STUDY OF SEALING PRACTICES FOR RIGID PAVEMENT JOINTS

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PREFACE

A portion of the Spring 1969 Pavement Research Advisory Committee Meeting was devoted to a discussion of research needs as seen by the committee members and guests. During this discussion J. M. Wray, Jr., state maintenance engineer, pointed out that the poor performance of joints in rigid pavements was creating one of the Highway Department's most pressing maintenance problems. He also indicated his belief that the Highway Department could profit from the experiences of other states with joint sealing materials, if information on their experiences could be obtained.

Following this meeting, the Pavement Section initiated studies of pavements requiring extensive joint maintenance in 1969. These studies, including field inspections and the examination of joint cores, suggested that much of the poor performance was related to the absence of effective joint sealants. Thus, joints were subject to infiltration by water, deicing chemicals, and incompressibles, which reduced subgrade support and destroyed the ability of the joints to accommodate movements resulting from changes in temperature and moisture conditions. Joint faulting, joint spalling, and blowups were among the defects noted on the affected pavements. Earlier studies of joint deterioration, related to a metal joint forming insert (Unitube), showed that where the joints were reasonably well sealed, deterioration was markedly reduced.

The results of those field studies were reported to the Pavement Research Advisory Committee at the Spring 1970 Meeting. Presented at the same time was a discussion of the experiences of other highway agencies with joint sealing and of the factors related to effective joint sealing. The committee then charged J. P. Bassett, committee chairman, and K. H. McGhee with the responsibility for developing such joint sealing recommendations as they deemed appropriate for the Highway Department.

This subcommittee held numerous meetings, conducted several field trips, and attended a FHWA sponsored joint sealing symposium before formulating the design recommendations, incorporated in the January 1971 edition of "Road Designs and Standards". The maintenance recommendations were recently developed and are reported here for the first time.

Interestingly, the FHWA, in a letter from H. C. King to J. E. Harwood dated May 7, 1971, outlined design recommendations nearly identical to those adopted earlier by the Highway Department.

SUMMARY AND RECOMMENDATIONS

The joint sealing materials and the rigid pavement joint sealing practices employed by Virginia and other highway agencies were studied. The purpose was to develop design and maintenance recommendations leading to improved sealant and joint performance in Virginia.

The studies showed that Virginia's sealant and joint designs were in need of updating and that higher quality poured sealants as well as preformed sealants could be used to advantage.

The following recommendations were developed through close cooperation with J. P. Bassett, pavement design engineer and chairman of the Pavement Research Advisory Committee, and with other representatives of the operating divisions within the Highway Department. They are set forth in the belief that improved sealant and joint performance, and consequently reduced maintenance costs, would result from their implementation.

Maintenance Recommendations

I. Joint resealing operations should give consideration to pavement characteristics (slab length, joint width, etc.) which influence sealant stresses and performance, and to the capabilities of currently available sealing materials. Most modern Virginia pavements fall within the scope of items (A) and (B) below:

A. Insofar as practical and economically feasible, pavements having contraction joints (usually 3/8 inch wide) spaced 61.5 feet apart should be reworked to provide 1/2 to 5/8 inch wide joints sealed with 1-1/8 to 1-1/4 inch wide preformed compression seals.

High quality poured sealants (polysulfides, etc.) are specifically not recommended for these pavements because of the excessive slab movements which could be accommodated only by sawing joints to a width of approximately $1\frac{1}{4}$ inch.

B. Pavements having nominal 3/8 inch or wider contraction joints spaced 20 feet apart should be resealed with either preformed compression seals (5/8 to 3/4 inch wide) or high quality poured sealants. Resawing joints to a 1/2 inch minimum width would enhance poured sealant performance. Poured sealants should have depths no greater than their widths.

II. Insofar as practical, joint cleaning and resealing should be done in cool weather (an air temperature range of from 40 to 70°F is recommended) to take advantage of wider joint openings at that time. This would serve the dual purposes of making infiltrated materials easier to remove and of lessening the maximum tensile stresses on poured sealants.

III. Sealing materials should be formulated and installed in strict conformance with the manufacturers' recommendations. If this is not feasible, poured sealants should not be used.

IV. When comprehensive resealing programs cannot be undertaken within a reasonable period of time, routine maintenance procedures should provide for periodic joint inspections, cleaning and resealing with lower quality sealing materials as needed (possibly as often as once a year). This interim measure would protect joints from further intrusion of incompressible materials until the higher quality materials can be provided.

It is also possible that routine maintenance operations could utilize some of the higher quality materials, especially the preformed sealants, which require little specialized equipment and personnel.

Design Recommendations

Recommended changes in design standards were formulated in late 1970 in cooperation with J. P. Bassett. Through the diligent efforts of Mr. Bassett and personnel in the Location and Design Division, they were incorporated in the January 1971 edition of "Road Designs and Standards". Implementation preceded the publication of this report because a number of rigid pavement projects were nearing the contract stage and the revised designs were considered to be necessary additions to these contracts. The recommendations are included here solely for the purpose of completeness of the report.

I. Recommended Joint Spacings

A. Plain Pavements: Retain a contraction joint spacing of 20 feet. The movement expected on these slabs can be accommodated with relatively narrow joints that can be effectively sealed.

B. Reinforced Pavements: Reduce the standard slab length to 40 feet (from the original 61.5 feet). This will provide pavements with the joints narrow enough to be acceptable yet wide enough to be effectively sealed with high quality sealants.

II. Recommended Joint and Sealant Designs
(for details see 1971 edition of "Road Designs and Standards")

A. Make joint widths a function of the slab length and of the sealant's capability to accommodate joint movements.

1. Plain pavements: Use 3/8 inch wide contraction joints and seal with 5/8 to 3/4 inch wide preformed compression seals, or use 1/2 inch wide contraction joints and seal with high quality poured sealants.

2. Reinforced pavements: Use 5/8 inch wide contraction joints and seal with high quality cold poured sealants or seal with $1\frac{1}{4}$ inch preformed compression seals.

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INTRODUCTION

The infiltration of incompressible materials, water and deleterious chemical agents such as deicers into the longitudinal and transverse joints of a concrete pavement promotes conditions which hasten the need for repair, reduce the riding quality, and generally shorten the useful life of the pavement.

Incompressible materials restrict the free joint movement (expansion and contraction) resulting from temperature and load variations and result in localized high compressive stresses. Such stresses all too often are relieved through undesirable spalling, crushing and cracking or by the explosive "blow-up" type failure.

Water infiltration (and the inevitable freeze-thaw cycle accompanying it) leads to concrete deterioration through frost action and to loss of the support capabilities of the subgrade. Such a loss, usually accompanied by slab pumping at the joints, accelerates the structural failure of the slab. Deicing agents may infiltrate a joint and cause damaging growth through aggregate reaction, deterioration of subgrade and joint edges, and damage to reinforcing steel.

In an attempt to prolong the useful life of a pavement through the prevention of infiltration, it is common practice to seal the joints between adjacent slabs with one of two sealants: (1) a hot or cold field-molded (poured-in-place) sealant, or; (2) an extruded preformed compression seal (neoprene, etc.)

Important factors influencing the effectiveness of these sealants are joint design, joint spacing, sealing material, installation procedures, and climatic conditions. These factors were considered in the summer of 1969 through an extensive survey of the literature relating to the experiences of other highway agencies. This survey was followed by field inspections of all jointed concrete pavements constructed in Virginia since 1965. Finally, based on the engineering considerations of joint design and on the experiences of other agencies, Virginia's current practices were analyzed and certain changes recommended.

