from joint edges at random positions.	Joint may not have been cleaned properly.
Sealant tracked on pavement.	Sealant overheated, contaminated, or has too low a softening point.

- Withstand *horizontal movement* and *vertical shear* at all temperatures to which they are exposed.
- Withstand environmental effects such as weathering, extreme temperatures, and excess moisture.
- Resist penetration by stones and sand at all temperatures.
- Maintain complete bond to concrete *joint sidewalls* at all temperatures.

There are a wide variety of sealant materials on the market, each with its own characteristics and costs. However, no one sealant can meet the demands of every resealing project. Sealant selection should be based on the objectives of the resealing project.

Table 6 contains a listing of sealant material types commonly used in resealing joints in PCC pavements. Applicable specifications are also listed. To help the designer in choosing a sealant material, the *allowable extension* and cost range are included. The allowable extension is the manufacturer-recommended maximum in-place sealant extension.

Table 6. Summary of sealant materials.

Sealant Material	Applicable Specifications	Design Extension, % [a]	Cost Range, $/L [b]
PVC Coal Tar	ASTM D 3406	10 to 20%	$1.75 to $2.75
Rubberized Asphalt	ASTM D 1190, AASHTO M 173, ASTM D 3405, AASHTO M 301	15 to 30%	$0.60 to $1.00
Low Modulus Rubberized Asphalt	Modified ASTM D 3405	30 to 50%	$0.70 to $1.20
Polysulfide (1 & 2 Part)	Fed SS-S-200E	10 to 20%	Not Available
Polyurethane	Fed SS-S-200E	10 to 20%	$5.20 to $7.20
Silicone (non-sag)	ASTM D 5893	30 to 50%	$6.50 to $9.00
Silicone (self-leveling)	ASTM D 5893	30 to 50%	$6.50 to $9.50

[a] Consult manufacturers for specific design extensions.
[b] Based on 1998 estimated costs.

Compression seals are not typically used when the pavement joints are spalled, since the seals tend to twist or move up or down in the joint at locations where the joint edge is not vertical and completely smooth.

Many agencies have full-scale testing programs to determine the performance of potential materials under local conditions. Thorough field and laboratory testing is recommended before any sealant is used on a large-scale project. Commonly used lab specifications are shown in appendix A.

A *life-cycle cost analysis (LCCA)* should be performed to determine the material with the least average annual cost over the expected life of the pavement. Section 3.11 includes a worksheet to assist in conducting an LCCA.

3.5 Selecting Backer Materials

Backer rod is typically inserted in PCC joints prior to resealing to keep the sealant from sinking into the reservoir. It also keeps the sealant from bonding to the bottom of the reservoir and, if properly selected and installed, it helps maintain the proper sealant thickness. The rod must be flexible, compressible, non-shrinking, non-reactive, and non-absorptive. Shrinking rod may allow sealant to flow past the rod before the sealant sets. Backer rod that reacts with certain sealants may produce bubbles in or staining of the sealant. Finally, backer rod that absorbs water may shorten the life of the sealant material.

Several currently available types of backer rod are described in table 7. Each type has specific properties and intended uses. For example, several backer rod types are designed to withstand the extreme temperatures of hot-applied sealants, while others are intended only for cold-applied sealants.

Softer, *extruded* foam rods have been developed to better seal joints with irregular edges. Backer tapes that require a more shallow joint have also been used.

The manufacturers' recommendations should be followed when selecting rod type, since sealant and backer rod must be compatible. The more commonly used backer rod materials for

Table 7. Backer rod materials.

Backer Material Type	Applicable Standard	Properties	Compatibility
Extruded closed-cell polyethylene	ASTM D 5249 Type 3	NMA, ECI, NS	Most cold-applied sealants
Cross-linked extruded closed-cell polyethylene	ASTM D 5249 Type 1	HR, NMA, ECI, NS	Most hot- and cold-applied sealants
Extruded polyolefin	ASTM D 5249 Type 3	NMA, NS, NG, CI, IJ	Most cold-applied sealants

CI = Chemically inert
ECI = Essentially chemically inert
HR = Heat resistant
IJ = Fills irregular joints well
NG = Non-gassing
NMA = Non-moisture absorbing
NS = Non-staining

hot-applied sealants are cross-linked extruded foam rods. For cold-applied sealants, extruded closed-cell polyethylene foam or extruded polyolefin foam rod is typically used. The rod diameter should be at least 25 percent larger than the joint width. Backer rod is available in diameters ranging from 10 to 75 mm or more. Since joint widths may vary within a rehabilitation project, a sufficient range of rod sizes should be on hand to obtain a tight seal in all joints.

3.6 Selecting Primer Materials

In areas where high humidity and moisture make it difficult to obtain a good bond between the sealant and the concrete, primer may be recommended by the planner or the sealant manufacturer. The purpose of a primer is to bond to the concrete surface and provide a surface to which the new sealant can bond well. Primer may also be used when past experience indicates that it is difficult to obtain a good bond with the specified sealant. Difficulties in obtaining a good bond with soft aggregate can also be reduced by use of a primer.

Primers are currently used in only a small percentage of major PCC resealing operations, with most of the use occurring in wet or cold climates. Consult sealant manufacturers for primer type recommendations when the need for priming the joints exists.

3.7 Selecting Joint Reservoir Dimensions

The width of a joint and the thickness of the sealant in that joint can significantly affect the performance of the seal (USAF, 1983; ACI, 1990). If a joint is too narrow and temperature changes cause the joint to widen significantly, the sealant may be stretched beyond its breaking point or pulled away from the concrete. In addition, if a thick sealant is stretched, it may tear or not stick to the concrete, in the same way that a thick rubber band cannot be stretched as far as a thin one before tearing.

In designing the dimensions of a joint sealant and the sealant reservoir, two major items must be determined: the shape factor and the expected joint movement. Figure 4 shows the dimensions of a typical *sealant reservoir* containing sealant material and backer rod. The shape factor is the ratio of the sealant width to the thickness (W:T). The sealant recess is designated as "R," and the joint channel depth is "D."

Manufacturers' recommendations should be followed when choosing a shape factor. Typical recommended shape factors are shown in table 8. Silicone manufacturers recommend a minimum thickness of 6 mm and a maximum of 13 mm.

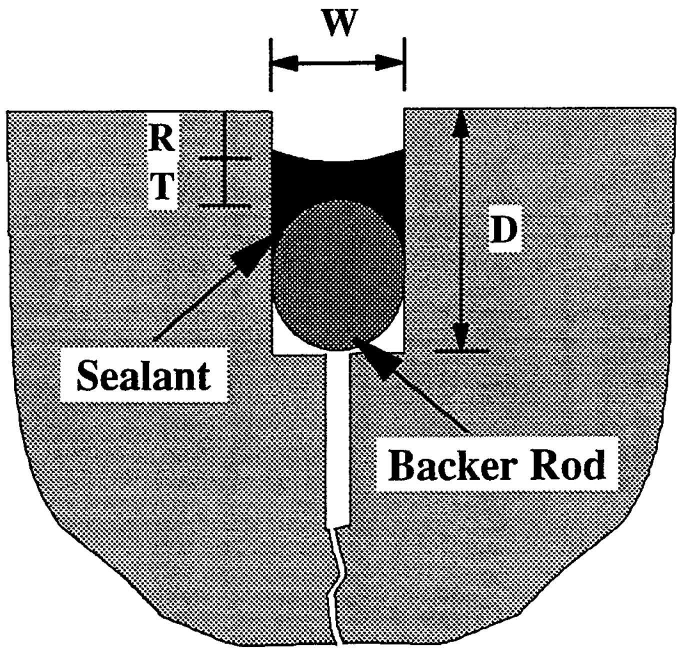

Figure 4. Typical joint cross section.

Table 8. Typical recommended shape factors.

Sealant Material Type	Typical Shape Factor (W:T)
Rubberized Asphalt	1:1
Silicone	2:1
PVC Coal Tar	1:2
Polysulfide and Polyurethane	1:1

The maximum joint opening movement for rehabilitated joint seals can be estimated using equation 4 (Bodocsi et al., 1992).

$$M = CL\,(\alpha T) \qquad \text{Eq. 4}$$

where:
M = Joint opening movement caused by temperature change of PCC, mm.
C = Subbase/slab friction resistance adjustment factor (0.65 for stabilized subbase, 0.80 for granular subbase).
α = Thermal coefficient of contraction for PCC (9.0 to 10.8 x 10^{-6}/°C).
L = Joint spacing, mm.
T = Temperature range (temperature at placement minus lowest mean monthly temperature), °C.

Based on equation 4, the percent elongation that the new sealant must allow is determined by the following equation:

$$\%E_{\max} = 100\left(\frac{M_{\max}}{W_{init}}\right) \qquad \text{Eq. 5}$$

where:
$\%E_{max}$ = Estimated elongation, percent.
M_{max} = Joint opening movement caused by change of PCC temperature, mm.
W_{init} = Joint width at the time of sealant placement, mm.

Some engineers prefer to determine M_{max} using the safer assumption that a joint between two slabs may be called upon to take the total movement of both slabs. In this assumption:

$$M_{\max} = 2(M) \qquad \text{Eq. 6}$$

Table 9. Typical joint design dimensions.

Maximum Joint Spacing, m	Minimum Joint Width, mm [a]	
	Nonfreeze Region [b]	Freeze Region [c]
≤ 4.6	6	10
4.7 to 7.6	6 to 10	10 to 13
7.7 to 12.2	10 to 13	13 to 19
12.3 to 18.3	13 to 19	19 to 29

[a] Installation temperature is 27°C, base is stabilized, $\%E_{max} \leq 20\%$.
[b] Minimum nonfreeze region temperature is -7°C.
[c] Lowest freeze region mean monthly temperature is -26°C.

The joint width, *W*, should be wide enough to keep the sealant from being stretched in cold weather more than the design amount, typically 20 percent. However, joints should not typically be wider than 19 mm (Collins et al., 1986; USAF, 1983). As a result, there is a tradeoff in the M_{max} approach between reduced sealant fatigue and reduced allowable future joint widening.

Suggested sealant thicknesses and minimum joint widths for various joint spacings are listed in table 9 as a check for more detailed joint design. This table is based on limiting the sealant stress to less than 20 percent.

The joint reservoir sawcut depth, D, should be the sum of the selected sealant thickness, the compressed backer rod thickness, and the depth that the sealant surface is to be recessed. Some manufacturers recommend that an extra 6 mm be added when resealing joints to prevent water and material beneath the sealant from pushing the sealant up and out of the joint. Extra depth is also needed to account for variability in the sawing operation.

3.8 Selecting Preparation and Installation Procedures

The type of joint cleaning procedures and the final cleanliness of the concrete joint walls prior to sealant installation can significantly affect the performance of sealant materials. As a rule, the cleaner and drier the joint surfaces are, the better a sealant will adhere, and the more effective it will be. Therefore, preparation and installation procedures should be chosen as carefully as sealant materials.

The selection of which combination of preparation and installation procedures to use should be based on the condition and requirements of each individual resealing project. Four combinations are shown in table 10. Each option, if followed completely, should result in clean joint surfaces and increase the chances for good performance.

Option 1 should be considered when:

- The resealing project carries a high volume of traffic.
- A high-quality sealant is being used.
- Joint widths or depths do not meet the minimum design requirements.
- The existing sealant is hardened and will not melt and "gum-up" the saw blades.

Option 2 differs from option 1 only by the elimination of water washing. This option can be used only when it can be demonstrated that sufficient joint surface cleanliness can be achieved without water washing.

Option 3 adds a plowing operation to the option 2 procedures. It should be used when:

Table 10. Joint preparation/installation procedures.

Option	Plow	Saw	Water Wash	Initial Airblast	Sand Blast	Final Airblast	Backer Rod	Recessed Sealant
1		✓	✓	✓	✓	✓	✓	✓
2		✓		✓	✓	✓	✓	✓
3	✓	✓		✓	✓	✓	✓	✓
4	✓				✓	✓	✓	✓

- A saw is melting the existing sealant and cannot remove the sealant efficiently by itself.
- The joint dimensions are not adequate.

Option 4 replaces the sawing operation with an effective plowing operation. It can significantly reduce the preparation time and, since it is a dry operation, it allows immediate cleaning and resealing. It may only be used if:

- The joint dimensions are adequate.
- The plowing equipment removes more than 95 percent of the sealant from the joint faces, leaving fresh, unspalled concrete.
- The sandblaster is able to efficiently remove any remaining sealant.

If compression seals are being replaced with formed-in-place sealant, sawing is not required when sandblasting can completely remove the old lubricant from the joint walls (Collins, 1986).

Several methods of sealant installation have also been used with varying results (Smith et al., 1991; Evans et al., 1993; Lynch et al., 1993; Evans et al., 1999). These include:

- Recessing the sealant below the pavement surface.
- Keeping the sealant surface level with the pavement surface.
- *Overbanding* sealant onto the pavement surface.

Overbanded seals tend to oxidize at a slower rate than recessed asphalt-based sealants because of the massaging action of traffic tires. As a result, adhesion failures may occur more quickly in recessed sealants. A 7-year study of joint seals in five States indicates that overbanded ASTM D 3405 seals have statistically outperformed recessed seals even when installed in transverse joints on heavily trafficked roadways (Evans et al., 1999).

