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16. Abstract

This report presents the results of laboratory tests, field studies, and literature searches which pertain to the behavior of concrete pavement joints, slabs, and joint sealing materials. A review of common pavement joint and pavement slab failures is presented. The properties of several commonly used joint sealant materials are also discussed.

The following sealants were chosen for laboratory study: (1) Dow Corning's 888 Silicone, (2) A. C. Horn's Traffic Grade Hornflex Polysulfide, (3) A. C. Horn's Daraseal-U Polyurethane, (4) Allied Materials' 9002 Rubberized Asphalt, and (5) Epoxy Industries' Evazote 50 Ethylene Vinyl Acetate.

Laboratory results include: (1) load vs. elongation, (2) ultimate extension, (3) modulus of elasticity at 50 percent elongation, (4) bond, (5) penetration, (6) flow, (7) stress relaxation, (8) compression set, and (9) shear fatigue.

Results of a field test of the silicone and polysulfide are presented. Observations of existing joints at various places in Texas and Oklahoma are also presented. Results of field tests reported in the literature on silicones, polysulfides, polyurethanes, rubberized asphalts, and preformed neoprene rubber seals are summarized.

A literature search was used to find the best joint preparation procedures and most accurate methods for calculating pavement slab movements and designing pavement slab joints. Common techniques used in pavement slab cutting and sawing are also presented.

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IMPROVED METHODS FOR SEALING JOINTS IN PORTLAND CEMENT CONCRETE PAVEMENTS

by

Alexander M. Collins, III
Wayne D. Mangum
David W. Fowler
Alvin H. Meyer
and
David P. Whitney

Research Report Number 385-1

Materials and Methods for Sealing Joints
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Texas State Department of Highway and Public Transportation

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by

Center for Transportation Research
Bureau of Engineering Research
The University of Texas at Austin

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

PREFACE

The research effort that culminated in this report was made possible by the cooperation of many people. Larry Buttler, D-18, served as Technical Coordinator and gave many valuable suggestions and participated in visits to districts. Jerry Daleiden, D-8, Associate Technical Coordinator was an active participant and also participated in district visits.

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Alexander M. Collins
Wayne D. Mangum
David W. Fowler
Alvin H. Meyer
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ABSTRACT

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A literature search was used to find the best joint preparation procedures and most accurate methods for calculating pavement slab movements and designing pavement slab joints. Common techniques used in pavement slab cutting and sawing are also presented.

SUMMARY

Laboratory tests and field studies were conducted on joint sealing materials and joint preparation procedures. Laboratory studies were conducted on silicone, polysulfide, polyurethane, rubberized asphalt, and ethylene vinyl acetate to determine tensile elongation, modulus of elasticity, bond, penetration flow, stress relaxation, compression set, and shear fatigue. Temperature was a variable.

Some of the sealants were field tested on new pavement joints. A survey of existing joints in Texas and Oklahoma was conducted. A literature search revealed useful information on sealant behavior and joint preparation methods. Methods for calculating joint movements and designing joints are presented.

IMPLEMENTATION STATEMENT

The proper selection of joint materials preparation methods, and installation procedures is very important to the proper funtioning of joints in concrete pavements. The implementation of the recommendations made in this report will result in more durable, longer-life joints which will lower maintenance costs to the Department.

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CHAPTER 1. INTRODUCTION

1.1 Background

The joints in portland cement concrete pavements are sealed to prevent the intrusion of water and incompressibles into the pavement system. Both water and incompressibles are detrimental to pavement behavior because their presence will lead to serviceability failure of the pavement system.

The low tensile strength of concrete makes it necessary to provide for the contraction of all concrete structures, including pavements. In fact, continuously reinforced concrete pavements and long-jointed concrete pavement slabs are expected to crack. These cracks, if left unattended, will lead to the same types of failure as inadequately sealed joints. Jointed concrete pavements with short (10 to 20-ft.) slab lengths are intended to keep the slabs from cracking.

In 1903, jointed concrete was first used as a paving system in the United States (1). Since then, wood, tar, asphalt, rubber, inorganic elastomers, and many other materials have been used to seal the joints. At present, hundreds of sealants are available for the pavement designer to choose from. Many papers, articles, and books, representing an extensive background of research, have been published on the subject of joint sealing in concrete pavements. Yet, even with all this experience and research, the acceptable sealing of joints continues to be one of the most difficult problems in concrete pavement design and maintenance.

1.2 Scope

The purpose of this report is to identify improved, economical methods for sealing joints in concrete pavements.

Chapter 1 includes overviews of the types of joints found in concrete pavement, joint movement, required sealant properties, typical joint sealant failures, and pavement system failures that result from inadequate joint sealing.

Chapter 2 describes the types of sealants that are currently used for sealing joints in concrete pavement systems.

Chapter 3 presents the laboratory testing phase of the program. The first part of the chapter discusses the materials that were studied. Next, the laboratory tests are described. Finally, the data from the different tests are analyzed and, wherever possible, compared with the results obtained by the Texas State Department of Highways and Public Transportation's asphalt testing laboratory in Austin.

Chapter 4 discusses the field testing of the more promising sealants as determined from the laboratory tests. The results of observations of in-place joints and joint sealants are also presented here.

Chapter 5 presents current methods of calculating the pavement movements that affect joint sealant performance.

Chapter 6 discusses the design of concrete pavement joints. An example calculation is included.

Chapter 7 is devoted to joint preparation and the cutting and sawing of concrete joints.

The final chapter summarizes the study and presents conclusions and recommendations for future study.

1.3 The Need for Joints and Sealants

Concrete pavements, as do all concrete structures, tend to move with time. Drying shrinkage and carbonation produce permanent contractions of pavement slabs. At the same time, cyclical expansions and contractions are caused by climatic changes. Vertical movements of pavement slabs are caused by traffic loading and climatic variations.

Joints are placed in the pavement system to allow the slabs to relieve stresses by moving horizontally and vertically. The joints are sealed with materials that have a much lower modulus of elasticity than the concrete. The sealants prevent the intrusion of incompressibles and water into the pavement and the subsequent serviceability failure of the system. Although some unsealed pavements have provided adequate service in Europe, studies in the United States have proven that sealed joints significantly extend the lives of pavement systems (2).

1.4 Types of Joints

Concrete pavement joints may be classified as either transverse or longitudinal.

1.4.1 Transverse Joints

Transverse pavement joints are designed to accommodate vertical and horizontal pavement movements so that slab cracking is controlled. They may be perpendicular to the lane direction or skewed slightly to keep the weight of both wheels of a vehicle axle from impacting the slab at the same time. The joints may be regularly spaced or staggered to relieve uncomfortable rhythmic noise and vibration as vehicles pass over the pavement. The two main types of transverse joints are expansion joints and contraction joints.

1.4.1.1 Expansion Joints. Expansion joints extend through the entire depth of the slab. They are usually 3/4 to 2 inches wide. These joints were originally designed to allow for all of the expansions that occur in pavement slabs. Many older pavements used as many as one expansion joint for every three contraction joints. However, experience has taught pavement designers that the compressive stresses generated in a properly functioning pavement system that utilizes only contraction joints are not great enough to require regularly spaced expansion joints. Therefore, more recent pavements utilize expansion joints only as a construction convenience at the end of a pour and at interruptions in the pavement such as at bridges. Regularly spaced dowels are used at expansion joints to transfer vertical loads from one slab to the next. Figure 1.1 shows a typical expansion joint.

1.4.1.2 Contraction Joints. Contraction joints are designed to control random cracking of pavements due to thermal stresses, shrinkage, and load stresses by providing a sealed, weakened plane at which the pavement may crack. Experience has taught designers that the depth of these joints should be at least one-fourth of the slab thickness. This depth assures that the first cracks will appear at the joint and not elsewhere in the slab. The original width of these joints varies from about 1/4 inch to 3/4 inch, depending on the expected magnitudes of slab movement. Most researchers agree that contraction joints should be spaced no more than 20 feet apart to ensure a properly functioning pavement system on free draining subgrades; on poor draining subgrades the spacing should not exceed 15 feet.

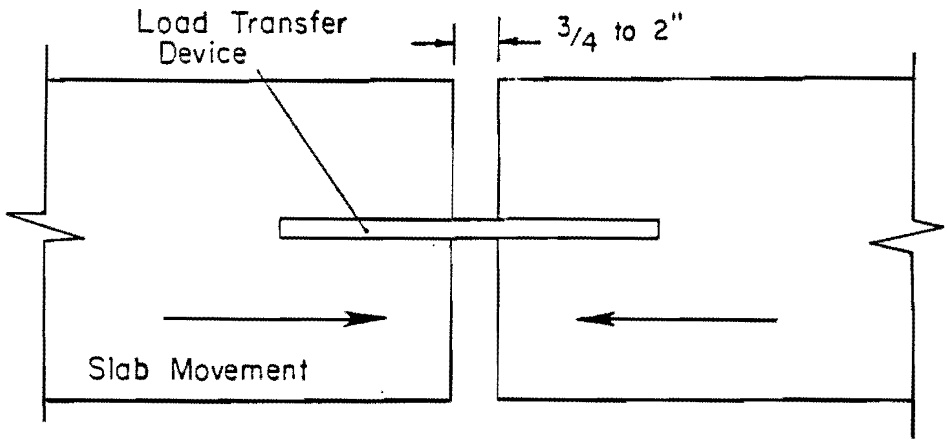

Fig. 1.1 Typical Expansion Joint

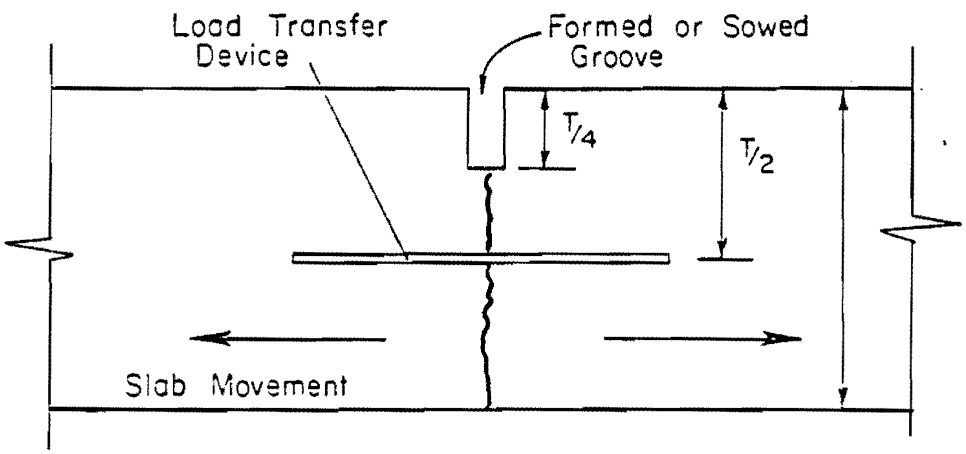

Fig. 1.2 Typical Contraction Joint

The vertical load carrying capacity of the slab must be insured even after the slab has cracked. Aggregate interlock may be relied upon to transfer vertical loads up to about 0.04 inch of joint expansion (3). However, the movements of a 20-foot slab are usually at least 0.08 inch. Therefore, dowels should be used at contraction joints also. Figure 1.2 illustrates a typical contraction joint.

1.4.2 Longitudinal Joints

Longitudinal joints perform the same functions as transverse joints. They are located between lanes and at the edge of the pavement, between a lane and the shoulder. Longitudinal joints normally do not have to accommodate movements as large as those at transverse joints, so they are usually more narrow.

Longitudinal joints are tied by incorporating tie bars into the pavement across the joints (3). The tie bars hold the slabs together and keep them in the same vertical plane so that very little strain is placed on a sealant. However, many pavements are designed with asphalt shoulders. It is impossible to tie asphalt into concrete and sealing the joints is a major problem.

1.5 Joint Movement

Joint movement may normally be classified as either horizontal or vertical. Horizontal movements are caused by shrinkage and climatic variations. Vertical movements are normally caused by vehicle loads and warping of the slabs. Pavement slab movement is investigated more fully in Chapter 5.

1.6 Required Joint Sealant Properties

A joint sealant should provide a watertight seal without allowing incompressibles to enter the joint for the life of the pavement system. The properties such a sealant should possess are listed and explained below:

(1) Impermeability to water - The sealant should not allow water to enter the joint.

(2) Toughness - The sealant should be able to resist incompressibles that are forced into the joint.

(3) Adhesive strength (bond strength) - The sealant must have enough bond strength to resist tensile forces when the joint is open.

(4) Cohesive strength - Tears should not form in the body of the sealant.

(5) Weatherability - The sealant should be able to withstand many years of extreme climatic conditions.

(6) Resilience - The sealant must be able to regain its original shape after repeated, long term extensions and contractions.

(7) Temperature stability - The sealant's modulus of elasticity and performance should not vary as the temperature ranges from its yearly low to about 40° above its yearly high.

(8) Insensitivity to preparation methods - The ideal sealant would be simple to prepare and place and would not be effected by dirty or damp joint walls (4).

Most of these requirements except the last one are met by today's joint sealing materials. In fact, all materials are very sensitive to joint cleaning and sealant installation procedures. The joint walls must be clean and dry or no sealant will adhere to them.

Overall, the slab dimensions and pavement design must be compatible with the sealant resevoir and the sealant properties.

1.7 Joint Sealant Failure

A joint sealant system is considered to have failed when any one of a number of conditions exist. These conditions include adhesive failure, cohesive failure, intrusion failure, extrusion failure, and impregnation of the sealant with incompressibles.

1.7.1 Adhesive Failure

Adhesive failure occurs when the sealant detaches from the joint wall due to tensile forces in the joint. Although most sealants develop adequate bond strength when joined with clean, dry concrete, all of them will fail during extension if the joint preparation is not carefully performed. Adhesive failure tends to occur intermittently along the length of the joint when joint preparation is not correct. Yet, even a short, 2-

or 3-inch long failure is enough to be detrimental to pavement behavior when water enters the system. Fig. 1.3 illustrates a typical adhesive failure.

1.7.2 Cohesive Failure

Cohesive failure is a tear in the body of the sealant which is also due to tensile stresses in the joint sealant. Yet, cohesive failure, unlike adhesive failure, will not occur because of inadequate joint preparation. Instead, cohesive failure occurs when the material is stressed beyond its tensile limit. Like adhesive failure, cohesive failure will allow water to enter the joint (Fig. 1.3).

1.7.3 Intrusion Failure

Intrusion failure begins when a sealant extends. As a sealant extends, it tends to neck down in the center. Dirt and debris then collect on top of the sealant. Finally, as the slabs expand and the joint contracts, the dirt is trapped within the sealant. The sealant may then fail during the following extension. Intrusion failure is most common when a sealant has relaxed during extension, that is, when the sealant does not possess adequate resilience to regain is original shape after long term extension or compression.

1.7.4 Extrusion Failure

Extrusion failure is most common when a joint has been resealed for maintenance reasons when the joint is open. As the joint closes at high temperatures, the material is placed in compression and the sealant either bulges or flows out of the joint. Once the sealant is higher than the pavement surface, it will be either flattened out onto the pavement or pulled out of the joint by passing vehicles. Then, when the joint again expands, there is not enough sealant left to properly seal it. The sealant may then fail as incompressibles puncture it or in either adhesion or cohesion (Fig. 1.3).

1.7.5 Impregnation with Incompressibles

Extremely high compressive stresses will develop in concrete pavements if the

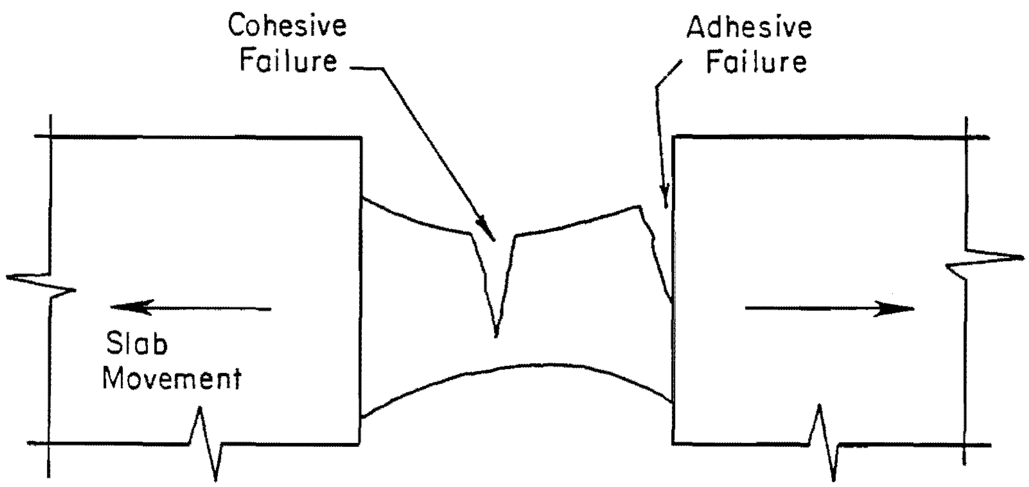

Fig. 1.3 Adhesive and Cohesive Joint Sealants

joints are prevented from closing because incompressibles have collected in the joints. Failure of the system will then occur as either the compressive strength or buckling strength of the pavement is surpassed. The sealant must have the ability to reject stones as they are pressed into the joint. This mode of failure is most common in sealants whose modulus of elasticity and resilience are significantly reduced at high temperatures.

1.8 Pavement System Failures

Each joint sealant failure will lead to one of several pavement system failures if left unattended. These pavement failures include random cracking of pavement slabs, pumping and the subsequent cracking or faulting of the slabs, crushing of the pavement slabs, pavement slab blow-up, and spalling at the joints.

1.8.1 Random Cracking

Random cracking of concrete pavements with 15- or 20-foot joint spacings usually begins when the normal contraction at the joints is immobilized, which results in a longer effective joint spacing. This "freezing" at a joint is usually due to the intrusion of water and de-icing chemicals into the system and the subsequent corrosion of the dowels. If a joint freezes, two 20-foot slabs behave as a 40-foot slab. This long slab must then crack to relieve tensile stresses. Random cracking may become very severe if the cracks are allowed to progress through the depth of the pavement. The cracks then begin to behave like unsealed joints and allow water to intrude into the system. Under the action of wheel loads, pumping, erosion of the base material, and further cracking then occur.

1.8.2 Pumping and Faulting

Pumping and faulting are two pavement failure modes that are closely related. As the pavement slabs curl at contraction joints and at pavement edges, the slab ends tend to lift off of the base material. Pumping occurs as the result of traffic passing over the curled slabs while water is present under the pavement at the joints. As vehicles approach the joint, the water and any dirt, debris, and loose subgrade material that are available are pushed beneath the leave slab. Then, as the wheels pass onto the leave slab, the water and material are pushed back under the approach slab. It is the buildup of material beneath the approach slab at a joint that causes the permanent vertical displacement of the approach slab relative to the leave slab, or fault. Also, consolidation of granular bases can occur and result in a fault.

The mechanisms of pumping and faulting have been well researched and many references are available to aid the pavement designer (1, 5, 6). It is very important that the designer not allow any excess free water to enter the system. A concrete/asphalt shoulder joint is especially susceptible to water intrusion. Also, the use of a cement or asphalt stabilized base is recommended over the use of a granular base so that fines are kept to a minimum.

1.8.3 Slab Crushing

The crushing of a pavement slab is due to the presence of incompressibles in a joint. When incompressibles enter an open joint, they do not allow the joint to close. If enough joints become immobilized, then the pavement will experience localized crushing at the joint.

1.8.4 Slab Blowup

Slab blowup occurs for the same reasons as pavement crushing. As compressive stresses increase in pavement slabs, the slabs actually buckle upwards at the joint. A study conducted at the University of Mississippi has shown that up to 80 percent of the states have experienced some form of pavement blowup (7).

1.8.5 Joint Spalling

The spalling of concrete pavement joints is not directly attributable to poor joint sealing, yet it adversely affects joint sealant and pavement performance. Spalling occurs when the upper or lower corners of a slab locally fail in shear at a joint.

When a large spall occurs on the upper corner of a pavement joint, the seal becomes ineffective and water may then enter the system. When spalls occur on the lower corner of a joint, the spalled concrete is then available as pumping and faulting debris if any water is present beneath the joint.

Resealing pavements with large spalls is nearly impossible. Even if the spalls are well cleaned and prepared to receive the sealant, the sealant will bond to the bottom and sides of the spall. The biaxial stresses induced in the sealant at joint extension, coupled with the contact of vehicle tires as they pass over the sealant reservoir in the spall cause the sealant to fail in adhesion. Therefore, large spalls in concrete pavements should be repaired before joint resealing takes place.

CHAPTER 2. JOINT SEALANT MATERIALS

This chapter was originally contained in Improved Methods for Sealing Joints and Cracks in Portland Cement Pavements by Mangum (8). It has been revised and expanded to reflect the changes in the joint sealant industry since the original report was published. Table 2.1 contains a summary of some common elastomeric sealants.

2.1 Polysulfide Sealants

2.1.1 Introduction

Polysulfide sealants were the first type of cold poured, elastomeric sealants to be used in highway work. The polysulfides currently used are competitively priced and possess properties in the good to intermediate range.

2.1.2 History

Polysulfide sealants were first introduced to the construction industry in 1952. They were immediately adopted by many states. However, many of the early installations of the sealants failed within a few years. Research and development have continued and today there are polysulfides which work well in pavement applications.

2.1.3 Formulation

Like most sealants, polysulfide sealants are composed of the base polymer, the curing agent, some fillers, and, in some cases, a plasticizing agent. Reinforcing fillers are added to strengthen the mixture. Fillers commonly used include carbon black, titanium dioxide, calcium carbonate, ground silica, and hydrated alumina. Acids tend to retard the cure of polysulfide sealants. Therefore, since clay fillers are usually acidic, they are not desirable for use with polysulfide sealants. Coal tar is also used as a filler for highway sealants. However, its only benefit is to lower the cost of the sealant.

TABLE 2.1 SUMMARY OF ELASTOMERIC SEALANT PROPERTIES*

	2-part Polysulfide Coal Tar	1-Part Silicone	2-Part Urethane Shore A 40-60	Hot-Poured Rubberized Asphalt**
Tensile Strength (psi)	60-125	60-150	250-600	NA***
Elongation (percent)	75-150	>800	200-350	600
Modulus at 100% elongation (psi)	50-150	10 - 30	100-150	5 -30
Shore A (initial)	35 - 50	15 - 20	40 - 60	15-20
Recovery after 100% elongation	50	83	75 - 82	80-90
Continuous service range (°F)	- 25 +210	- 90 +400	- 45 +275	-20 150
Solvent Resistance	very good	Excellent	Excellent	Fair
Aging Properties	good	Excellent	Excellent	Good
Usual Recommended Joint Movement	± 25	±50%	± 25	±12.5%

*Note: Since many references were used in the compilation of this report, the values in this table may not correspond exactly with those in the body of the report.

** At 77°F

***Not Available

The amounts of the major components of polysulfide sealants may be shown as

Liquid Polymer	100 parts
Reinforcing Filler	100 parts
Plasticizer	50 parts
Curing Agent	15 parts

2.1.4 Curing

Polysulfide sealants are supplied in both one-component and two-component systems. The two-component system consists of a component which contains the polymer, filler, and most of the plasticizer and a component which contains lead dioxide paste, which acts as the curing agent and the remainder of the plasticizer. The two components are mixed immediately before application of the sealant. The pot life is generally three hours, but it can be shortened to as little as ten minutes. Polysulfide sealants do not cure well at low temperatures and should not be applied at temperatures below 40°F.

The one component polysulfide system is more difficult to manufacture and more expensive than the two-component system. The cure of the one-component system is accomplished by the absorption of water from the atmosphere. A tough rubbery skin forms at the surface of the sealant, acting to slow the cure rate for the remainder of the sealant mass.

2.1.5 Properties

2.1.5.1 Odor. In the uncured state polysulfide sealants emit a very disagreeable odor. Therefore, when working with this material, adequate ventilation is necessary. However, after curing the sealant is virtually odor-free.

2.1.5.2 Solvent Resistance. One of the strong points of polysulfide sealants is solvent resistance. Polysulfide sealants have good water immersion resistance and are also very resistant to a number of organic solvents, oils, and a wide range of chemicals.

2.1.5.3 Toxicity. Polysulfide sealants have been tested and shown to be non-toxic and non-allergenic.

2.1.5.4 Hardness. By varying the type and amount of filler loading, the hardness of polysulfide sealants can be varied from Shore A values of virtually 0 to values in excess of 50. It should be noted that the polysulfide liquid polymer consists of a whole family of polymers and the amount of cross-linking in the polymer greatly affects the hardness of the sealant. The hardness of a polysulfide sealant also varies with temperature and tends to harden at cold temperatures. Polysulfides for highway joint sealing usually possess Shore A hardness values of between 20 and 40.