PURPOSE AND SCOPE

As indicated in the preface, the purpose of these studies was to develop improved joint design standards and practices which would result in the construction of relatively maintenance free joints. A secondary objective was to consider routine maintenance practices (primarily sealing) on in-place pavements in an effort to advise the Highway Department on the adequacy of these practices.

The joint sealing problem will be discussed in the pages which follow. Initially slab and joint motions will be analyzed and related to their effects on joint sealants. The design of typically used sealant types will then be discussed along with a summarization of the findings of several agencies which are actively researching joint preparation and the characteristics of the available sealing materials. The final sections will attempt to analyze Virginia's practices and to draw meaningful conclusions about the selection of sealants and make general recommendations wherever applicable and possible.

JOINT MOVEMENT

Temperature changes are the primary force causing the opening and closing of joints in concrete pavement slabs. The largest temperature variations occur at the slab-atmosphere interface and are due primarily to the daily (and seasonal) heating and cooling of the atmosphere. The subgrade below the slab acts as a heat reservoir and generally tempers the effect of the large daily atmospheric temperature variations upon the slab. Experimentation(1) has shown that temperatures at the slab-subgrade interface show little variation due to daily temperature changes in the air above the slab. Thus, at night when the air is cool, the bottom region of the slab may, in fact, be warmer than the upper regions, while during the day, the reverse is true. However, the seasonal variations in the average daily ambient air temperature are reflected in subgrade-slab interface temperatures so that joints are generally open in the cool winter months and closed in the warm summer months.(1) An example of joint movements measured on I-64 near Charlottesville is seen in Figure 1. Note that the 3/8 inch wide joint (20-foot spacing) underwent a 14 percent maximum variation in opening during a 12 month period. The joint was most tightly closed in May 1970(pavement temperature, 111°F) and was at its most open position in January 1971 (pavement temperature, 35°F).

One might assume that with a slow, uniform change in temperature the slab length (and correspondingly, the joint width) would change in a slow,uniform manner as well. Recent research(1) has shown, however, that such might not always be the case and that some slabs tend to move in an incremental fashion (with jerky movements). It is hypothesized that frictional resistance at the slab-subgrade interface and/or a restraint to free movement caused by the load transfer device is gradually overcome by increasing thermal stresses. At the time these thermal stresses exceed the restraining stresses, the slab tends to move incrementally to a point where the restraints again govern. Thus the slab tends to expand and contract in a jerky, nonuniform manner. In addition, in a structure such as a concrete pavement, which has many equidistant, equidimensional joints, it would seem that each joint would experience

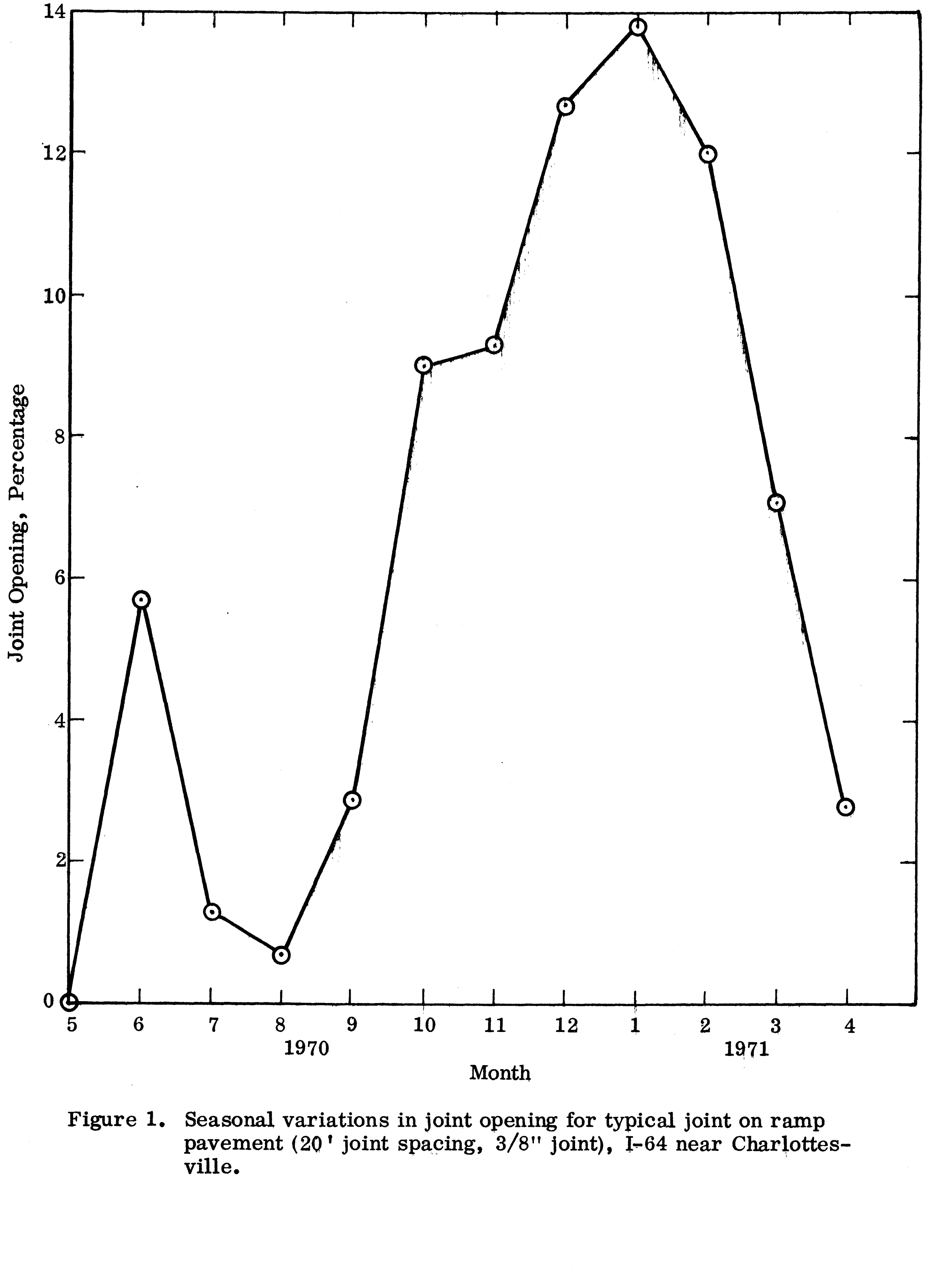


Figure 1. Seasonal variations in joint opening for typical joint on ramp pavement (20' joint spacing, 3/8" joint), I-64 near Charlottesville.

the same expansion and contraction. However, observations have shown that this is not always the case either. One joint may "freeze up" (due to intrusion, aggregage growth, etc.) and become immobile, and the joints in adjacent slabs may have to accommodate additional movement as a result.

Generally speaking, the percentage change in width that a normal joint in a portland cement concrete pavement will undergo due to a temperature change will be determined primarily by the amount of that change, by the length of the slab, and by the original joint width.[2] Egon Tons[3] of Purdue University in his 1965 study, "Materials and Geometry in Joint Seals" has included a chart (Figure 2) showing the interrelationship of the effective yearly temperature change in the slab to the slab length, the joint width, and the linear joint expansion, in percent.

To use the chart, one enters portion (A) at the lower left base line marked "slab length" (40 feet, for example). A vertical line is drawn from the base line to intersect the inclined line designated "field curve". Then, a horizontal line is extended from the field curve to portion (B) to intersect one of the inclined lines corresponding to a selected temperature change (assume 100°F seasonal change, for example). From the temperature change line extend a vertical line through portion (C) of the chart. At a point corresponding to the desired joint width, extend a horizontal line to the left to intersect the vertical line corresponding to linear joint expansion. By a trial and error procedure, an appropriate joint width can be chosen for any joint spacing. Note that in the example given, the linear joint expansion is 30 percent and 45 percent for 1/2 inch and 3/8 inch joints, respectively.