In longitudinal lane-shoulder joints, overbanding may provide better performance than recessed seals. Therefore, in reduced traffic areas, such as low-volume roads or lane-shoulder joints, overbanded sealants may be the most effective choice.

There are two drawbacks of overbanding on PCC pavements. First, overbanded sealant material is typically worn away by traffic within 1 to 3 years. After it is worn, traffic tires tend to pull the sealant from the joint edge, leading to adhesion failure. Second, the scraping action of ice blades on highways in cold regions tends to pull up overbanded seals from the pavement surface.

Silicone sealants should never be overbanded or flush with the pavement surface. Manufacturers recommend a minimum of 7 to 10 mm recess below the pavement surface for all silicone sealants to avoid the premature adhesion failure noted in the Long-Term Pavement Performance (LTPP) Specific Pavement Studies (SPS)-4 test sections in four States (Smith et al., 1999).

3.9 Selecting Equipment

Selection of equipment for the resealing process should be based on its ability to complete the task. This ability should be proven prior to beginning the resealing operation by constructing a test resealing section.

A contractor or highway maintenance crew should be allowed to choose the equipment that will effectively clean and reseal concrete joints in the most efficient manner. However, several items have been shown to be important to successful use of each piece of equipment. These requirements are listed in table 11.

3.9.1 Joint Plows

A joint plow used only to remove sealant prior to sawing must remove enough sealant to keep the saw blades from gumming up. A shop-made, rear-mounted plow for this purpose is shown in figure 5. If the plow is used without resawing, it must be able to efficiently remove at least 95 percent of the old sealant from the joint walls and not spall the joint sidewalls. Plowing has also been successfully accomplished by attaching a hydraulically controlled carbide-tipped blade to the underbody of a small (13.4 to 17.9 kW) tractor, as shown in figure 6. Multiple blade sizes should be on hand to keep the blades from binding in narrow joints.

Plow blades generally have straight sides, but they may be tapered. Tapered blades tend to spall the joint edges, especially at intersections with other joints, at pavement edges, and where the joint width changes quickly. Straight-sided blades must be forced against the side of the joints to more thoroughly clean them, but the risk of spalling is greatly reduced when the blade width is narrower than the joint width.

Table 11. Joint resealing equipment requirements.

Equipment	Requirements
Joint Plow	Non-tapered, carbide-tipped blades. Sufficient blade sizes. Ability to control blade height. Ability to force blade against sidewall.
Concrete Saw (includes saw, hose, and water truck)	Self-propelled, water-cooled saw ≥ 26 kW. Diamond saw blades designed to cut hardened PCC to uniform width. Controllable, does not pull to one side.
Sandblast Equipment (including sandblast unit, air compressor, hoses, nozzles, and safety equipment)	Acceptable air compressor. Recommend Venturi tungsten nozzles.
Airblast Equipment (includes air compressor, hose, wand, and safety equipment)	Functional oil and water removal filter on compressor. Min 620 kPa at 0.07 m^3/s. ≥ 19-mm ID hose. Nozzle with shut-off valve. Face shield, ear protectors.
Backer Rod Installation Tools	Maintains proper recess, ± 3 mm. Does not damage backer rod.
Hot-Applied Sealant Installation Equipment (includes portable melter–applicator, hose, wand, and safety equipment)	Mechanical agitator (recommend full-sweep agitator). Separate automatic temperature controls for oil and melting chambers. Sealant heating range to 260°C. Sealant recirculation system.
Silicone Sealant Installation Equipment (includes pump, compressor, hose, and wand)	Minimum flow rate 0.025 L/s. Recommend hose lined with Teflon, all seals and packing made with Teflon.

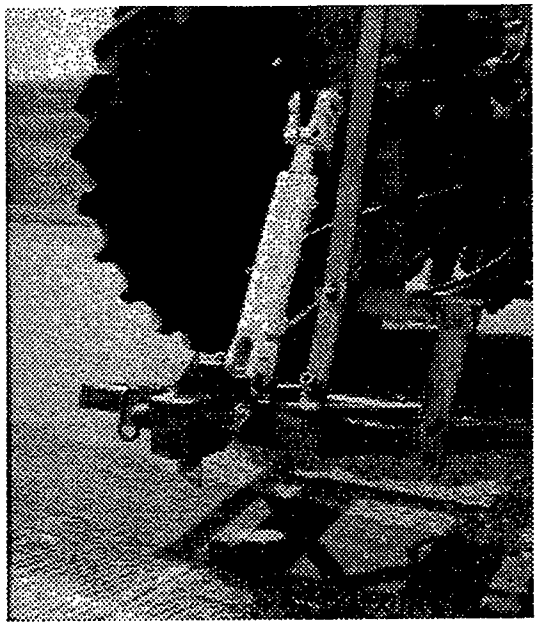

Figure 5. Rear-mounted joint plow.

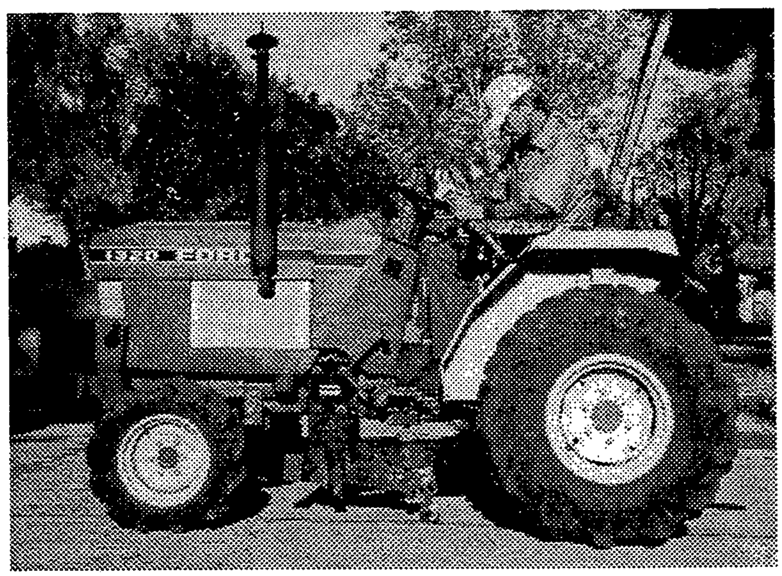

Figure 6. Undercarriage-mounted joint plow.

3.9.2 Concrete Saws

Saws used for refacing the joint should remove the minimum amount of concrete to achieve the design width and produce freshly sawn, clean joints of uniform width and depth. Self-propelled, water-cooled power saws with diamond blades, as shown in figure 7, are typically used for joint refacing.

In many cases, blades are ganged side-by-side on the blade arbor with a solid metal spacer to allow the saw to *reface* the joint to a proper, uniform width in one pass (Darter et al., 1985). The spacer diameter must be sized to prevent sealant from building up between the blades. Ganged blades can be exchanged on the arbor to provide more even wear, more uniform sawing widths, and longer blade life. Single, full-width blades are also used to resaw joints for resealing.

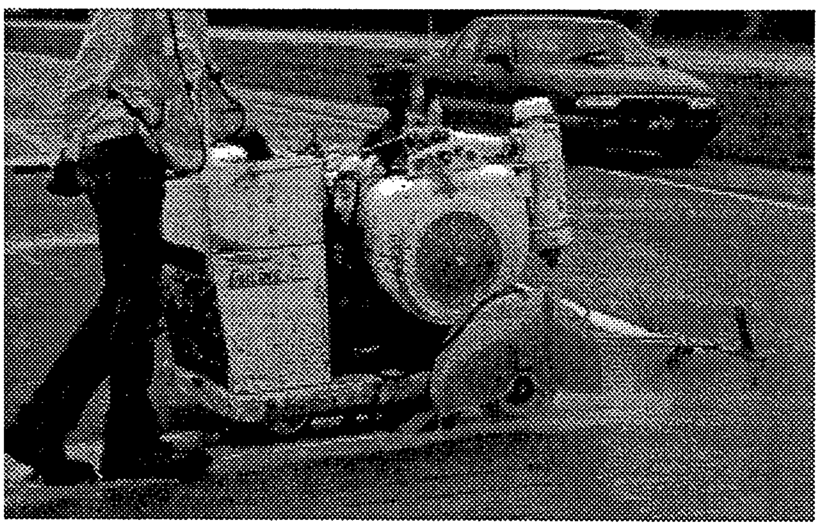

Figure 7. Concrete joint saw.

Blades should be no larger than necessary to achieve the required depth, since smaller blades are less expensive and make the saw easier to maneuver. Blades specifically designed for resawing hardened concrete should be used, and the body of these blades must be thick enough to resist warping.

3.9.3 Abrasive Blasting Equipment

Sandblasting equipment must be able to completely remove dried sawing *slurry*, dirt, and any old sealant from the joint faces. To efficiently accomplish this for a medium to large resealing project, an abrasive blasting unit, as shown in figure 8, should maintain a minimum nozzle pressure of 620 kPa at 0.07 m^3/s. The air supply must be clean, dry, and free from oil. This may require the installation of an oil and moisture filter on the air compressor.

Tungsten carbide nozzles should be used for larger projects, and ceramic nozzles are more useful for 3- to 4-h projects. Tungsten carbide and ceramic nozzles are available in several diameters, lengths, and shapes. A 5- to 6-mm-diameter Venturi nozzle has been used successfully for sandblasting joints. A sandblast chamber that allows continuous sand loading increases production rates.

Attaching an adjustable guide to the nozzle to keep it 25 to 50 mm from the pavement promotes consistent results and reduces operator fatigue.

For worker protection and to conform to State and Occupational Safety and Health Administration (OSHA) requirements, all necessary safety equipment must be present and in good working condition. This equipment may include:

Figure 8. Abrasive blasting equipment.

- A remote shut-off valve.
- An air-fed protective helmet.
- An air supply purifier.
- Protective clothing for the operator.
- Portable protective barriers between the sandblaster and adjacent traffic.

3.9.4 Airblasting Equipment

An air compressor, as shown in figure 9, is used for final cleaning, and must produce sufficient air quality, pressure, and

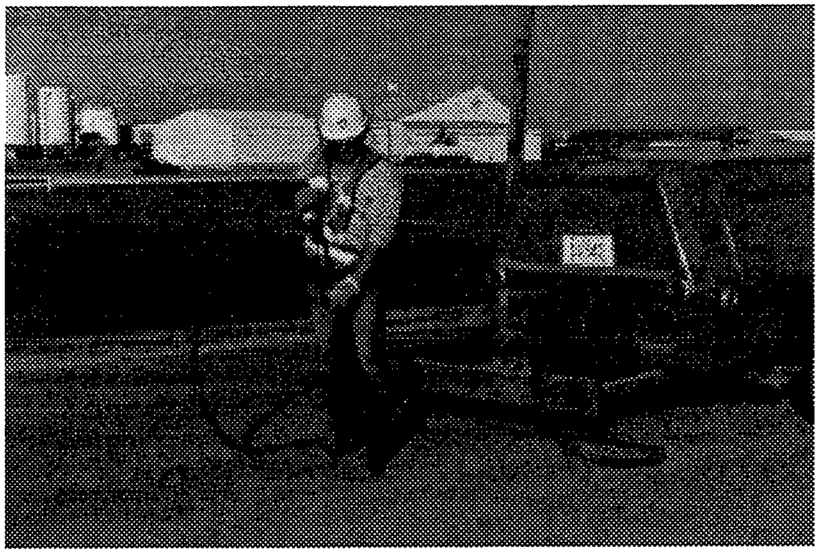

Figure 9. Airblasting operation.

volume to thoroughly clean the joints. This requires the following:

- The air supply must be clean, dry, and contain no oil.
- A compressor with a minimum of 0.07 m^3/s at the nozzle and 690 kPa must be used.

Many modern compressors automatically insert oil into the air lines to lubricate air-powered tools. For joint cleaning, this must be disconnected and an effective oil and moisture trap must be installed. In most cases, the inside of the hose for a lubricating air compressor is coated with oil. This oil must be removed or the hose must be replaced to keep oil from reaching the joints. Attaching a balanced wand with a shut-off control increases safety and improves worker comfort. Proper eye and ear protection should also be used.

3.9.5 Hot Airblasting Equipment

A hot compressed air (HCA) lance, or heat lance, used to dry slightly damp joints must supply heated air at about 1,100°C with a supply velocity of more than 300 m/s. The temperature and movement rate must be closely controllable to reduce the possibility of overheating the pavement, since overheating can produce chalking and temperature/steam-induced stress fractures.

Several heat lance options are available, including push-button ignition, wheels, and balancing straps. Eye, ear, and body protection devices must be used, due to the heat and noise produced by this equipment.

3.9.6 Backer Rod Installation Tools

A backer rod installation tool must be able to push the backer rod into a joint to the specified depth without tearing, stretching, or damaging the rod. Many sealant contractors make their own installation tools, as shown in figure 10.

Figure 10. Hand-operated backer rod installation tool.

However, a lightweight, adjustable tool is commercially available, as is an automated, self-guiding unit like the one shown in figure 11.