2.1.5.5 Aging and Weathering. The better polysulfide sealants exhibit good resistance to aging and weathering. Early polysulfides showed surface crazing or "alligatoring" after exposure to road dirt, traffic, and highway salt. However, the current polysulfides successfully withstand an exposure of more than one thousand hours in the weatherometer. Extended exposure to UV radiation will cause some surface crazing, but, in the higher grade polysulfides, these defects do not extend much below the surface. Several manufacturers report examples of polysulfide sealants functioning well, especially in longitudinal joints, for over five years.

2.1.5.6 Ultimate Elongation. As with its hardness, the ultimate elongation of polysulfide sealants can be varied over a wide range by varying the polymer, the filler loading, and the plasticizer. Laboratory specimens of polysulfide have been compounded with elongation values of over 1000 percent. However, these materials have virtually no shape recovery from such excessive deformations, and available materials are usually limited to 50 percent elongation or less.

2.1.5.7 Creep and Stress Relaxation. A polysulfide sealant when extended 50 percent will flow internally and relieve the resulting stress by as much as one-third in the first twenty minutes. The stress relief is a disadvantage because it is accompanied by a corresponding lack of recovery. Common recovery values of the polysulfide sealant are between 70 and 80 percent.

2.1.6 Summary

In a subsequent section, the properties of different sealants are compared.

2.2 Silicone Sealants

2.2.1 Introduction

Silicones are considered to be high quality sealants, and can be higher in price than other sealants commonly used in the construction industry. They are noted for their ability to withstand many years of exposure to a constantly changing environment and maintain their initial physical properties. Silicone sealants are available in several hardnesses. Low modulus silicones, with Shore A hardnesses of about 15, have had success in several states.

2.2.2 History

Silicone sealants were first introduced to the construction industry in 1960. The first silicone sealants evolved acetic acid during their cure. This acid reacted with the calcium of the concrete and led to uncertain adhesion between the sealant and the substrate. However, since the early days of development, several silicone sealants have been developed tht evolve neutral by-products, such as alcohol, amides, or amines, which do not react with the concrete.

2.2.3 Formulation

In the uncured state the silicone sealant material has three basic ingredients: long chain silicone polymer, curing agents, and fillers. The silicone polymer is formed by the reduction of silica sand. Fillers commonly used include calcium carbonate, clay, and ground silica. The sealant in the uncured state is quite workable and soft. Solvents are therefore not necessary, and the result is an almost 100 percent solid sealant. Consequently, shrinkage of the sealant after its placement is almost negligible and its shelf life is somewhat better than that of other one-component materials.

In the cured state, the polymer structure consists of alternating silicon and oxygen atoms. This polymer linkage is similar to that of glass and quartz. Silicone sealants are therefore transparent to ultraviolet radiation and virtually unaffected by weathering.

2.2.4 Curing

Silicone sealants are usually supplied as one-part packages containing the liquid silicone sealant material which cures to an elastomeric rubber. The curing process, often referred to as room temperature vulcanization, takes place upon the exposure of the sealant to atmospheric moisture. During the curing process the curing agent, also called the cross-linker, reacts with the silicone polymer, forming a continuous Si-O-Si network. By-products are simultaneously released.

2.2.5 Properties

2.2.5.1 Odor. The by-products released during the cure of silicone sealants may be either acidic or neutral. The acidic by-product, acetic acid, gives off a strong vinegar odor, while the neutral by-products, such as alcohol, amides, and amines, emit a musty odor.

2.2.5.2 Hardness. In the cured state silicone sealants exhibit exceptionally stable hardness over a large range of temperatures. They will maintain their rubbery property with less stiffening in the cold and less deterioration in the heat than the organic sealants. The hardness of the silicone sealant will seldom vary more than five points on the Shore A hardness scale over a temperature range of -40°F to +180°F even after extended exposure. A typical Shore A hardness for a high modulus silicone sealant material is 35. A low modulus silicone will have a Shore hardness of about 15.

2.2.5.3 Abrasion and Tear Resistance. Due partly to its high recovery, the high modulus silicone sealant is characterized by low tear resistance and low abrasion resistance. Silicone sealants have a typical tear resistance value of 40 lb/in. compared to values of 70 to 80 lb/in. for polysulfide and polymercaptan sealants.

However, low modulus silicones have tear resistances that are the same or higher than polysulfides and polyurethanes.

Silicones also have a low abrasion resistance. For this reason it is recommended that silicone sealant be recessed 1/4-in. to 1/2-in. (0.6 cm to 1.3 cm) below the road surface. In order to minimize or eliminate the possibility of spalling of the exposed joint edges, it is recommended that the edges be beveled and the sealant tooled to a concave or semicircular shape.

2.2.5.4 Aging and Weathering. The silicone sealants exhibit excellent weathering resistance. They can withstand many times the minimum one thousand hours in a weatherometer without any significant change in their physical properties. This is partially due to their excellent ultraviolet resistance.

2.2.5.5 Ultimate Elongation. Low modulus silicones have displayed ultimate elongations of 1200 percent. It is recommended, however, that the joint seal be designed for a maximum elongation of 50 percent because of the shape of the specimen and other field factors.

2.2.5.6 Creep and Stress Relaxation. The property that sets the silicone sealants apart from other sealants is their high recovery. Silicones will generally exhibit recovery values of between 90 and 100 percent after compression. Specimens compressed and held for one year may show recovery values of as much as 98 percent upon load removal. Because of its high recovery, silicone performs well in cyclic tension and compression tests.

2.2.6 Summary

In a subsequent section the properties of different sealants are compared.

2.3 Polyurethane Sealants

2.3.1 Introduction

The polyurethanes are considered to be high quality and competitively priced sealants with the characteristics of high recovery, good workability, and good adhesion. The properties of the polyurethanes are, in general, between those of the polysulfides and the silicones. However, one major difference between the silicones and the polyurethanes is that the silicones do not exhibit as great a stress relaxation and are, therefore, less resistant to puncture and tear propagation.

2.3.2 History

One of the problems experienced with the early polyurethanes was water sensitivity. When the urethane sealant was exposed to moisture prior to complete cure, bubbles would form in the sealant, thereby causing irregularities or large voids in its cross section. Newer polyurethanes avoid this type of distress. However, this problem is recent enough to still adversely affect the image of the sealant.

2.3.3 Formulation

Polyurethane sealants can be formulated in a variety of ways. Various organic constituents can be used to prepare the basic urethane polymer. The polyurethanes can also be prepared as a combination of sealants such as a polyurethane acrylic or polyurethane epoxy. A third compounding route entails blending and modifying the urethanes with fillers and plasticizers, as can be done with other elastomers. With the possibility of these three methods of compounding, the urethanes offer the widest possible range of sealant properties and also prove to be the lowest cost premium sealant on the market.

2.3.4 Compounding

In general, the formation of polyurethane sealants results from the combining of a isocyanate component and a hydroxyl component. Since these components are usually viscous liquids, mixing is relatively easy. However, mixing is critical. Since there is no diffusion cure in the urethanes they must be mixed thoroughly and uniformly.

2.3.5 Properties

2.3.5.1 Odor. Polyurethane sealants have not been known to cause any significant odor problems.

2.3.5.2 Solvent Resistance. The polyurethanes have very good oil resistance. However, they have only fair resistance to water immersion. For this reason the urethanes, especially one-component systems, must be applied to dry substrates.

2.3.5.3 Toxicity. Polyurethane sealants are neither toxic nor allergenic.

2.3.5.4 Hardness. Polyurethane sealants can be formed with the hardness required for traffic bearing joints. The variation of hardness with temperature for polyurethane sealants is between that of silicone and polysulfide sealants.

2.3.5.5 Abrasion and Tear Resistance. Because of their hardness properties, polyurethane sealants have very good abrasion resistance. The tear resistance of urethane sealants, which is also related to their hardness, is in the intermediate range for sealants.

2.3.5.6 Aging and Weathering. The better urethanes are generally considered good weathering sealants, although they have only fair resistance to water immersion. Polyurethane sealants will survive well over 1000 hours in the accelerated weathering chamber. They also show very little surface wrinkling and maintain their elasticity over long periods of time without excessive chalking or crazing.

2.3.5.7 Ultimate Elongation. The ultimate elongation of urethane sealants can be varied over a wider range than any other sealant. Polyurethane sealants have been shown to withstand 400 percent extension with portland cement concrete blocks before failing in adhesion (9).

2.3.5.8 Creep and Stress Relaxation. Polyurethane sealants display very little creep or flow and a high recovery value,70 to 90 percent, although not as high as that of the silicones. However, since recovery is almost inversely proportional to tear strength, the tear strength of the urethanes is better than that of the high modulus or low modulus silicones but not as good as the tear strength of the polysulfides. Urethanes can tolerate cyclic deformation of up to 50 percent for long periods without failure.

2.3.6 Summary

In a subsequent seciton, the properties of different sealants are compared.

2.4 Rubberized Asphalt Sealants

2.4.1 History

Hot poured materials have been used more often to seal joints and cracks than any other substance. The materials have been used since the early part of the century and have evolved into good quality, extremely inexpensive sealants. Like other classes of sealants, though, there are good and poor rubberized asphalts available.

2.4.2 Formulation

Initially straight asphalt was used as a joint sealer, it was not found to be durable. Recycled rubber from devulcanized tires was added and rubberized asphalts were developed. Today, the medium and lower quality rubberized asphalts are still made from used rubber, asphalt, plasticizers, and fillers. However, higher quality rubberized asphalts are made using virgin synthetic rubbers, such as neoprene.

Rubberized asphalts are hot-poured sealants and require strictly controlled heating practices. For example, if a rubberized asphalt should be heated to 400°F, then it should be kept at that temperature during installation. A temperature of 450°F will render the sealant useless. Also, rubberized asphalts may not be cooled after use and then reheated at a later time.

2.4.3 Properties

2.4.3.1 Odor. In the unheated state, rubberized asphalts have no odor. When heated, they smell like any other bituminous compound.

2.4.3.2 Toxicity. Rubberized asphalts are non-toxic materials.

2.4.3.3 Hardness. At 77°F, most rubberized asphalts have Shore A values that are comparable to other joint sealant materials used in highway work. However, they tend to become significantly harder at low temperatures and very soft at temperatures approaching 150°F.

2.4.3.4 Recovery. At room temperatures, rubberized asphalts show recoveries of 80 to 90 percent. Yet, at higher temperatures, they tend to flow and do not recover as well as most other sealants.

2.5 Preformed Compression Seals

2.5.1 History

Neoprene rubber preformed compression seals are the type of preformed seal most used in highway joint sealing. They gained popularity in the 1960's, after the first unsuccessful polysulfides and polyurethanes were introduced and failed. Other preformed sealants have been made using EPDM, silicone, and butyl rubbers, but these have not enjoyed the popularity of the neoprene seals. Preformed compression seals are the most expensive type of seal, but a properly intalled neoprene seal may perform well for 20 years or more. The most commonly used shape for preformed seals for highway joints is the chevron.

2.5.2 Installation

Preformed seals arrive ready to install. Typically, manufacturers require that they be supplied with the expected low and high temperatures at the site in order to select the correct size seal. The seal must have a recovery pressure of 3 pounds per square inch at the maximum joint width. A lubricant-adhesive is used to ease installation and assure adequate bond. However, the lubricant-adhesive has no true load carrying capacity by itself. Power operated machines capable of placing about 20 feet of seal per minute are currently available. These machines precompress the seal, coat the joint wall with lubricant-adhesive, and insert the seal into the joint. It is very important that the seal not be stretched during placement or it will not perform correctly.

2.5.3 Properties

2.5.3.1 Odor. Since the seals arrive fully cured, there is no appreciable odor.

2.5.3.2 Toxicity. Preformed compression seals are neither toxic nor allergenic.

2.5.3.3 Solvent Resistance. Although the seals have very high resistances to all types of solvents, the system is not completely water-tight. Therefore, it is very important that adequate drainage be provided by the base material.

2.5.3.4 Abrasion and Tear Resistance. The high hardness values of preformed seals, as compared to elastomeric sealants, make them the best at resisting puncture and tearing. Therefore, they are the best sealants at rejecting stones and other incompressibles.

2.5.3.5 Aging and Weathering. The preformed sealants possess excellent aging characteristics. De-icing chemicals and UV radiation generally have little effect on the performance of these seals.

2.5.3.6 Creep and Stress Relaxation. Early forms of compression seals usually failed due to poor compression set characteristics. The newer seals must pass ASTM requirements that call for at least 85 percent recovery after 70 hours at 212°F. However, if a compression seal is going to fail, it will probably be due to compression set. A related type of failure occurs due to the shrinkage of concrete slabs. When new pavement slabs begin to shrink, some joints crack before others. If the compression seals were designed for the unopened joint size, they may not be able to extend far enough to serve the full range of motion of the joints that were open when the seals were placed. Thus, like a compression set failure, the seals fail in bond. The active response in the formulations will affect the properties and the life, and the designer needs to assure that the seal will be able to serve the full range of motion required.

CHAPTER 3. LABORATORY TESTING PROGRAM

3.1 Materials Tested

The joint sealants used in the laboratory testing program were selected to provide a cross section of the many different sealant types that are available and most frequently used in practice. The tested materials include a silicone, a polysulfide, a polyurethane, a rubberized asphalt, and a preformed ethylene vinyl acetate material. Table 3.1 compares the physical characterisitcs of each material as quoted by the manufacturers.

3.1.1 Silicone Sealant

The silicone is. Dow Corning's low modulus 888 joint sealant. It is a one-part, gunnable sealant which requires no primer. This silicone has been used in many states and has proven very reliable when properly installed.

3.1.2 Polysulfide Sealant

The polysulfide is manufactured by A. C. Horn, Inc., under the name Horn-flex Traffic Grade. The sealant is a two-component, pourable, self-leveling material which requires a primer. It, as do the rest of the sealants, requires correct joint preparation and installation procedures to perform well.

3.1.3 Polyurethane Sealant

The polyurethane sealant is also manufactured by A. C. Horn, Inc. Its trade name is Daraseal-U. Like the polysulfide, this is a pourable, self-leveling sealant which requires a primer.

3.1.4 Rubberized Asphalt Sealant

The rubberized asphalt is manufactured by Allied Materials Corporation under the trade name 9002. It is a single component, hot-poured material which requires no primer.

TABLE 3.1. TESTED MATERIAL CHARACTERISTICS

Type of Material	Number of Components	Time to Full Cure (days)	Time at Which Traffic is Allowed (min)
Silicone[a]	1	7 - 14	10
Polysulfide[a]	2	4	60
Polyurethane[a]	2	4	60
Preformed Material	1	0.5[c]	60
Rubberized Asphalt[b]	1	when cool	when cool

[a]Cold-application
[b]Hot-poured
[c]For adhesive to cure

3.1.5 Preformed Ethylene Vinyl Acetate Sealant

The preformed sealant is Epoxy Industries' Evazote 50 material. The material is placed in a joint at 25 percent compression and is bonded to the joint walls using a two component epoxy manufactured by Epoxy Industries. This material has found extensive use in parking garages and short span bridge deck joints. It was included in hopes that it would provide an "upper limit" for both price and performance.

3.2 Laboratory Tests

The laboratory tests of the joint sealant materials were designed to determine the characteristics which effect the sealant performance in the field. The seven tests that were performed included a tensile test, a bond test, a penetration test, a flow test, a stress relaxation test, a compression set test, and a shear fatigue test.

3.2.1 The Tensile Test

The tensile tests were conducted on all the materials using a Tinius Olsen deflection controlled loading machine. The sealant samples were attached to concrete end blocks and these blocks were gripped and pulled apart. The loading rate was 1/2 inch per minute and the load was recorded at specific elongations until the material failed. Three samples of each material were tested at temperatures of 20, 72, and 130°F.

Since the sealants would be bonded to concrete joint walls in the field, it was felt that the tension test should be performed on each sealant "system" (sealant, binder, and concrete) rather than thin samples of the sealant material only. Thus, the load vs. elongation curves would give an indication of how each system would behave. A 1:1 thickness to depth ratio for the sealant samples was selected even though some manufacturers recommend a 1:2 ratio because the 1:1 ratio would more likely represent construction errors that would be detrimental to a system's tensile behavior.

3.2.1.1 Specimen Preparation. The specimens were prepared as shown in Fig. 3.1. The concrete end blocks were poured in 3 x 3 x 16- inch molds which were blocked off so that 3 x 3 x 5-inch blocks were obtained. The end blocks were released

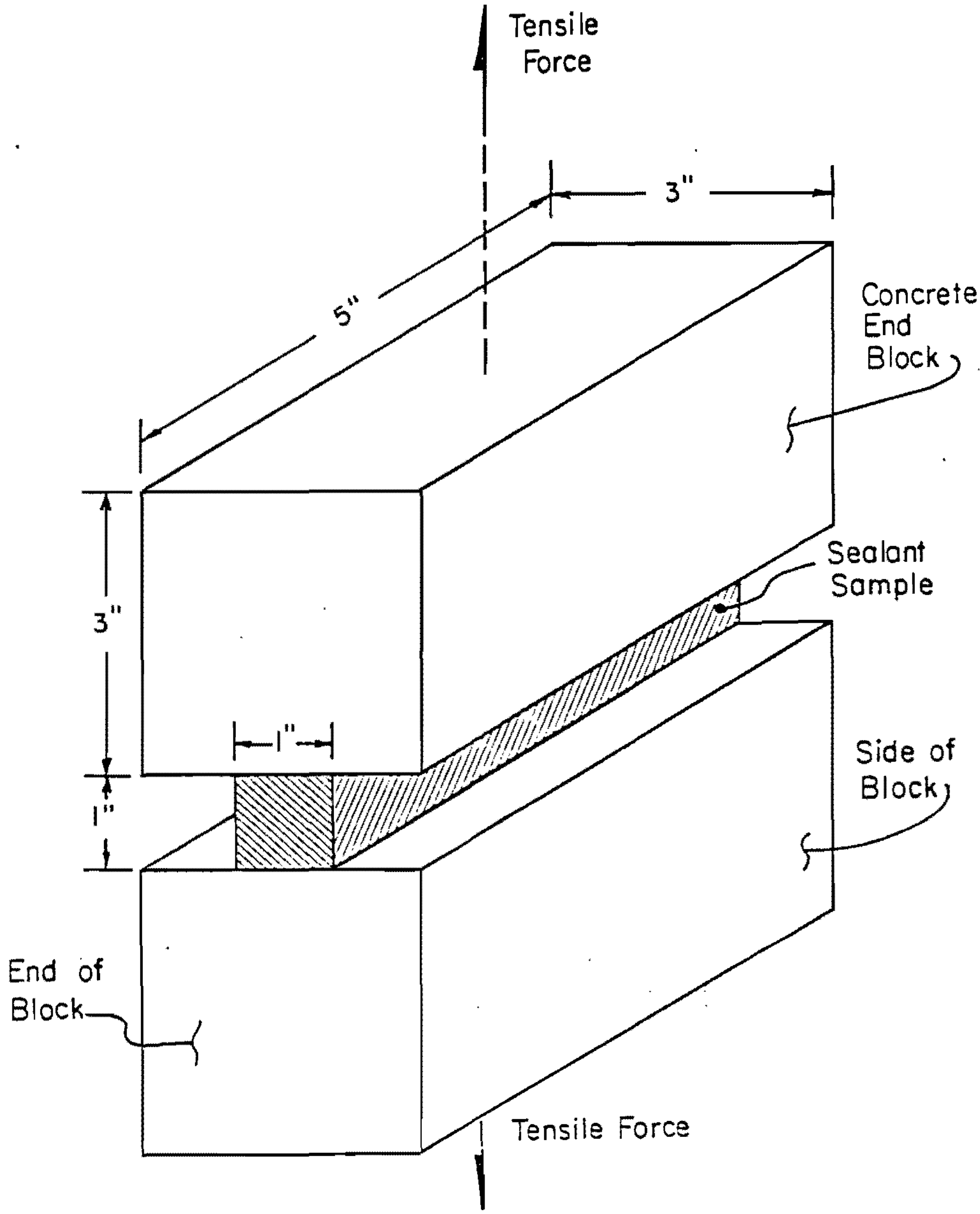

Fig. 3.1 Typical Specimen Used in Tensile and Stress Relaxation Tests

from the molds after 24 hours and placed in a curing chamber at 72°F and 100% humidity until needed. When a test was to be performed, the blocks were removed from the chamber, well-cleaned with a wire brush under hot water to remove any residue of release agent, and dried for at least 24 hours in a 160°F oven. Next, primer (if it was required) was appled to the blocks and allowed to dry. Two pieces of 1 x 1 x 5-inch square aluminum tubing were then treated with bond breaker and placed between the concrete blocks so that a 1 x 1 x 5-inch void was left for the sealant to occupy. The assembly was held together with rubber bands and placed on a steel plate that had also been treated with release agent.

Next, the sealant sample was placed in the mold. The polysulfide, polyurethane, and hot rubberized asphalt sealants were poured into the mold. The silicone, however, was a more viscous material and was placed 1 inch at a time using a 1 x 1 x 5-inch tamper to ensure that the mold was completely filled. To place the preformed sealant, only one aluminum tube was used and the block assembly was laid on its side. Then, the portions of the concrete blocks and sealant sample that were to be in contact with each other were treated with the epoxy binder supplied by the manufacturer. Finally, the preformed sealant sample was slid into place. All specimens were allowed to cure at room temperature for 14 days before testing.

3.2.2 The Bond Test

Bond tests as specified in ASTM D3408-78, "Standard Methods of Testing Joint Sealants, Hot-Poured, Elastomeric Type, for Portland Cement Concrete Pavements", were performed on the elastomeric sealers.

The bond test is a qualitative measure of a sealant system's slow, cold temperature extensive and warm temperature recompressive capabilities. The test is cyclic, with five cycles performed on cold-applied compounds and three cycles performed on hot-poured sealants. The rate of extension is 1/8-inch per hour to 1/2-inch (50 percent) total extension at 0°F. After extension, the samples are examined for failure as it is defined in the specification. Then they recompress from their own weight at room temperature for one hour. The test is performed simultaneously on three samples of each material.

The testing machine is shown in Fig. 3.2. It consists of a Dayton model 5K933A electric motor geared down so that a worm gear raises a threaded rod at the specified rate. The lower threaded rod is fixed to the base of the loading device. Two clamps hold the sealant samples in place. After extension, the lower threaded rod is released from the base of the apparatus so that the load is removed and the sealant samples may be taken out of the machine. The required 0°F temperature was maintained by placing the entire machine in a freezer at the correct temperature.

3.2.2.1 Specimen Preparation

Specimens were prepared in accordance with ASTM D3408. In each case, a 1 x 2 x 2-inch specimen is poured between two 1 x 2 x 3 inch mortar blocks. The system is extended in the one inch direction of the sealant sample so that 1/2 inch of extension is 50 percent.

3.2.3 The Penetration Test

The penetration test is a measure of a sealant's ability to resist the embedment of rocks and other incompressibles in the joint. This test is also specified in ASTM D3408. In the penetration test, a 150-gram cone is allowed to rest on a sample of joint sealant for 5 seconds. The penetration number is 10 times the number of millimeters that the cone sinks into the sample due to its own weight. Four readings were made for each material. The materials were tested at 77°F and 140°F after 8 days of curing and after 25 days of curing.

3.2.3.1 Specimen Preparation

Samples were placed in cylindrical molds 2-1/2 inches high, and 3 inches in diameter. They were cured in the laboratory at 72°F until the tests were made.