It should be noted that for a constant joint width and temperature change, the linear joint expansion, in percent, will increase with increasing slab length. Conversely, a smaller percent expansion should be expected in a one inch joint between 40 ft. slabs undergoing a yearly temperature change of 80°F than in a 1/2 inch joint in the same circumstances. The lower left portion of the figure gives both field and theoretical curves as turning points. However, since the field curve gives consideration to subgrade friction, its use is recommended for design purposes. The validity of Figure 2 in predicting joint movements has been partially verified by Research Council measurements such as was seen in Figure 1. In that particular case, the measured movement was 14 percent while the movement predicted from the chart is approximately 15 percent. Other measurements, on Interstate 95, showed that 3/8 inch joints spaced 61.5 feet apart moved an average of 39 percent for a temperature change of 55°F. The chart prediction for this situation is 35 percent movement.

In addition to representing the above relationships, the chart also attempts to relate an expected percentage linear joint expansion to that type of sealant which would be most suitable for use in a joint undergoing such an expansion. For example, Tons recommended poured-in-place sealants for expansions between 10 and 30 percent, neoprene compression seals for those between 30 and 80 percent, etc. These suggestions will be more fully examined later.

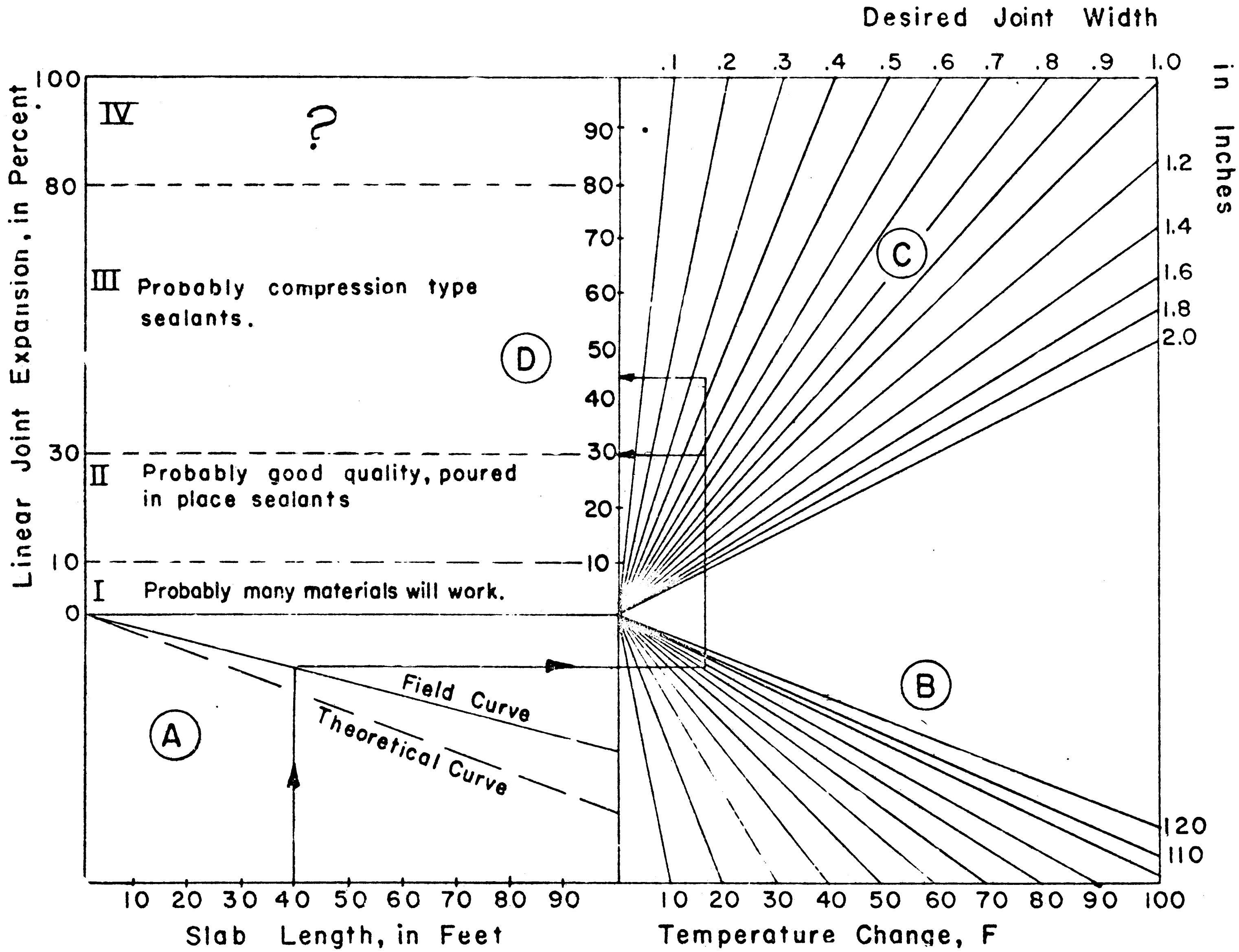


Figure 2. Simplified graphical method for determining joint expansion in portland cement concrete pavements, after Tons.(3)

SEALANT DESIGN

The question now naturally arises, "What effects do joint motions have upon the sealants in them?"

Naturally, for a sealant to be effective, it must follow the joint motions exactly, changing its shape, length, etc., so as to maintain its integrity and contact with the joint walls. Sealant motion at any time is a composite of plastic and elastic behavior — the type of behavior predominating being dependent upon the joint configuration, ambient temperature, and rate and type of motion.

As was mentioned previously, there are two main types of sealants, field molded and preformed. The field molded sealants are those poured directly into the joint being sealed. They are normally prepared on the spot and take the basic joint geometry as their own by closely conforming to the joint walls. The preformed sealants are normally plant fabricated and arrive at the job site in rolls of some sort. They are placed into the joint opening in a compressed state. Such sealants are designed to remain in partial compression and their initial stress serves to keep them in contact with the joint wall at all times.

In order to illustrate the nature and characteristics of these two sealant types, the following discussions are presented. Following these will be a section that will concern itself with the performance that each type has given under service conditions.

Poured Sealants

Sealant Behavior

Field molded sealants depend primarily upon their elastic properties to withstand joint movements. Initial installation requires that the sealant be plastic enough to bond to the joint walls but, after installation, deformations and recoveries should be largely through elasticity in order for the sealant to maintain its integrity. The diagrams shown in Figure 3 illustrate more fully the behavior of a field molded sealant in a vertical joint.