3.9.7 Hot-Applied Sealant Installation Equipment

The equipment used for installing sealant materials that must be heated should be able to:

- Effectively raise the temperature of the sealant without overheating portions of the sealant.
- Allow the operator to maintain exact sealant temperatures in the range of 160 to 250°C.
- Be large and powerful enough to heat a sufficient amount of sealant so that installation is not delayed.

Many companies manufacture mobile equipment that will melt and pump sealant into pavement joints. The sealant capacity of most melter–applicators ranges from 190 to 1,325 L.

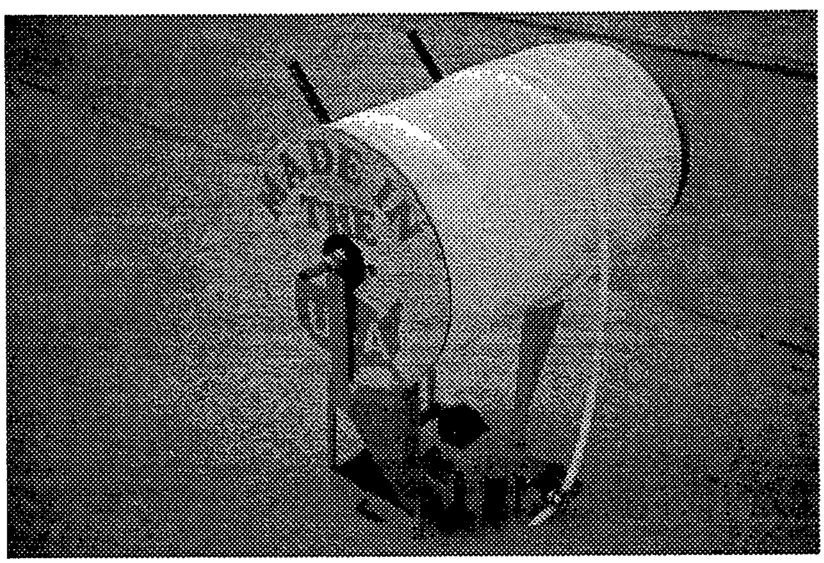

Figure 11. Automated backer rod installation tool.

Characteristics of the melter–applicator equipment should include the following:

- A double-walled heating chamber with heating oil between the walls as the heat transfer medium.
- A mechanical agitator.
- Accurate thermostats to monitor both the sealant and the heating oil temperatures (these thermostats should control the operation of the burners).
- A reversible pump that can feed sealant to the applicator wand or recirculate the sealant into the melter vat.
- Nozzle attachments with outside diameters that are small enough to allow it to be pulled through the narrowest joint without binding and large enough to maintain a good installation rate.

Options that may be helpful include electronic ignition, diesel heating fuel, wand nozzles that maintain the sealant at a certain depth, and hoses and wands that are insulated or heated (Bugler, 1983).

3.9.8 Silicone Sealant Applicators

Silicone pumps and applicators should provide sealant to the joint at a rate that does not slow the operator. The applicator equipment should:

- Not introduce bubbles into the sealant.
- Not allow air to reach the sealant before it enters the joint, to prevent premature curing.
- Maintain a feed rate of at least 0.025 L/s.
- Have a nozzle designed to fill the joint from the bottom.

Applicators that have Teflon-lined hoses and Teflon seals are less likely to allow the sealant to cure in the pump or hose than those that use neoprene seals and standard hoses.

3.9.9 Other Equipment

Under some conditions, a self-propelled vacuum sweeper or portable air blower may be useful for removing sand and dust from the pavement surface prior to backer rod installation. Rotary wire brushes have been used for joint wall cleaning with very limited success, due to their tendency to scrape the cement (which produces dust) and to smear old joint sealant over the dust (USAF, 1983). They are not generally recommended.

A long rod with properly sized flexible plastic tubing attached to the end is useful for forming the surface of non-self-leveling silicone sealants. Also, for hot-applied sealant installation, a hand-held infrared thermometer can provide quality control checks of melter–applicator and nozzle sealant temperature and the temperature of the pavement joints.

3.10 Estimating Material, Labor, and Equipment Requirements

The information in table 12 is provided to help with estimating the material, labor, and equipment requirements. This table contains estimated material amounts and preparation and installation rates. Costs and rates for two scenarios are shown. The first is a self-leveling silicone with a shape factor of 2:1, and the second is a hot-applied, low-modulus rubberized asphalt.

The plowing rate can be influenced by the number of passes required and the difficulty in aligning the blade with the joint.

Table 12. Production rates, costs, and amounts.

	No. of Workers	Amounts/Rates (per 300 m)	
		Silicone	Hot-Applied
Average sealant amount [a]		26 to 38 L	49 to 57 L
Average plowing rate	2	2 to 3 h	2 to 3 h
Average sawing rate	1	3.5 to 7.5 h	3.5 to 7.5 h
Average sandblast rate	2	1.5 to 4 h	1.5 to 4 h
Final airblast rate	2	1.5 to 4 h	1.5 to 4 h
Backer-rod installation rate	2	1 to 3 h	1 to 3 h
Sealant installation rate	2	1.5 to 2.5 h	1.5 to 2.5 h

[a] Based on 13-mm joint width.

Sawing rates are influenced by the power of the saw, the blade speed, the type and width of blade, the cutting depth and pressure, the hardness of the concrete, and the size of the aggregate in the concrete.

Production rates for initial and final airblasting can vary with the capacity and pressure provided by the air compressor. Large amounts of debris in the joint or on the pavement surface will slow the airblasting operation. The rate of sandblasting is a function of the equipment, nozzle, and abrasive type used. Where old sealant remains on the joint walls, the rate of sandblasting will decrease. A 270-kg capacity sandblast unit with a 6-mm nozzle and 25-mm inside diameter sandblast hose can use about 270 kg of abrasive per hour.

The rate of primer installation varies greatly with the application method. Large-volume spray units result in much greater production rates than brushing the sealant on by hand. The speed of backer rod installation is dependent upon the consistency of the joint width. If joint widths vary significantly, backer rods of different diameters must be used to fill the joints. This, in turn, requires the installer to carry backer rods of various sizes, and to sometimes install very short lengths of rod.

The rate of sealant application is controlled by the skill of the operator, the distance between joints, the dimensions of the sealant reservoir, and the production rate of the melter–applicator (hot-applied) or pump (silicone). High rainfall frequency can significantly reduce the rate of sealant installation, since time must be allowed for the concrete to dry.

3.11 Determining Cost-Effectiveness

Steps for determining the cost-effectiveness of methods and materials for resealing joints in PCC pavements include the following:

1. Determine the amounts and costs of the materials needed.
2. Estimate the labor needs and costs.
3. Determine the equipment requirements and costs.
4. Estimate the effective service life of each resealing option.
5. Calculate the average annual cost for each method under consideration.

Example calculations are included in appendix B.

3.11.1 Material and Shipping Costs

Material and shipping costs can be determined using table 13. Material costs for sealant, backer rod, blasting abrasive, primer, and other required materials can be obtained from local suppliers or manufacturers. Coverage rates for sealant can be

Table 13. Material and shipping costs.

Material, unit	Material Cost, $/unit	Coverage Rate, m/unit	Length Required, linear m	Total Cost, $
	a	b	c	a x b x c
Sealant, L				
Backer Rod, linear m				
Blasting Sand, kg				
Primer, L				
Total Material Cost:				

estimated by using equation 7 or by consulting manufacturers' literature. By multiplying the material cost, the coverage rate, and the length of the joint to be resealed, the total cost for each material and the overall material cost can be estimated.

$$CR = (0.001)(WF)(ST)(W)(T) \qquad \text{Eq. 7}$$

where: CR = Sealant coverage rate, L/m.
WF = Waste factor (WF = 1.2 for 20 percent waste).
W = Joint width, mm (see figure 4).
T = Thickness of sealant, mm (see figure 4).
ST = Surface type constant (tooled surface: ST = 1.1; non-tooled surface: ST = 1.0).

3.11.2 Labor Costs

Labor costs can be determined using table 14. Using the wages for each worker, the number of workers required for each operation, and the expected time necessary to complete each operation, the total labor costs can be estimated. The production rates and amounts in table 12 should be helpful in determining labor requirements. In addition to wage rates, labor costs are greatly influenced by crew productivity and the need for night work or extra traffic control.

3.11.3 Equipment Costs

The cost of equipment will be affected by the availability of adequate equipment and the need for equipment rental. The amount of time that each piece of equipment is needed also greatly influences equipment costs. By completing table 15 and multiplying the daily equipment costs by the number of pieces of equipment required and the number of days the equipment is needed, the cost of resealing equipment can be estimated. Production rates should be based on local experience, although the rates shown in table 12 may be used to obtain rough estimates.

3.11.4 User Delay Costs

Although difficult to determine, there is a cost of delay to roadway users during the time that joints are cleaned and resealed. It should be included in cost-effectiveness calculations if the options being evaluated require significantly different amounts of lane closure. Experienced traffic engineers or agency guidelines should be consulted in defining the cost of user delays.

Table 14. Labor costs.

Crew Labor	Wages, $/day	Number in Crew	Days Required	Total Cost, $
	d	e	f	d x e x f
Supervisor				
Traffic Control				
Plowing				
Sawing				
Initial Airblast				
Sandblast				
Final Airblast				
Backer Rod				
Sealant Installation				
Total Labor Cost:				

Table 15. Equipment costs.

Equipment	Daily Cost, $/day	Number of Units	Number of Days	Total Cost, $
	g	h	i	g x h x i
Traffic Control				
Joint Plow				
Concrete Saw				
Air Compressor				
Sandblast Equip.				
Installation Equip.				
Other Trucks				
Total Equipment Cost:				

3.11.5 Cost-Effectiveness Comparisons

After the material, labor, equipment, and user costs have been determined, the worksheet in table 16 can be used to determine the annual cost of each resealing option. The expected rate of inflation and the estimated lifetime of each material-placement method option are required inputs for the worksheet.

By comparing the average annual cost of various materials and repair procedures, the most cost-effective resealing option can be determined.

Table 16. Cost effectiveness worksheet.

Total Material Cost [table 13]	$ ________	
Total Labor Cost [table 14]	$ ________	
Total Equipment Cost [table 15]	$ ________	
Total User Delay Cost [table 16]	$ ________	
	========	
Total Resealing Cost	$ ________	(A)
Project Length (lane-km)	________	(B)
Average Cost ($/lane-km)	$ ________	(C)
Estimated Lifetime of Seal, years	________	(D)
Interest Rate (typ. 0.05)	________	(E)

$$Average\ Annual\ Cost = C\left[\frac{(E)[(1+E)^{D}]}{(1+E)^{D}-1}\right] \quad \text{Eq. 8}$$

Average Annual Cost
($/lane-km) $________

4.0 Construction

Once the design and planning stages are completed, joints can be prepared in the chosen manner and the sealant can be installed. This construction stage is just as critical as the design stage, since preparing clean joints and correctly installing the sealant material in an effective manner will largely determine the overall performance of the sealant system design.

This chapter presents the objectives and steps required for cleaning and resealing joints in concrete pavements. Troubleshooting procedures for solving the problems potentially encountered in each operation are also included.

4.1 Traffic Control

Whenever a joint resealing operation is performed, it is critical that adequate traffic control be in place to provide a safe working environment for the installation crew and a safe travel lane for vehicles. It should also cause the least amount of disturbance possible to the flow of traffic.

Besides normal signs, arrow boards, cones, and attenuators, flaggers may be required to accompany the sawing and plowing operations if the plow or saw is allowed to extend into the lane carrying traffic.

4.2 Safety Precautions

The equipment and materials used in a joint resealing operation can present safety hazards to workers if appropriate precautions are not taken. All guards must be in place, operational worker protection devices must be used, and appropriate clothing should be worn.

Material Safety Data Sheets (MSDS's) should be obtained for each sealant material to be installed, and proper care should be taken to protect workers from any potentially harmful materials. A more detailed description of safety precautions required for each step of the sealing operation is included in appendix C.

4.3 Preparing the Joint

Objective: To provide clean, dry, and properly dimensioned joints that are free from sawing dust, old sealant, or any other contamination, and to which sealant material can adequately bond.

Good joint preparation is essential to good sealant performance. No matter what the sealant material quality is, if the joint faces are not clean and dry, the sealant will pull away from the joint walls prematurely. Appropriate sealants placed in joints that are clean and dry should provide effective, long-term performance. Successful steps for preparing joints for sealant installation include removing old sealant, refacing joint sidewalls, abrasive blasting, airblasting, and installing primer. Hydroblasting has been used successfully for joint preparation. Care must be taken with this operation to ensure that oils from the original oil-based sealant that have penetrated the joint edge are sufficiently removed.

4.3.1 Removing the Old Sealant

Plows can be used to remove old sealant from concrete joints prior to or in place of sawing. Preformed compression seals should be removed by hand or by pulling out longer sections with a tractor. Plowing involves pulling a thin blade through a joint to remove old sealant and backer material from the reservoir and to clean sealant from the sides of the joint.

To effectively remove sealant prior to sawing, the plowing operation must achieve the following results:

- Sufficient sealant and debris must be removed so that saw blades are not "gummed-up" during sawing.
- Joint walls must not be spalled by the plow.

If sawing will not follow the plowing operation, the following additional results must be achieved:

- At least 95 percent of old sealant must be removed from the joint sidewalls.
- All sealant remaining on joint sidewalls must be easily removable by sandblasting.