3.2.4 The Flow Test

The flow test is described in ASTM D3408. It is a measure of a sealant's tendency to flow at high temperatures. This test is especially significant for joint maintenance. If a joint is resealed when the joint is open, then at higher temperatures the joint will close and the sealant will be placed in compression. If a material tends to

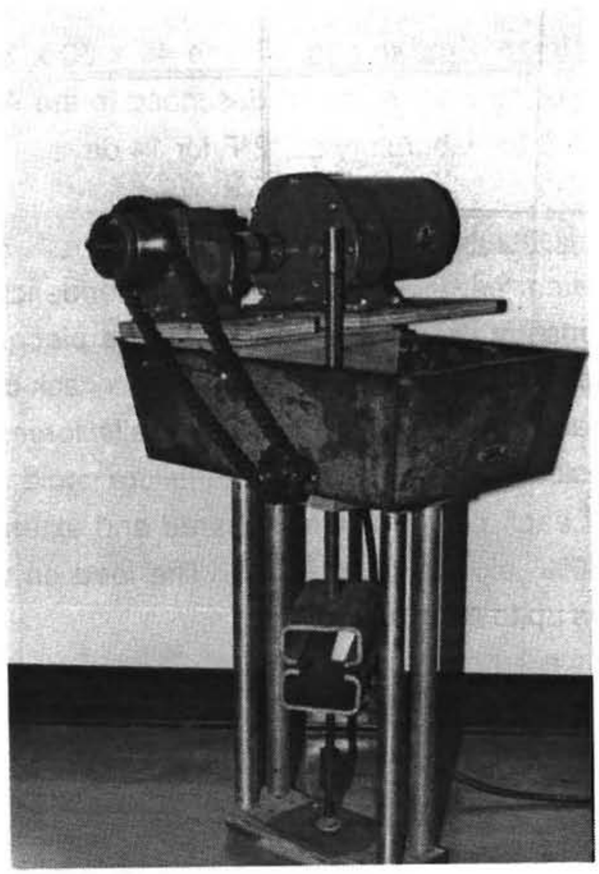

Fig. 3.2 Testing Machine Used for Bond Tests

flow at these elevated temperatures, it may extrude from the joint with failure occurring soon afterwards.

In the test, thin samples of a material are placed on a 75 degree incline at a temperature of 158±2°F. The flow is recorded as the number of millimeters the sample flows from its original shape.

3.2.4.1 Specimen Preparation. Three 40 x 60 x 3.2-mm samples were formed for each material using steel strips as described in the ASTM standards. The samples were then cured in the laboratory at 72°F for 14 days.

3.2.5 The Stress Relaxation Test

The stress relaxation test illustrates a sealant's tendency to relieve stress by "flowing" while under constant deflection. If a sealant is placed in a joint while it is closed, then, when the joint opens, the sealant will tend to neck down under the tensile forces. Then, if the sealant flows or relieves the tensile forces, it may tend to sag during the next compression cycle and an intrusion failure could occur.

Three samples of each sealant were prepared and extended at 10 inches per minute to a 1/2-inch (50%) elongation at 72°F. The load on the sample was then recorded at specific times up to 60 minutes.

3.2.5.1 Specimen Preparation. The samples used in the stress relaxation test were prepared and cured in the same manner as those in the tension tests (Fig. 3.1).

3.2.6 The Compression Set Test

The compression set test is a measure of a sealant's resilience, specifically, of the sealant's ability to regain its original shape after long-term compression.

Two 2 x 1-1/2 x 1/4 x 13-inch steel angles were used to compress three 2 x 1 x 1-inch samples of each sealant material. The two-inch faces of the angles were placed back to back with the sealant samples between them. Two 1/4-inch diameter bolts placed 3/4-inch from each end of the two-inch faces of the angles were used to compress the samples. Fig. 3.3 shows the experimental set-up with the sealant samples in place.

The samples were compressed to 1/2-inch or 50 percent for 24 ± 1/2 hours at 72°F. Measurements of the initial set of the sealants were taken immediately after the samples were removed from the apparatus. Then, the samples were placed in the laboratory and readings were again taken at 48 ± 1/2 hours after the samples had been released.

3.2.6.1 Specimen Preparation. Samples were prepared in the same manner as the bond test specimens, except that steel plates coated with bond breaker were used in place of the concrete end blocks. After 14 days, the 2 x 2 x 1-inch sealant specimens were removed from the molds and cut into 1 x 1 x 2-inch samples using a hot, oiled knife.

3.2.7 The Shear Fatigue Test

The shear fatigue test simulates the vertical movements of a dowelled joint as a truck passes over it. The test apparatus and loading pattern are briefly described here. A more in-depth description is available in reference 10.

The shear fatigue tests on joint sealant materials were conducted on the testing apparatus for a laboratory study of the behavior of reinforced concrete pavement slabs during cyclic vertical loading. A fatigue-rated loading actuator was used to deflect two pavement slabs. A dowelled joint connected the two slabs, held the sealant samples, and accomplished load transfer from the loaded slab to the non-loaded slab. Deflections of each slab were measured and recorded, and the difference represented the amount of shear present on the sealant samples in the joint.

3.2.7.1 Test Slabs. The test apparatus was designed as a half-scale model of two pavement slabs joined by a dowelled contraction joint. The pavement slabs were each 3 feet wide by 6 feet long by 4 inches deep. The transverse contraction joint was formed during pouring by using a 1/2-inch wide by 1-inch deep by 3-foot long wood strip as a block out. The dowels were placed at the joint location

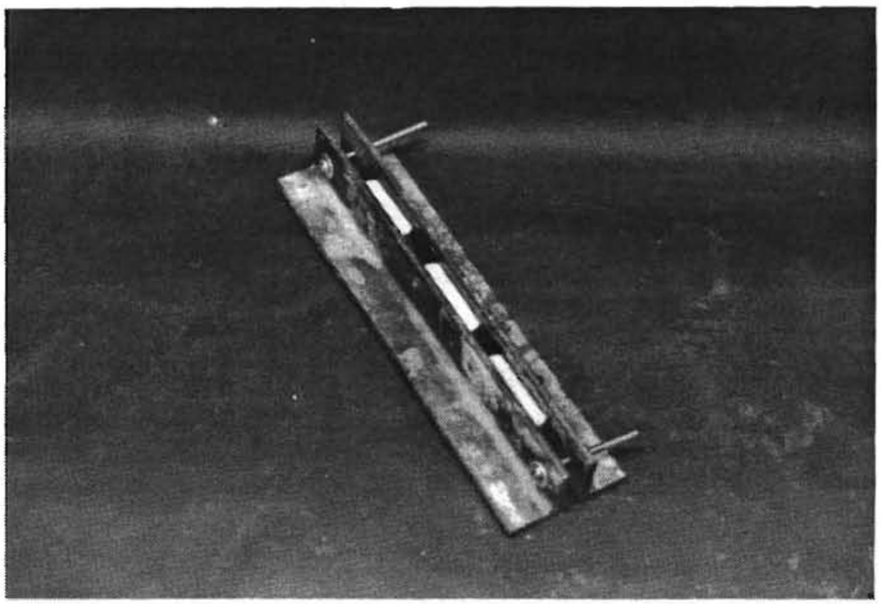

Fig. 3.3 Compression Set Apparatus

before pouring. They were placed at the mid-depth of the slab on 6-inch centers. The dowels were 1/2-inch in diameter. The slabs were placed in tension 24 hours after pouring. This tensile stress cracked the joint completely through the slab so that a working joint was formed. The crack width was 0.079 inch on the average.

3.2.7.2 Base Material. Six 1-inch-thick neoprene rubber pads with a durometer of 50 and a modulus of elasticity of 7,000 psi were used as a base material for the slab.

3.2.7.3 Loading Apparatus and Deflection Measurement. A loading plate 11 inches long by 6 inches wide by 1 inch thick was placed on the slab as shown in Fig. 3.4. Electronic deflection measuring devices, or DCDT's, were placed on the slab in the positions shown in the figure. The electronically controlled fatigue loading actuator was then connected to the base plate. The entire loading system was designed to simulate the stresses in a slab due to the passage of an 18,000 pound axle load over the joint.

3.2.7.4 Loading History. Two studies were made for each slab. First, only the pair of pavement slabs were loaded until failure. Then, the cracks in the destroyed slabs were repaired using a monomer system, and a 1-1/2-inch-thick concrete overlay was poured on top of the slabs. The overlay also had a joint in it, and the loading and deflection apparati were reattached to the overlay in the same positions as are shown in Fig. 3.4. Finally, the slab and overlay system were loaded until failure.

The load on the slabs and then the slab and overlay system was applied at five cycles per second until each set-up failed. Originally, the loads were cycled between 5,000 pounds and 500 pounds. The minimum of 500 pounds was used to reduce the impact on the hydraulics of the loading system. For each seperate system (slabs and slabs with overlay), the load was increased to 10,000 pounds to speed failure. For the system with only slabs, the load was increased to 10,000 pounds after 930,000 cycles. For the slab and overlay system, the load was increased to 10,000 pounds after 4,724,000 cycles.

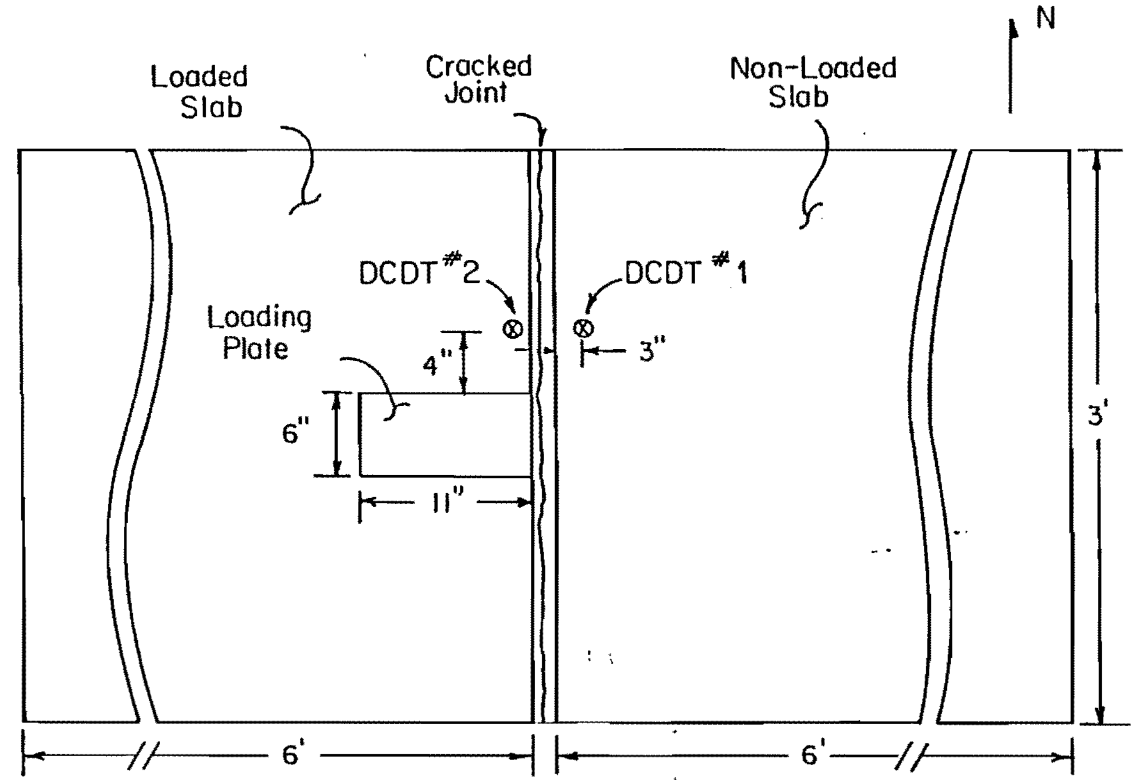

Fig. 3.4 Positions of Loading Plate and DCDT's #1 and #2 in Shear Fatigue Testing Apparatus

Deflections at DCDT's number 1 and number 2 (as shown in Fig. 3.4) were recorded continuously. The difference in deflection between DCDT 1 and DCDT 2 represents the amount of differential movement at the joint. These differences for both systems are plotted in Fig. 3.5. Although shear displacements in pavements with eroded subbases have been shown to be up to 2 times as large as the differential vertical deflections recorded here, these deflections are what may be expected to occur in a properly functioning pavement system.

3.2.7.5 Specimen Preparation. The sealant samples were placed in the joint after the concrete had cured for 7 days. Two samples each of silicone, polyurethane, polysulfide, and preformed material were placed in the slab joint first, and later in the joint in the 1-1/2-inch concrete overlay.

First, the joint was prepared using a wire brush and hot water to remove any foreign substances from the joint walls. Then, the joint was blown out with compressed air and wiped with a clean rag. After the joint had dried, a backer rod was placed so that each sample was 1/2-inch deep in the 1/2-inch-wide joint. Next, very thin wooden shims were placed in the joint to separate the sealants. Finally, the 1/2 x 1/2 x 4-1/2- inch samples were placed, using a primer when appropriate. Fig. 3.6 shows the schedule of placement in the slab and in the overlay. Figs. 3.7 and 3.8 show the base slab and overlay with sealants in place, respectively.

3.3 Results

3.3.1 The Tensile Test

3.3.1.1 Load vs. Elongation and Ultimate Extension. The tension test illustrates the load vs. elongation properties, ultimate extension, and modulus of elasticity for each system at low, room and high temperatures. The load vs. elongation curves and ultimate extension of each system at 20°F, 72°F, and 130° are shown in Figs. 3.9, 3.10, and 3.11, respectively.

At 20°F, the rubber asphalt material became very stiff and yielded only a small amount before it suddenly failed in adhesion. This lack of ductility shows that it may

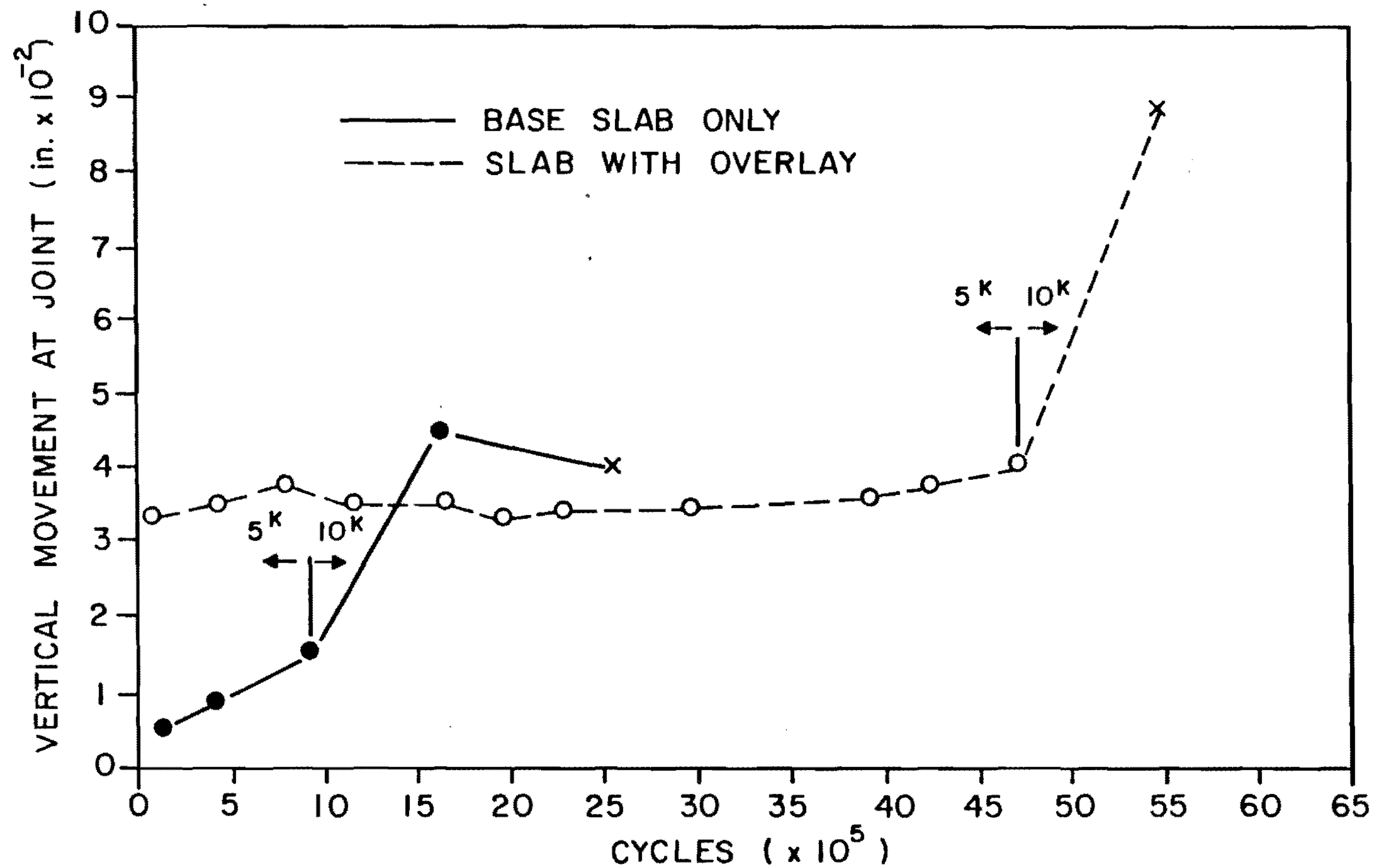

Fig. 3.5 Loading History for Shear Fatigue Test

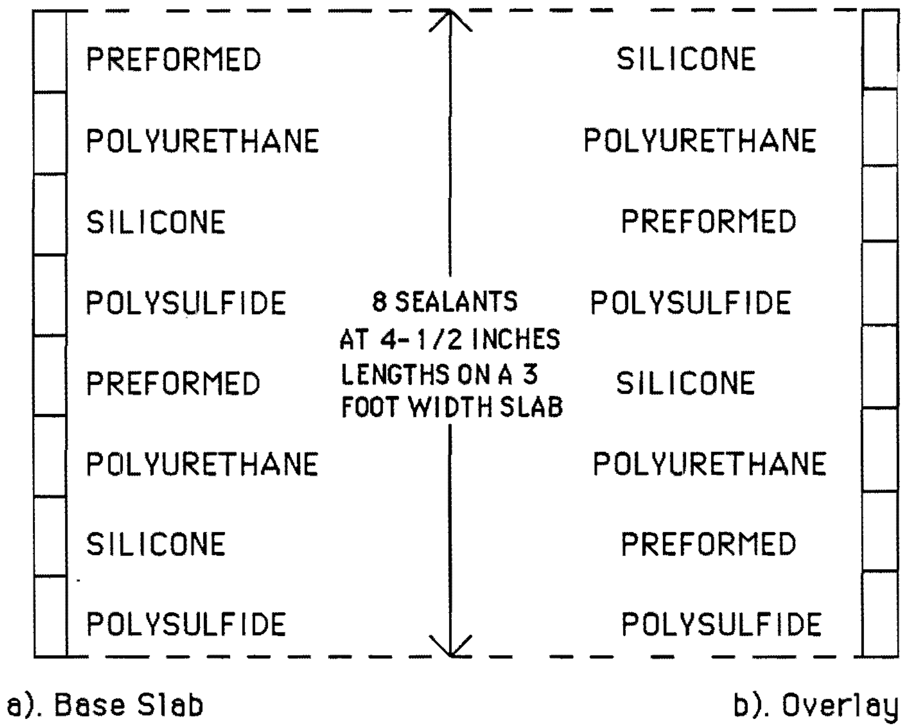

Fig. 3.6 Locations of Sealants in Base Slab and Overlay Joints for Shear Fatigue (Sealants separated from each other by 1/8" plywood.)

Fig. 3.7 Base Slab with Sealants in Place

Fig. 3.8 Overlay with Sealants in Place

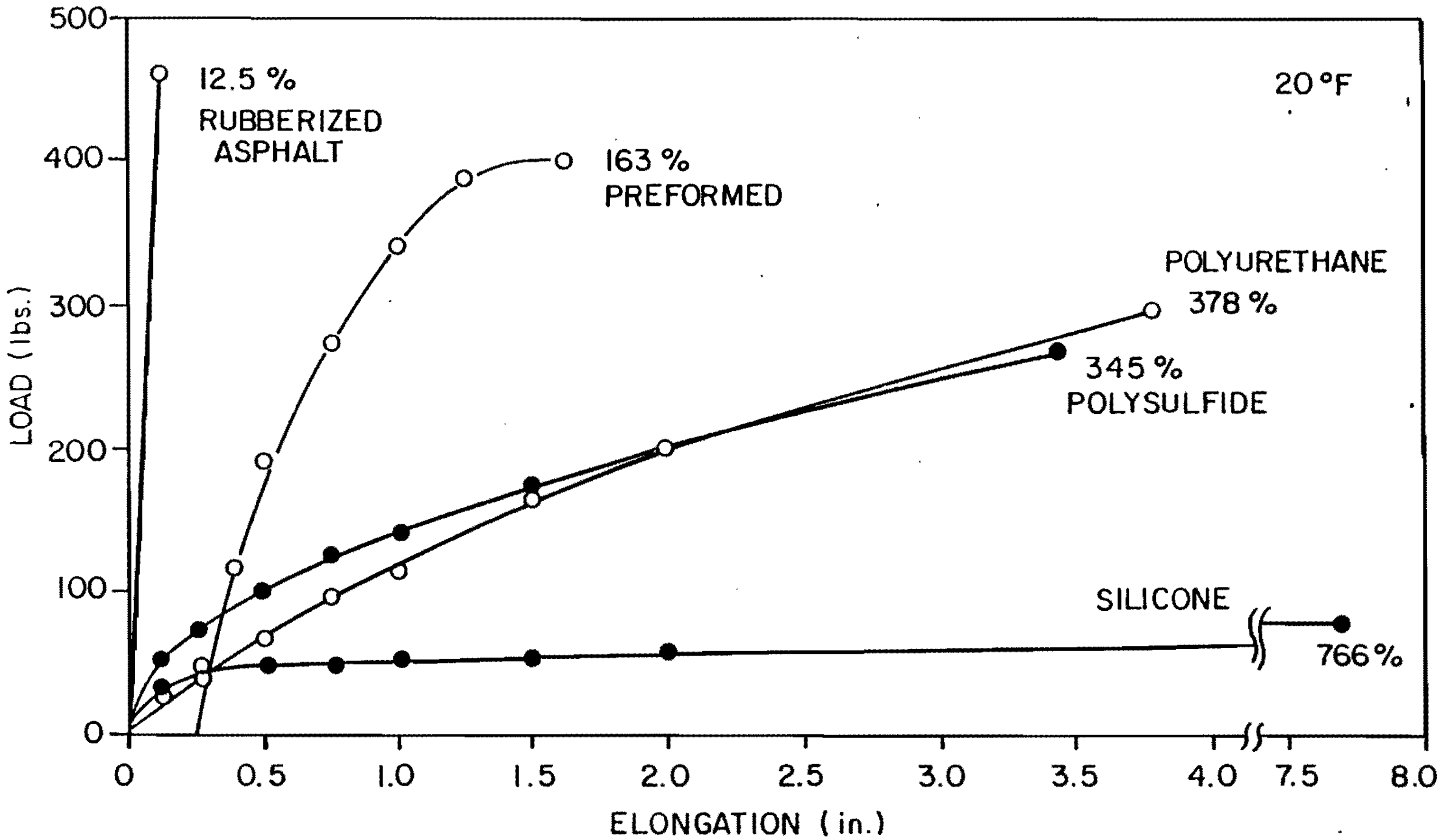

Fig. 3.9 Load vs. Elongation: 20°F

Gage Length: 1 in.