It is obvious from the diagrams that a poured-in-place sealant undergoes periodic stress reversals and places the concrete edges of the joint in tension periodically as well. The primary stresses undergone by this type of sealant are tension and compression; shear considerations are negligible.[2]

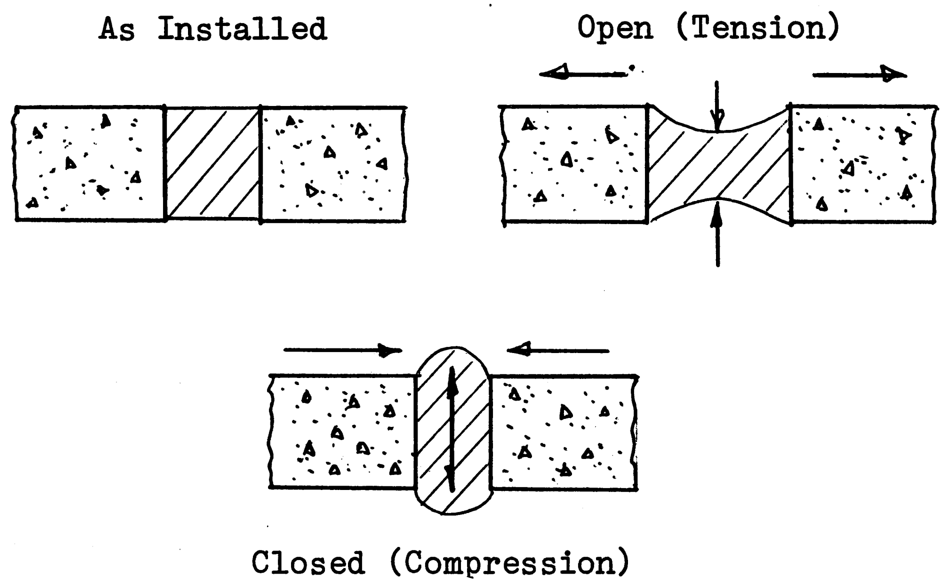


Figure 3. Behavior of poured joint sealant subjected to joint movement. After ACI Committee 504.(4)

Typical Failure Modes

The principal modes(1) of poured sealant failure consist of (1) tearing at the sealant-concrete interface (adhesive failure), (2) tearing of the sealant itself (cohesive failure), (3) the intrusion of incompressibles into the sealant, and (4) the extrusion of the sealant above the pavement surface. In the first two cases, joint effectiveness is reduced because the seal is broken so that foreign materials have access to the joint below. In the third case, the sealant can become so filled with compressibles as to act as a rigid mass in resisting joint closure. When the fourth condition occurs the sealant is destroyed quickly by traffic action. Complete loss of the sealant may occur in a short time.

Cases (1), (2) and (4) may result from either design (excessive joint movement) or materials deficiencies, while case (3) is primarily a materials deficiency. Assuming that due consideration has been given to joint design, cases (1) and (2) result from inadequate adhesive strength or cohesive strength, respectively. Case (3) results from low resiliency of the sealing material so that incompressibles coming into contact are captured rather than rebounded. Case (4) is the result of overfilled joints, excessive joint movement, or both.

The Appendix gives a more detailed discussion of the desirable poured sealant properties and of the failure modes which may be encountered.

Shape Factor

While essentially a design matter, another factor influencing the stresses and, thus, performance of poured sealants is the shape factor, or ratio of the sealant depth to its width. Sealants are constant volume solids at normal service temperatures and adjust their shape to follow joint movements. Because of the Poisson effect, the sealant cross section is reduced as the joint opens and the sealant is extended. Schultz(5) and Tons(6) have shown that sealant strain is greatly increased when the width to depth ratio (shape factor) exceeds 1/2. Thus, where practical a shape factor of 1/2 is recommended.(1)

In practice this value is difficult to maintain for very narrow joints. Sealant manufacturers indicate (personal communication) that sealants much less than about 3/8 inch deep are subject to penetration by sharp incompressible particles. For this reason, 3/8 inch is often considered the minimum desirable thickness, so that if the nominal joint width is 3/8 inch (as is often the case) the effective shape factor is 1. This factor should never be exceeded because of the resulting high strains on the sealant.

Bond Breaker

The diagrams in Figure 3 indicate that when the sealant is extended both the bottom and top faces of the sealant tend to move vertically. Schultz(5) shows that when the sealant is bonded to the concrete at its lower face, strains are increased by as much as 100 percent. Thus, a bond breaker at the lower sealant-concrete interface is always recommended. In Figure 4 is shown an example of the behavior of a sealant with and without a bond breaker. Bond breakers commonly used include polyethylenes, wax paper, and aluminum foils.

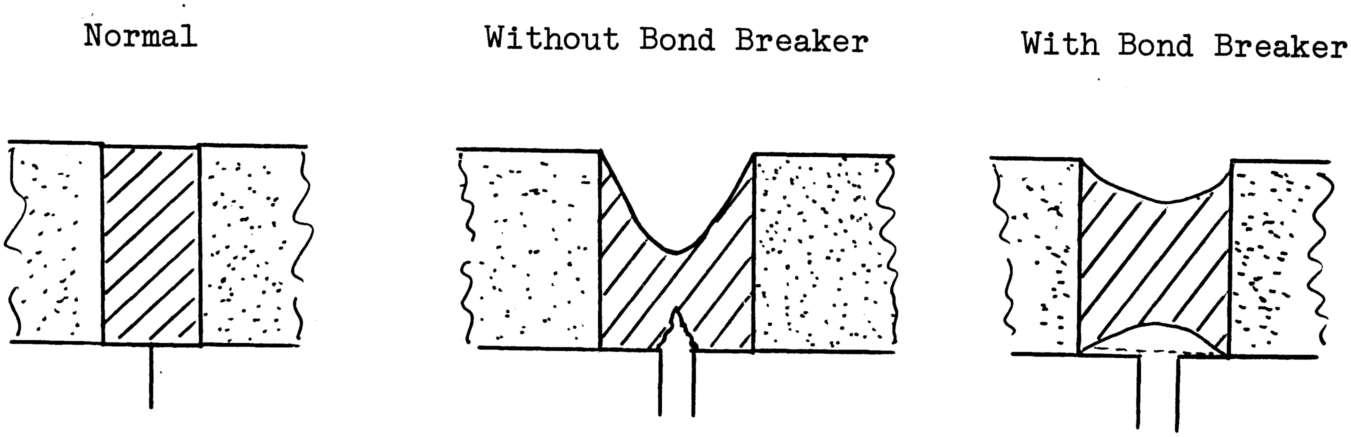


Figure 4. Sealant behavior with and without a bond breaker at the lower seal-concrete interface. After Schultz.(5)

Design Steps

To complete this discussion of poured-in-place sealant design, a general outline of design steps is in order.

The first considerations are the joint spacing and width. These will be determined primarily by the construction method desired and by the extent and frequency of the movement anticipated from an analysis of the temperature variations. The previously given chart (Figure 2) relating linear joint expansion to slab length (joint spacing), temperature change, and joint width will be helpful here. The selected spacing and width can next be used to estimate the percentage of width change that a sealant must undergo. Then, a sealant material can be chosen after due consideration of its properties and the conditions under which it must perform. Knowing the physical properties of the sealant material and the joint's width and movement characteristics, an appropriate shape factor can be chosen.

It is appropriate to emphasize at this time that poured sealants are relatively restricted in their capabilities. As indicated earlier, no materials suppliers recommend the use of higher quality poured sealants where joint movement is in excess of 50 percent of its original or nominal width. Tons (Figure 2), on the other hand, suggests a maximum of 30 percent movement for the sealants.

If 30 percent is taken as the maximum for all poured materials, it can be shown from Figure 2 that either very wide joints or very short slabs are required. A conventional 3/8 inch wide joint, for example, would require that the joint spacing not exceed 20 to 25 feet. Conversely, if a 60 foot slab length is designed, a joint in excess of 1 inch wide would be required. Both these calculations assume a 100°F annual temperature range and make use of the field curve portions of Figure 2. These factors will have a bearing on Virginia design practices, as will be discussed later.

Preformed Sealants

To reiterate, a premolded compression seal is one that is manufactured in strip or roll form. It is transported to the site of sealing, mechanically compressed and inserted into the joint being sealed, and then its ends are trimmed to coincide with the pavement edges. The initial compression is retained in the installed seal and the frictional component of its normal force on the joint walls holds the seal at the proper height in the joint. This frictional holding force is normally augmented by a liquid adhesive that is applied to the joint wall prior to seal insertion and serves the dual purpose of lubricant and adhesive.

Sealant Behavior

Compression seals are of the webbed or cellular configuration, Figure 5.

Webbed Cellular

Figure 5. Preformed seal typical configurations.