Several types of plows have been used, and a few have functioned successfully. Descriptions of joint plows are given in section 3.9.1. Successful use of a joint plow typically requires the following equipment and procedures:

- A rear- or front-mounted, carbide-tipped plow blade for partial sealant removal (shown in figure 12), or an undercarriage-mounted carbide blade with hydraulic controls for complete sealant removal.
- Multiple passes of a blade that is narrower than the joint, cleaning each channel face individually.
- Carbide-tipped, steel plow blades of various widths.
- Sufficient tractor weight to maintain blade depth and remove the old sealant.
- Effective traffic control and equipment guards to protect workers from flying debris and moving traffic.

Operators must use special care or an alternate procedure if difficulties with spalling or improper cleaning are encountered. Several common plowing problems and possible solutions are listed in table 17.

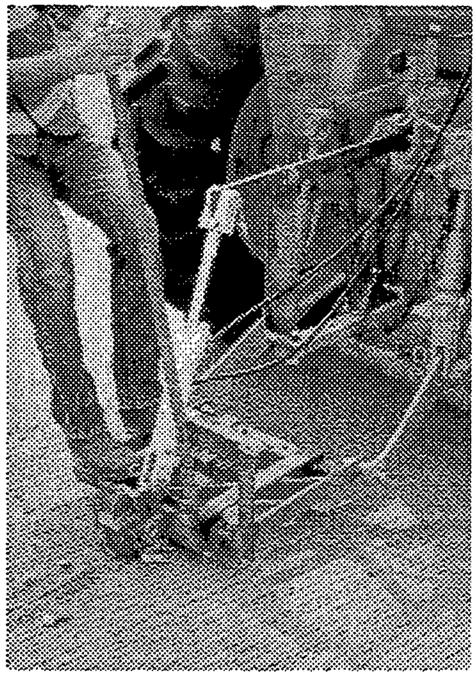

Figure 12. Joint plowing operation.

Table 17. Troubleshooting procedures for plowing.

Problems Encountered	Possible Solutions
Plow is spalling joint edges.	Use an untapered plow bit or a narrower blade.
Plow not completely removing sealant.	Increase pressure on the joint sidewall.
Undercarriage-mounted plow places tractor in traffic.	Use rear- or front-mounted blades, hand tools, or a vertical-spindle router. Redirect traffic.
Guardrail or curb keeps plow from reaching the entire joint.	Use rear-/front-mounted blades. Reverse plowing direction. Use hand tools or a vertical-spindle router.
Trouble lining up plow with joint.	Use undercarriage-mounted plow. Use an assistant.
Original sawcuts are offset.	Use additional care in plowing. Use hand tools or a vertical-spindle router.

Removing old joint material and other debris should be a continual process during joint preparation. The following concurrent work is recommended with the plowing operation:

- Blowing sealant and debris from the plowed joints.
- Vacuuming, blowing away, or picking up debris from the plowing operation.
- Removing the old sealant and properly disposing of it. Some materials may require hazardous or specialized waste disposal methods.

4.3.2 Refacing the Joint Sidewalls

Sawing, or refacing, joints in concrete pavements, shown in figure 13, is done either to increase the joint width and depth to the design requirements, or to expose clean, fresh concrete to which new sealant can adhere. Recommendations for water-cooled saws and blades are discussed in section 3.9.2. The following results of sawing must be achieved for the entire project:

- Uniform width and depth of joint in compliance with the design dimensions.
- No spalls resulting from resawing.
- Sealant completely removed and concrete freshly exposed on both sides of each joint.

If the resawing operation is properly completed, the remainder of the preparation tasks are greatly simplified. Therefore, care should be taken to ensure accurate and complete sawing, and if

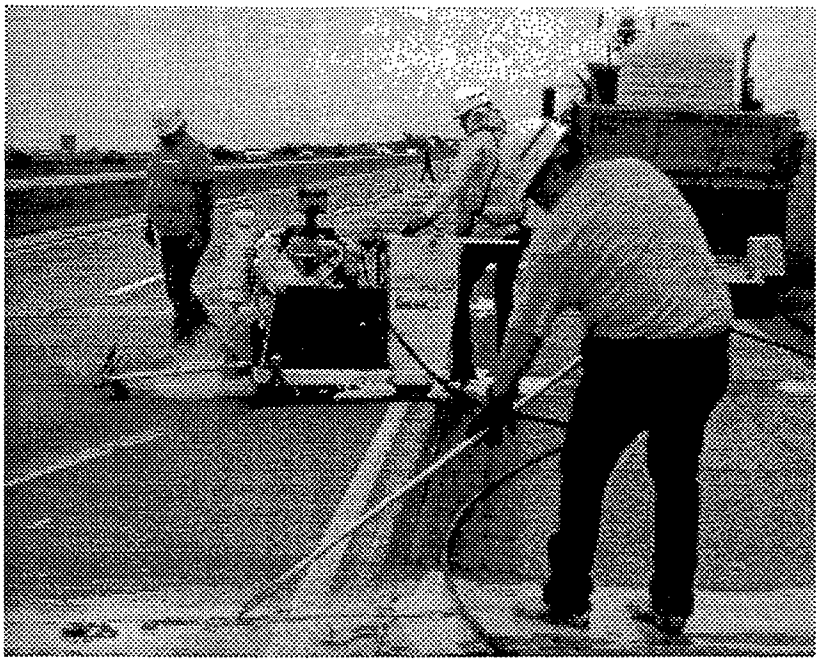

Figure 13. Joint resawing operation.

poor results are noticed, they should be corrected promptly. Several common problems encountered in resawing are noted in table 18, along with recommended solutions. Consult saw manufacturers for solutions to other problems.

Wet-sawing leaves behind old sealant and a slurry of water and concrete dust in the joint. If this slurry dries on the joint walls, it is very difficult to remove; if it is not removed, it will keep new sealant from bonding to the concrete. Therefore, the sealant and slurry must be removed immediately after sawing by one of the following methods:

Table 18. Troubleshooting procedures for resawing.

Problems Encountered	Possible Solutions
Blade pulling to one side.	Change the rate of sawing. Check rear-wheel alignment.
Blade not cleaning both sides.	Narrow blade—use wider blades. Poor control—use a more skilled operator.
Sealant "gumming-up" blade.	Remove (plow) sealant before sawing.
One side of ganged blades worn.	Switch the inside and outside blades.
Saw cut does not begin in the center of the joint.	Have the saw operator take more care. Provide an assistant to the operator.
Sawing is slow.	Use a more powerful saw. Use a more appropriate blade. Adjust the water feed. Increase the cutting rate.

- Flush the joints with low-pressure water, simultaneously blowing the slurry out with high-pressure air until all sawing waste is removed (Darter et al., 1985).
- Flush the joints with high-pressure water until all sawing waste is removed.
- Clean the joints with high-pressure air until all sawing waste is removed.

The first and second methods are more effective than the third at removing concrete dust slurry.

4.3.3 Abrasive Blasting the Joint Sidewalls

An abrasive blasting apparatus is used to direct a mixture of clean, dry air and abrasive material onto the walls of concrete joints. Results of abrasive blasting include the removal of sawing dust, old sealant, and other foreign material from the concrete joint surfaces, as well as the roughening of the concrete surface in order to create a better bonding surface. To achieve these results, the abrasive blasting operation must produce the following effects:

- Joint walls to which sealant must bond must be free from all sawing dust, old sealant, lubricant adhesive, discoloration or stain, or any other form of contamination.
- Joint walls must be completely clean and dry, and have newly exposed concrete.

The following procedures can provide successful abrasive blast-cleaning results:

1. Use approved sandblast units, safety equipment, and safety procedures, as described in section 3.9.3.
2. Hold the sandblast nozzle no more than 50 mm from the pavement surface. A long handle attached to the hose and extending slightly past the nozzle will allow this to be done from an upright position, as shown in figure 14.
3. Make one complete pass for each joint wall at an angle from the pavement that directs the blast onto the surface to which sealant must bond.
4. Remove any old sealant with repeat passes or with a knife and repeat passes.
5. Protect traffic in nearby lanes from sand and dust, as necessary, by using a portable shield and low-dust abrasive.
6. Remove sand and dust from the joint and nearby pavement to prevent recontamination, using airblasting or vacuuming equipment.

Figure 14. Abrasive blasting operation.

Problems that are encountered in sandblasting must be solved quickly. Several common sandblasting problems and possible solutions are listed in table 19.

The sand and dust must be removed from the joints and pavement surfaces before sealing can begin. If this is not done, sand and dust can be blown back into the joints, reducing sealant performance. Self-propelled vacuums and portable blowers can be used for debris removal.

Table 19. Troubleshooting procedures for sandblasting.

Problems Encountered	Possible Solutions
Sandblast not removing sealant.	Ensure that sandblaster is functioning. Blast joint edges separately. Cut old sealant away and reblast. Use a different blaster or abrasive or larger hoses. Improve the accuracy of sawing.
Sandblast quality not consistent.	Ensure that sandblaster is functioning. Keep the nozzle height and alignment consistent. Use a nozzle guide attachment.
Sandblast progress too slow.	Ensure that sandblaster is functioning. Use a different blaster or abrasive or a larger hose.
Oil or moisture in sandblast stream.	Install a functional oil/moisture filter. Use another compressor that doesn't add oil or moisture. Use dry abrasive.
Operator fatigue.	Use a guide and handle for upright sandblasting. Use alternating operators.

4.3.4 Airblasting the Joint Reservoir

After the joints have been sandblasted, and immediately before sealant installation, the dust, dirt, and sand must be blown from the joints and pavement surface using a compressed air stream. The following results of airblasting are desired over the entire project:

- Sand, dust, and dirt must be completely removed from the joint reservoir.

- Any sand, dust, and dirt that may recontaminate the joints must be removed from the surrounding pavement surface.

In general, joints should be airblasted immediately prior to backer rod installation. The airblasting, rod placement, and sealant installation operations must occur on the same day. If rain or dew recontaminate the joints, they must be sandblasted and airblasted again after drying.

Successful airblasting methods for accomplishing the above results are as follows:

1. Use approved air compressors, safety equipment, and safety procedures, as described in section 3.9.4.
2. Hold the nozzle no more than 50 mm from the pavement surface, as shown in figure 15.
3. Blow debris in front of the nozzle. Do not walk backwards.

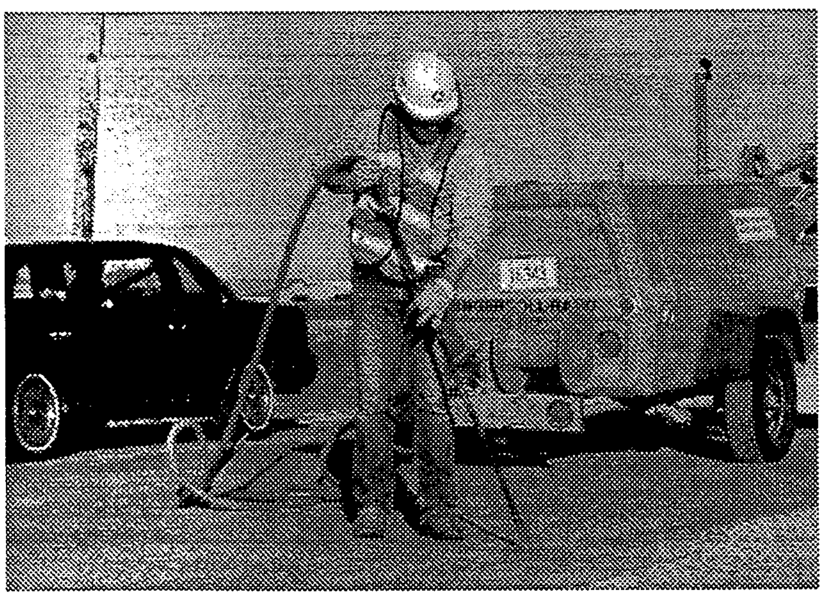

Figure 15. Airblasting operation.

4. Make slower or repeated passes until the joint reservoir is completely clean.
5. Elevate and fan the nozzle across the pavement on the last pass to remove debris from the joint area to a place where it cannot recontaminate the joints.

The most common problems encountered in airblasting are related to contamination of the air stream or lack of air volume and pressure. Joint seal materials will not adhere well to dirty or damp joints. Methods for addressing these problems are described in table 20.

If the joints are slightly damp, a heat lance may be used to dry the joints prior to installing backer rod (Mildenhall, n.d.). The extreme temperatures that a heat lance can produce (820 to 1,650°C) can severely spall concrete pavement that is exposed to the heat for more than a very short length of time. Extreme care must be taken to keep the heat lance from remaining in one location for more than 1 to 2 s. Pavement that is saturated must be allowed to dry before resealing. A heat lance may dry the surface of such a pavement for a short time, but capillary action in the concrete will bring the moisture back to the joint very quickly.

Table 20. Troubleshooting procedures for airblasting.

Problems Encountered	Possible Solutions
Oil in airstream.	Ensure oil/moisture filter is functional. Clean or replace the hose.
Moisture in airstream.	Ensure that oil/moisture filter is functional.
Air not removing dust, dirt, and sand.	Use a larger compressor. Use a larger diameter hose. Reduce the diameter of the nozzle opening.