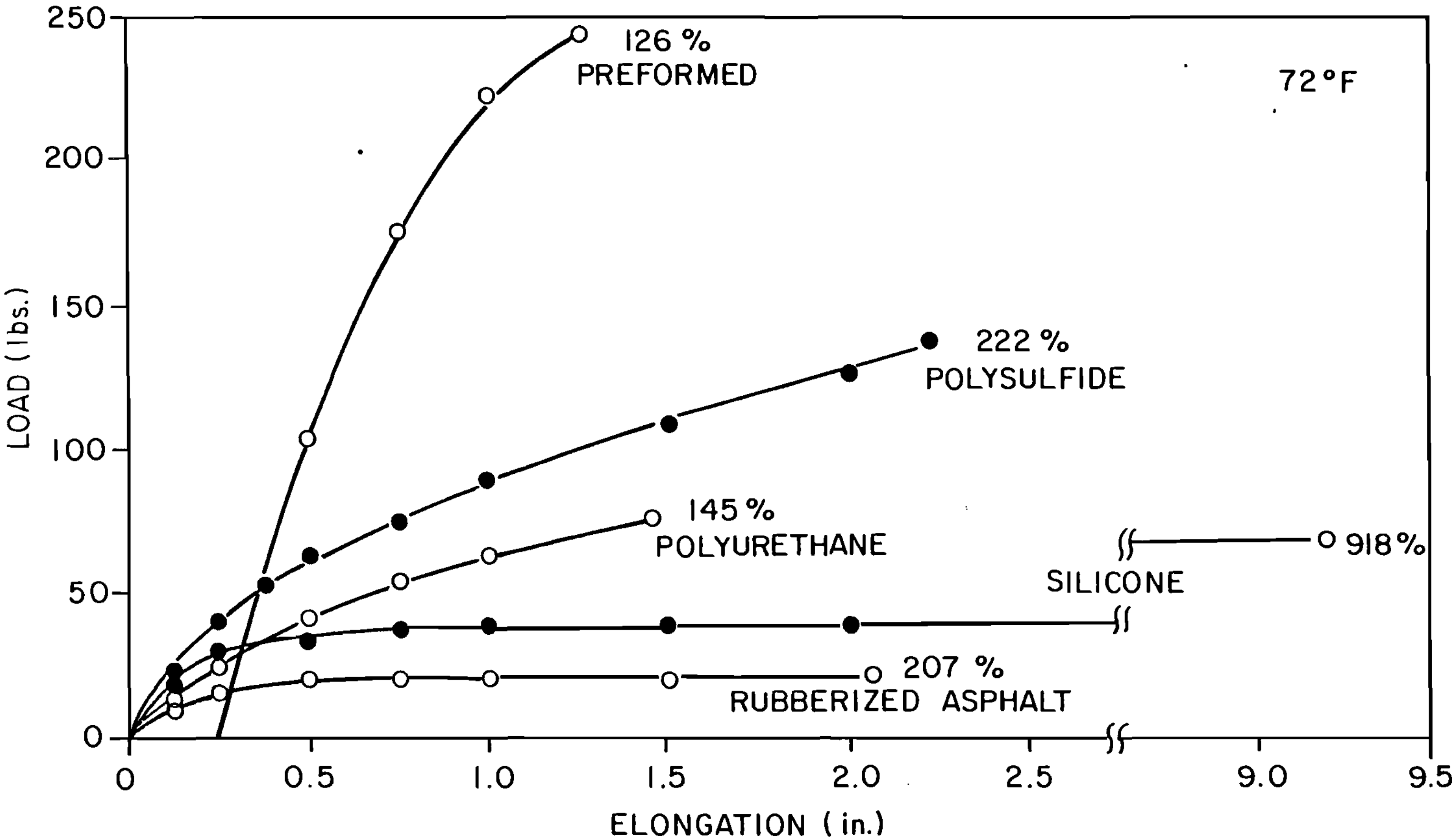

Fig. 3.10 Load vs. Elongation: 72^{0}F

Gage Length: 1 in.

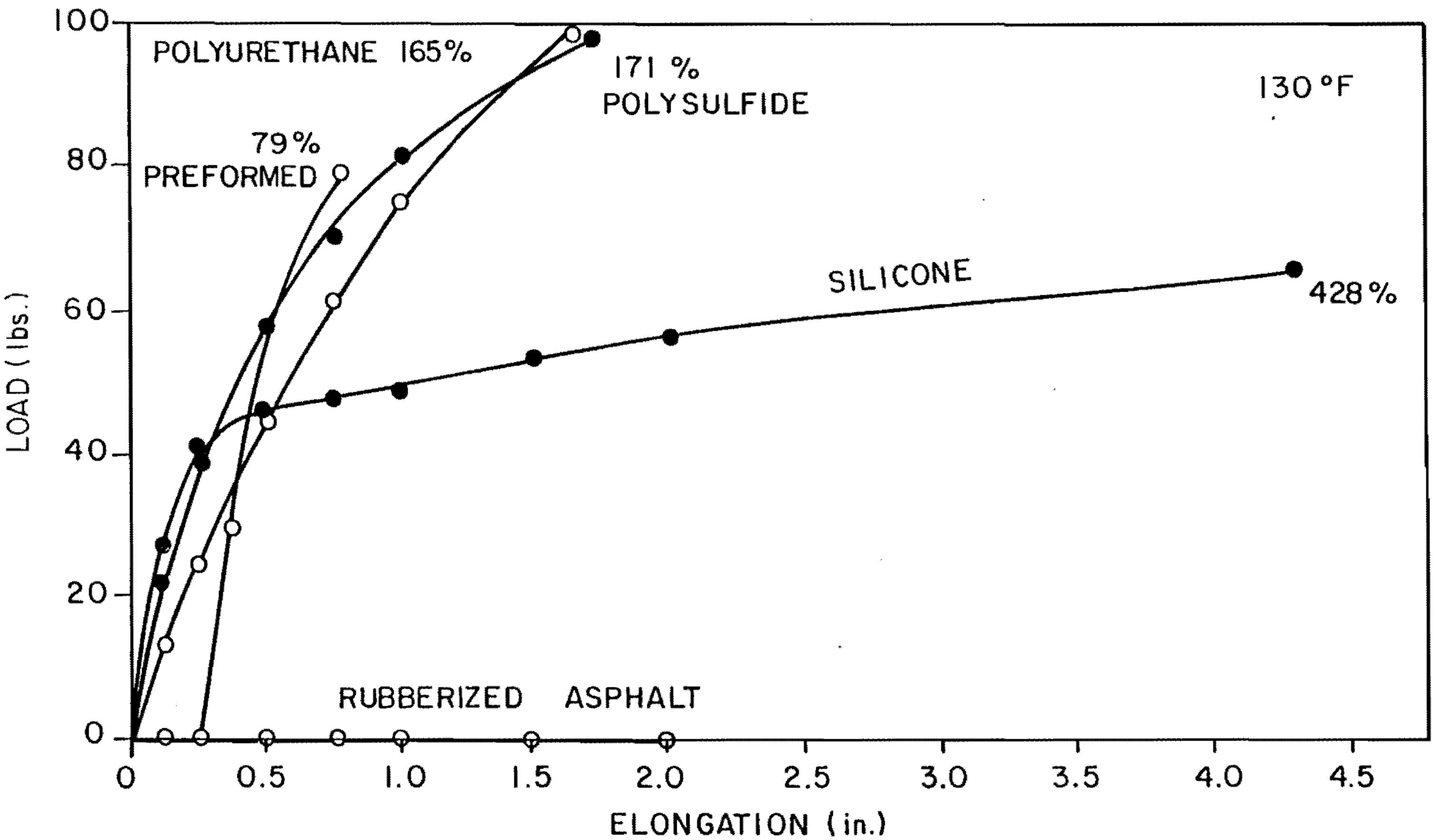

Fig. 3.11 Load vs. Elongation: 130^{o}F

Gage Length: 1 in.

not extend sufficiently when pavement slabs contract. Instead, adhesive failure would occur and water and incompressibles would be free to enter the joint. At 72°F, the rubber asphalt's stiffness, ductility, and ultimate extension were all acceptable. However, at 130°F, the material flowed before testing began, indicating a severe loss of stiffness. Thus, as pavement slabs expand at high temperatures, the material would tend to extrude from the joint and be flattened onto the pavement by passing vehicles.

The polyurethane and polysulfide materials showed somewhat similar characteristics throughout the tensile test. The polysulfide showed slightly more stiffness than the polyurethane and its ultimate extension capabilities were slightly greater than the polyurethane's. Both materials' properties were acceptable.

The silicone showed the most consistent and best performance in the test. Its stiffness during the first 200 percent elongation was nearly constant throughout the temperature range tested. Also, it showed ultimate extension capabilities far beyond what would be required for a sealant material, about 700 percent at 20°F.

The preformed material was under 25 percent compression initially and did not begin picking up load in tension until the elongation of the system was 0.25 inch. Its performance throughout the range of temperatures was adequte but seemed to be governed by the performance of the epoxy binder. For example, the failures at 20°F and 72°F occurred at extensions greater than 100 percent and were adhesive and cohesive in nature. Yet, failure at 130°F was adhesive only and occurred at only 80 pounds and 0.79 inch of extension. Thus, the bonding agent failed - not the sealant material. However, at high temperatures the sealant will most likely be in compression due to closing of the joint.

3.3.1.2 Modulus of Elasticity. The modulus of elasticity of each sealant system may be calculated at each temperature. The stress in the sealant is calculated by dividing the load in pounds by the original cross-sectional area of the sealant (5 square inches) (Fig. 3.1). The modulus is calculated at a strain of 50 percent, which is about the maximum that a joint sealant system would be expected to accomodate in the field. Table 3.2 shows the modulus of elasticity for each sealant system at 20°F, 72°F, and 130°F. Table 3.2 also shows the percentage of variation in modulus of elasticity for each system as the temperature changes from 20°F to 130°F.

Table 3.2 Summary of Moduli of Elasticity
at Different Temperatures

SYSTEM	MODULUS OF ELASTICITY (PSI) 20°F	72°F	130°F	% DIFFERENCE 20°F AND 130°F
Silicone	19.54	13.32*	18.0	8.56
Polysulfide	40.26	24.0	22.92	75.65
Polyurethane	25.48	15.92	17.52	60.05
Rubber Asphalt	184.0	7.4	0**	2,386.5***
Preformed	75.04	40.72	22.96	226.8

*Value is low due to voids in samples.
**System flowed before testing (Fig. 3.11)
***Calculated between 20°F and 72°F

3.3.2 The Bond Test

The bond test forms the backbone of the ASTM specifications for testing sealant materials. The first material tested, the silicone, failed during the fifth extension phase of the test. It was determined that the mortar end blocks were insufficiently cleaned before the sealant was placed. The mortar blocks were cleaned more carefully for subsequent tests.

With properly prepared end blocks, no debonding was evident for any of the materials after 5 extensions of the cold-applied sealants or 3 extensions of the hot-poured one. The silicone was retested and also passed the test. The rubber asphalt material, although required to undergo only 3 cycles, was tested to 5 cycles so that a direct comparison could be made with the cold-applied sealants. The material failed in the fifth cycle of extension.

3.3.3 The Penetration Test

Fig. 3.12 is a bar graph showing the penetration of the elastomeric materials at the two different ages and temperatures which were tested. In general, the penetrations of the polysulfide, polyurethane, and silicone materials were fairly consistent over the ages and temperatures tested. Only the hot-poured rubber asphalt lost its integrety as the temperature reached 140°F.

Surprising tendencies were demonstrated by the polyurethane. The penetration of this material actually decreases as temperature increased from 72 to 140°F. This property is also represented by an increase in the modulus of elasticity at high temperatures (Table 3.2).

The silicone is a one-part, atmospherically cured material. Thus, since the surface area to volume ratio of the penetration samples was very low (0.4 sq. in./ cu. in. for the penetration sample as compared to 8.0 sq. in./cu. in. for a 1/2-inch wide x 1/4-inch deep joint), much of the silicone sample was not completely cured at 8 days. Therefore, the silicone was tested only in the parts of the sample that had cured so that penetration values would relate more closely to those that would be attained in an actual joint.

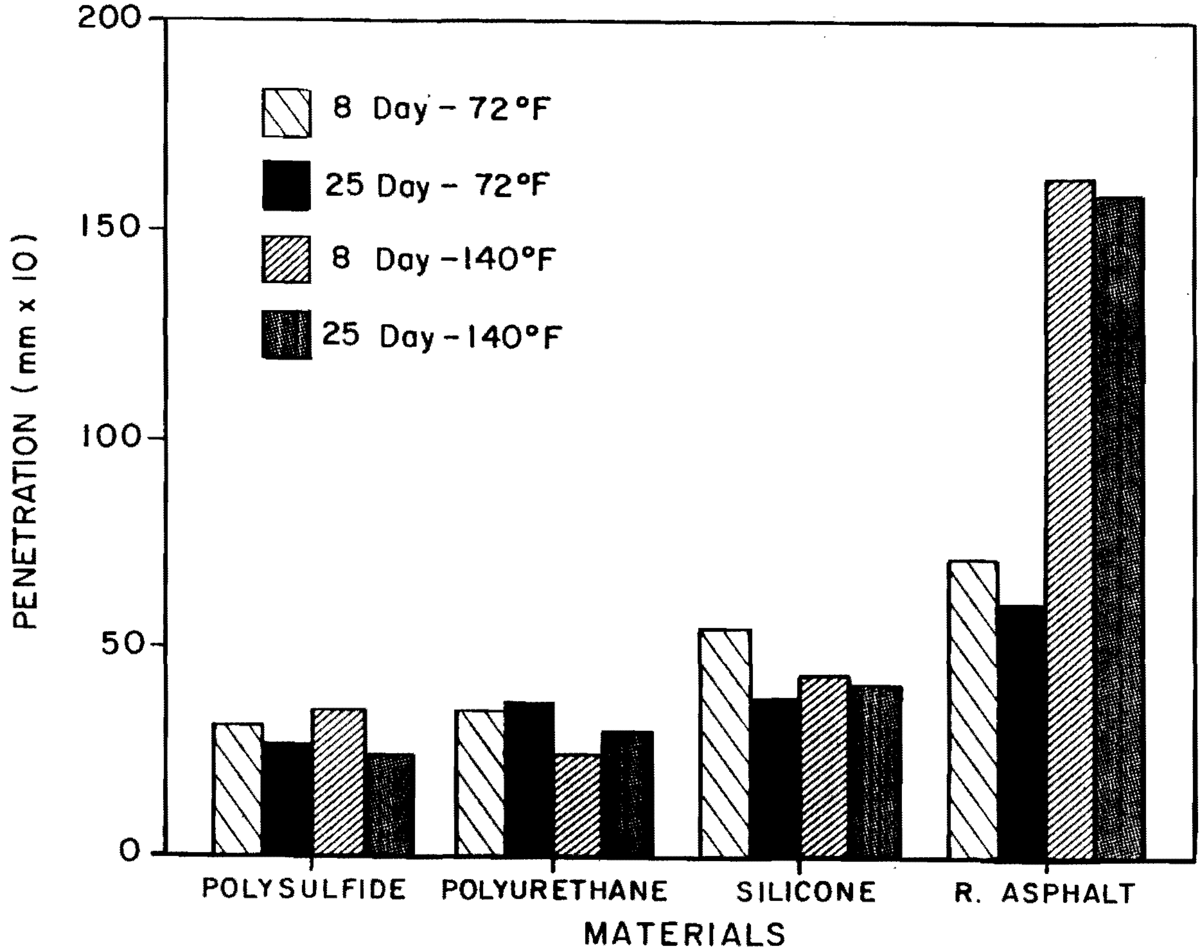

Fig. 3.12 Penetration Test

Penetration tests on several materials have been conducted by the Texas State Department of Highways and Public Transportation's asphalt testing laboratory in Austin. The tests were conducted on four hot-poured rubberized asphalt materials and two cold applied polysulfides at 77°F. Fig. 3.13 shows the penetrations of the materials tested by the asphalt laboratory. In Fig. 3.13, the polysulfides tested by the asphalt laboratory are designated as PS1 and PS2. These two polysulfides have significantly higher penetrations than the polysulfide tested under this report. However, the figure shows that all the rubberized asphalts have similar penetration values. Again, the rubberized asphalts which were tested at the asphalt laboratory are designated RA1, RA2, RA3, and RA4.

3.3.4 The Flow Test

Fig. 3.14 shows the results of the flow tests performed on the elastomeric materials in the laboratory at The University of Texas. All values of flow were zero except for the rubberized asphalt, which was 2.

Fig. 3.15 is a bar graph which shows the results of flow tests performed at the Texas State Department of Highways and Public Transportation's asphalt testing laboratory in Austin. These results compare two polysulfides, PS1 and PS2, a low modulus silicone, SI1, and four rubberized asphalt materials, RA1, RA2, RA3, and RA4. Again, the flows for the cold-applied sealants were zero, while the flows of the rubberized asphalt materials were between 1 and 2.

ASTM D3406 specifies that the flow should not be greater than zero. Thus, all materials except the rubberized asphalts, were within the requirements of the specifications.

3.3.5 The Stress Relaxation Test

The results of the stress relaxation tests are shown in Fig. 3.16. None of the sealant systems showed visible signs of failure at 50 percent elongation. The results of this test tend to agree with what one might expect from the results of the other tests. Namely, at 72°F, the rubberized asphalt shows the greatest tendency to relieve stress while the preformed material shows the least relaxation.