The webbed type is made up of solid elastomeric web members and compression is accommodated by deformation of the members. Cellular seals are constructed of foam elastomers and are relatively less deformed when joint movement occurs. Both types are shaped so that the top surface recedes into the joint when the seal is compressed, thus reducing the danger of traffic damage. They are installed about 1/4 inch below the pavement surface. Webbed seals are available in almost any size, while the cellular type is generally available only up to 3/4 inch in width.

In the case of a properly functioning seal, neither the seal nor the concrete joint wall undergoes a stress reversal such as that which is inevitable with a poured-in-place seal. Compression seals must remain compressed approximately 15 percent at all times to maintain friction forces sufficient to hold them in place. In addition, at compressions above approximately 55 percent they show a pronounced tendency toward compression set and/or web welding, which renders them useless. The allowable range of joint movement is therefore 40 percent of the uncompressed seal width. Trial and error experimentation in both America and Europe[1] has shown the most critical condition under which the sealant must perform is that of the widest joint opening during the winter months. At that time, either compression set, from the previous summer, or lack of low temperature recovery may prevent the sealant from expanding to fill the joint, thus reducing its effectiveness to zero.

During installation of the seal, proper care and inspection are necessary to ensure that the seal is not severely stretched. Such stretching and the resulting tension in the seal coupled with the inherent compression, cause internal stress conditions that are very harmful to its integrity and life expectancy. Currently accepted installation practices tend to limit the elongation of the seal to somewhere between 5 and 8 percent of the total joint length, with the upper percentage being the maximum allowable.[1]

In addition, it has been recommended that the joint be formed or sawed in such a manner that an internal shoulder is present below the seal to prohibit any movement of the seal to the lower regions of the joint. This is relatively easy to accomplish with the sawing techniques now in common use and is a practice that should definitely improve seal performance.

Typical Failure Modes

The most common failure modes of preformed compression seals are adhesive failure (pulling away from the joint walls) and extrusion above the pavement surface. These are most often caused by the use of too small a seal and of too large a seal, respectively. As mentioned above, compression set (web sticking) and loss of recovery capabilities also are failure mechanisms, both of which result in an adhesive failure at the seal-concrete interface.

Proper attention to design procedures so that the appropriate seal is chosen for a given joint is usually sufficient insurance against the above conditions, provided adequate materials are available. A more complete discussion of the failure modes and required materials properties is offered in the Appendix.

Design Procedure

The problem of selecting a compression seal is similar to that of selecting a poured-in-place seal. Joint spacing and width should be estimated as well as the type and extent of movement they will induce. This information can then be utilized to estimate the percentage of width change that the seal must undergo. Knowing these data and having a knowledge of the properties of the seals available, one can select an appropriate seal. It should be noted that several design aids exist at this time, among them the previously included Egon Tons chart and others provided by seal manufacturers.

Just as is the case for poured sealants, preformed materials have limitations beyond which they cannot perform satisfactorily. Most importantly, joints should be so designed that the seals are never subjected to less than about 15 percent nor more than about 55 percent compression, based on the original seal width. Thus, the seals would be protected from dropping into the joint in cold weather and from compression set in hot weather. Note that the permissible joint movement (percentage) would be considerably greater than the permissible seal compression range. For example, calculations show that a nominal 3/8 inch wide contraction joint could open by 67 percent before a 3/4 inch wide seal would be under-compressed.

JOINT PREPARATION

Manufacturers of joint sealing materials are careful to emphasize the importance of placing the materials in clean, well shaped, and well designed joints. In most cases, a joint coating of an epoxy compound or other adhesive is recommended for both poured and preformed materials.

Since one of the principal modes of poured sealant failure is in adhesion at the joint-sealant interface, the need for a bonding agent there is evident. The coating serves both as a lubricant during installation and as a bonding agent under service, for preformed materials. In this case, there are no tensile stresses to overcome (for properly designed seals) so that the bonding agent is intended to prevent vertical movements of the sealant.

Joint cleaning is normally accomplished through use of air pressure, water pressure, sand blasting, or a combination thereof. Joints under construction are usually easier to clean than for resealing operations. Newly formed joints can present something of a problem because of the "slick" surface and laitance present. For this reason, formed joints are often sandblasted and washed to provide a good bonding surface. New York[7] has used an acid compound to etch formed joints. Joints which are sawed immediately prior to sealing present no such problems and may require only an air or water cleaning.

Old joints to be prepared for resealing can be difficult to clean if intruded by debris, old inserts, etc. Cleaning should be done in cooler weather so as to take advantage of the wider joint opening. Cleaning tools include bars, chisels, power driven brooms and cutters as well as high capacity air compressors.[8]

Unlike poured materials, which can flow to fill small irregularities in joint shape, the preformed materials require joints having straight, vertical walls. While not too difficult to achieve during construction, resealing operations with preformed materials can be expensive and difficult because of small spalls, cracks, etc. The need for patching the small irregularities to reseal with preformed seals has led some agencies to use poured materials as replacements. However, unless joints were originally wide enough to avoid over-stressing the poured materials, they will not perform satisfactorily. One state[7] used poured materials to replace neoprene compression seals which were too small for the joints. However, the poured materials soon failed so that they, in turn, were replaced with larger neoprene seals.

In summary, joint preparation is a critical aspect of the sealing operation. Since various sealants are compounded from different materials, have different capabilities, and are compatible with different bonding agents, it appears that manufacturers' recommendations must be followed.

MATERIALS AVAILABLE

Performance

Poured Materials

The available poured sealants consist principally of materials classified as (1) hot poured bituminous, (2) cold poured bituminous, and (3) cold poured elastomers. NCHRP Report No. 38[1] points out that there is almost universal dissatisfaction with the hot poured materials but that there is greater use of these than of the other two because of the economics involved. Cold poured bituminous materials (applied with a solvent) have given uniformly poor performance and are rarely used today.

Cold poured elastomers (polysulfides, polyurethanes, silicones, etc.) have had spotty performance records with most failures reported in the first two winters after installation.[1] Many of these failures have been traced to improper design, installation, or specifications. Often quality materials have been installed in narrow joints between long slabs where failure was assured because of the high stresses.[7] Other failures have resulted from improper field proportioning of multi-component materials so that the inplace joint sealant does not have the required properties.

Preformed Materials

Among the materials used as preformed seals are polyurethanes, silicone rubbers, bituminous impregnated fibers, and neoprenes. From this group, the preformed neoprenes have become the most popular because of good performance in test installations.

For example, during the past decade the Department of Transportation of the State of New York conducted extensive survey and field experimentation work in an effort to find a material with which to seal the concrete pavement joints on their high volume arterial roadways. During those years, it studied 90 test installations and 14 different types of sealants of both main types. To quote from Research Report 68-6:[7]

> Preformed neoprene has given excellent service... where joint edges were in good condition, and the section intended for the specific joint groove dimensions was installed at the proper elevation without twisting or undue stretching. It is the only sealer ... that has performed satisfactorily for more than 3 years.

The report goes on to state that preformed rubber sealers gave good performance for over $2\frac{1}{2}$ years while 10 of 13 other liquid sealants and 4 other preformed seals failed to last 1 year in service.

An FHWA informational memorandum[9] summarizes a nationwide survey of preformed neoprene usage. The report shows that in nearly every case where the proper size seal has been used in a properly prepared joint the performance has been satisfactory.