4.3.5 Installing Primer

To effectively and economically prime joint surfaces, the primer installation process must achieve the following:

- Primer must very thinly and uniformly coat all joint surfaces to which sealant must bond.
- Primer should not be wasted by applying thick coats or covering non-essential concrete surfaces.

Primer can be installed using a brush or spray equipment. Spray equipment is much more efficient, generally resulting in a thinner coat, and spray nozzles can be designed to coat only the upper joint wall surface. It is critical that the primer be allowed to dry, since as it dries, it gives off gas (ACI, 1990). If hot-applied sealant is installed before the primer has dried, bubbles will form in the sealant as the gas tries to escape.

All required operator safety equipment must be used. This may include goggles, gloves, protective clothing, and respirators. Manufacturers' recommendations for installation methods and safety procedures must be followed.

4.4 Material Preparation and Installation

Objective: To properly install backer rod in clean joint channels and to adequately prepare, install, and shape sealant material.

The preparation and sealing operations should be scheduled so that joints are cleaned and left open a minimum amount of time before resealing. Prepared joints that are left open overnight must be airblasted again and reinspected for cleanliness and dryness. Primer, installed before backer rod installation, must be dry and tack-free. Only a minimum amount of time must be allowed to pass between backer rod installation and sealant placement.

No matter how good the joint preparation has been, improper sealant installation can result in rapid seal failure. Therefore, the manufacturer's recommendations must be followed regarding minimum placement temperatures, sealant heating temperatures, extended sealant heating, and pavement moisture conditions. Most sealant manufacturers recommend installing sealant when the pavement is dry and the air temperature is 4°C and rising. Recommended application temperatures for rubberized asphalt sealants generally range from 185 to 200°C. Hand-held, calibrated infrared thermometers can be used to easily check sealant, air, and pavement temperatures.

Polymers used in some hot-applied sealants are susceptible to damage from overheating and from extended heating. The allowable time such sealants may remain at application temperature ranges from 6 h to 5 days, depending on the sealant properties. Check with sealant manufacturers for exact heating time and temperature limits.

4.4.1 Installing Backer Rod

Backer rod should be installed immediately after airblasting and immediately before placing the sealant. Joint reservoirs and pavement surfaces must be completely clean before backer rod is inserted. If unclean joint walls are noted during backer rod installation, they should be marked for recleaning.

The backer rod serves two purposes. It helps keep the sealant at its design thickness, and it keeps sealant from bonding to the bottom of the joint reservoir. Both thicker sealant and bonding to the reservoir bottom place additional stress on the sealant. To perform properly and reduce sealant stress, the installed backer rod must meet the following requirements:

- The backer rod must be compatible with and appropriate for the sealant.
- Backer rod must be at the depth required in the plans.
- No gaps should be evident between the backer rod and joint walls.
- The rod must be compressed in the joint sufficiently that the weight of uncured sealant or the tooling operation do not force it down into the reservoir before curing.
- The rod must be dry and clean.
- The surface of the rod must not be damaged during installation.
- No gaps should form between backer rods that are butted together in a joint or at a joint intersection.

Many methods have been used to insert backer rod into joints, ranging from poking it in with a screwdriver to using automated, self-guided installation equipment. Using a screwdriver may damage the surface of the rod and result in bubbles forming in the sealant. Automated equipment is most effective for continuous joints where only one size of backer rod is generally needed. The steps for the most commonly used and successful method of installing backer rod are as follows:

1. Have enough rod sizes available to fit all of the joint widths at the project.
2. Use a long-handled installation tool with a large-diameter central disk that fits into all joints and does not cut or damage the backer rod, as shown in figure 16.
3. Insert one end of the proper size of rod into the end of a joint.
4. Tuck the rod loosely into the joint and push the rod into the joint by rolling the installation tool along the joint.
5. Roll over the rod a second time with the installation tool to ensure proper depth.
6. Cut the rod to the proper length, making sure no gaps exist between segments of backer rod.

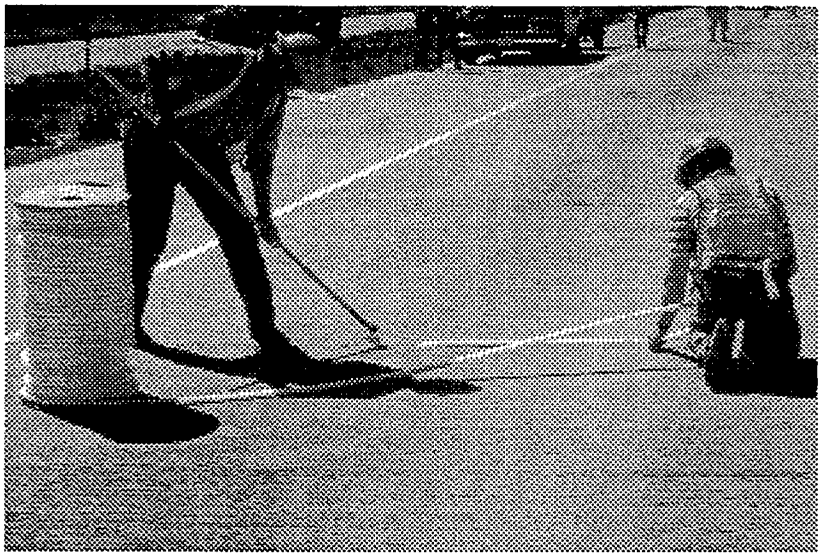

Figure 16. Backer rod installation.

7. In sections where the rod does not fit tightly to the joint walls, install larger diameter backer rod.

The depth of the installation tool must be slightly greater than the required depth of backer rod because the rod compresses slightly when installed (Blais, 1984). Certain rod materials are more compressible and require additional tool depth.

Stretching and twisting of backer rod must be minimized during installation, since as the material relaxes, gaps may form at joint intersections and result in sealant failure. When transverse and longitudinal joints are being sealed in one operation, better results are obtained if rod is installed in the entire length of the transverse joints. That rod is then cut at the intersection with longitudinal joints and the rod is installed in the longitudinal joints. Possible solutions to common problems encountered when installing backer rod are described in table 21.

Table 21. Troubleshooting procedures
for backer rod installation.

Problems Encountered	Possible Solutions
Rod is tearing (slivers formed) when installed.	Use a smaller diameter backer rod. Ensure that installation tool is smooth.
Side gaps are evident or rod is slipping or is easily pushed down in joints.	Use a larger diameter rod.
Rod depth is inconsistent.	Check the installation tool for depth. Repeat passes with the installation tool.
Rod is shrinking in joint. Gaps are forming between rod ends.	Do not stretch the rod when installing. Use a larger diameter roller.

If delay occurs before installing the sealant, dirt and sand can be blown into the cleaned joints, or moisture can enter the joints. When dirt has re-entered the joints after the backer rod has been installed, blow out the dirt using a clean, dry, low-pressure airstream, taking care not to force the rod deeper into the joint. Damp or wet backer rod must be removed from the joints and replaced with dry rod after the reservoir is completely dry and has been recleaned.

4.4.2 Sealant Installation

When the joints are clean, the backer rod is installed and, if the temperatures are within the required limits, sealing can begin. If rain interrupts the sealing operation, reclean the open joints before installing the sealant. The sealing operation should progress quickly and result in a seal with the following characteristics:

- Prevents infiltration of water through the joints.
- Remains resilient and capable of rejecting incompressible materials at all pavement temperatures.
- Maintains a tight bond with the sidewalls of the joint.
- Has no bubbles or blisters.
- Is not cracked or split.
- Is well bonded to the joint walls.
- Cannot be picked up or spread on adjacent pavement surfaces by tires or the action of power-vacuum rotary-brush pavement cleaning equipment after the specified curing period.
- Provides a finished exposed joint surface that is non-tacky and will not permit the adherence or embedment of dust, dirt, small stones, and similar contaminants.

Hot-Applied Sealant

To install hot-applied sealant that successfully meets the above requirements, proper heating and installation methods must be used. Suitable cleanup and safety procedures, as described in appendix C, must also be followed to ensure worker protection and properly functioning equipment.

<u>Heating the Sealant</u>

Hot-applied sealant performance can be significantly changed by the procedures used to heat and maintain its temperature during installation. Prior to heating sealant, the melter-applicator should be checked for the following properties and modified if necessary:

- Carbon buildup on the sides of the heating chamber should be removed.
- All temperature gauge sensors should be cleaned and accurately calibrated.

Heating should be scheduled so that the sealant will be at the recommended temperature when the sealing operation is to begin. During initial heating, the following guidelines should be adhered to:

1. Keep the heating oil temperature no more than 24°C above the safe sealant heating temperature stated on the sealant packaging.
2. Keep sealant temperatures between the recommended pouring temperature and the safe heating temperature printed on the sealant packaging.
3. Start the agitator as soon as possible.
4. Do not hold the sealant at application temperatures for a long period before using it.

If sealant is heated above the safe heating temperature, it should not be used because rubberized sealants break down and become very thin or very stringy when heated above this temperature. The recommended pouring temperature is the temperature of the sealant that will achieve the best performance. If the sealant is installed below this temperature, it may cool before it fills the voids in the concrete, and a poor bond may result. Recommended pouring temperatures vary between sealant manufacturers and types. Therefore, the pouring and safe heating temperatures of the sealant in use should be obtained from the sealant packaging, and all sealant operators must be made aware of it. Supervisors and equipment operators can use infrared sensors to check pouring temperatures at the nozzle.

The procedures listed below should be followed during installation.

1. Check to ensure that the pavement temperature is above the minimum recommended installation temperature and above the dew point.

2. Check the temperature of the sealant at the nozzle and adjust the melter controls to obtain the recommended pouring temperature at the nozzle.
3. Regularly check the sealant temperatures and adjust as necessary.
4. Watch for carbon buildup on the sidewalls of the heating chamber. This is a sign of overheating.
5. Do not use sealant that has been overheated or heated for an extended period of time, or that remains tacky and shows signs of breakdown.

Methods of Installation

Trial installation of at least 15 transverse joints should be completed using the methods scheduled for use in cleaning and installing sealant on each project. The sealed trial joints should be inspected after curing and approved or rejected prior to sealant placement. Hot-applied seals can be cut on three sides after cooling for a 50-mm length and can be stretched to observe material and adhesive properties. A similar test can be conducted on silicone and other chemically cured materials after curing is complete.

Upon approval, the remaining joints should be cleaned and resealed in the same manner as the trial joints. Sealing should begin only when the air temperature is 8°C and rising and the air temperature is above the dew point. The following installation practices are recommended:

1. Pour the sealant with the nozzle in the joint so that the joint is filled from the bottom and air is not trapped beneath the sealant.
2. Apply the sealant in one continuous motion while moving the wand in a way that the sealant flows out behind the wand, as shown in figure 17 (Darter et al., 1985).

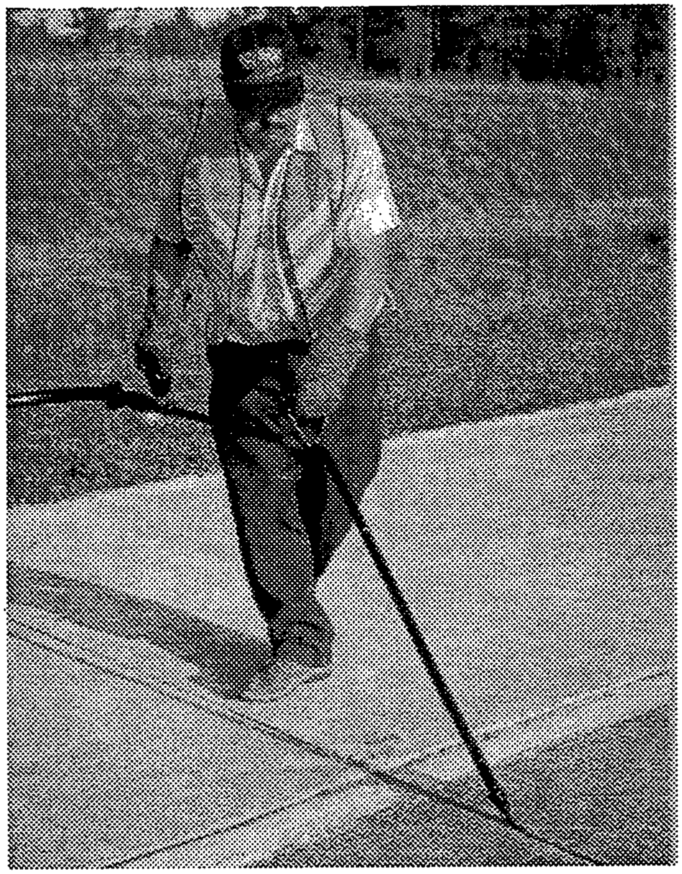
Figure 17. Hot-applied sealant installation.

3. Apply sealant in one pass, filling the reservoir to the recommended level. If additional sealant is required in low sections, it should be added as soon as possible. Inform the backer rod installation crew if leaks are occurring at backer rod joints.
4. Recirculate sealant through the wand into the melting chamber when not applying sealant.