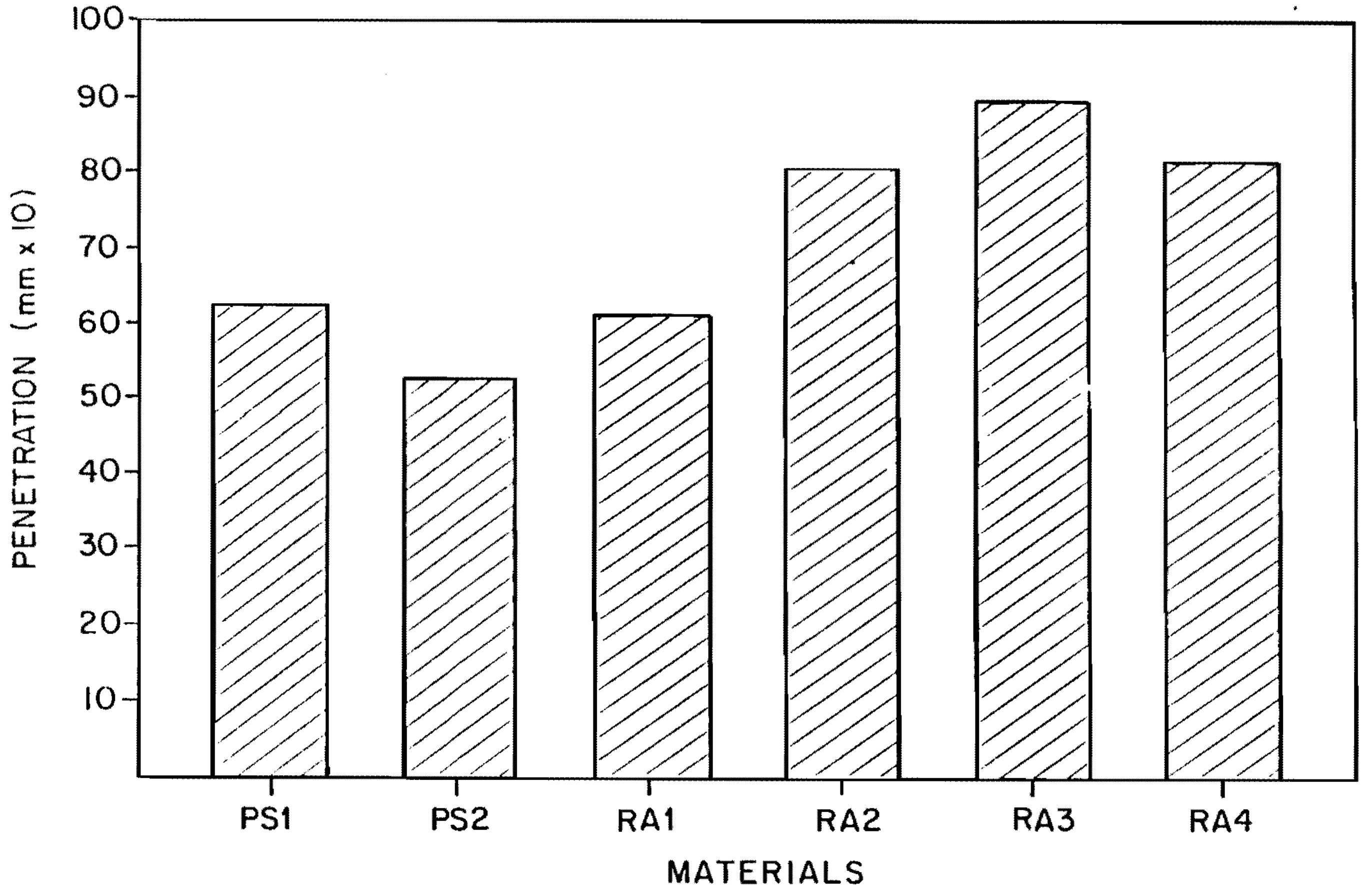

Fig. 3.13 Penetrations of Materials Tested at S.D.H.P.T. Asphalt Lab: 70°F

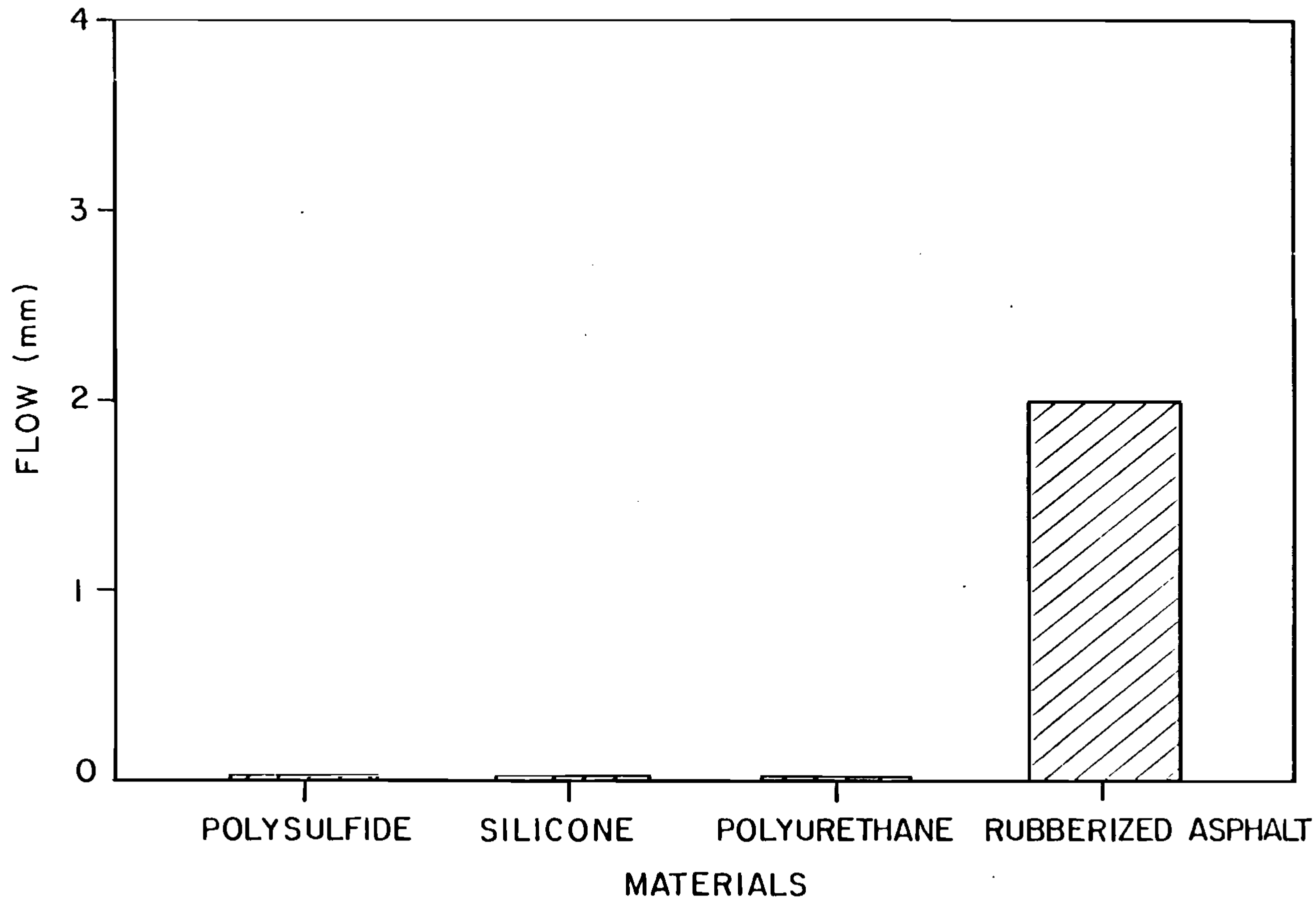

Fig. 3.14 Flow Test

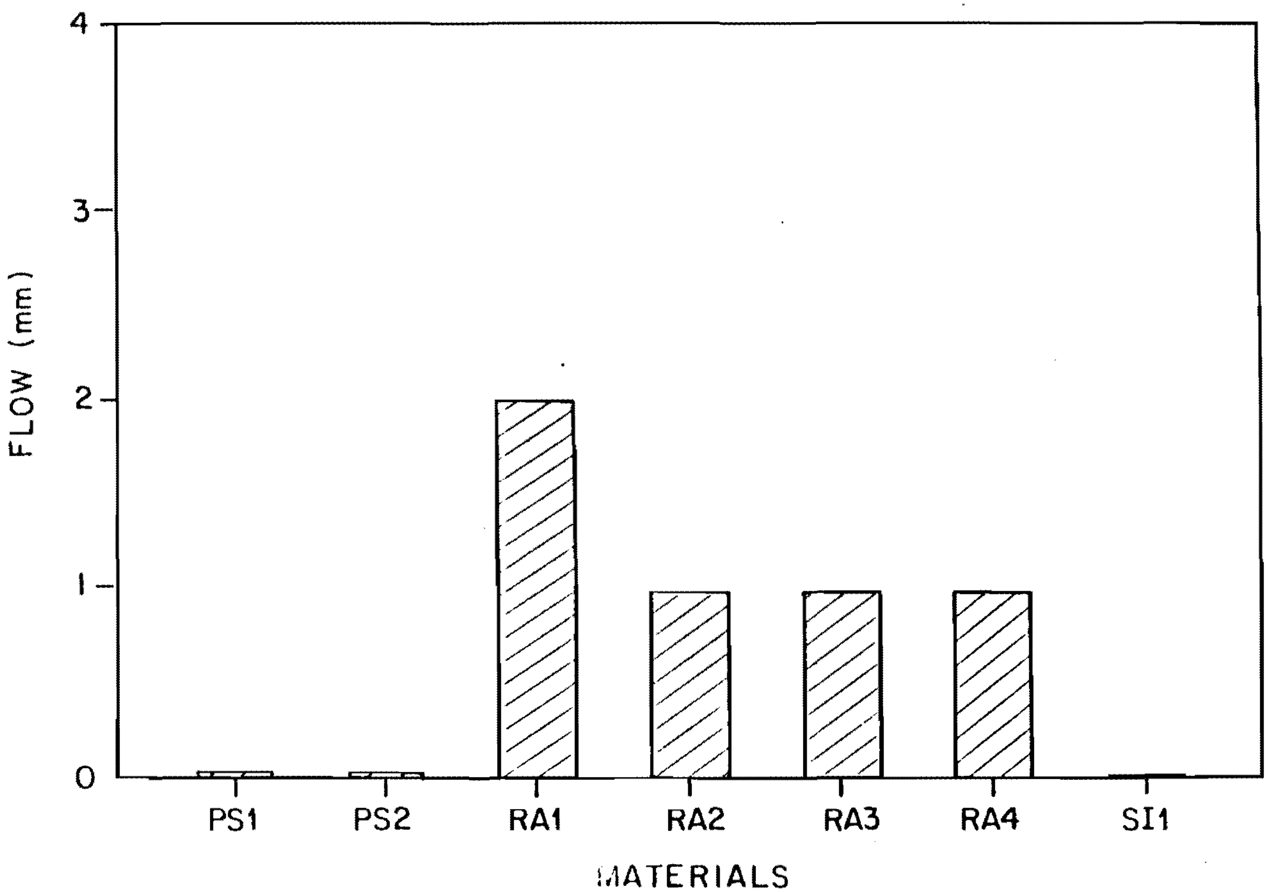

Fig. 3.15 Flow Tests by S.D.H.P.T. Asphalt Laboratory

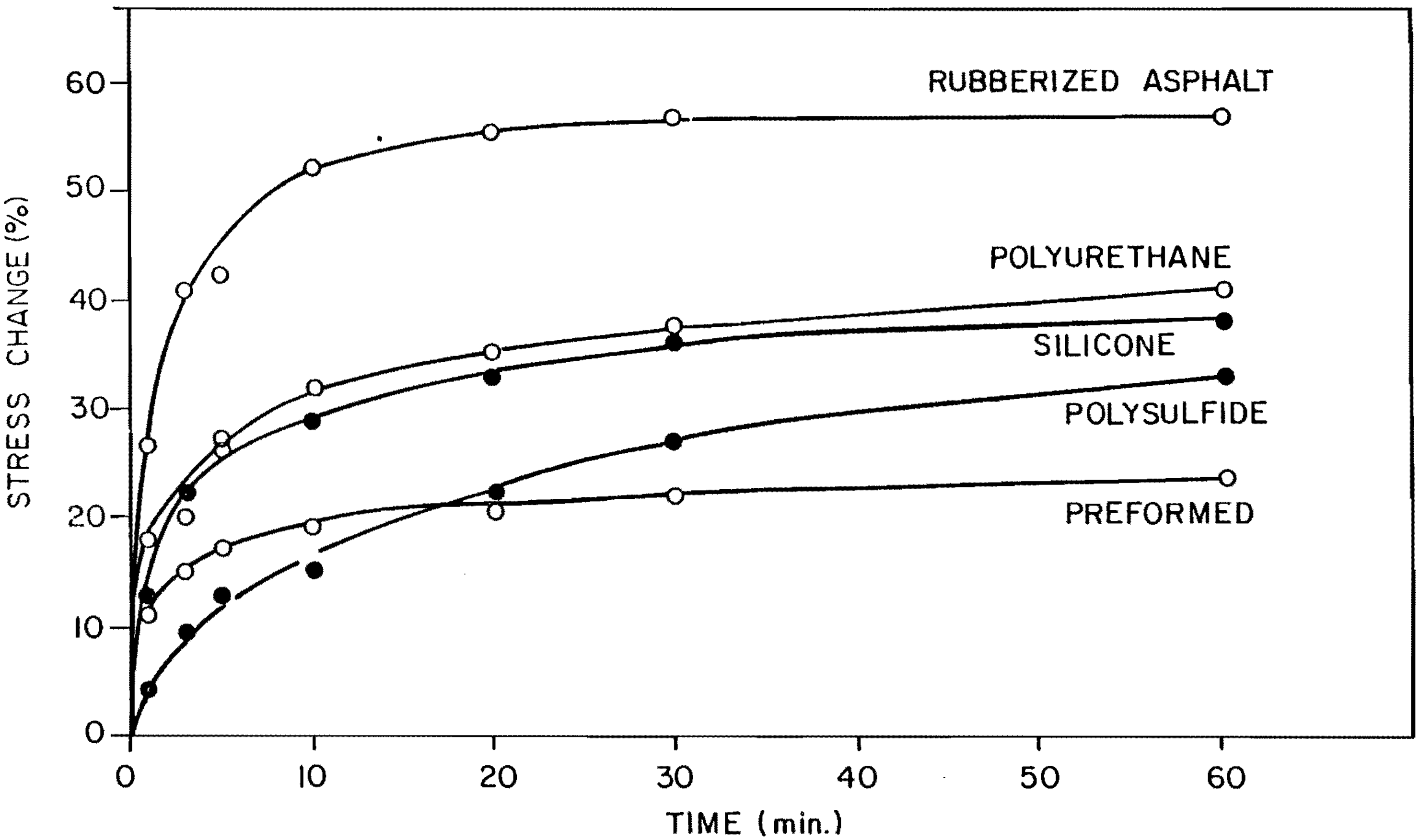

Fig. 3.16 Stress Relaxation Test: Stress Change vs. Time

3.3.6 The Compression Set Test

The results of the compression set test are shown in Figure 3.17. All of the materials showed very little compression set, except for the polysulfide. However, poor compression set characteristics are an expected shortcoming of this material. The preformed material showed excellent long-term recovery, which was surprising because its instantaneous compression set was surpassed only by the polysulfide.

The Austin Asphalt Laboratory of the Texas State Department of Highways and Public Transportation has also tested a polyurethane sealant for compression set. It is recorded as PU1 in Fig. 3.17. The stated value for PU1 is its compression set after 48 hours of recovery.

3.3.7 The Shear Fatigue Test

All the sealant materials performed excellently in the shear fatigue test. There were no visible failures in any of the samples tested.

3.4 Discussion of Specifications for Testing Joint Sealant Materials

An excellent critique of the specifications for joint sealant materials is given by Panek (25). Yet, a comprehensive specification for methods of testing sealant materials needs to be developed. Such a system would test the joint sealant system over a wide range of conditions in order to predict its behavior in the field. A comprehensive specification should be written for all elastomeric highway pavement joint sealants, since they all perform the same tasks.

3.4.1 ASTM Requirements

The material requirements for the tests outlined in ASTM D3408 are specified in ASTM D3406-78, "Standard Specifications for Joint Sealants, Hot-Poured, Elastomeric-Type, for Portland Cement Concrete Pavements." The specification includes requirements for safe heating temperature, penetration, flow, bond, resilience, artificial weathering, and tensile adhesion.

Although these requirements cover nearly the full range of properties a sealant must possess, they are somewhat limited in scope. For example, the penetration, resilience, and tensile adhesion properties are all tested at 77°F. Yet, stones are more

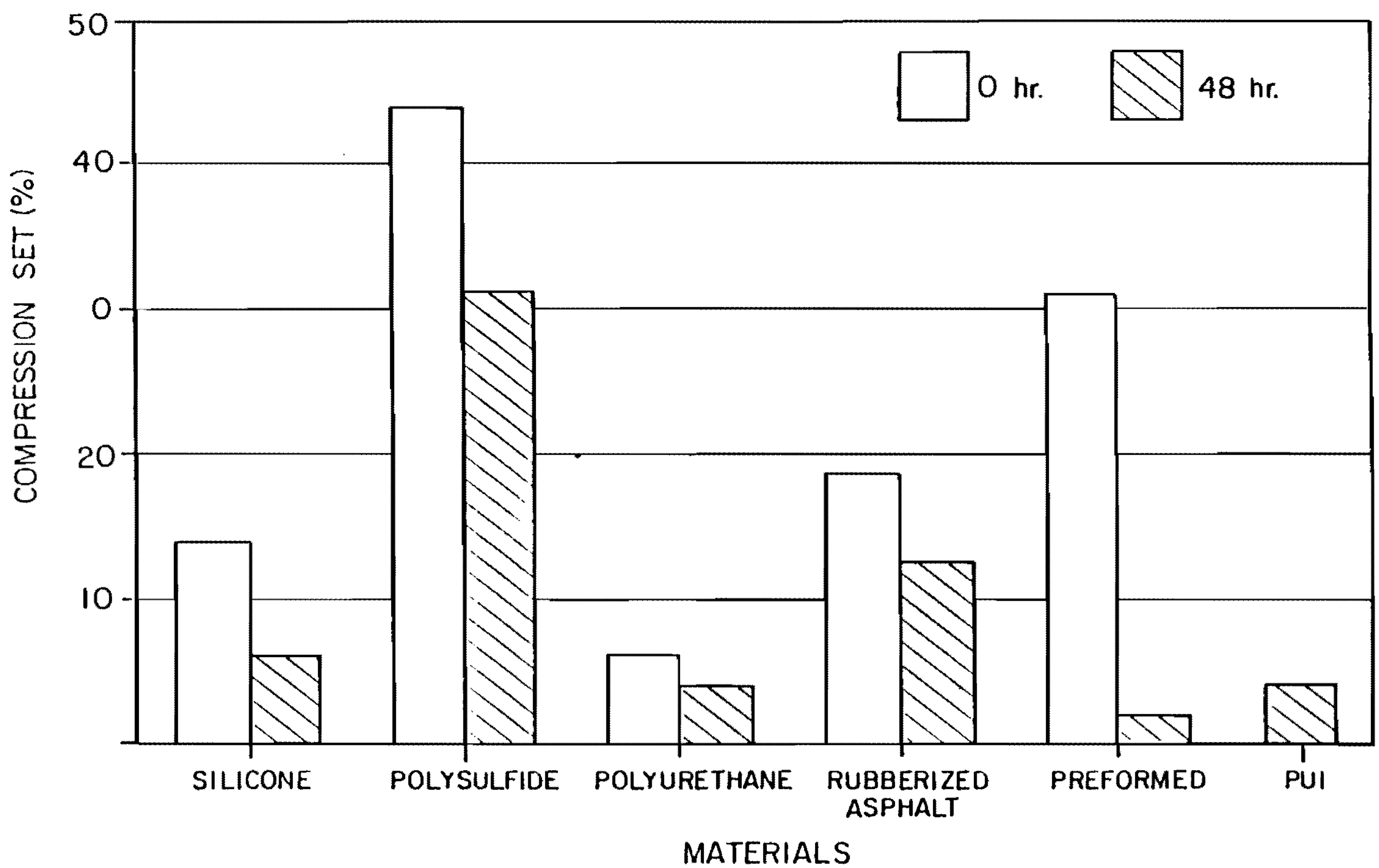

Fig. 3.17 Compression Set

likely to be embedded in a sealant if it gets softer at high temperatures. The penetration and resilience tests, then, should be conducted at high temperatures as well as at room temperature. Performing the tensile adhesion test at low, room, and high temperatures would indicate how a sealant's stiffness varies as temperatures change. It is very important to remember that when a sealant is first placed (usually near 77°F) it is unstressed. A sealant becomes highly stressed only when temperatures or other climatic factors are at their extremes. Thus, laboratory studies should test joint sealants at these climatic extremes if they are to accurately predict a sealant's field performance.

CHAPTER 4. FIELD TESTING OF JOINT SEALANTS

4.1 Introduction

Many field studies of many different joint sealant materials have been conducted over the years. The field studies for this report were divided into three phases. The first phase included the installation and observation of two sealant materials near Dallas. The second phase included observations of in-place joints and materials at various places in Texas and Oklahoma. The final phase included comparing the results of several studies which have been reported in the literature.

4.2 Field Installation, I-30 East, Dallas

In March, 1986, test joints were placed at a new pavement construction site on I-30 East, near Dallas. A map of the location is included in Appendix B. Twelve transverse contraction joints in the east-bound lane were sealed in a pavement that had been placed and sawed several weeks earlier.

The first four joints, numbered West to East, were sealed with polysulfide. The next eight joints were sealed with low modulus silicone. All joints are doweled and are 3/8 inch wide, 38 feet across lanes, and spaced 20 feet apart.

4.2.1 Joint Preparation

Since the joints were sawed several weeks before sealing, it was necessary to remove dirt and incompressibles that had been deposited in the joints by construction vehicles and runoff. Therefore, the joints were water blasted and blown dry with air.

The water blasting of the joint faces was accomplished by making two passes on each joint - one for each joint face. Fig. 4.1 shows that the nozzle of the spray gun was held to within 6 inches of the joint. After the joints were water blasted, compressed air was used to dry them. The air hose was held 1 to 2 feet from the joints. Fig. 4.2 shows the air drying operation. The next step was to install backer rod at the proper depth. A small, aluminum wheel mounted on a handle was used to roll the backer rod into place. Fig. 4.3 shows the backer rod installation. Finally, the joints that were to receive polysulfide were primed.

Fig. 4.1 Water Blasting Joints

Fig. 4.2 Drying Joints with Compressed Air

4.2.2 Sealant Installation

4.2.2.1 Polysulfide Sealant. The two-component polysulfide was mixed by hand for 10 minutes, until it was a uniform color. It was poured into the joints using small buckets with spouts that allowed the sealant to be placed without spilling it. The joints were filled to within 1/4 inch of the surface (3/8-inch depth).

The first four joints were filled. The only imperfections that were present in the joints were two large spalls in joint number 1. It was impossible to completely fill these spalls because the pourable polysulfide ran beneath the backer rod and into the crack beneath the joint.

4.2.2.2 Silicone Sealant. The silicone was placed in joint numbers 5 through 12. A pump supplied by Dow Corning was used to place the sealant. Fig. 4.4 shows the installation of the silicone. The sealant was placed even with the pavement surface and then tooled with small pieces of backer rod to a concave shape. Fig. 4.5 (a) and (b) show the tooling process.

Joint number 5 was primed for polysulfide, but there was not enough sealant to fill the jont, so silicone was used in its place. Joint number 7 had some tar on one joint wall, about 6 feet from the north end of the joint. It was impossible to remove the tar by water blasting, so the tar was scraped off the wall as well as possible. However, the silicone was not expected to adhere there. There were no problems with the remainder of the joints.

4.2.3 Performance

The initial observation of both sealants was made in July, 1986, four months after installation. Neither sealant had shown any failures as of that time. The polysulfide was holding well in the partially filled spalls in jont number 1. Also, the silicone was well-bonded at the position in joint number 7 where tar covered one joint wall.

4.3 Joint Observation Program

In an effort to evaluate the performance of different sealant materials, several

Fig. 4.3 Rolling Backer Rod into Place

Fig. 4.4 Placing Silicone Sealant

(a)

(b)

Fig. 4.5 Tooling Silicone Sealant

qualitative field observations of in-place sealants were made during the study. The materials and joints which were observed included two low modulus silicone sealants in Dallas, two silicones in Oklahoma City, a rubberized asphalt in Dallas, a rubberized asphalt in Laredo, and an emulsified latex in Fort Worth. The data sheets and maps of the locations may be found in Appendix B.

4.3.1 Silicone Sealants

4.3.1.1 Loop 12, Dallas. The first observation site is located in the right-hand, east-bound lane of Loop 12 (Ledbetter Drive) at the Polk overpass in Dallas. Twelve test joints of Dow Corning's silicone 888 were placed in 1979.

The sealant was first observed in November, 1985. A follow-up observation was made in July, 1986. The results from both observations are typical of most silicones that were studied. Even after 7 years, bond was excellent, with a total of only about 5 percent showing failure. There was no extrusion, intrusion, or incompressible embedment. At the time of placement, several large spalls existed and were filled with sealant. Portions of the sealant in all the spalls had come unbonded. In general, the performance is excellent for a 7-year-old sealant.

4.3.1.2 I-30 East, Dallas. Twenty test joints on I-30 were sealed in May, 1984, using General Electric's primerless SCS4400 low modulus silicone highway joint sealant. The first twelve of these joints, numbered from West to East, have been observed on three occasions: first in January, 1985, next in November, 1985, and finally in July, 1986. These joints were sandblasted and then cleaned with compressed air before sealing.

At the time of the first observation, only joint number 11 showed any failure. Intermittent adhesive failure occurred along the length of the joint. The second inspection revealed a small cohesive failure in joint number 5. The final inspection showed one more small, unbonded area. Overall, the sealant is performing excellently. Fig. 4.6 shows one of these joints.

4.3.1.3 I-44 East, Oklahoma City. These joints were observed in February, 1986. The sealant is Dow Corning's 888. At the time of observation, the sealant was 6 months old. All joints were in excellent condition, and no failures of any kind were visible.

4.3.1.4 I-240 West, Oklahoma. These joints were sealed with General Electric's primed 2342 silicone. They were observed in February, 1986. The joint sealant was installed in 1984. No adhesive, intrusion, extrusion, or embedment failures were visible upon inspection. However, the sealant seemed to be bubbling in the joint. In general, it is performing well.

4.3.2 Rubberized Asphalt Sealants

4.3.2.1 I-30 East, Dallas. Directly adjacent to and east of the G.E. Silicone test section, seven joints sealed in 1984 with an Allied Materials rubberized asphalt were studied. This sealant was the standard material used to seal the I-30 new pavement project. Joint preparation included simply blowing out the joints with compressed air. The joints have been observed twice: once in November, 1985, and again in July, 1986.

At the time of the first observation, the sealants had experienced up to 40 percent adhesive failure in some joints. Incompressibles were embedded in up to 10 percent of the joints' lengths. By July, 1986, the condition of the sealant had deteriorated. The adhesive failures had increased only slightly, but the sealant had experienced serious intrusion failures. In several places, the sealant had extruded and been flattened onto the pavement. Also, the incompressible embedment had increased, and up to 60 percent of some joints' lengths were embedded. The performance of this sealant is very poor, especially for a sealant that is ony two years old. Compare Fig. 4.7 with Fig. 4.6.

4.3.2.2 I-35 South, Laredo. This is an older pavement section which was sealed in 1980. It was observed once, in February, 1986. The condition of the sealant is common for pavements that have been sealed with rubberized asphalts. Sealant

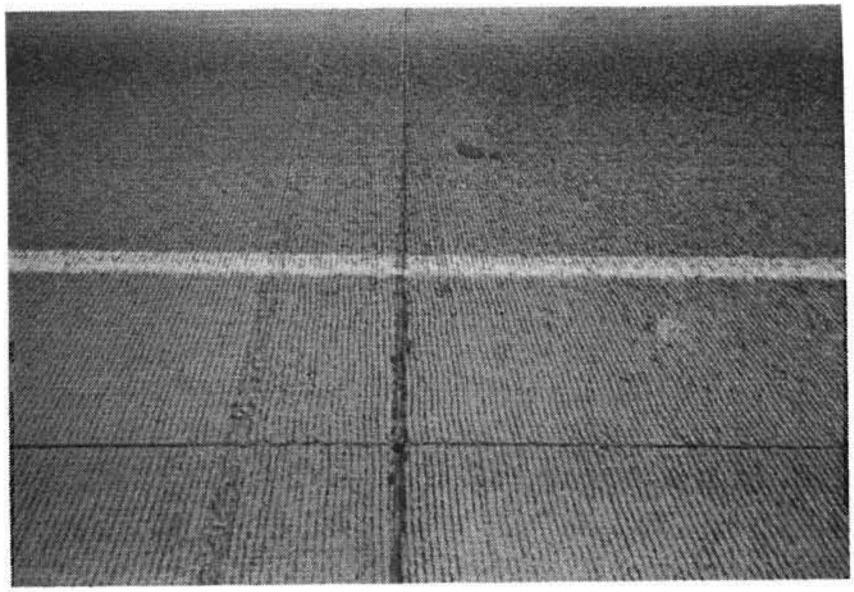

Fig. 4.6 Two-Year-Old Silicone Sealant - I-30 East, Dallas

Fig. 4.7 Two-Year-Old Rubberized Asphalt Sealant - I-30 East, Dallas

has been extruded onto the pavement surface along the entire lengths of most joints. The sealant which remains in the joints has failed in adhesion or cohesion in many places. Also, embedment is present in all joints. Overall, the joints are in poor condition.

4.3.3 Emulsified Latex, US 80, East, Fort Worth.

Emulsified latex was used as a joint sealant before polysulfides and polyurethanes were introduced. The pavement was placed in the 1930's and last resealed in 1962. The joints were observed in November, 1985.

Only a small amount of sealant remains in the joints. The pavement is in good condition, yet the sealant has come completely unbonded and is not functioning at all.

4.4 Field Performance in Other States

Many field studies of sealant materials have been conducted in different parts of the country. Table 4.1 is a summary of the performance of various types of joint sealants as reported in the National Cooperative Highway Research Program Synthesis of Highway Practice 98 (NCHRPSHP 98) (11). The results shown are for sealants with which five or more state agencies reported experience. The materials discussed here are those most commonly reported in the literature. The performances of silicone, rubberized asphalt, preformed neoprene, polyurethane, and polysulfide are summarized.

4.4.1 Silicone Sealants

After a large study in Georgia found no other elastomeric sealants that could perform adequately, a study of silicone was begun in 1974 (4). Soon afterward, silicone sealant became Georgia's first choice for a joint sealing and resealing material. Overall, the sealant's performances have been excellent (4).

Averages from the reports of 7 states shown in Table 4.1 show that silicones have had very good performance.

TABLE 4.1
MATERIALS USED TO RESEAL CRACKS AND JOINTS IN RIGID PAVEMENTS (10)

Material Type	Number Listings By Agencies	Effectiveness Rating Range	Average Effectiveness Rating[a]	Comments
Asphalt Cement	11	Poor - Good	3.15	Does not penetrate; must reseal often.
Cutback Asphalt	17	Very Poor - Good	2.29	Generally requires blotter; relatively short life.
Emulsion	10	Very Poor - Good	3.22	Seasonal; Generally must reseal often.
Rubberized Asphalt - Not Applied	36	Very Poor - Very Good	4.12	Relatively long life.
Silicone Dow 888	7	Good - Very Good	4.60	Relatively limited data but good performance to date.
Preformed Joint Seal	5	Poor - Very Good	3.60	Expensive.

[a]Rating Scale: Very Good - 5.00
Good - 4.00
Fair - 3.00
Poor - 2.00
Very Poor - 1.00

4.4.2 Rubberized Asphalt Sealants. As shown in Table 4.1, the results of studies involving rubberized asphalts are mixed. At the end of a 5-1/2-year study in Pennsylvania, the performances of two rubberized asphalts were second only to preformed seals (12). The performances of the rubberized asphalts were rated as good in the studies (13). Arizona has reported that, in 1982, rubberized asphalts were performing well after 6 years of service (11). North Dakota and Maine have also reported a service life of up to 5 years for this material (11).

On the other hand, Georgia has reported unacceptable performance of rubberized asphalts (4). New York results varied, with rubberized asphalts lasting from 4 to 30 or more months (14). However, all the joints showed severe infiltration of incompressibles (14). It should be noted, though, that in many of these early applications that the results indicated that joint reservoirs were to narrow to allow for enough joint material to accommodate the strains encountered. Therefore, earlier field tests may have actually tested the application techniques more than they tested the joint materials themselves.