Specification Requirements

NCHRP Report No. 38[1] summarizes the specification requirements for highway sealing materials. These are broadly classed as (1) physical-chemical (hardness, tackiness, ozone resistance, viscosity, etc.) and (2) kinematic (extensibility, compression set, resilience, etc.). Most agencies are satisfied with the physical-chemical requirements and tests, but almost all are unhappy with the kinematic specifications and tests, primarily because of the difficulty in testing. Most specifications are modeled after a parent ASTM or Federal Government Specification.[1] While some agencies tend toward performance specifications, these are costly so that the majority still specify materials properties. Analyses of the complex organic chemistries of the modern materials are beyond the capabilities of most highway agencies. Thus, most new developments come about from the manufacturer's initiative and the field is changing so rapidly that specification developments do not keep abreast.

Since reliable tests are not yet available for all the properties mentioned above, the usual procedure is to use the laboratory tests for screening before materials are tested in the field.[1] There is a consensus[1] that field testing will be required for several more years before definitive laboratory tests will be available.

Cost

In-place costs of sealing materials is quite variable because of uncertainties involved in joint preparation, traffic control requirements, and quantities of materials. For this reason, figures given in the literature are based on averages and, thus, are subject to extreme variations for various locations.

One survey[1] gives the costs listed in Table I, where $0.07 per linear foot is allowed for joint cleaning.

TABLE I

REPRESENTATIVE COSTS FIGURES FOR JOINT SEALANT MATERIALS

	Cost ($/ft.)	
Type of Materials	Original Installation	Resealing of Joints
Hot poured rubber asphalt	0.10 - 0.30	0.20 - 0.35
Elastomeric (cold poured)	0.40 - 0.60	0.30 - 0.50
Preformed	1.00 - 3.00	1.00 - 4.00

It should be noted that the cost of preformed sealants is much more than that of the poured-in-place type. However, performance histories seem to be showing the preformed to be much more durable, so that the reduction in pavement damage and in maintenance costs should make the preformed sealant the better investment.

VIRGINIA PRACTICES AND EXPERIENCE

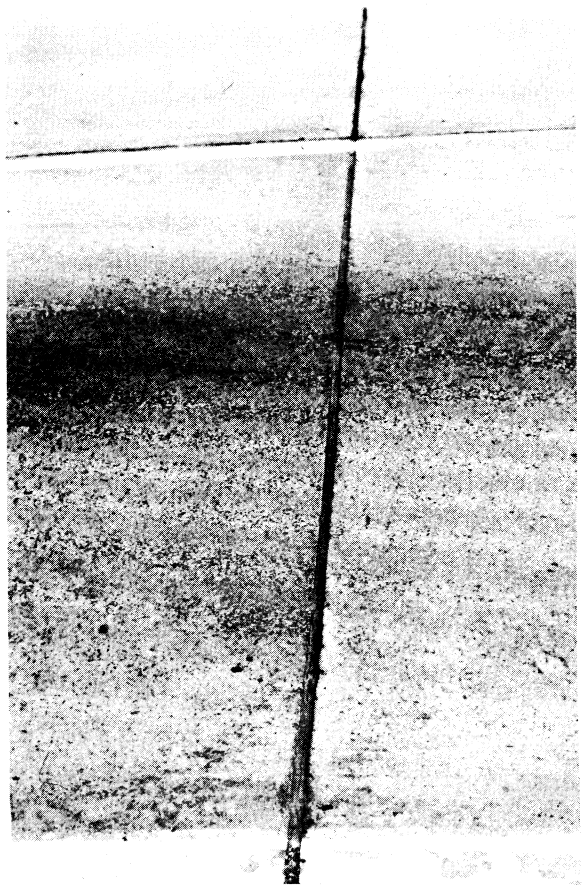
Until very recently, the mainline rigid pavements on Virginia's interstate and primary systems were constructed of 61.5 foot long reinforced slabs with 3/8 inch wide contraction joints.[10] Expansion joints, except at structures, have been omitted for several years. These pavements were the primary focus of a survey, conducted by one of the authors during the summer of 1969, of most of the concrete pavements that had been constructed since 1965. During this investigation, he determined that fewer than 1 percent of all the joints surveyed had adequate seals. There were, at that time, no interstate highways in Virginia which had preformed neoprene in their joints and all joints which were surveyed contained some type of poured-in-place sealants. It can be stated with certainty that these did not perform satisfactorily for periods exceeding 3 years, but no information is readily available that might give evidence of exactly how long they did perform well. It is the opinion of the authors that few, if any, of these seals lasted a year. The majority of the joints surveyed were heavily infiltrated with rocks, sand and other debris (wire, spark plugs, etc.) and showed spalling, chipping, and other evidences of slab deterioration resulting from open joints.

The previous chart (Figure 2) is useful in analyzing the poor performance of the above seals. Tests have shown that a 100°F seasonal temperature range is reasonable for concrete pavements in Virginia. If the chart is entered at this temperature change, a 60 foot joint spacing, and a 3/8 inch joint width, the indicated joint expansion is approximately 85 percent. Since the maximum allowable movement for poured sealants is some 30 percent, early failure of the badly over-stressed sealants is not surprising. As indicated earlier, to maintain movement below the maximum allowable for paved sealants would require a joint about 1 inch wide at the 61.5 foot spacing. An acceptable alternative would be to provide a 5/8 inch joint with a preformed seal.

Fortunately, much of the state's incidental paving (ramps, acceleration lanes, etc.) within the past few years has incorporated unreinforced concrete with 3/8 inch wide joints spaced 20 feet apart. As again can be seen in Figure 2 (100°F temperature range) the joint movement to be expected here is approximately 25 percent, so that a good quality poured sealant should be satisfactory, but will have little factor of safety. This has been shown to be true on Interstate 95 south of Emporia. Here a three year old installation of twenty joints sealed with a two component polysulfide (cold poured) sealant shows excellent performance. Adjacent joints sealed later with supposedly the same material failed after only one year of service. The newer, failed materials were visibly less pliable (and, therefore, less able to sustain movement), as was also indicated by the manufacturers' tests on both materials. The good installation was by the materials manufacturers' representatives, while the poor one was by a sealing contractor who formulated his own mixture from the same basic materials. Photographs of these two materials are shown in Figure 6. More recent installations of the successful material on Interstate 64 near Charlottesville were in 1/2 inch wide joints spaced at 20 feet. These are approaching one year of age and show only an occasional defect.

Preformed materials have been used but rarely in Virginia on pavement joints. A ten joint experimental installation on U. S. Route 13 in Northampton County has given excellent performance for over 4 years. In this case, the 3/8 inch wide joints are spaced 20 feet apart, so that the movement is well within the limitations of compression seals. Joints outside the limits of the experimental section were sealed with a hot poured bituminous material. These seals appear to have failed quite early in the life of the pavements so that the joints show some distress due to infiltration and are noticeably faulted. The contrast between the preformed and hot poured sealants is very marked in this case. A photograph of one of the preformed seals at an age of four years may be seen in Figure 7.

2514



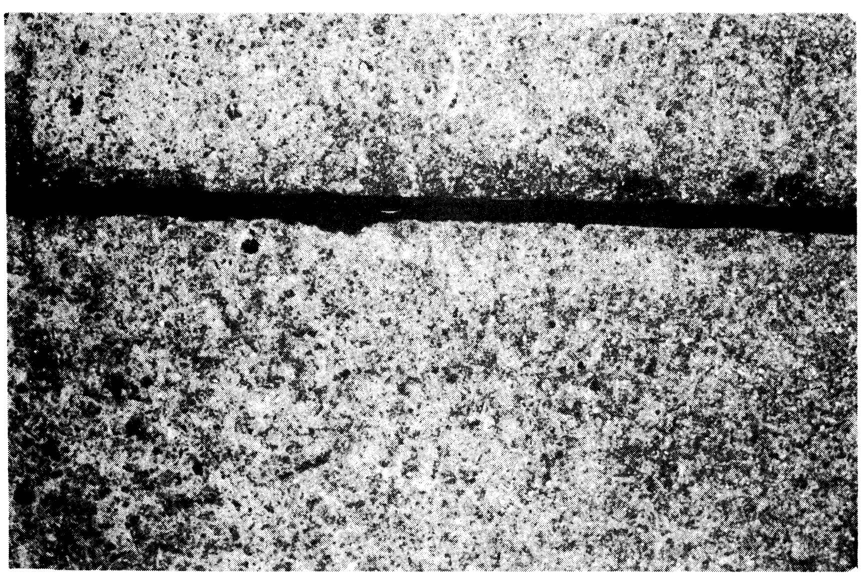


Figure 6. Examples of good (upper picture) and poor performance of polysulfide joint sealants on I-95, Emporia.