5. Watch for bubbles, areas of sunken sealant, sealant that remains tacky, and sealant that has not bonded to the joint walls, and solve these problems as soon as they are identified. Several solutions are listed in table 22.
6. Use equipment and installation practices that result in consistent sealant thickness, little waste, and low operator fatigue. Support plates on the wand tip may be useful for this purpose.
7. Do not allow construction equipment or vehicle traffic onto the pavement until the sealant has set and there is no danger of tracking or stone intrusion.

Cleanup Requirements

Follow the melter–applicator manufacturers' instructions as to the frequency of cleaning. If carbon is built up on the heating chamber walls, remove it completely by scraping and flushing. Flush the pump and hose with solvent, if recommended, and waste the first 10 L of the day to remove any traces of solvent. Dispose of the wasted sealant/solvent solution properly.

Safety Precautions

Obtain the MSDS's for each sealant material and follow the worker protection and disposal instructions outlined in them. Several safety precautions should be followed before, during, and after installation. These include the following:

1. Be careful when loading blocks of sealant—splashing can occur.
2. Have operators wear protective gloves and clothing. Sealant and oil temperatures can reach 200°C and can cause serious burns.

Table 22. Troubleshooting procedures for hot-applied sealant installation.

Problem Encountered	Possible Causes	Possible Solutions
Bubbles in sealant	Reaction with backer rod.	Use nonreactive backer rod.
	Damaged backer rod.	Change the rod installation method or rod diameter.
	Moisture in joint.	Allow the joints to dry. Install sealant above the dew point.
	Bubbles in melter.	Add sealant material. Reduce the agitator speed.
	Air trapped by sealant.	Fill joints from the bottom.
Sealant is deeply sunken in joint	Gap remains between rod and wall. Rod slipping into joint.	Use proper diameter backer rod.
	Gap remains between backer rod ends.	Do not stretch rod. Install rod carefully.
Sealant recess is not consistent	Operator control is poor. Operator movement is uneven. Joint width is variable. Hoses are unmanageable.	Use a nozzle with a depth control plate. Use a wand with a shut-off valve at the nozzle. Use an experienced operator. Provide a hose support.

Table 22. Troubleshooting procedures for hot-applied sealant installation (continued).

Problem Encountered	Possible Causes	Possible Solutions
Sealant is not sticking to concrete walls	Joint walls are not clean.	Remove all old sealant, oil, dust, dirt, sawing slurry, and other contaminants.
	There is moisture on the walls from rain, dew, or condensate.	Wait for concrete to dry. Install above the dew point temperature.
	Sealant temperature is too low.	Maintain recommended sealant temperature. Insulate and heat hoses.
	Pavement temperature is too low.	Wait for warmer conditions. Insulate and heat hoses.
Sealant remains tacky after installation	Kettle contaminated with asphalt, heat transfer oil, solvent, or other sealant.	Remove sealant. Clean and flush kettle. Replace with uncontaminated sealant.
	Sealant has been overheated or heated too long.	Remove and replace with fresh sealant. Check melter temperatures.

3. Do not overheat the sealant—it is flammable.
4. Make sure the appropriate hoses (manufacturer recommended) are used.
5. Follow manufacturers' safety instructions when using coal tar compounds. Excessive breathing of fumes or skin contact with coal tar compounds may cause irritation (ACI, 1990).
6. Follow disposal instructions for cleaning solvent and wasted sealant.

Cold-Applied Sealant

Several types of sealant are installed without heating. These include polysulfides, polyurethanes, and silicones. Consult manufacturers' literature for installation recommendations for each sealant type. The discussion in this manual is limited to the installation of one-part, cold-applied sealants.

Loading Sealant in Pumping Apparatus

Typically, silicone sealant is pumped from storage containers through compressed-air-powered pumping equipment to a wand with an application nozzle, as shown in figure 18. The sealant is pumped from 19-L buckets or 208-L drums. Two important precautions should be observed when loading silicone into an approved pumping apparatus.

- Load the sealant in the apparatus in a manner that keeps bubbles from becoming trapped in the sealant.
- Limit the exposure of the sealant to air and moisture. Premature curing can result from such exposure.

Methods for Installation

The following practices have been used successfully and are recommended for installing silicone sealants:

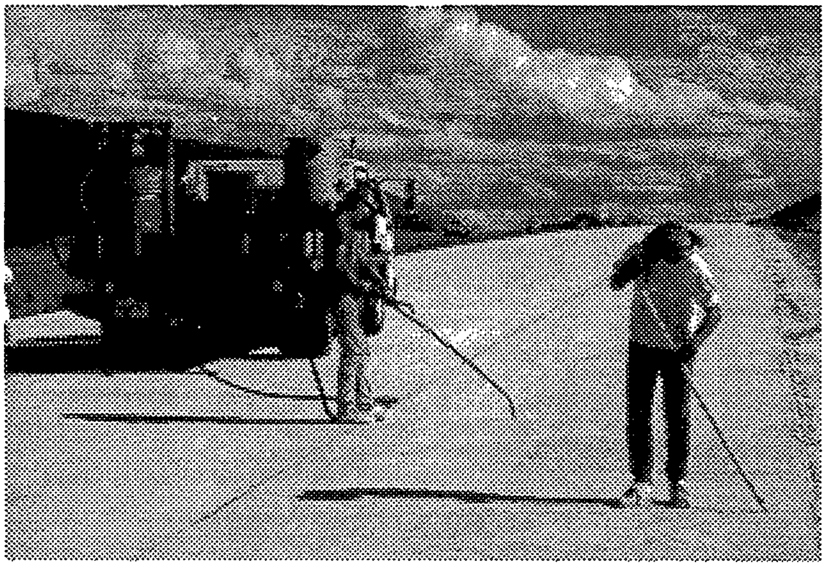

Figure 18. Silicone sealant installation.

1. Pour the sealant with the nozzle in the joint, so that the joint is filled from the bottom and air is not trapped beneath the sealant.
2. Use a nozzle that applies sealant at a 45° angle, and push the bead along the joint rather than draw it with the gun leading.
3. Apply the sealant in one continuous motion, moving steadily along the joint, so that a uniform bead is applied without dragging, tearing, or leaving unfilled joint space (USAF, 1983).
4. Adjust the pump rate, nozzle type, and nozzle diameter to control the speed of application.
5. Tool (i.e., form a concave surface in) the non-self-leveling sealant using a piece of oversized backer rod, plastic tubing on a fiberglass rod, a dowel, or other suitable instrument.

6. When tooling is required, press the sealant around the backer rod, forming a uniform concave surface with no wasted sealant on the pavement surface. The bottom of the concave tooled surface should be at least 7 mm below the pavement surface.
7. The surface of the self-leveling silicone sealant must be recessed 7 to 10 mm below the pavement surface and should never be exposed to traffic wear.
8. Watch for bubbles, sunken sealant, a non-uniform surface, and other installation deficiencies, and solve these problems as soon as they are identified. Several solutions are listed in table 23.
9. Allow non-self-leveling sealant to become tack free and self-leveling sealant to skin over before opening the pavement to traffic. If large pavement deflections are expected, allow a longer cure time.

Non-self-leveling silicone sealant is generally tack free within 90 minutes at temperatures above 4°C, and it cures within 7 days. Self-leveling silicone sealant typically skins over within 60 minutes and cures in about 21 days.

Cleanup Requirements

Cleaning of the applicator equipment apparatus will be required if the sealant begins to cure in the pump or hose. Follow the sealant pump manufacturer's instructions for cleaning frequency and required solvents.

Table 23. Troubleshooting procedures for cold-applied sealant installation.

Problem Encountered	Possible Causes	Possible Solutions
Sealant is not sticking to concrete walls	Joint walls are not clean.	Remove all old sealant, oil, dust, dirt, sawing slurry, and other contaminants.
	Moisture remains on the walls from rain, condensate, or dew.	Wait for concrete to dry. Install above the pavement dew point temperature.
	Tooling was inadequate.	Use more tooling care. Use another strike-off tool.
Sealant is deeply sunken in joint	Gap between rod and wall. Rod is slipping into joint.	Use larger diameter backer rod.
	Gap between backer rod ends.	Do not stretch rod. Install rod carefully.
Installed sealant contains bubbles	Reaction with backer rod.	Use nonreactive backer rod.
	Damaged backer rod.	Change rod installation method, tool, or rod diameter.
	Bubbles in pump lines.	Set the pump diaphragm into sealant better.
	Air was trapped by the sealant.	Fill the joint from the bottom.

Table 23. Troubleshooting procedures for cold-applied sealant installation (continued).

Problem Encountered	Possible Causes	Possible Solutions
Sealant recess is not consistent	Operator control is poor. Operator movement is uneven. Joint width is variable.	Use a more experienced operator. Use a "dog leg" applicator.
	Nozzle tip is wrong size.	Reduce nozzle tip size to easily insert to top of backer rod.
	Surface tooling is poor.	User more tooling care. Use another strike-off tool (large backer rod, plastic or rubber tubing on flexible handle).

5.0 Evaluation of Joint Seal Performance

Monitoring the performance of joint seal treatments is good practice, and it can be done rather quickly (in 1 or 2 h) with fair accuracy. At least one inspection should be made after the first winter, and subsequent evaluations should be conducted at regular intervals to chart the rate of failure and plan for subsequent maintenance. A mid-winter evaluation is highly recommended, since at that time, joints will be near their maximum opening and, as a result, adhesion loss can be seen more easily. Visual evaluation, alone or in conjunction with the IA-VAC joint seal tester, can provide seal performance information. The IA-VAC system can easily determine joint seal effectiveness in a consistent manner any time of the year until failure rates become moderate or greater (Steffes, 1993). Visual evaluation methods will become more necessary as failure rates increase.

As discussed in section 2.1, a small representative sample of the pavement section should be selected for the evaluation. Resistance to the entrance of water and debris to the joint should be measured by noting the percentage of water resistance loss using equation 1 provided earlier. The joint seal effectiveness can then be calculated using the following equation:

$$\%L_{eff} = 100 - \%L_{fail} \qquad \text{Eq. 9}$$

where: $\%L_{eff}$ = Percent joint seal effectiveness.
$\%L_{fail}$ = Percent length allowing water to enter joints.

After a few inspections, a graph of seal effectiveness versus time can be constructed, such as the one in figure 19.

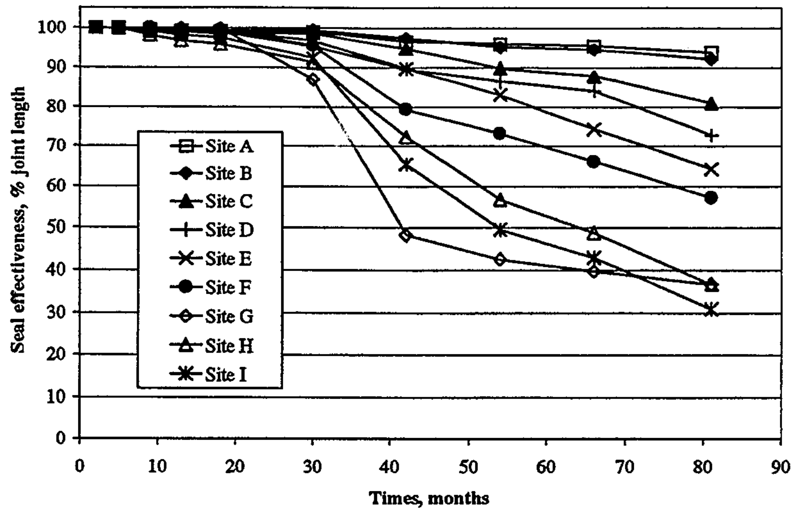

Figure 19. Example joint seal deterioration chart.

A minimum allowable effectiveness level, commonly 50 percent, will help to indicate when additional joint seal treatment is required. For example, a resealing plan using figure 19 could include immediate resealing of sites G, H, and I. A budget for resealing in the next 2 years could be prepared for sites E and F. Moreover, estimates of the time to 50 percent effectiveness could be obtained for planning the resealing of the remaining sites.

Appendix A

Material Testing Specifications

Material testing specifications are listed in tables A-1 and A-2. These specifications are based on specifications prepared by the American Society for Testing and Materials (ASTM), the American Association of State Highway Transportation Officials (AASHTO), and by States having significant joint resealing experience. Specifications are revised frequently, and the sponsoring society should be contacted to obtain the latest edition. Information regarding the availability of specifications can be obtained from the agencies listed below.

ASTM Specifications
American Society for Testing and Materials
100 Barr Harbor Drive
West Conshohoken, PA 19428
610-832-9500
www.astm.org

AASHTO Specifications
American Association of State Highway and Transportation Officials
444 North Capitol Street, NW, Suite 249
Washington, DC 20001
202-624-5800
www.aashto.org

U.S. Federal Specifications
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
800-553-6847
www.ntis.gov
www.fhwa.dot.gov

Table A-1. Rubberized asphalt specifications.