4.4.3 Preformed Seals

All field studies reported here have used preformed neoprene rubber compression seals. Minnesota, North Dakota, Michigan, Ohio, and California have all had success with neoprene seals (15). In fact, as far back as 1963, New York reported excellent service from preformed seals (16). The Pennsylvania study also showed that preformed seals work well. At the end of 65 months, the preformed seals had far out-performed the liquid sealants in that study (12). The problem with preformed seals is illustrated in Table 4.1 - these seals are expensive in first cost.

4.4.4 Polyurethane Sealants

Most of the reported results for polyurethane sealants show that these materials have performed rather poorly in the field. The Pennsylvania study showed that a polyurethane out-performed two rubberized asphalts for the first few years of pavement life (12). However, its condition deteriorated rapidly and at 65 months the joints sealed with polyurethane had failed (12). Georgia also rated a polyurethane as unsatisfactory in 1975 (4). However, it must be noted that not all polyurethanes are alike. Table 4.1 shows results ranging to good for polyurethanes and, as of 1982, at least six states accepted it as a sealant (11).

4.4.5 Polysulfide Sealants

Polysulfides have experienced about the same field results as the polyurethanes have. Polysulfide performance, like polyurethanes, depends on the particular product's formulation and how well it is mixed in the field. In the Pennsylvania study the polysulfide performed well for the first years, but failed before 65 months of service (12). New York found the same results in 1965 (16). Minnesota has reported that polysulfides show erratic performance, varying from poor to good (15).

4.4.6 Other Sealants

Results of field studies for other materials including asphalts, hot-poured polyvinyl chloride (PVC), and emulsifide latex have been reported in various places. However, the use of these materials has not been widespread, and the results concerning them have been inconclusive.

CHAPTER 5. JOINT MOVEMENT

5.1 Introduction

The movement of concrete pavement slabs, as of all concrete structures, is influenced by many factors. Shrinkage, temperature, humidity, loading, support conditions, and concrete composition all contribute to the horizontal and vertical movements of pavement slabs. Concrete pavements are fully supported on bases whose behavior is not fully understood. Thus, the prediction of the movements of concrete pavements is especially difficult.

Many studies of pavement slab movement have been undertaken since concrete has been used as a paving material. Some of these studies are very useful in explaining the general tendencies of concrete pavement slab movement. However, the extrapolation of the results of most of these studies to accurately predict movements under other conditions is impossible due to the studies' limited scopes. The pavement designer, then, is left to design by trial and error because he knows what the movements may be but he does not know exactly why they occur. This chapter discusses pavement slab movement and the factors which influence it.

5.2 The Prediction of Concrete Pavement Slab Movements

The movement of concrete pavement slabs at the joints consists of both horizontal and vertical movements. Pavement slabs experience horizontal movements due to pavement shrinkage, thermal effects, and humidity changes. These longitudinal expansions and contractions are resisted by frictional forces caused by the interaction between the pavement slab and the base material. The vertical movements of pavement slabs are caused by climatological changes, vehicle loading, and support conditions. Temperature and humidity changes cause warping and curling of the pavement slabs. Passing vehicles induce dynamic vertical movement of slabs. These dynamic movements increase when the slabs are warped or curled or when uneven support conditions are present.

5.2.1 Horizontal Slab Movement

The horizontal movements of pavement slabs may be thought of as a combination of three types of motion: Long term effects, seasonal or cyclic movements, and short term movements. Long term effects include pavement shrinkage and the effects of slab-base interaction. Cyclic movements are caused by changes in climatic and pavement conditions due to temperature and humidity variations. Short term movements include relatively large but unexplained movements which have been observed in some studies.

5.2.1.1 Long Term Effects

(1) Shrinkage: The shrinkage of concrete structures is a complex phenomenon that depends on many factors. The shrinkage of concrete pavement slabs is especially difficult to predict because of the friction induced at the slab-base interface. Values of shrinkage strain that are commonly used for the design of pavements vary from 50 x 10^{-6} in/in (1, 17) to 300 x 10^{-6} in/in (18). This wide variation in shrinkage values reflects the need for more research into the nature of pavement slab shrinkage.

If pavements were constructed on frictionless bases and behaved ideally, the movements due to shrinkage would be zero at the center of each slab and would vary linearly out to the slab edges. However, the unpredictable variations in bond between the slab and base cause some sawed contraction joints to crack through and become working joints before others. These joints that open first tend to remain more open than others. Therefore, while the apparent shrinkage may be small at joints which do not crack quickly, it will be very large at joints which crack first. Until the shrinkage (and contraction) of pavement slabs is more fully understood, the designer must be conservative in his estimate of shrinkage.

One possible method of estimating the shrinkage of concrete structures is given in ACI SP-27 by ACI committee 209 (19). Committee 209's method estimates shrinkage strain as a function of time after 7 days of curing. Equation 5.1 gives the basic equation for shrinkage strain:

$$ESH = 800 \times 10^{-6} \text{ in/in} \times ST \times STH \times SS \times SE \times SC \times SF \times SH \qquad (5.1)$$

where

ESH	=	the total shrinkage strain (in./in.),
ST	=	modification based on time after seven days of curing,
STH	=	modification based on the least thickness of the member,
SS	=	factor based on the slump of the mix,
SE	=	factor based on the percentage of air entrained in the mix,
SC	=	factor for the cement weight per cubic yard,
SF	=	factor based on the percent of fines in the mix,
SH	=	factor based on the average ambient relative humidity.

The calculation of each of the modification factors is explained below:

$$ST = \frac{T}{35 + T} \qquad (5.2)$$

where T is the time in days after 7 days moist curing.

$$STH = 0.70 \qquad TH = 8 \text{ in.} \qquad (5.3)$$

Since pavement slabs rest completely on grade, they may be considered to be very thick members.

$$SS = 0.89 + 0.04\,(\text{slump of mix in inches}) \qquad (5.4)$$

$$SE = 0.95 + (\%E/120) \qquad (5.5)$$

where %E = percentage of air entrained in the mix.

$$SC = 0.72 + (WT/2500) \qquad (5.6)$$

where

WT	=	cement weight in lb/cu. yd.,		
WT	=	(# sacks/cu. yd.) x (94 lb/sack).		

$$SF = 0.33 + (F/75) \qquad F \leq 50\% \qquad (5.7)$$

$$SF = 0.88 + (F/430) \qquad F > 50\% \qquad (5.8)$$

where F = percent of fines in mix.

$$SH = 1.40 - 0.01(H) \qquad 40\% \leq H < 80\% \qquad (5.9)$$

$$SH = 3.00 - 0.03(H) \qquad 80\% \leq H < 100\% \qquad (5.10)$$

where H = average ambient relative humidity.

ESH is calculated for a hypothetical situation on pages 83 to 84.

As stated previously, this method predicts shrinkage beginning at 7 days. However, the joint designer is interested only in shrinkage that occurs after the joints are sealed, since the joint sealant system will have to accomodate only that movement. For example, if the joints are expected to be sealed 14 days after the concrete is poured, the designer must calculate the shrinkage from 7 to 14 days, then calculate the shrinkage from 7 days to 1 year (at which time most of the shrinkage will have occured), and subtract the two in order to find the shrinkage expected between 14 days and 1 year. An example calculation is included in Chapter 6.

This method gives a conservative estimate of shrinkage strain. It may be used when the designer does not have access to better information.

(2) Base Effects: The purpose of the base and sub-base system is to provide drainage and support for the pavement material. Graded aggregate, lean portland cement concrete pavement, asphaltic concrete pavement, and stabilized soil have all been used successfully (20).

The effects of pavement slab-base interaction are what make pavement systems unique when compared with other concrete structures. Unfortunately, the effects of this interaction are difficult to accurately quantify due to variations in the friction developed along the length of the slab. Base effects also vary with the age of the system. Research on short pavement slabs on granular bases at the Bureau of Public Roads in the 1930's showed that the amount of friction increased with the first few movements, then decreased with subsequent movements (21). Friberg found the same effects controlled, but to a lesser degree, for long (100-ft) pavement slabs (22). Results of a Michigan joint movement field study indicate that joint movements are greatest in the first year of pavement life and then begin to level off as the system ages (23).

5.2.1.2 Cyclic Movements.

(1) Thermal Movement: Significant expansion and contraction of concrete pavement occurs with increasing and decreasing temperatures. In fact, the thermal movements of concrete pavement are large enough so that some designers use only thermal effects when calculating horizontal joint movements (25). These thermal movements may be visualized as occurring on a seasonal basis, with daily movements superimposed on the seasonal ones.

It is now understood from many experimental studies that the horizontal thermal movements of pavement slabs tend to follow the concrete temperature variations at the center of the slab (25). One method of calculating the actual movement at a joint, ΔL, is to take the difference between the unrestrained movement (UM) and the restrained movement (RM):

$$\Delta L = UM - RM \tag{5.11}$$

where

UM	=	$L\alpha\Delta T$,
RM	=	$(\mu WEL)/A$,
L	=	joint spacing (in.),
α	=	thermal coefficient of contraction of concrete (in./in./°F),
ΔT	=	temperature range in the concrete,
μ	=	coefficient of friction of the concrete at the base,
W	=	weight of the concrete between joints (lbs.)

E = modulus of elasticity of the concrete (lbs./sq. in.)
A = cross-sectional area of the pavement slab.

AASHTO recommends the following method for calculating joint opening due to temperature (24):

$$\Delta L = (CL\alpha\Delta T)/S \qquad (5.12)$$

where

C = adjustment factor due to subbase/slab friction restraint,
C = 0.65 for stabilized subbases;
0.80 for granular base,
S = allowable strain of joint sealant material; 25 percent is a conservative value.

Minkarra has shown that no direct correlation exists between the temperature at the center of the slab and the ambient temperature (20). Many observations of pavement slab temperatures have shown that the temperature at the centers of the slabs may be 30 to 40°F higher than the ambient temperature on sunny days. Yet, on cloudy days, the slab temperature may not reach the ambient temeprature level. These facts suggest that the center of slab temperature is dependent not only on the ambient temperature but also on base temperature, solar intensity, wind speed, and any other factors that would dictate the rate at which pavements collect, store, and radiate heat.

In order to design for the contraction of pavement slabs, the designer should select the lowest temperature which he feels the pavement will reach. If he is designing a pavement for, say, a 20-year life, he should select the 25 or 50-year mean recurrence interval (MRI) low temperature for the area. On the other hand, expansion joint design requires that he select the 25 or 50-year MRI high temperature and then add 30 to 40°F to account for slab temperature. This method of estimating concrete slab temperatures must continue to be used until better methods of predicting pavement temperatures are developed.

(2) Humidity Variation: Many published works which discuss slab movements mention humidity changes as an important influence on concrete pavement slab expansion and contraction. Yet designers almost never include humidity effects in the design of concrete pavement joints. Indeed, very little research has been conducted which includes humidity variations as a parameter in horizontal movement studies. Lang found that the humidity at the center line of the slab may vary as little as 4 percent (26). Much more research needs to be conducted into the effects of humidity changes on the horizontal movements of slabs.

5.2.1.3 Short Term Movements. Pavement slabs do not necessarily move smoothly. In fact, most horizontal movements are of a sudden, jerky fashion (25). This motion is caused by the pavement slabs' tendencies to build up stresses until the static friction caused by the base is overcome. In an 8-year study in Ohio, most of the pavement slabs studied underwent short term movements of about ± 0.25 inch at some point during the study (20). The magnitudes of the movements were the same for both 20-foot and 40-foot-long slabs (20). These movements occurred in individual slabs and were eventually distributed over other joints in the pavement system (20). It was impossible to explain these large, short term movements within the parameters of the study (20). Once again, research needs to be conducted into the causes of short-term movements because movements as large as those found in this study may place significant stresses on joint sealants if the movements are not accounted for during design.

5.2.1.4 Other Types of Movement - Dowel Bars: Properly placed dowel bars are very important to the performance of concrete pavement joints. However, poorly placed or corroded dowel bars can seriously effect horizontal pavement movement. When dowels lock or freeze, the joint they span is suddenly no longer able to expand and contract. Then, the adjacent joints must each facilitate the movements of the two frozen slabs.

Plastic or epoxy coated and stainless steel dowels have been used as a method of extending dowel bar life. The plastic coatings are meant to slow corrosion and help the bars to move more smoothly than uncoated bars.

The Ohio study showed that plastic coated bars did cause a more even distribution of horizontal movements than standard dowels for the first few years of pavement life (20).

However, after a few years, the pavement with plastic coated bars showed the same behavior as the pavement with standard bars (20). Also, at the end of the 8-year study, there were no noticeable differences in the corrosion of the two types of dowels (20).

5.2.2 Vertical Pavement Movements

The natural warping and curling of pavements mainly due to temperature gradients over the slab depth are even less understood than horizontal pavement movements. The presence of deteriorated or non-functioning load transfer devices or an eroded base material will amplify any vertical movements of the pavement slabs when traffic passes over the joint. While prediction of these deflections is still nearly impossible, observations have shown that the greatest vertical movements of pavement slabs occur near the shoulder at transverse joints (27). When the base material has eroded due to pumping, these movements may reach as much as 0.26 inch when heavy trucks pass over the joint (27). In such cases, the deflection of the pavement slab is significantly reduced when thicker slabs are used. Packard gives an excellent model for the design of pavement slabs to reduce vertical deflection (6).

CHAPTER 6. JOINT DESIGN FOR CONCRETE PAVEMENTS

6.1 Introduction

Proper joint design coupled with correct joint preparation and sealant installation procedures (Chapter 7) will result in joints that perform well for many years. Since most failures occur in transverse joints, this discussion deals mainly with those joints, although longitudinal joint design is also discussed.

6.2 Transverse Joint Design

Experience has shown that regularly spaced expansion joints are unnecessary to ensure proper pavement performance. Therefore, the designer is left mainly with contraction joints to design. Figure 6.1 shows a standard sawed joint and Fig. 6.2 shows a step cut joint.

The first calculation the designer will make is to determine the required joint width. The required joint width is a function of the expected joint movement and the extensibility of the selected joint sealant material. For example, most sealant manufacturers rate their sealants' working ranges for between 12.5 percent and 50 percent extension. Therefore, if the expected joint movement is 0.125 inch and the manufacturer rates his sealant for 50 percent expansion, then the joint must be at least 0.25 inch wide when it is sealed. Or, in equation form,

$$WR = ME/EX \qquad (6.1)$$

where

WR	=	the required joint width (in.),
ME	=	the expected joint movement (in.),
EX	=	the sealant manufacturers recommended extension, expressed as a decimal.

The joint movement, ME, is a function of shrinkage, thermal, and any expected short term movements.

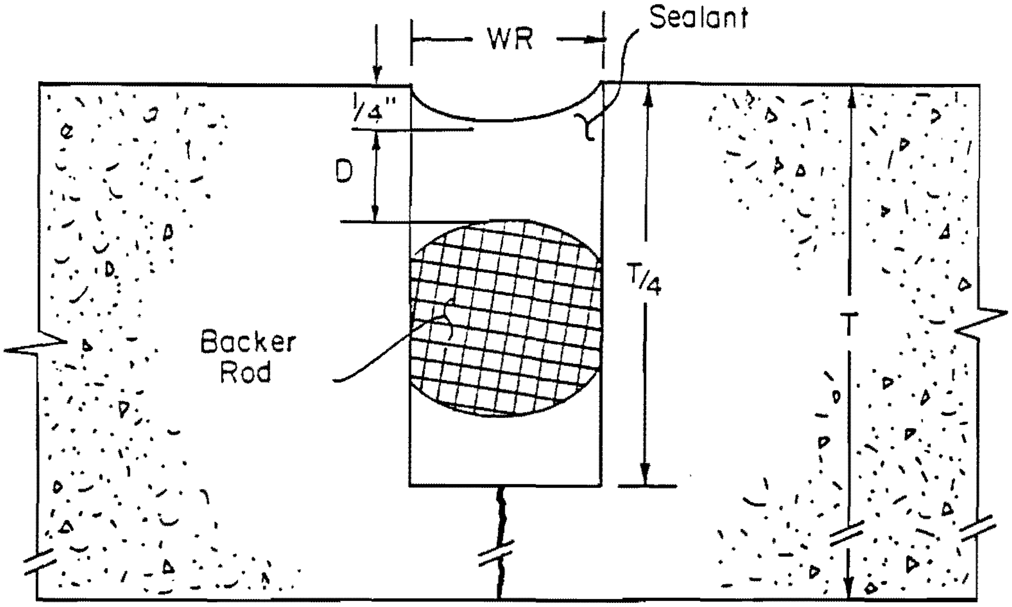

Fig. 6.1 Standard Cut Joint with Tooled Sealant

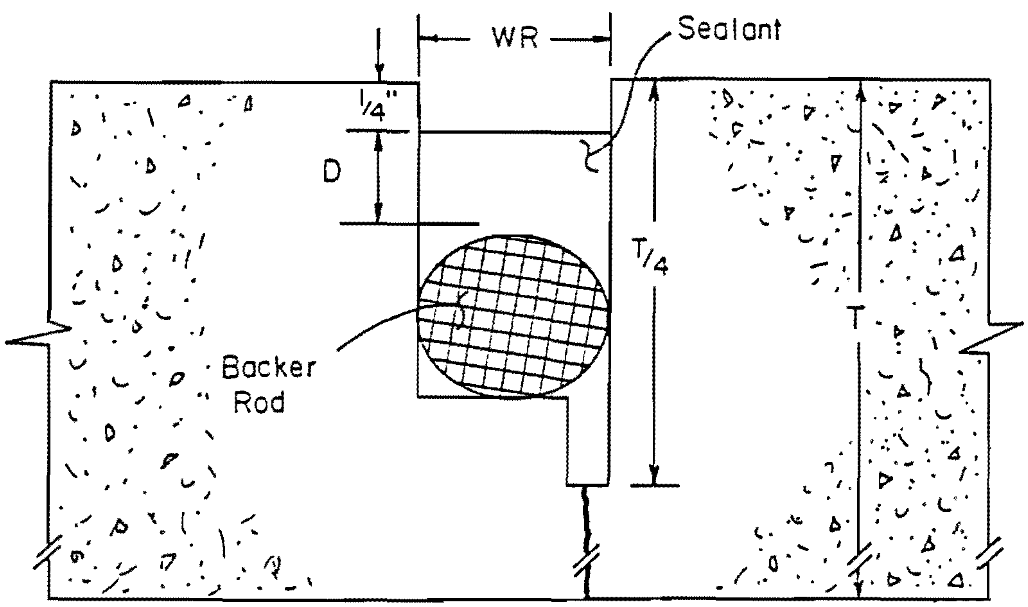

Fig. 6.2 Step Cut Joint with Poured Sealant

$$ME = f(MSH, \Delta L, MST) \tag{6.2}$$

where

MSH = expected shrinkage,
ΔL = expected thermal movements,
MST = any short term movements that may occur.

Combining Eqs. 5.1 and 5.12, an equation of the following form is usually used to calculate the total expected horizontal joint movement:

$$ME = C\,L\,(\alpha \times \Delta T + ESH) + MST \tag{6.3}$$

where

ME = expected joint movement (in.),
C = correction factor (usually near 0.7),
L = slab length (in.),
α = coefficient of thermal expansion (in./in./°F),
ΔT = expected change in temperature at the center of the slab (°F),
ESH = shrinkage strain of slab, per unit of slab length (in./in.),
MST = any expected short term movements.

There are both maximum and minimum joint widths which are recognized for jointed concrete pavements with short slab lengths (less than 20 feet). Excessively wide joints cause very uncomfortable rides in most vehicles due to the noise made as tires pass over the joints. The contraction joints in such pavements should not be greater than 0.75 inch wide (28). It is reported that some states have increased maximum joint width to 1-1/2 inches. Very narrow joints, on the other hand, are extremely difficult to properly prepare and seal. Therefore, most sealant manufacturers recommend that joints be not less than 0.25 inch wide.

Next, the designer must decide what the depth, D (Figs. 6.1 and 6.2), of the sealant will be. The work of Tons (29), Cook (30), and others is very explicit about the detriments of having a large depth to width ratio in a sealed joint. A deeply sealed joint under extension causes greater strain, stress, and shear angle on the sealant than a shallow joint under the same amount of extension. For example, a 0.5-inch wide x 0.25-inch-deep joint under 50 percent extension experiences 70 percent strain along the necked down edges (top and bottom) of the sealant. However, a 0.5-inch-wide x 1-inch-deep joint subjected to the same amount of extension develops 160 percent strain along the top and bottom edges of the sealant. Even these values, reported by Tons (29), have been shown to be up to 25 percent conservative (31). Therefore, research and experience have shown that the most effective shape factors are 1:1 or less for concrete pavement joints.

There are other factors which the joint designer must specifiy. For example, the sealant material must be recessed 0.25 inch from the surface of the pavement. Experience has shown that unrecessed sealants tend to extrude above the surface of the pavement when placed in compression. The recesses are formed by tooling a non-flowable sealant or not completely filling the joint when a pourable sealant is used. Figures 6.1 and 6.2 illustrate the proper recessing of a non-pourable and pourable sealant, respectively.

The total sawed depth of each of the joints shown in Figs. 6.1 and 6.2 is one-fourth (T/4) of the pavement thickness except for pavements in which siliceous aggregates are used in which the sawed depth is T/3. This depth has been determined by many years of experience and insures that the pavement will crack at the joints.

A backer rod, as shown in Figures 6.1 and 6.2, should be used for all elastomeric sealants in both new pavement construction and joint maintenance operations, including jobs which specify hot-poured sealants. The backer rod insures that the correct joint sealant shape factor is maintained and serves as a debonder so that no biaxial stresses are present in the sealant.

6.3 Longitudinal Joint Design

Longitudinal joints between lanes and at shoulders are tied joints and do not experience the same, relatively large, movements as contraction joints. Very little research into the behavior of these joints has been conducted. However, experience has shown that the longitudinal joints need not be over 3/8 inch wide. Like transverse contraction joints, they are typically sawed to a depth of T/4. The proper sealant shape factor for longitudinal joints should be maintained. Also, backer rods should be placed in these joints to ensure proper joint selant shape factors and performance.

6.4 Example Problem

Design a standard saw cut contraction joint for a typical concrete pavement system.

6.4.1 Design Data

Concrete Data: Type I cement; weight = 150 pcf; water/cement ratio = 0.53; percent fines = 40%; air entrainment = 0%; concrete slump = 2; sacks of cement per cubic yard = 5; $\alpha = 6.0 \times 10^{-6}$ in/in/°F.

Joint Data: Joints sawed at age = 72 hours; sealant placed at age = 14 days; slab length (variable) = 13 ft., 15 ft., 18 ft., 20 ft.

Climate Data: Expected temperature when joints are placed = 70°F; expected low temperature (50 year mean recurrence interval) = -10°F; expected average relative humidity = 55%.

Joint Sealant Data: Manufacturer's recommended extension = 50%; manufacturer's recommended shape factor = 1:2 depth to width ratio; minimum 1/4 inch depth.

6.4.2 Solution

Use slab length, L, = 20 x 12 = 240 in.

$$WR = ME/EX \qquad (6.1)$$

$$ME = C\,L\,(\alpha \times \Delta T + ESH) + MST \qquad (6.3)$$

Shrinkage calculation:

$$ESH = 800 \times 10^{-6} \times ST \times STH \times$$

		SS x SE x SC x SF x SH	(5.1)
STH	=	0.70	(5.3)
SS	=	0.89 + 0.04 (2") = 0.97	(5.4)
SE	=	0.95 + 0/120 = 0.95	(5.5)
SC	=	0.72 + WT/2500 = 0.908	(5.6)
SF	=	0.33 + 40/75 = 0.863	(5.7)
SH	=	1.4 - 0.01 (55) = 0.85	(5.9)

$$ESH = 800 \times 10^{-6} (0.70)(0.97)(0.95)(0.908)(0.863)(0.85)(ST)$$

$$ESH = 344 \times 10^{-6} (ST)$$

Calculate ST from 14 days to 1 year:

$$ST = \frac{T}{35 + T} \qquad (5.2)$$

From 7 days to one year:

T = 358 days

ST_1 = 358/35 + 358 = 0.910

ESH_1 = $344 \times 10^{-6} (0.9109) = 313 \times 10^{-6}$ in/in

From 7 to 14 days:

T = 7 days

ST = 7/35 + 7 = 0.1667

ESH_2 = 57.3×10^{-6} in/in

$ESH = ESH_1 - ESH_2\ x = 313 \times 10^{-6} - 57.3 \times 10^{-6}$

$ESH = 256 \times 10^{-6}$ in/in

Expected movement, ME:

$$ME = C\,L(\alpha \times \Delta T + ESH) + MST$$

where

C = .70
L = 240 in
α = 6.0×10^{-6} in/in/°F
ΔT = 70 - (-10) = 80°F
ESH = 256×10^{-6} in/in

$$ME = (1/1.5)240(6.0 \times 10^{-6} \times 80 + 256 \times 10^{-6})$$
$$ME = 0.1178 \text{ in}$$

Recommended width, WR:

$$WR = 0.1236/0.5 = 0.247 \text{ in.}$$

Use a joint width = 0.25 inch;
Choose joint depth, D, = 0.25 inch;
Recess sealant 1/4 inch from top of pavement;
Choose polyethylene backer rod with diameter = 1/4 + 1/8 = 3/8 inch.