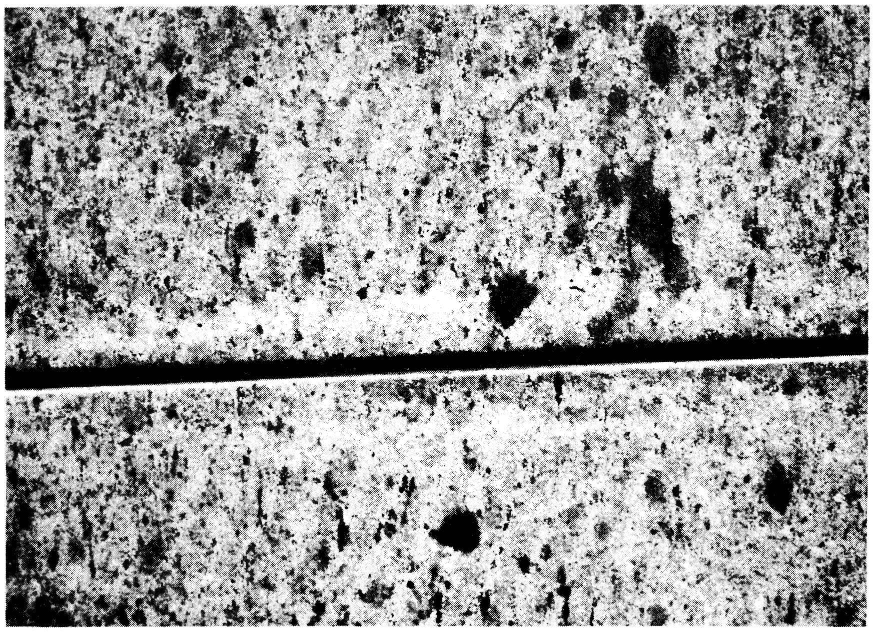


Figure 7. Preformed neoprene seal after 4 years of service.

A recent installation of a number of preformed seals in ramp joints on I-64 near Charlottesville are in excellent condition, but are too new to be properly evaluated.

REVISED JOINT AND SEALANT DESIGNS

When the preceding sections of this report were summarized at its fall 1970 meeting, the Pavement Research Advisory Committee charged J. P. Bassett, committee chairman, and the senior author with the responsibility for developing revised joint and sealant design standards. There was a consensus that the application of engineering principles and quality materials to the joint sealing problem would result in joints requiring substantially less maintenance than has been experienced in the past.

The approach to developing the design revisions was basically one of establishing joint widths and spacings such that the available sealing materials would not be overstressed in service. There was general agreement among those concerned that joints should be no greater than 5/8 inch wide, to lessen the chances of tire bumping and noise. It was also agreed that, because of the expense of the preformed type, the new designs should be compatible with both poured and preformed sealants. This feature was furthermore considered desirable from a maintenance-replacement standpoint, where engineers may wish to replace preformed seals with the poured type because of joint irregularities developed under traffic.

It was immediately evident that designs incorporating 61.5 feet joint spacings would be unacceptable because the high movement (50 percent movement of a 5/8 inch joint) would over-stress any poured sealant. Further studies showed that the maximum permissible joint spacing with poured sealants would be 40 feet (27 percent movement of the 5/8 inch joint). Therefore, the recommended design for reinforced concrete pavements called for reducing the joint spacing from 61.5 feet to 40 feet and increasing the joint width from 3/8 inch to 5/8 inch.

Similar reasoning led to the retention of the unreinforced design standard of a 20 foot joint spacing but utilizing a joint width of 3/8 inch and 1/2 inch for preformed and poured sealants, respectively. While a 1/2 inch joint width provides a better factor of safety for poured sealants, the width for preformed sealants was established as 3/8 inch because the cellular sealant is not available in widths sufficient to seal wider joints.

Preformed sealant widths of 5/8 to 3/4 inch for 20 foot slab lengths and $1\frac{1}{4}$ inch for 40 foot slab lengths were established.

The changes indicated above were incorporated in the Department's January 1971 edition of "Road Designs and Standards".

CONCLUSIONS

Based on the experiences reported by other agencies, those observed in Virginia, and on the engineering characteristics of available joint sealing materials, the following conclusions appear warranted:

1. The limitations of sealing materials and the engineering characteristics of joint movements must be considered if adequately sealed pavement joints are to be achieved.

2. Preformed elastomeric sealants (primarily neoprenes) offer the best potential for effective joint sealing.

3. Virginia's older rigid pavements having 3/8 inch joints spaced 61.5 feet apart cannot be effectively sealed with currently available materials. Widening the joints to 5/8 inch will make preformed sealants applicable.

4. Virginia pavements constructed with 3/8 inch joints spaced 20 feet apart are capable of being sealed with either high quality poured or preformed sealants.

5. Because of the sealing difficulty, many of the older pavements have become infiltrated with foreign materials to the extent that joint damage in the form of spalls and blow-ups is prevalent. Others show a significant degree of faulting, which may be attributable to water entering poorly sealed joints.

6. Effective joint sealing requires careful attention to joint preparation in accordance with the recommendations of sealant manufacturers.

7. Poured sealants are subject to errors or inconsistencies in materials proportions. These can significantly detract from sealant performance.

8. Seasonal joint movements of Virginia pavements can be approximately determined from the chart given earlier in this report (Figure 2).

REFERENCES

1. Highway Research Board, National Academy of Sciences, National Research Council. National Cooperative Highway Research Program, Report 38, "Evaluation of Pavement Joint and Crack Sealing Materials and Practices".

2. Chojnacki, B., "Evaluation of Field Moulded Joint Sealants for Concrete Pavements and Structures", D. H. O. Report No. RR118, Department of Highways, Ontario, Canada, October 1966.

3. Tons, Egons, "Materials and Geometry in Joint Seals", Joint Highway Research Project, Purdue University, Lafayette, Indiana, 1958.

4. "Guide to Joint Sealants for Concrete Structures", reported by A. C. I. Committee 504, Draft for Committee Review Purposes Only, February 1969.

5. Schutz, Raymond J., "Shape Factor in Joint Design", Civil Engineering, The Magazine of Engineered Construction, October 1962, Vol. 32, #10.

6. Tons, Egons, "A Theoretical Approach to Design of a Road-Joint Seal", Bulletin 229, Highway Research Board, 1959.

7. Graham, Malcolm D., "Joint Seal Materials: Final Report", Research Report 68-6, Department of Transportation, State of New York.

8. Portland Cement Association, Concrete Information, Maintenance Practices for Concrete Pavement, 1956.

9. Federal Highway Administration, Informational Memorandum CMPB-8-69. "Usage and Performance of Preformed Compartmented Neoprene Joint Sealers".

10. Virginia Department of Highways, "Road Designs and Standards", January 1970.

APPENDIX

POURED JOINT SEALANTS

A survey of the pertinent literature has yielded the information in the following pages, where the desirable properties of poured sealants and the potential failure modes of such sealants are summarized.