Test Description [a]	Test Criteria					
	Other		Standard			Low Modulus
	ASTM D 1190	AASHTO M 173	ASTM D 3405	AASHTO M 301	Federal SS-S-1401	State Specification
Cone penetration (25°C, dmm)	≤ 90	≤ 90	≤ 90	≤ 90	≤ 90	110 to 150
Flow (60°C, mm)	≤ 5	≤ 5	≤ 3	≤ 3	≤ 3	≤ 3
Resilience (25°C, % recovery)			≥ 60	≥ 60	≥ 60	≥ 60
Bond (-18°C, 50% ext.)	Pass 5 cycles	Pass 5 cycles				
Bond (-18°C, 100% ext.) or (-29°C, 50% ext.)					Pass 3 cycles	
Bond (-29°C, 100% ext.) or (-29°C, 200% ext.)			Pass 3 cycles	Pass 3 cycles		Pass 3 cycles
Asphalt compatibility					Pass	
Cone penetration (-18°C, dmm)						≥ 40

[a] 1 dmm = 0.1 mm

Table A-2. ASTM D 5893 silicone sealant specifications.

Test Description	Test Method	Silicone Type [a]	
		Non-Sag	Self-Leveling
Rheological properties	ASTM D 2202	≤7.6 mm slump	Type 1, smooth
Extrusion rate, mL/min	ASTM C 1183	≥ 50	≥ 50
Tack-free time, h	ASTM C 679	≤ 5	≤ 5
Bond (-29°C, 100% ext., immersed, non-immersed, oven-aged)	ASTM D 5893	Pass	Pass
Hardness (-29°C, type A2)	ASTM C 661	≤ 25	≤ 25
Hardness (23°C, type A2)	ASTM C 661	≥ 30	≥ 30
Flow	ASTM D 5893	No flow	No flow
Ultimate Elongation, %	ASTM D 412(C)	≥ 600	≥ 600
Tensile stress at 150% strain (23°C), kPa	ASTM D 412(C)	≤ 310	≤ 310
Accelerated weathering (500 h)	ASTM C 793	Pass	Pass
Resilience, %	ASTM D 5893	≥ 75	≥ 75

[a] 21-day cure time.

Appendix B

Sample Cost-Effectiveness Calculations

Sample worksheets for cost-effectiveness calculations are presented in this section. The forms included in section 3.11 are used to illustrate the method discussed in that section. Data used for calculation of cost-effectiveness are listed below and in tables B-1 through B-3.

Sealant Type =	Self-leveling silicone sealant
Shape Factor =	2:1
Joint Width =	13 mm
Joint Length to Seal =	6.0 km
Project Length =	4.0 km
Primer =	None required
Estimated Lifetime =	8 years
Plow Rate =	160 m/h
Saw Rate =	84 m/h
Airblast Rate =	152 m/h
Sandblast Rate =	114 m/h
Backer Rod Install Rate =	165 m/h
Sealant Installation Rate =	165 m/h
Labor Rates =	$150/day
Supervisor Rates =	$200/day

The sealant coverage rate is calculated in the following equation:

$$CR = (0.001)(1.2)(1.0)(12.7)(6.4) = 0.0975$$

where: CR = Coverage rate, L/m
WF = Wastage factor = 1.2
W = Joint width, mm = 12.7
T = Thickness of sealant = 6.4
ST = Surface type constant = 1.0

Table B-1. Example material and shipping costs.

Material, unit	Material Cost, $/unit	Coverage rate, unit/m	Length required, m	Total cost $/material
	a	b	c	a x b x c
Sealant, L	7.40	0.0975	6,100	4,401
Backer rod, m	0.011	1.05	6,100	211
Blasting slag, kg	0.11	0.30	6,100	201
Primer, L	-0-	-0-	-0-	-0-
Total material cost:				4,813

Table B-2. Example labor costs.

Crew Labor	Wages, $/day	Number in Crew	Days Required	Total Cost, $
	d	e	f	d x e x f
Supervisor	200	1	14	2,800
Traffic control	150	1	14	2,100
Plowing	150	2	5	1,500
Sawing	150	1	3.5	525
Initial airblast	150	2	3.5	1,050
Sandblast	150	2	6	1,800
Final airblast	150	2	3.5	1,050
Backer rod	150	2	4.6	1,380
Sealant installation	150	2	4.6	1,380
Total labor cost:				13,585

Table B-3. Example equipment costs.

Equipment	Daily Cost, $/day	Number of Units	Number of Days	Total Cost, $
	g	h	i	g x h x i
Traffic control	450	1	14.0	6,300
Joint plow	150	1	5.0	750
Concrete saw	225	2	3.5	1,575
Air compressor	175	1	7.5	1,125
Sandblast equip. (including compressor)	200	1	6.0	1,200
Installation equip.	200	1	4.6	920
Other trucks	100	2	14.0	2,800
Total equipment cost:				14,670

Table B-4. Example cost-effectiveness calculations.

Total material cost [table B-1]	$ 4,831	
Total labor cost [table B-2]	$ 13,585	
Total equipment cost [table B-3]	$ 14,670	
User delay cost	$ 2,250	
Total resealing cost	$ 35,336	(A)
Project length, lane-km	6.1	(B)
Avg. resealing cost, $/lane-km	$ 5,793	(C)
Estimated lifetime of seal, years	$ 8	(D)
Interest rate (typically 0.05)	$ 0.05	(E)

$$Avg.\ Annual\ Cost = C\left[\frac{(E)[(1+E)^{D}]}{(1+E)^{D}-1}\right]$$

$$Avg.\ Annual\ Cost = 8{,}834\left[\frac{(0.05)[(1+0.05)^{8}]}{(1+0.05)^{8}-1}\right] = \$1{,}367$$

Average Annual Cost, $/lane-km $ 1,367

Using an ASTM D 3405 sealant that costs $1.10/L and lasts 5 years, together with the same preparation methods listed above and a shape factor of 1:1, the computed average annual cost is:

$$Avg.\ Annual\ Cost = 8{,}510\left[\frac{(0.05)[(1+0.05)^{5}]}{(1+0.05)^{5}-1}\right] = \$1{,}966$$

Appendix C

Material and Equipment Safety Precautions

Mandated highway safety attire, such as vests and hard hats, should always be worn by crews and supervisors during sealing operations. In addition, individual crews should be made aware of all safety precautions associated with the materials and equipment with which they are working.

C.1 Materials

In order to protect the health and well-being of maintenance workers who handle the various sealant materials, MSDS's should be obtained from the manufacturers of all materials to be installed, and these sheets should be reviewed by those handling the materials. These sheets provide important information about health hazards, fire and explosion data, reactivity data, and safe usage and disposal. Every effort should also be made to determine the type of sealant material to be removed and to address any safety hazards that it may present.

C.1.1 Hot-Applied Sealants

Hot-applied sealants require that several safety precautions be followed:

1. Be careful when loading blocks of sealant—splashing may occur.
2. Have operators wear protective gloves and clothing. Sealant and oil temperatures can reach 200°C and can cause serious burns.
3. Do not overheat the sealant—it is flammable.

4. Follow manufacturers' safety instructions when using coal tar compounds. Excessive breathing of fumes or skin contact with coal tar compounds may cause irritation or possibly more serious health problems.
5. Use care with any solvents required for cleanup.
6. Dispose of diluted or wasted sealant as specified in the MSDS.

C.1.2 Cold-Applied Sealants

When working with cold-applied sealants, care should be taken to protect workers from skin, eye, or internal contact with sealant materials. MSDS and the manufacturer's recommendations should be consulted to determine specific safety requirements for each sealant material.

Appendix D

Inspection Checklists for Construction

This section is intended for use by inspectors of resealing processes, as well as by supervisors and contractors. It contains discussions of planning, equipment, and procedures critical to the successful completion of a resealing project. Checklists pertaining to each step of the process, including planning, equipment, material preparation, joint preparation, sealant installation, final inspection, and safety precautions, are included.

Field experience has shown that each step in the resealing process requires careful supervision and inspection. An inspector must continually observe the various operations to ensure that proper procedures are being performed. In most cases, it is the contractor's responsibility to effectively clean and reseal the joints, and it is the inspector's responsibility to continually monitor the work and ensure that corrections are made if requirements are not met.

D.1 Preconstruction Plans and Specifications

Plans must be prepared and distributed to the inspectors and the supervisors of the installation crew. It is recommended that the inspectors and the construction supervisors meet before work begins to discuss the plans and specifications. Information that must be contained in the **plans** includes the following:

☐ 1. Project layout, including stationing and slab lengths.

- ☐ 2. Original joint reservoir dimensions, including existing variability.
- ☐ 3. Original sealant material type.
- ☐ 4. Location and type of required pre-resealing repairs.
- ☐ 5. Required reservoir dimensions.
- ☐ 6. Required sealant thickness.
- ☐ 7. Required sealant recess below pavement surface.

Specifications may be based on adherence to designated procedures, on achieving a quality end product, or a combination of the two. Information that must be contained in **procedure-based specifications** includes the following:

- ☐ 1. Lot testing requirements.
- ☐ 2. Delivery and storage requirements.
- ☐ 3. Repair methods and materials for pre-resealing repairs.
- ☐ 4. Equipment requirements.
- ☐ 5. Material requirements.
- ☐ 6. Preparation procedure requirements.
- ☐ 7. Installation procedure requirements.
- ☐ 8. Weather condition limitations.
- ☐ 9. Traffic shutdown requirements.
- ☐ 10. Safety requirements.
- ☐ 11. Material disposal requirements.

If **end-result specifications** are used, the following information must be included:

- ☐ 1. Lot testing requirements.
- ☐ 2. Delivery and storage requirements.
- ☐ 3. Repair methods and materials for pre-resealing repairs.
- ☐ 4. Required results of each preparation procedure and acceptance/rejection criteria.

- ☐ 5. Required results of the installation process and acceptance/rejection criteria.
- ☐ 6. Weather condition limitations.
- ☐ 7. Limitations of traffic shutdown.
- ☐ 8. Safety requirements.
- ☐ 9. Material disposal requirements.

An example of installation acceptance criteria is included in section D.4. In most cases, a combination of procedure-based and end-result specifications is used, and the following inspection process is based on a combination of the two.

D.2 Equipment Inspection

All equipment must be inspected and approved before the project begins, as well as during joint preparation and sealant installation. A list of proposed equipment should be submitted for approval before installation. During pre-installation inspection, the inspector should check all equipment to be used on the project, making sure that each piece meets the requirements of the project specifications or the suggested requirements listed previously in table 11. If questions arise about the suitability of the equipment, a statement from the sealant manufacturer should be supplied, indicating that the equipment is acceptable for installing the sealant.

The condition and effectiveness of each piece of equipment should be checked during trial installation and at the beginning of each day of preparation and installation. Criteria for equipment effectiveness are listed in the sections below.

D.3 Field Installation Inspection

After all required spall repair, load transfer restoration, slab stabilization, grinding, and other rehabilitation have been completed and approved, the resealing process can begin. It is recommended that the inspectors and supervisors meet before work begins to discuss the following subjects:

1. Exact locations and number of joints to be resealed (boundaries should be clearly marked).
2. Traffic control requirements and lane closure time limitations.
3. Methods required for cleaning and resealing joints (if procedure-based specification).
4. Criteria for approval of all cleaning and installation equipment and processes.
5. Final criteria for approval of resealing work, including procedures and penalties for rejection.
6. Any localized variations from the specified methods.
7. Safety requirements for all equipment and procedures (including material disposal requirements).
8. Procedures in the event of wet or cold weather.
9. Procedures in the event that seal quality requirements are not met.

D.3.1 Inspection of Joint Preparation

Joint preparation, as discussed in this manual, refers to sealant removal, joint refacing, final cleaning, primer installation, and backer rod insertion. Sealant manufacturers' instructions should be followed when preparing joints unless noted otherwise in the plans and specifications. The following inspection checklist can be used to ensure that joint preparation is completed properly

(USAF, 1983), although not all of these cleaning processes are used, in many cases.

- ☐ 1. **Joint plowing:**
  - ☐ Plow is removing the required amount of sealant.
  - ☐ Plow is not spalling the joint edges.
  - ☐ Worker and driver safety are not compromised.

- ☐ 2. **Concrete sawing:**
  - ☐ Saw is removing the required amount of concrete and sealant.
  - ☐ Saw is uniformly cutting to the proper width and depth (depth and width can be checked quickly using a metal template).
  - ☐ Saw is refacing both sides of the joint.
  - ☐ All guards and safety mechanisms are functioning properly.
  - ☐ All sawing slurry is immediately removed from the joints.

- ☐ 3. **Waterwashing:**
  - ☐ Equipment is removing all sawing slurry and old sealant from the joints.
  - ☐ No standing water remains in the joints.

- ☐ 4. **Abrasive blasting:**
  - ☐ The nozzle is being held 25 to 50 mm from the pavement.
  - ☐ Two passes are made for each joint, directing the nozzle toward one side of the joint for each pass.
  - ☐ No old sealant, oil, or dried sawing slurry remains on the joint walls.

- ☐ The blaster does not introduce oil or moisture to the joint.
- ☐ The operator is using all OSHA- or State-required protective devices.
- ☐ Following sandblasting, all joint walls exhibit freshly exposed concrete.

☐ 5. **Airblasting**:

- ☐ Equipment is removing all dirt, dust, and sand from the dry joint reservoir.
- ☐ The airblaster does not introduce oil or moisture to the joint (check for oil by directing the airstream onto a tire or a piece of paper and noting any discoloration).
- ☐ The operator is wearing required eye and ear protection.
- ☐ Following airblasting, the joint is clean and dry.