CHAPTER 7. JOINT PREPARATION AND CONCRETE CUTTING

7.1 The Need for Joint Preparation

Joint preparation includes all of the steps leading up to the placement of the joints for both new pavement construction and joint maintenance operations. In new construction, the joints must first be created. Then they are cleaned, primed (if necessary), and backer material and sealant are installed. Joint resealing first requires that the old sealant material be stripped from the joint. Then, any large spalls or other serious joint damage should be repaired. Joint walls should then be cleaned by removing all traces of old sealant material, and finally primer, backing material, and sealant may be placed.

When the joint walls are not properly prepared before sealant installation, bond failure may occur as soon as the pavement slabs contract. This failure mode is extremely common in both new pavement construction and joint resealing operations and represents the most serious problem in modern joint sealing operations. It is usually characterized by intermittent adhesive failures along the joint, although bond failure along almost the full length of the joint may also occur. In many cases, this early bond failure tends to be blamed on the sealant material. However, the sealant that is still functioning when intermittent failure is present shows that it can withstand the conditions at the site. Therefore, the inspector must be very careful not to blame early bond failure on the sealant material if poor joint preparation is actually at fault.

7.2 Joint Preparation Techniques

There are many methods that have been used to prepare the joints in concrete pavements. The following sections discuss some of the more common techniques used to accomplish the steps in joint preparation. New pavement construction and joint maintenance resealing operations will be discussed separately.

7.2.1 New Pavement Construction

7.2.1.1 Joint Creation. Transverse and longitudinal joints are usually created by sawing the concrete while it is still green. Since the 1950's, large, self-propelled, water-cooled saws have been used to form joints (32). The sawing operation leaves two vertical, straight, precisely spaced joint walls when it is properly performed. High speed saws, with tangential blade surface speeds of 9,000 to 10,000 feet per minute tend to do very little damage to the concrete adjacent to the sawed joint (28). However, a concrete saw will always leave a layer of dust on the joint walls as the water used for cooling evaporates. This residue must be removed after sawing.

7.2.1.2 Joint Cleaning. Poorly cleaned joints represent one of the biggest problems in pavement joint sealing. Sand blasting, low and high pressure water blasting, high pressure air, and abrasive techniques such as wire brushes and arbors have all been used successfully to clean joints in new pavements. In fact, most contractors use combinations of the above methods to clean joint faces.

Joints in new pavement construction do not require the removal of old sealant from the joint walls as joint resealing operations do. Therefore, manufacturers of joint sealant materials tend to agree that if the joints are sealed immediately after swing, it is only necessary to flush them with water then dry them using high-pressure air or a flame dryer. If the joints are sealed several days after the saw cuts are made, it becomes necessary to use high pressure water or sandblasing to remove all material deposited in the joints by sawing, nature, and construction vehicles. In both cases, when water is used to clean the joints, it is very important to use an excess of water so that materials will not redeposit on the joint walls.

Sand blasting has been shown to be perhaps the most effective way of cleaning joints, but it must be done correctly (9, 13). The nozzle must be held within inches of the joint - an unpleasant but necessary task (33). It may be necessary to make 3 passes on each joint: one for each joint face and one using air only to blow the sand from the joint.

Cleaning the joints by only blowing them out with high pressure air has been shown to be the least effective method of joint preparation (9). Up to 50 percent failure was recorded on one test seciton in Iowa (9). Whenever air is used to dry jont walls it is very important that the compressor have an effective trap to remove moisture and oil from the air (28).

Whatever methods are used to clean joints in new pavement construction, it is very important that the joint be free of any debris, sawing residue, and that they be completely dry before sealing takes place.

7.2.1.3 Backer Material. Backer material, usually a polyethylene rod, performs two functions in the joint. First, the backer material controls the sealant's depth in the joint. It also serves as a bond breaker so that the sealant adheres only to the joint walls and not to the base of the joint. Backer rod should be used with all elastomeric sealant materials. Special materials are available which may be used at the elevated temperatures necessary for placing hot-poured sealants.

7.2.1.4 Primer. If primer is necessary, it should be applied to the cleaned, dry jont walls before the backer material is placed. Then, the sealant will not bond to the top of the backer material. Primer should be applied according to the manufacturer's instructions. It may be applied by hand with a brush or by equipment as recommended by the manufacturer.

7.2.2 Joint Resealing and Maintenance

7.2.2.1 Stripping Old Sealant. In joint resealing operations, the old sealant must be stripped from the joint if the new sealant is to function properly. Many state departments of transportation suggest using either hand held cleaning hooks or a small, rectangular tooth attached to a backhoe to remove sealant from joints (11). In both cases, the device is dragged down the length of the joint, stripping the sealant from the joint. Other states advocate sawing as a method to remove sealant and to reshape the joint at the same time (11). However, if the joint is in poor condition, it may be difficult to determine where to saw if the sealant is not removed beforehand.

7.2.2.2 Reshaping the Joints. Where joints have spalled severely or otherwise deteriorated, it becomes necessary to restore them to proper condition (34). Observations of resealed pavement in Dallas show that the new sealant is performing very well under normal conditions. However, where the workers tried to fill in spalls with joint sealant, at the spalled areas, the sealant has completely lost its bond and is not protecting the pavement system from the intrusion of water (Fig. 7.1).

Resawing the joints is a very effective way of reshaping them. The resawing operation, when performed on pavement that is not severely spalled, leaves two smooth, vertical joint faces. This method requires that a saw be used to remove about 1/16 inch from each of the joint faces. This method also removes any sealant or primer that may have leached into the joint walls from the previous sealing system. However, resawing the joints cannot be done indefinitely. Each time a joint is resawed, it is widened by about 1/8-inch. As stated previously, joints over about 3/4-inch wide produce an uncomfortable ride when used with pavement slabs less than 30 feet long.

Quick calculations show that a joint that is initially 3/8-inch wide may be resawed three times before it reaches 3/4-inch wide. Also, a 1982 study shows that most states reseal joints at five year intervals (11). Therefore, the expected service life of such a pavement is only between 10 and 15 years. Of course, there are many ways to increase the lives of concrete pavements, but one of the simplest is to use excellent quality materials and careful joint cleaning procedures. Then, maintenance will not be required as often and pavement service life will be extended.

7.2.2.3 Joint Cleaning. The method used to clean joint walls in resealing operations are the same as those used in new pavement construction. Sand blasting, water blasting, and abrasive methods have all been used to clean joints in resealing operations.

Sand blasting has been used for many years as a method to clean joints in resealing operations. It may be used to remove residue from resawing operations. Sand blasting may also be used once the sealant has been stripped to remove any remaining sealant from joint walls. However, sandblasting must be done correctly to be effective. One of the best specifications for insuring proper sandblasting is outlined by J. W. Bugler of the New York State Department of Transportation. The New York D. O. T. specification reads:

> The sandblast.....joint cleaning operation shall be such that when completed the concrete joint surface which is

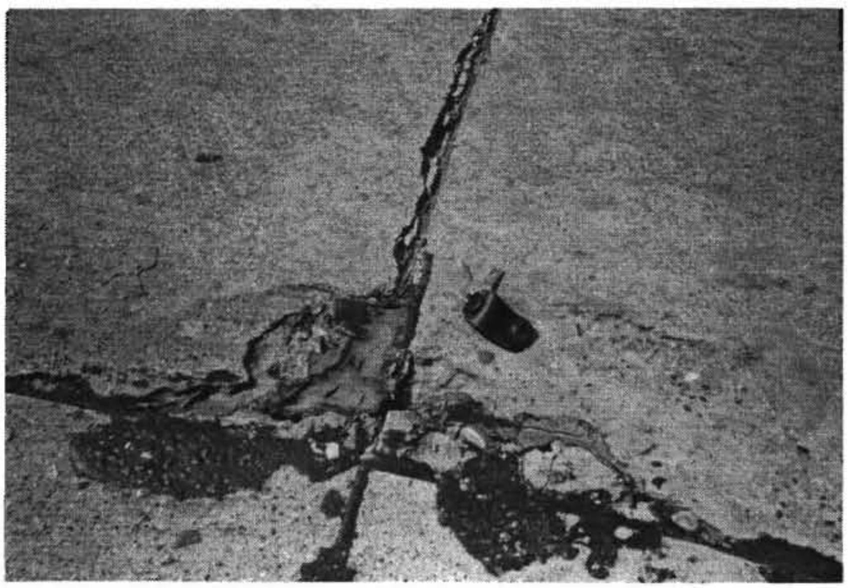

Fig. 7.1 Debonding of a Joint at a Large, Sealed Spall

> to recieve the new joint sealant shall be free of all constituents of the lubricant adhesive used to place the original.....seals; all tar and asphalt; all discoloration and stain; as well as any and all other forms of contamination, leaving a clean, newly exposed concrete surface (33).

This part of the specification defines exactly what is meant by "clean." To insure that sandblasting is done correctly in maintenance operations, the New York D. O. T. advises that one inspector be with the sandblast operation at all times (33).

Water blasting is usually only used when the joint has been resawed. The water is able to remove sawing residue if enough water is used. However, high pressure water alone will not usually remove any old sealant that may be adhered to the joint walls (9).

Abrasive techniques such as mechanical wire brushes or arbors may also be effective for cleaning joints. However, the same type of strict quality control as is used in sand and water blasting is necessary to ensure a properly cleaned joint.

7.2.2.4 Other Tasks. The remainder of the resealing operation, namely backer rod, primer, and sealant placement, should be identical to methods used in new pavement joint sealing operations.

7.3 Pavement Cutting and Sawing

7.3.1 Methods Used

The sawing or cutting of pavements may represent a significant percentage of the total outlay of both time and money in new pavement construction or, especially, in old pavement maintenance. New pavement construction requires transverse and longitudinal joints to be sawed in the pavement slabs. If skewed transverse joints are used, then the lineal feet of concrete to be sawed increases. In maintenance work, full or partial depth concrete removal is necessary when a section of pavement is severely deteriorated. Also, pavement joints may require concrete removal before they can be resealed.

At the present time, the methods commonly used to remove unwanted concrete fall mainly into two broad categories. The first category includes all methods that use impact as a means of breaking up and removing concrete. The second category is concrete sawing and removal.

7.3.1.1 Impact Methods. The impact category includes all types of jackhammers and percussion bits and also includes all machines that use very high pressure water to remove unwanted concrete. Jackhammers may be hand-held, with an external pneumatic source, or self-propelled, in which case the air compressor and hammer are mounted on a self propelled cart. The self propelled cart is generally faster at concrete removal than the hand held jackhammers are.

Jackhammers are generally used to break up unwanted concrete or cut out sections of pavement for removal. Today, they are used mainly for small jobs and when the work is to be performed on plain concrete slabs. Jackhammers cannot cut through rebar. If a section of a pavement slab is to be removed, then the reinforcing steel must be cut with a cutting torch. If partial depth pavement removal is required, then the reinforcing steel must be sandblasted to remove the bonded concrete.

Machines that use very high water pressure to remove concrete are usually fully automated. One system, developed in Switzerland, consists of a nozzle that travels on a 12 foot shaft. A shield surrounds the shaft and the assembly moves, on wheels, perpendicular to the long axis of the shaft. Thus, the system may travel down the pavement, cutting away a 12 foot wide section of concrete. The water leaves the nozzle at about 16,000 psi.

This system is most effective for partial depth pavement removal. Unlike a jackhammer, the water is able to selectively leave strong concrete while removing unsound concrete. Also, this machine cleans the reinforcing steel as it removes concrete. However, if full depth pavement slab removal is required, then the reinforcing steel must be cut with a torch.

The main disadvantage inherent to the impact methods of concrete removal is that during full depth slab removal the base is disturbed. It then becomes necessary to repair the base before the pavement section can be replaced.

7.3.1.2 Concrete Sawing. Sawing of concrete pavements is normally performed for three reasons: 1) forming joints in new concrete pavements, 2) repairing joints in old pavements, 3) sawing out sections of pavement that will be removed and replaced. The saws and methods used will depend on the particular contractor's equipment, previous experience, and on the size of the job.

Many different types of saws are currently used for forming joints in new concrete pavement. However, longitudinal joints are normally sawed with relatively small, self-propelled saws. Transverse joints, on the other hand, may be sawed with anything from a single blade, 35 horsepower handsaw, which the operator pushes, to a large, 4 bladed "span saw," which the operator rides on.

References (34, 35) give summaries of patching procedures at joints. Whether joints are patched to repair severe spalling, or simply "shaved" to produce a clean surface for joint resealing, hand saws are usually used because they are more maneuverable than large saws.

Concrete sawing is used to separate sections of concrete that will be removed from the sound pavement that surround them. Reference (36) gives an excellent discussion of the techniques involved. The newest procedure is to saw out a 12 by 12 foot section of pavement and then lift it completely out using a crane. For small jobs, normal diamond blade saws may be used. Larger jobs may allow the use of large, carbide tipped blades which dry-cut the concrete (36).

As mentioned above, the type of saw, blade, and speed selected will depend on many factors: The type of aggregate; the presence of reinforcing steel; operating speed; depth of cut; coolant; and horsepower all affect the system that will be chosen. Reference (37) presents an excellent discussion of these factors.

CHAPTER 8. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

8.1 Summary

The problem of effectively and efficiently sealing joints in portland cement concrete pavement dates back to the early 1900's. There are many different types of joint sealants available to the pavement designer and maintenance engineer. However, each class of materials has different characteristics and even the materials within a class may have considerably different properties.

The objective of this research was to find an effective and economical method to seal joints in portland cement concrete pavements. Five types of materials were selected for evaluation from those most commonly used to seal jointed concrete pavements in the United States. The materials selected for study included Dow Corning's low modulus silicone 888, A. C. Horn's Hornflex Traffic Grade polysulfide, A. C. Horn's Daraseal-U polyurethane, Allied Material's 9002 rubberized asphalt, and E-poxy Industries' Evazote 50 preformed ethylene vinyl acetate.

This report presents the results of laboratory testing and field studies of these materials and others in the same classes.

Laboratory results presented in this report include: 1) load vs. elongation; ultimate extension; and modulus of elasticity of the systems at 20°F, 72°F, and 130°F, 2) slow extension, cyclic bond at 0°F, 3) penetration of the materials at 77°F and 140°F, 4) flow of the materials at 158°F, 5) stress relaxation of the systems, 6) compression set of the materials, 7) shear fatigue testing.

Results of the field testing portion of this study include: 1) Installation and observation of the two most promising materials as detemined by the laboratory tests 2) Observations of different in-place materials around Texas and in Oklahoma, and 3) a review of the various field studies that were found in the literature.

A review of the existing literature yielded the most effective procedures for calculating pavement slab movement, designing pavement joints, preparing joints for sealing, and cutting and sawing pavement slabs. Results from these investigations are presented herein.

8.2 Conclusions

8.2.1 Sealant Materials

Each class of elastomeric joint sealants has properties that distinguish it from the other classes of materials. Polysulfides have excellent solvent resistance, but show poor compression set tendancies. Silicones show excellent weathering and compression set tendencies. They also have very consistent properties over a wide range of temperatures. However, they possess low abrasion resistance. Polyurethanes generally show excellent resilience and recovery tendencies. Rubberized asphalts are one of the least expensive joint sealants. However, they tend to become stiff at low temperatures and very soft at high temperatures. Preformed compression seals exhibit excellent abrasion, weathering, and solvent resistances. However, they are by far the most expensive type of joint seals, and require unspalled, evenly spaced joint walls to be effective.

8.2.2 Laboratory Testing

1) The tensile test showed that the silicone's load vs. elongation, ultimate extension, and modulus of elasticity are the most consistent of the materials tested at 20°, 72°, and 130°F, silicone had the most consistent values for load vs. elongation, ultimate extension, and modulus of elasticity. The rubberized asphalt exhibited the poorest properties, becoming very stiff at low temperatures and flowing at high temperatures. The performances of the polysulfide, polyurethane, and preformed materials were acceptable but not outstanding.

2) All materials passed the bond test.

3) The penetration of all the materials except the rubberized asphalt were consistent and acceptable at 77° and 140°F. The rubberized asphalt shows acceptable penetration at 77°F, but shows very high penetration at 140°F.

4) All materials except the rubberized asphalt passed the flow test.

5) The preformed sealant showed the least tensile stress relaxation. The rubberized asphalt showed the highest.

6) All materials except the polysulfide showed excellent compression set resistance.

7) The fatigue test produced no visible failures in the samples.

8.2.3 Field Testing

The field tests and literature review showed that silicone sealant and neoprene preformed compression seals tended to perform better than most other materials. Polysulfides and polyurethanes performed very well for a few years before failing. Rubberized asphalts showed mixed results, but tend to become embedded with incompressible several months after installation.

8.2.4 Joint Preparation

The methods which should be used for joint preparation in new pavement construction differ from those used in maintenance resealing operations.

8.2.4.1 New Pavement Construction. If joints are sealed immediately after sawing; 1) flush joints with an excess of water or carefully sandblast, 2) dry or clean joints with compressed air, 3) inspect joints, 4) place backer rod, primer, and sealant.

If joints are sealed several days after sawing; 1) flush with high pressure water or carefully sandblast, 2) dry or clean with air, 3) inspect, 4) place backer rod, primer, and sealant.

8.2.4.2 Maintenance Resealing

1) Strip old sealant and backer material from joint, 2) repair any large spalls which will affect the new sealant's performance, 3) resaw joints, removing approximately 1/16 inch from each joint face, to expose new concrete, 4) flush with water or sandblast, 5) dry or clean with compressed air, 6) inspect joints, 7) place backer rod, primer, and sealant.

If joints become excessively wide, 1) strip old sealant and backer material, 2) repair spalls, 3) thoroughly sandblast joint faces, 4) clean with compressed air, 5) inspect joints, 6) place backer rod, primer, and sealant.

Inspection of the cleaned joints is critical. Joints must be clean, dry, and sound or the sealant will not adhere to the joint walls.

8.2.5 Pavement Slab Movement

Until more accurate methods are developed, pavement slab movement should be calculated using an equation of the following form:

$$ME = C\,L(\alpha \times \Delta T + ESH) + MST \qquad (6.3)$$

8.2.6 Joint Design

1) Required joint width should be calculated using the following equation:

$$WR = ME/EX \qquad (6.1)$$

2) The depth of a sealant should be no greater than its width.

3) The sealant should be recessed 1/4 inch from the pavement slab surface.

4) Backing material, preferably polyethylene rod, if chemically compatible with the sealant, should be used with all elastomeric sealants in both new pavement construction and maintenance resealing operations.

8.3 Recommendations

1) Laboratory studies should continue to be performed on new sealants and all sealant systems that are to be used in Texas. The tests performed should be the same for all materials so that direct comparisons among the sealant systems can be made. A testing program should be developed which illustrates how a material's properties vary with changing climatic conditions, such as temperature.

2) Long term observations of in-place sealants should be continued. The observation techniques and parameters should be standardized so that direct comparisons among sealants in different locations can be made. Data from these observations, coupled with material, labor, and maintenance costs could then be used to select the most economical joint sealing system.

3) A comprehensive horizontal pavement slab movement testing program should be underaken. Some of the independent variables to be considered would be base type; temperature of the base, slab, and atmoshere; wind speed; humidity; slab thickness; and solar intensity. The dependent variables would be the horizontal pavement slab movement during and after shrinkage. Such a study would produce

reliable pavement joint movement equations which could be extrapolated to fit many different climatic and base conditions.

4) Industry should continue to attempt to develop a joint sealant that is less effected by poor or careless joint preparation techniques and inspection procedures.

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APPENDIX A:

LITERATURE REVIEW

APPENDIX A: LITERATURE REVIEW

The Transportation Research Board, formerly the Highway Research Board, has provided an excellent source of information concerning concrete pavement design and maintenance problems.

A fairly complete bibliography on joints is maintained by the Transportation Research Board Sealants Committee.

Its publications, many of which may be found in the bibliography of this report, follow the development of rigid pavement joint sealing and maintenance as it has evolved through the years. Most notable among these publications are the National Cooperative Highway Research Program Systhesis of Highway Practice (NCHRPSHP) numbers 19, 38, 56, and 98. These publications give excellent summaries of nationwide practices of sealing and maintaining jointed concrete pavements. The Transportation Research Record (formerly Highway Research Record) presents both analytical and field results from joint sealant test programs.

The American Concrete Institute's Special Publication SP-70 contains several papers which discuss the behavior and design of joint sealants, joints, and concrete pavements. In fact, Minkara, et al.'s paper "Effect of Different Variables on Horizontal Movement of Concrete Pavement" is perhaps the most complete study undertaken in the area of horizontal pavement slab movement. Other conference proceedings can be just as valuable for providing state-of-the-art information. ACI also has published ACI committee 504's report "Guide to Joint Sealants for Concrete Structures."

Magazines, most notably Adhesives Age, also provide excellent information on the latest developments in joint sealant technology. Concrete Construction is also an excellent source for up-to-date maintenance proceedures and sealant development.

The American Society for Testing and Materials publishes a great deal of helpful information pertaining to joints and joint sealing. Pertinent specifications and test methods (D1850, D1851, D1854, D1855, D3405, D3406, and D3569) are found in volumes 04.02 and 04.03 of ASTM'S Annual Book of ASTM Standards. Additionally, ASTM C962 (Volume 04.07) as a guide for use of elastomeric joint sealants.

The American Association of State Highways and Transportation Officials publishes AASHTO Guide for Design of Pavement Structures and Standard Specifications for Transportation Materials and Methods of Sampling and Testing. Both of these contain many important references to joints and sealants.

The University of Texas Center for Transportation Research has published Research Report 401-3, by Diaz and McCullough, entitled Behavior of Long Pre-stressed Pavement Slabs and Design Methodology, which evaluates many of the pavement considerations affecting joint and sealant design.

APPENDIX B:

Joint Observation Information
and
Data Forms

FIELD OBSERVATION

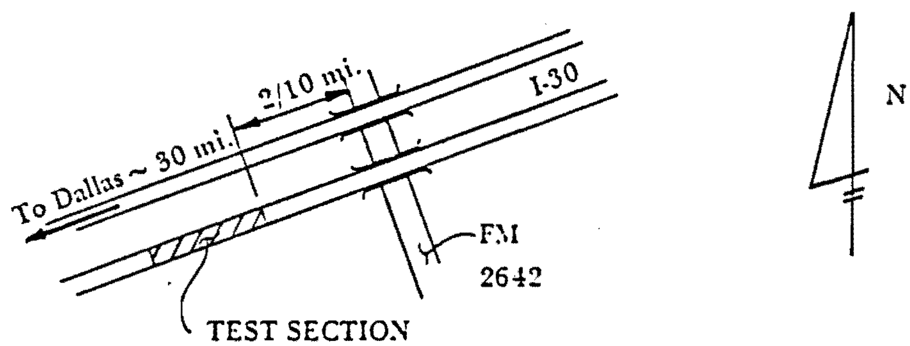
OF EXISTING JOINTS

Date: 3-21-86

Location:

District: 18 Highway: I-30 East From Mile: ______ To Mile: ______

Please use a description and sketch to locate the joints that are to be studied. Indicate joint numbers and convenient references.



12 joints, numbered West to East

Nos. 1-4 polysulfide
Nos. 8-12 Silicone

Original Joint Data:

Joint Width: 3/8 in. Joint Spacing: 20 ft.

Traffic: Heavy Joint Depth: 3/8 in.

Sealant Type: Polysulfide; Silicone Brand: A. C.Horn Hornflex; Dow Corning 888

Installation Date: 3-21-86 Contractor: Test Section

Note methods used by contractor to clean joints and install sealant in original joint: Joints were cleaned with high pressure water and blown dry with compressed air.