There is to a degree agreement that poured sealants should possess the following properties:

1. The sealant must be easy to install. It must either come prepared or be easy for a relatively unskilled person to prepare and apply quickly.

2. It must be initially plastic in order that it bonds well to the joint walls.

3. It must be homogenous throughout.

4. It must not be subject to shrinkage or swelling after installation due to chemical interactions with the surrounding atmosphere, i.e., it must be inert.

5. It must have a high ultimate strength and a low modulus of elasticity. In other words, it must be strong and flexible as it will be subjected to both tension and compression.

6. It must not harden and become brittle due to age or weathering.

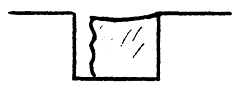
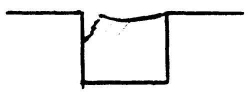
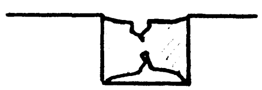
7. It must act elastically primarily and resist flow as a mode of stress relief. It should not deform permanently.

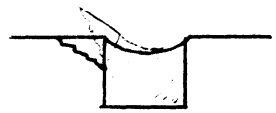
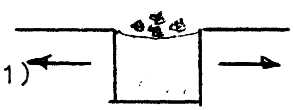
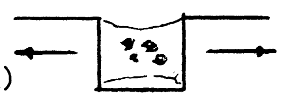
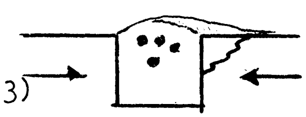
8. Finally, it should resist intrusion by foreign matter.

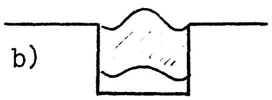
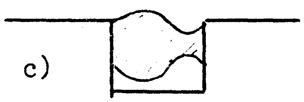
Table A-1 diagrams the most common failure modes of poured-in-place sealants and relates these to the material characteristics that are necessary to prevent them. In addition, it suggests other procedures and methods necessary to improve poured-in-place sealant performance in each area.

TABLE A-1

Common Failure Modes of Poured-in-Place Sealants

Mode No.	Diagram and Failure Type	Sealant Characteristics required to resist	Additional Criteria to be considered--comments
I	a)  Adhesion b)  Peeling	2,3,4,5,8	1 - joint faces must be cleaned prior to installation of sealant 2 - bond breaker will decrease stress in peeling failure 3 - shape factor analysis and design should be made to reduce strains to those sealant can resist 4 - brittleness due to deterioration will hasten failures of this type 5 - an ideal opportunity for penetration by destructing water and debris.
II	 Cohesion	3,4,5,6,8	1 - bond breaker will decrease stresses and lessen cohesive failures 2 - shape factor analysis and design required to minimize 3 - cohesive failures lead to openings through which water and debris may enter sealant 4 - a tendency to weather extensively with brittleness as a result will hasten this failure.

III	 Tensile Failure of Concrete--Impact Spall	5,7	1 - saw joint edges--rather than forming the joints--such forming tends to produce weaker regions in the vicinity of a sharp corner 2 - need to go to a stronger concrete or consider armored joint edges 3 - shape factor analysis could be used to decrease stresses carried to concrete by sealant at this extremity.
IV	Intrusion 1)  2)  3)  NOTE: Arrows show joint movement	4,6,7,8	1 - weathering of a sealant tends to make intrusion by incompressible debris much more possible 2 - elastic behavior is particularly desirable here in that a flow type behavior may tend to make the sealant actually move to enclose the debris 3 - sketch 3 shows the results of intrusion by compressibles. 3a shows a spall: a spall results when the concrete cannot resist the excessive compressive stresses resulting from the joint clamping down on the trapped incompressible debris 3b shows extrusion: extrusion of seal occurs because the debris has replaced the sealant in the joint--this is usually evidenced by tracking of the sealant in the direction of traffic flow. 4 - better shape factor will help 5 - avoid trapping air in sealant during installation 6 - do not overfill joints 7 - a routine program of debris cleanup might be considered as a solution.

V	Flow-Stress Relaxation Failures a)  b)  Sags and Humps after extension as joint closes c)  Necks after compression as joint opens	8	1 - such behavior makes inclusion and intrusion of debris much more probable 2 - if best possible sealant is being used, there is no solution to this; if not, choose sealant with greater elasticity and less tendency to relieve stress by flowing. GENERAL NOTES: All of the modes of failure shown herein will be minimized by decreasing the spacing of joints. However, this soon reaches a point of diminishing returns in terms of construction and sealing costs. In addition, the more joints, no matter what the spacing, the greater are the chances for sealant failure with resulting pavement deterioration.

PREFORMED JOINT SEALS

A literature survey comparable to that conducted for poured sealants has shown the following to be often stated requirements for preformed seals:

1. The sealant and its accompanying adhesive material must be easy to install. This requires that the seal be of proper size and shape to fit the joint and that it possess rubber-like properties that enable it to be placed into the joint under compression.

2. In the case of a solid sealant, the materials must be homogenous throughout. In the case of a two phase sealant, the material and geometry must be homogeneous.

3. It must not be subject to deleterious interactions with the surrounding atmosphere and other compounds with which it may be associated.

4. It should be capable of strain recovery without permanent deformation. In the case of a two phase seal, this means that the webs should have no tendency to weld together during periods of extreme compression as it will have to change its shape as the joint reopens.

5. It should not be subject to compression set.

6. It should resist intrusion by water and puncture by gravel or other debris.

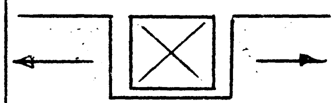
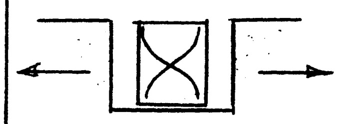
7. The friction and adhesion forces should be sufficient to keep the seal from moving vertically.

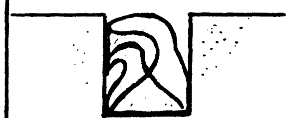
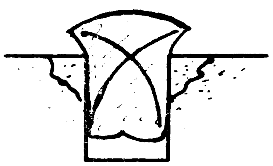
8. Finally, the seal should not have an inherent tendency to expand upward as it is compressed, thereby extruding itself from the joint. In other words, when it does expand vertically, the expansion should primarily be downward.

Table A-2 diagrams the most common failure modes of compression seals and relates these and other material characteristics that are necessary to prevent them. In addition, it makes other pertinent suggestions that tend to improve performance.

TABLE A-2

Common Failure Modes of Compression Seals

Mode No.	Diagram and Failure Type	Sealant Characteristics required to resist	Additional Criteria to be considered--comments
I	 Seal too Small	1,4,7	1 - the use of a wider seal here would work to prevent such action 2 - proper analysis of expected joint movement with seal chosen accordingly should prevent this 3 - saw the joint in such a manner that a shoulder is present below the installed seal--such shoulder will prohibit such movement 4 - avoid stretching the seal during installation 5 - ideal opportunity for debris entrance and joint destruction.
II	 Loss of recovery capability--compression set	3,4,5,7	1 - comments 3, 4 and 5 above apply here.

III	 Folded or twisted at installation	1,7,8	1 - comments 4 and 5 from comments of Mode I apply here 2 - careful installation and inspection to see that seal is straight should prevent this 3 - an adhesive that also lubricates the joint faces will make installation easier.
IV	 Overcompressed and Extruded Seal	1,8,7	1 - leads to the destruction of the seal by traffic and to an increased rate of joint deterioration through spalling of concrete 2 - usually occurs in a pavement system having both expansion and contraction joints 3 - results from a seal that is too large for the joint--select smaller seal or saw joint wider 4 - leave an air gap at the lower face of seal so that downward expansion is possible.