☐ 6. **Vacuum or compressed-air cleaning**:

- ☐ Cleaning equipment is removing all old sealant, sand, dirt, and dust from the pavement surface.
- ☐ Debris has no potential for re-entering the joints, especially on windy days or when traffic is moving next to the cleaned joints.

☐ 7. **Primer application**:

- ☐ Primer applicator is applying a thin layer of sealant uniformly over joint faces to receive sealant.
- ☐ All required safety protection equipment is in use and is operational.
- ☐ Primer is allowed to dry before backer rod is inserted.

- ☐ 8. **Backer rod installation**:
  - ☐ The rod is inserted into the joint uniformly to the required depth without stretching or tearing it. Depth can be checked using a template (slivers of rod in the joint indicate that the rod is too large).
  - ☐ The rod remains tight in the joint without gaps along the sides, at joint intersections, or between rod segments.
  - ☐ The rod is compressed in the joint enough that the weight of the uncured sealant or installation equipment or tooling equipment will not force it down into the joint.
  - ☐ A larger diameter rod is used in wide joint sections.

- ☐ 9. **Low-pressure air cleaning**:
  - ☐ When needed, all dust or dirt that has re-entered clean joints that contain backer rod is blown out.
  - ☐ The backer rod is not pushed into the joint by the airstream.

Water on the joint walls during sealing will severely reduce the ability of the sealant to bond to the walls and can result in bubbles in some sealants. Check frequently for dew that may collect in the joints and remain after the surface is dry, particularly if temperatures and humidity levels have been at or near the dew point. If cleaned joints are recontaminated by rain, dew, dirt, or oil, they should be recleaned in a manner that restores cleanliness. This may require sandblasting and airblasting or merely airblasting. Cleaned joints that are left overnight should, at a minimum, be airblasted again. Moist backer rod should be replaced after drying and joint recleaning.

One method that an inspector can use to communicate the need for additional preparation at a particular joint is to mark near it with a particular color of paint (USAF, 1983). A possible pattern that could be used is the following.

1. Yellow—Repairs must be made to joint before sealing.
2. Orange—Joint is not the proper size.
3. Red—Joint is not properly cleaned.
4. Blue—Backer rod is not tight or is not at proper depth.
5. Brown—Improper sealing technique (too full, too low, tacky sealant, not tooled correctly, bubbles in sealant, sealant not bonded, etc.).

The contractor or supervisor can use green spray paint to indicate that the problem is repaired and the inspector should re-examine the joint for approval.

D.3.2 Inspection of Joint Sealant Installation

The inspector should watch for several items prior to and during installation of the sealant material. The following section is a checklist for inspection of joint sealant installation.

D.3.2.1 Hot-Applied Sealant Installation Inspection

When inspecting the installation of hot-applied sealant materials, the information listed below must be determined **before heating begins**. This information can be obtained from sealant manufacturers and from the project plans and specifications:

- ☐ 1. The recommended sealant application temperature.
- ☐ 2. The safe sealant heating temperature.

☐ 3. The length of time that a sealant can be heated before it begins to break down.
☐ 4. The required thickness of sealant.
☐ 5. The required sealant recess below the pavement surface.
☐ 6. The air temperatures allowable for sealing.
☐ 7. The average sealant curing time and the time before traffic can be allowed on the pavement after resealing.
☐ 8. The MSDS's.
☐ 9. The criteria for acceptance/rejection of resealing work, and the penalties associated with rejection.
☐ 10. Acceptable test results for all materials to be installed.
☐ 11. The production date and shelf life of all materials.

During installation of hot-applied sealants, the following items should be regularly checked to ensure that they meet the requirements:

☐ 1. All joints remain clean and dry.
☐ 2. All backer rods remain tight in the joint at the correct height with no gaps.
☐ 3. The melter–applicator maintains the sealant at the required temperature without overheating.
☐ 4. Sealant leaving the nozzle is at the application temperature.
☐ 5. The agitator is functioning properly.
☐ 6. No carbon is built up on the melting chamber walls.
☐ 7. All thermometers and temperature controls are monitored and functioning properly.
☐ 8. The operator is not trapping bubbles in the sealant or overfilling or underfilling the joints.
☐ 9. Spilled sealant is removed from the pavement surface.

- ☐ 10. Areas of low sealant are not present or are quickly filled. Steps are taken to eliminate the cause of the low sealant.
- ☐ 11. All required operator safety equipment is in use. This applies especially to D 3406 materials.

Warning: If white smoke is seen rising from the kettle, stop the operation immediately and check the sealant temperature. If the sealant remains tacky in the joint long after placement, or the sealant becomes stringy inside the melting chamber, the sealant has been overheated and should be completely removed from the chamber and wasted.

D.3.2.2 Silicone Sealant Installation Inspection

Prior to installation of silicone sealants, the following information should be obtained by the inspector:

- ☐ 1. The expiration date of the sealant material.
- ☐ 2. The air temperatures allowable for sealing.
- ☐ 3. The required thickness of sealant.
- ☐ 4. The required sealant recess below the pavement surface.
- ☐ 5. The need for tooling the surface of the sealant.
- ☐ 6. The average sealant curing time and the time before traffic can be allowed on the pavement after resealing.
- ☐ 7. Safety data from the MSDS.
- ☐ 8. The criteria for acceptance/rejection of resealing work and penalties for rejection.
- ☐ 9. The acceptable results of lot tests for all materials.
- ☐ 10. The production dates and shelf life of all materials.

As sealant installation continues, the following items should be regularly checked for compliance with the plans and specifications:

- ☐ 1. All joints remain clean and dry.
- ☐ 2. Backer rods remain tight in the joint at the correct height with no gaps.
- ☐ 3. The silicone applicator system is not introducing bubbles to the sealant.
- ☐ 4. The applicator, wand, and controls allow the operator to fill the joint uniformly to the correct level.
- ☐ 5. The operator is not trapping bubbles in the sealant.
- ☐ 6. The operator is not overfilling or underfilling the joints (sealant thickness and recess can be checked by inserting a thin ruler through the uncured sealant to the top of the backer rod).
- ☐ 7. Non-self-leveling silicone sealant is tooled immediately, forcing sealant against the joint walls and creating a smooth concave surface.
- ☐ 8. Any sealant that remains on the pavement surface is removed.
- ☐ 9. Areas of low sealant are not present or are quickly filled. Steps are taken to eliminate the cause of the low sealant.
- ☐ 10. All required operator safety equipment is in use.
- ☐ 11. Traffic is not allowed on the pavement until the sealant is skinned over and cannot be damaged.

D.4 Final Inspection

During installation and prior to approval, the resealed joints should be individually inspected, ensuring that the sealant meets the following criteria, and noting the presence and severity of any distresses (Darter et al., 1985; USAF, 1983):

☐ 1. Sealant is bonded firmly to the joint sidewalls (cured sealant material should not separate from the sidewalls when pulled lightly with the fingertips across the joint).

☐ 2. Sealant is not tacky after curing and will not permit adherence of dust, dirt, or small stones.

☐ 3. Sealant material contains no cracks, bubbles, or blisters.

☐ 4. Sealant cannot be picked up or spread on adjacent pavement surfaces by tires, rubber-tired vehicle traffic, or the action of power-vacuum rotary-brush pavement-cleaning equipment after the specified curing period.

☐ 5. Sealant is resilient and capable of rejecting stones at high pavement temperatures.

☐ 6. Sealant is recessed to the correct depth below the pavement surface (this is critical for silicone sealants, as they are not resistant to traffic wear).

☐ 7. Sealant spilled on the pavement surface has been removed.

☐ 8. No debris remains on the pavement surface.

Appendix E

Partial List of Material and Equipment Sources

This section contains information for contacting several manufacturers of sealant materials, backer rod, and installation equipment. Addresses and phone numbers are given for manufacturers and suppliers who can provide the inquirer with information regarding material properties, recommended installation practices, safety procedures, and local suppliers.

MSDS's that describe the material components, any hazardous properties, and any required protective equipment, should be available from all sealant manufacturers.

E.1. Sealant Material

E.1.1. Manufacturers of Hot-Applied Rubberized Asphalt Sealant

Crafco Incorporated
6975 W. Crafco Way
Chandler, AZ 85226
(602) 276-0406
(800) 528-8242
www.crafco.com

W.R. Meadows, Inc.
300 Industrial Drive, Box 338
Hampshire, IL 60140-0338
(847) 683-4500
(800) 342-5976
www.wrmeadows.com

Koch Materials Company
4111 East 37th Street North
P.O. Box 2338
Wichita, KS 67220
(316) 828-8399
(800) 654-9182
www.kochmaterials.com

E.1.2. Manufacturers of Self-Leveling and Non-Self-Leveling Silicone Sealant

Crafco Incorporated
6975 W. Crafco Way
Chandler, AZ 85226
(602) 276-0406
(800) 528-8242
www.crafco.com

Dow Corning Corporation
P.O. Box 994
Midland, MI 48686-0994
(517) 496-4000
www.dowcorning.com

E.2. Backer Rod Material

E.2.1. Manufacturers of Expanded Closed-Cell Foam Rod

Nomaco, Inc.
501 NMC Drive
Zebulon, NC 27597
(919) 269-6500
(800) 345-7279
www.nomaco.com

Industrial Thermo Polymers Limited
153 Van Kirk Drive
Brampton, ON, Canada L7A 1A4
(905) 846-3666
(800) 387-3847

E.3. Sealant Installation Equipment

E.3.1. Manufacturers of Melter–Applicators for Hot-Applied Sealants

Cimline, Inc.
2601 Niagra Lane
Minneapolis, MN 55447
(800) 328-3874
www.cimline.com

Crafco Incorporated
6975 W. Crafco Way
Chandler, AZ 85226
(602) 276-0406
(800) 528-8242
www.crafco.com

Stepp Manufacturing Company, Inc.
12325 River Road
North Branch, MN 55056
(612) 674-4491
(800) 359-8167
www.steppmfg.com

E.3.2. Manufacturers of Pump Applicators for Cold-Applied Sealants

Graco, Inc.
P.O. Box 1441
Minneapolis, MN 55440-1441
(612) 623-6000
(800) 367-4023
www.graco.com

Glossary

Adhesion failure–Complete loss of bond between a sealant material and the concrete joint wall.

Allowable extension–The amount of stretching of a sealant material under which performance is estimated to be adequate.

Average daily traffic (ADT)–The total traffic volume carried by a pavement during a given period (in whole days), greater than 1 day and less than 1 year, divided by the number of days in that period.

Blowups–The result of localized upward movement or shattering of a slab along a transverse joint or crack.

Channel face–The vertical concrete sidewall of a sawed joint sealant reservoir.

Compression seals–Preformed seals, generally made from neoprene, that can be compressed and inserted into concrete joints for sealing purposes.

Corner break–A diagonal crack forming between transverse and longitudinal joints that extends through the slab, allowing the corner to move independently from the rest of the slab.

D-cracking–The breakup of concrete due to freeze-thaw expansive pressures within certain susceptible aggregates (also called durability cracking).

Embedment–To become fixed firmly in a surrounding mass, as stones sink into and become fixed in soft sealant material.

Extruded–Forced through a die to give the material a certain shape.

Flow–The sinking of unstable sealant into a sealant reservoir.

Horizontal movement–Opening and closing of joints resulting from pavement expansion and contraction.

Incompressible material–Material that resists compression, such as stones, sand, and dirt in a crack or joint reservoir that is closing.

Joint growth–The gradual increase in joint width resulting from the filling of joints with incompressible materials during cold cycles.

Joint sidewalls–The vertical concrete edges of a sawed joint reservoir.

Life-cycle cost analysis (LCCA)–An investigation of the present and future costs of each repair alternative, taking into account the effects of both inflation and interest rates on expenses over the life of the project.

Load transfer–The transfer of load across a joint or crack in concrete pavement resulting from aggregate interlock, dowels, or other load-carrying devices.

Overbanding–Spreading a thin layer of sealant (about 38 mm wide) onto a pavement surface centered over a joint or crack at the same time that the sealant reservoir is filled.

Pumping–The ejection of water and fine materials from beneath a concrete pavement through cracks or joints under pressure from moving loads.

Refacing–Removing about 1 to 2 mm of concrete from each wall of a sealant reservoir using diamond saw blades.

Resealing–Replacing sealant in joints or cracks, preferably using good-quality methods and materials.

Sealant/channel interface–The vertical edge of a sealed joint where sealant material and concrete joint face meet.

Sealant reservoir–The channel along a joint or crack that has been widened by sawing to allow sealant to be placed in it.

Sealant system–All components that function to seal joints (i.e., sealant material, surrounding concrete, and sealant/concrete interface).

Slurry–The mixture of water, concrete dust, old sealant, and dirt that results from resawing a joint in concrete pavement.

Subdrainage–Drainage of moisture from beneath a pavement by means of a porous subbase material connected to outlet drain lines.

Track–The spreading of unstable sealant material along the pavement surface by traffic tires.

Undersealing–Filling voids beneath a concrete pavement using a pressurized slurry or hot asphalt material.

Vertical shear–Vertical stress along the sealant/concrete interface resulting from traffic loading, curling, or pavement faulting.

Weathering–Breakdown of sealant material resulting from the effects of moisture, ultraviolet rays, and time.

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