JOINT OBSERVATION

Date 7-5-86

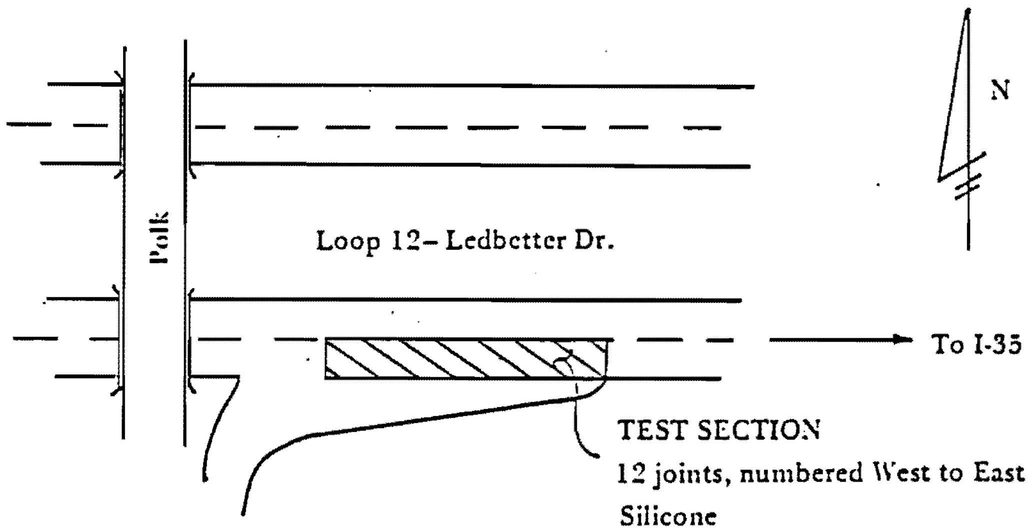
JOINT NUMBER	BOND (%)	EXTRUSION (%)	INTRUSION (%)	INCOMPRESSIBLE IMBEDMENT (%)	SEALANT CRACKING (%)	SPALLING (%)	JOINT WIDTH (in.)
1	100	0	0	0	0	15 sealed	3/8
2	100	0	0	0	0	0	3/8
3	100	0	0	0	0	0	3/8
4	100	0	0	0	0	0	3/8
5	100	0	0	0	0	0	3/8
6	100	0	0	0	0	0	3/8
7	100	0	0	0	0	0	3/8
8	100	0	0	0	0	0	3/8
9	100	0	0	0	0	0	3/8
10	100	0	0	0	0	0	3/8
11	100	0	0	0	0	0	3/8
12	100	0	0	0	0	0	3/8

FIELD OBSERVATION OF EXISTING JOINTS

Date: 11-15-86

Location:
District: 18 Highway: Loop 12, Dallas From Mile: ______ To Mile: ______

Please use a description and sketch to locate the joints that are to be studied. Indicate joint numbers and convenient references.



Original Joint Data:

Joint Width: 1/4 in. Joint Spacing: 20 ft.

Traffic: Moderate Joint Depth: 1/4 in.

Sealant Type: Silicone Brand: Dow Corning 888

Installation Date: 1979 Contractor: Test Section

Note methods used by contractor to clean joints and install sealant in original joint: Joints were sandblasted and cleaned with compressed air.

JOINT OBSERVATION

Page 2 / 3
Date 11-15-85

JOINT NUMBER	BOND (%)	EXTRUSION (%)	INTRUSION (%)	INCOMPRESSIBLE IMBEDMENT (%)	SEALANT CRACKING (%)	SPALLING (%)	JOINT WIDTH (in.)
1	90	0	0	0	0	15	1/2
2	100	0	0	0	0	0	3/8
3	100	0	0	0	0	0	1/2
4	100	0	0	0	0	0	1/2
5	90	0	0	0	0	20	1/4
6	90	0	0	0	0	15	1/4
7	100	0	0	0	0	5	1/4
8	100	0	0	0	0	5	1/2
9	95	0	0	0	0	0	1/4
10	85	0	0	0	0	20	1/2
11	100	0	0	0	0	0	1/4
12	90	0	0	0	0	0	1/2

JOINT OBSERVATION

Page 3 / 3
Date 7-5-86

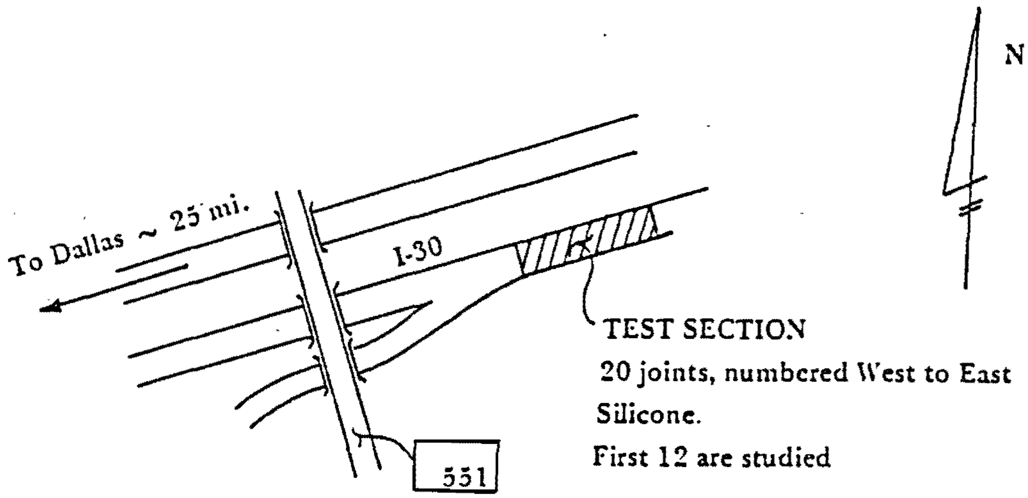
JOINT NUMBER	BOND (%)	EXTRUSION (%)	INTRUSION (%)	INCOMPRESSIBLE IMBEDMENT (%)	SEALANT CRACKING (%)	SPALLING (%)	JOINT WIDTH (in.)
1	90	0	0	0	0	15	3/8
2	100	0	0	0	0	0	1/4
3	100	0	0	0	0	0	3/8
4	100	0	0	0	0	3	1/4
5	85	0	0	0	0	20	1/4
6	90	0	0	0	0	15	1/4
7	100	0	0	0	0	5	1/4
8	100	0	0	0	0	5	1/4
9	93	0	0	0	0	3	1/4
10	85	0	0	0	0	20	3/8
11	100	0	0	0	0	5	1/4
12	90	0	0	0	5	5	5/8

FIELD OBSERVATION OF EXISTING JOINTS

Date: 11-12-86

Location:
District: 18 Highway: I-30 East From Mile: ______ To Mile: ______

Please use a description and sketch to locate the joints that are to be studied. Indicate joint numbers and convenient references.



Original Joint Data:

Joint Width: 1/2 in. Joint Spacing: 15 ft.

Traffic: . Heavy Joint Depth: 1/4 - 1/2 in.

Sealant Type: Silicone Brand: G.E. SCS4404

Installation Date: May, 1984 Contractor: Test Section

Note methods used by contractor to clean joints and install sealant in original joint: Joints were sandblasted and blown clean with compressed air.

JOINT OBSERVATION

Page 2 / 4

Date Jan. 1985

JOINT NUMBER	BOND (%)	EXTRUSION (%)	INTRUSION (%)	INCOMPRESSIBLE IMBEDMENT (%)	SEALANT CRACKING (%)	SPALLING (%)	JOINT WIDTH (in.)
1	100	0	0	0	0	0	1/2
2	100	0	0	0	0	0	1/2
3	100	0	0	0	0	0	1/2
4	100	0	0	0	0	0	1/2
5	100	0	0	0	0	0	1/2
6	100	0	0	0	0	0	1/2
7	100	0	0	0	0	0	1/2
8	100	0	0	0	0	0	1/2
9	100	0	0	0	0	0	1/2
10	100	0	0	0	0	0	1/2
11	98	0	0	0	0	0	1/2
12	100	0	0	0	0	0	1/2

JOINT OBSERVATION

Page 3 / 4
Date 11-12-85

JOINT NUMBER	BOND (%)	EXTRUSION (%)	INTRUSION (%)	INCOMPRESSIBLE IMBEDMENT (%)	SEALANT CRACKING (%)	SPALLING (%)	JOINT WIDTH (in.)
1	100	0	0	0	0	0	1/2
2	100	0	0	0	0	0	1/2
3	100	0	0	0	0	0	1/2
4	100	0	0	0	0	0	1/2
5	100	0	0	0	1	0	1/2
6	100	0	0	0	0	0	1/2
7	100	0	0	0	0	0	1/2
8	100	0	0	0	0	0	1/2
9	100	0	0	0	0	0	1/2
10	100	0	0	0	0	0	1/2
11	100	0	0	0	0	0	1/2
12	100	0	0	0	0	0	1/2

JOINT OBSERVATION

Page 4 / 4
Date 7-5-86

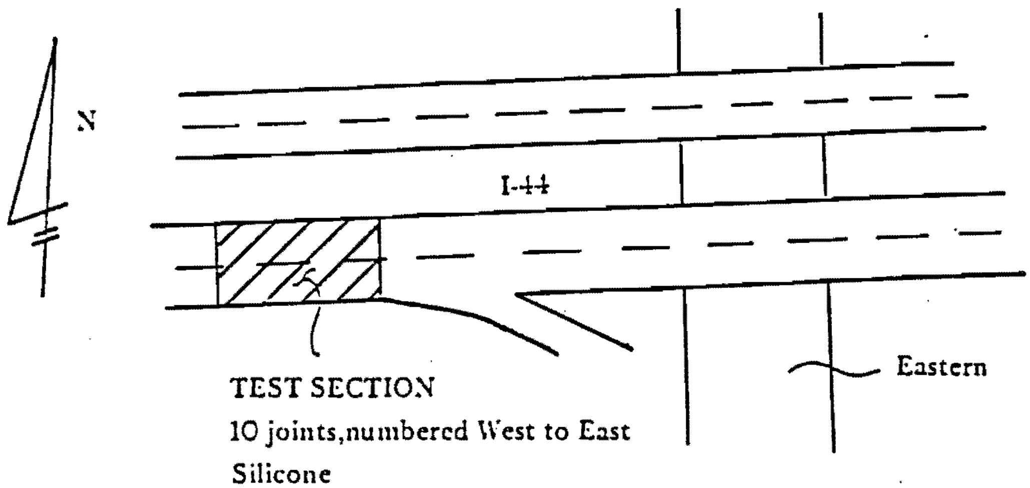
JOINT NUMBER	BOND (%)	EXTRUSION (%)	INTRUSION (%)	INCOMPRESSIBLE IMBEDMENT (%)	SEALANT CRACKING (%)	SPALLING (%)	JOINT WIDTH (in.)
1	100	0	0	0	0	0	1/2
2	100	0	0	0	0	0	1/2
3	100	0	0	0	0	0	1/2
4	100	0	0	0	0	0	1/2
5	100	0	0	0	1	0	1/2
6	100	0	0	0	0	0	1/2
7	98	0	0	0	0	0	1/2
8	100	0	0	0	0	0	1/2
9	100	0	0	0	0	0	1/2
10	100	0	0	0	0	0	1/2
11	90	0	0	0	0	0	1/2
12	100	0	0	0	0	0	1/2

FIELD OBSERVATION OF EXISTING JOINTS

Date: 2-13-86

Location: Oklahoma
District: City Highway: I-44 East From Mile: ______ To Mile: ______

Please use a description and sketch to locate the joints that are to be studied. Indicate joint numbers and convenient references.



Original Joint Data:

Joint Width: 1/2 in. Joint Spacing: 20 ft.

Traffic: Moderate Joint Depth: 1/4 - 1/2 in.

Sealant Type: Silicone Brand: Dow Corning 888

Installation Date: Oct., 1985 Contractor: Unknown

Note methods used by contractor to clean joints and install sealant in original joint: Joints were sandblasted and blown clean with compressed air.

JOINT OBSERVATION

Page 2 / 2
Date 2-13-86

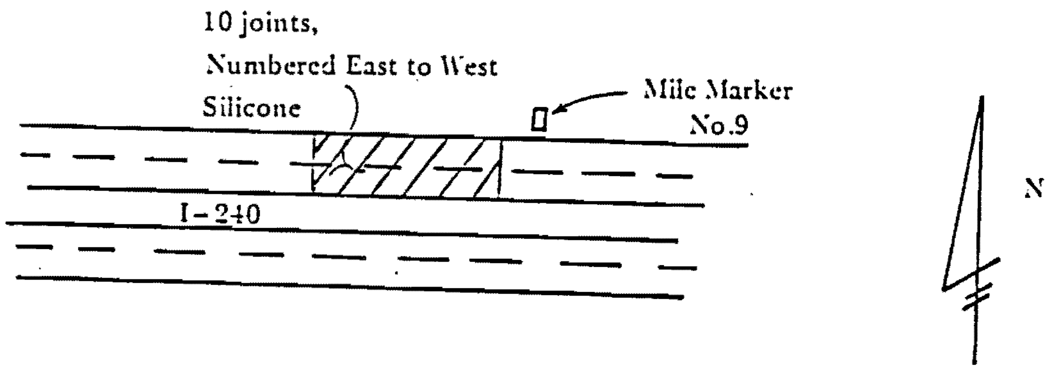
JOINT NUMBER	BOND (%)	EXTRUSION (%)	INTRUSION (%)	INCOMPRESSIBLE IMBEDMENT (%)	SEALANT CRACKING (%)	SPALLING (%)	JOINT WIDTH (in.)
1	100	0	0	0	0	0	1/2
2	100	0	0	0	0	0	1/2
3	100	0	0	0	0	0	1/2
4	100	0	0	0	0	0	1/2
5	100	0	0	0	0	0	1/2
6	100	0	0	0	0	0	1/2
7	100	0	0	0	0	0	1/2
8	100	0	0	0	0	0	1/2
9	100	0	0	0	0	0	1/2
10	100	0	0	0	0	0	1/2

FIELD OBSERVATION OF EXISTING JOINTS

Date: 2-13-86

Location: Oklahoma
District: City Highway: I-240 West From Mile: 9 To Mile: 10 joints

Please use a description and sketch to locate the joints that are to be studied. Indicate joint numbers and convenient references.



Original Joint Data:

Joint Width: 3/4 to 7/8 in. Joint Spacing: 20 ft.

Traffic: Moderate Joint Depth: 1/2 to 5/8 in.

Sealant Type: Silicone Brand: G.E. 2342

Installation Date: 1984 Contractor: Keystone Services of Tulsa

Note methods used by contractor to clean joints and install sealant in original joint: Unknown

Date 2-13-86

JOINT OBSERVATION

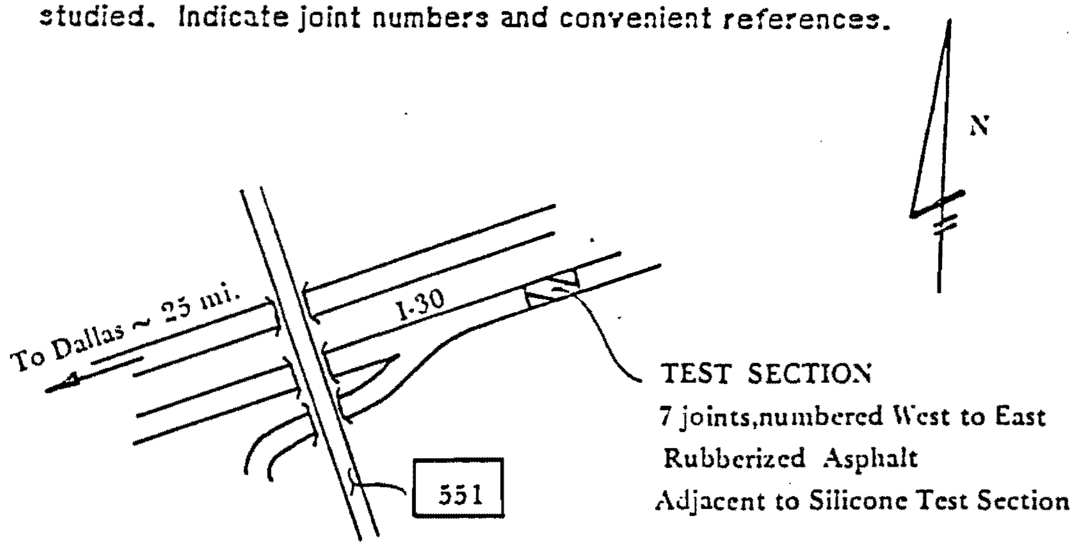
JOINT NUMBER	BOND (%)	EXTRUSION (%)	INTRUSION (%)	INCOMPRESSIBLE IMBEDMENT (%)	SEALANT CRACKING (%)	SPALLING (%)	JOINT WIDTH (in.)
1	100	0	0	0	5	0	7/8
2	100	0	0	0	0	5	7/8
3	100	0	0	0	0	10	3/4
4	100	0	0	0	0	5	3/4
5	100	0	0	0	0	5	3/4
6	95	0	0	0	10	0	3/4
7	100	0	0	0	0	0	7/8
8	90	0	0	0	0	0	3/4
9	95	0	0	0	0	0	7/8
10	100	0	0	0	0	10	3/4

FIELD OBSERVATION
OF EXISTING JOINTS

Date: 11-12-86

Location:
District: 18 Highway: I-30 East From Mile: ______ To Mile: ______

Please use a description and sketch to locate the joints that are to be studied. Indicate joint numbers and convenient references.



Original Joint Data:

Joint Width: 1/2 in. Joint Spacing: 15 ft.

Traffic: Heavy Joint Depth: Full

Sealant Type: Rubberized Asphalt Brand: Allied Materials

Installation Date: May, 1984 Contractor: Primate, Dallas

Note methods used by contractor to clean joints and install sealant in original joint: Joints were blown with air before sealing.

JOINT OBSERVATION

Page 2 / 3
Date 11-12-86

JOINT NUMBER	BOND (%)	EXTRUSION (%)	INTRUSION (%)	INCOMPRESSIBLE IMBEDMENT (%)	SEALANT CRACKING (%)	SPALLING (%)	JOINT WIDTH (in.)
1	70	0	0	5	0	0	1/2
2	60	0	0	10	0	0	1/2
3	60	10	0	7	0	0	1/2
4	70	0	0	5	0	0	1/2
5	70	0	0	5	0	0	1/2
6	80	0	0	10	0	0	1/2
7	70	0	0	5	0	0	1/2

JOINT OBSERVATION

Page 3 / 3
Date 7-5-86

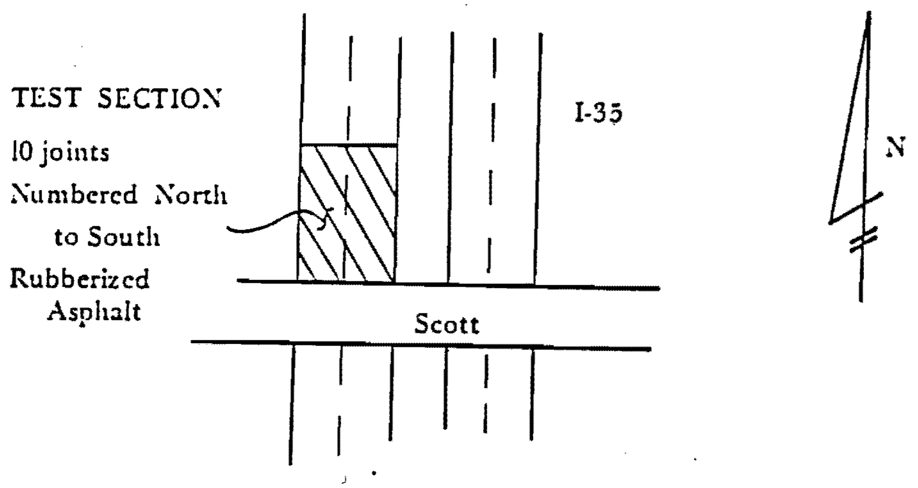
JOINT NUMBER	BOND (%)	EXTRUSION (%)	INTRUSION (%)	INCOMPRESSIBLE IMBEDMENT (%)	SEALANT CRACKING (%)	SPALLING (%)	JOINT WIDTH (in.)
1	80	0	100	60	100	0	1/2
2	90	5	70	60	80	5	1/2
3	70	10	70	40	80	5	1/2
4	90	50	0	5	0	0	1/2
5	40	10	5	40	20	0	1/2
6	80	5	10	15	20	0	1/2
7	80	0	20	20	50	0	1/2

FIELD OBSERVATION OF EXISTING JOINTS

Date: 2-10-85

Location:
District: 21 Highway: I-35, S. Laredo From Mile: ______ To Mile: ______

Please use a description and sketch to locate the joints that are to be studied. Indicate joint numbers and convenient references.



Original Joint Data:

Joint Width: 1/2 in. Joint Spacing: 20 ft.

Traffic: Heavy Joint Depth: Full

Sealant Type: Rubberized Asphalt Brand: Allied Materials

Installation Date: 1980 Contractor: Unknown

Note methods used by contractor to clean joints and install sealant in original joint: Unknown

JOINT OBSERVATION

Date 2-10-86

JOINT NUMBER	BOND (%)	EXTRUSION (%)	INTRUSION (%)	INCOMPRESSIBLE IMBEDMENT (%)	SEALANT CRACKING (%)	SPALLING (%)	JOINT WIDTH (in.)
1	50	85	0	5	100	5	1/2
2	50	70	10	0	90	10	1/2
3	40	60	0	10	95	5	1/2
4	70	90	15	15	100	0	1/2
5	70	50	10	5	100	0	1/2
6	50	55	0	5	100	5	1/2
7	60	50	0	5	100	5	1/2
8	50	60	0	15	90	5	1/2
9	70	85	10	25	90	0	1/2
10	50	90	0	5	80	5	1/2

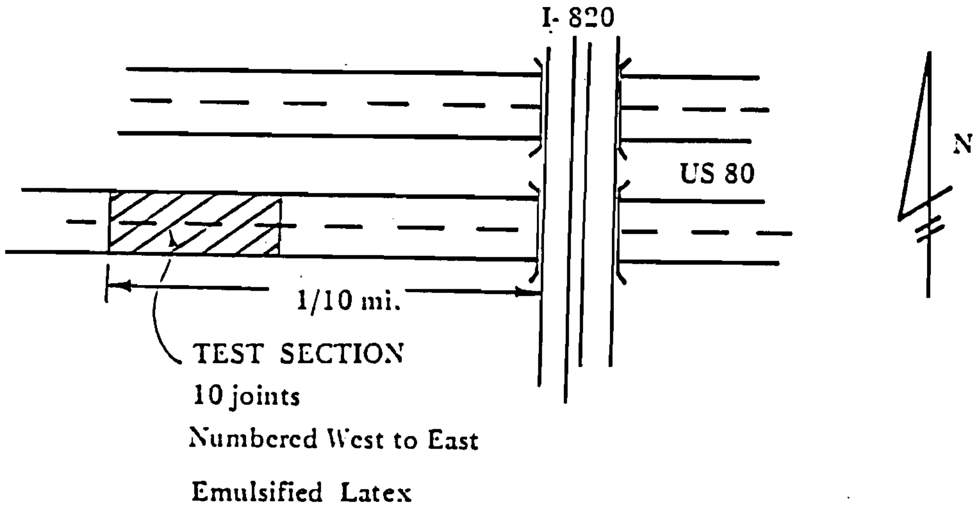
FIELD OBSERVATION OF EXISTING JOINTS

Date: 11-12-86

Location:

District: 2 Highway: U.S. 80 Fort Worth From Mile: ______ To Mile: ______

Please use a description and sketch to locate the joints that are to be studied. Indicate joint numbers and convenient references.



Original Joint Data:

Joint Width: 1/2 in. Joint Spacing: 20 ft.

Traffic: Moderate Joint Depth: Full

Sealant Type: Emulsified Latex Brand: Unknown

Installation Date: 1962 Contractor: Unknown

Note methods used by contractor to clean joints and install sealant in original joint: Original joints were blown clean with air before sealing.

Date 11-12-85

JOINT OBSERVATION

JOINT NUMBER	BOND (%)	EXTRUSION (%)	INTRUSION (%)	INCOMPRESSIBLE IMBEDMENT (%)	SEALANT CRACKING (%)	SPALLING (%)	JOINT WIDTH (in.)
1	0	0	0	100	50	100	1/2
2	0	0	0	100	90	100	3/4
3	10	0	0	100	100	100	3/4
4	0	0	0	100	100	100	1/2
5	15	0	0	100	40	100	3/4
6	10	0	0	100	90	100	3/4
7	0	0	0	100	90	100	1/2
0	0	0	0	100	95	100	3/4
9	10	0	0	100	100	100	3/4
10	0	0	0	100	100	100	3/4