HIGHWAY RESEARCH BOARD

Bulletin 78

# *Filling and Sealing of Joints and Cracks in Concrete Pavements*

National Academy of Sciences—
National Research Council

publication 276

# HIGHWAY RESEARCH BOARD

## 1953

2101 Constitution Avenue, Washington 25, D. C.

# HIGHWAY RESEARCH BOARD

## Bulletin 78

# *Filling and Sealing of Joints and Cracks in Concrete Pavements*

PRESENTED AT THE

Thirty-Second Annual Meeting

January 13-16, 1953

1953
Washington, D.C.

## DEPARTMENT OF MATERIALS AND CONSTRUCTION

C. H. Scholer, Chairman
Head, Applied Mechanics Department
Kansas State College

## COMMITTEE ON JOINT MATERIAL IN CONCRETE PAVEMENTS

Van Breemen, William, Chairman; Supervising Engineer, Engineering Research & Soils, New Jersey State Highway Department, 1035 Parkway Avenue, Trenton, New Jersey

Anderson, A. A., Manager, Highways and Municipal Bureau, Portland Cement Association, 33 West Grand Avenue, Chicago 10, Illinois

Baumann, F. H., Supervising Engineer, Testing Laboratory, New Jersey State Highway Department, State House Annex, Trenton 1, New Jersey

Finney, E. A., Research Engineer, State Highway Research Laboratory, Olds Hall of Engineering, Michigan State College, East Lansing, Michigan

Herman, W. H., Chief Research Engineer, Pennsylvania Department of Highways, 1118 State Street, Harrisburg, Pennsylvania

Lehmann, H. L., Testing and Research Engineer, Louisiana Department of Highways, Baton Rouge 4, Louisiana

Rowell, R. I., Vermont Department of Highways, Montpelier, Vermont

Scrivner, Frank H., Texas Highway Department, Austin 26, Texas

Wilson, Dean, Missouri State Highway Department, Jefferson City, Missouri

Worth, Warren J., Engineer of Tests, Board of Wayne County Road Commissioners, 3800 Cadillac Tower, Detroit 26, Michigan

# FILLING and SEALING of JOINTS and CRACKS in CONCRETE PAVEMENTS

THE problem of preventing the infiltration of water, silt, sand, and other earthy materials into the joints and cracks in concrete pavements is one that has been exceedingly troublesome to highway engineers ever since concrete pavements first came into existence more than 40 yr. ago. Despite determined and prolonged efforts on the part of engineers, chemists, technicians, and the producers of filling and sealing materials, the problem remains to a large extent unsolved. Substantial progress has been made, but the final answer is not yet at hand.

In recent years there has been an increasingly greater need for more-effective sealing, for the following reasons:

1. The extensive development of a highly destructive phenomenon known as "pumping", which is a process wherein free water that has accumulated in vacancies between the pavement and the subgrade is ejected by the downward movement of the pavement under the action of heavy loads. In the case of fine-grained subgrade soils, such as the silts and clays, the finer soil particles combine with the water and, in a state of suspension, are ejected along with the water. The progressive loss of subgrade support resulting from this process leads ultimately to serious failure.

Exhaustive investigations have disclosed that the water involved in this process is almost invariably surface water which, during rains, has infiltrated to the subgrade through unsealed joints and cracks and along the pavement edges adjacent to the shoulders. The exclusion of this water, in so far as possible, is obviously desirable. Although it is an established fact that the complete sealing of joints and cracks will not in itself prevent pumping, if only because of continued leakage along the shoulder edges, the reduction in the amount of leakage resulting from such measures does, nevertheless, have a significant effect on reducing the magnitude of the pumping action and, in turn, on retarding the rate of failure. (For further data on pumping, see "Final Report of Project Committee No. 1, Maintenance of Concrete Pavement as Related to the Pumping Action of Slabs", Proceedings, Vol. 28, 1948, Highway Research Board, pp. 281-310).

2. The current widespread practice of omitting expansion joints and substituting contraction joints in their place. The indications are that the infiltration of inert foreign materials of a solid nature, such as silt and sand, into the contraction joints can sooner or later result in serious damage.

## PURPOSE

This bulletin has several purposes: (1) To present and discuss certain basic facts that are pertinent to the problem. (2) To promote a more-widespread understanding of the various aspects of the problem and of the conditions that must be taken into account; this applies especially to the engineers entering the highway field and to the producers and potential producers of filling and sealing materials. (3) To discuss the various kinds of filling and sealing materials most commonly employed, and the functions, capabilities, and limitations of these materials.

Much of the information presented in this bulletin is of a basic nature, and is familiar to most highway engineers. This information has, however, been included for the sake of comprehensive coverage of the subject, and because all too frequently the fundamental aspects of the problem are overlooked.

## DEFINITIONS

As used throughout this bulletin, the term filler applies exclusively to the premoulded or prefabricated strips of compressible material that are installed during construction, such as most commonly employed in connection with expansion joints.

The term sealer applies exclusively to the liquid form of material that is usually poured into joint spaces shortly after construction and, as a maintenance operation, at periodic intervals thereafter. The same type of material is used for the sealing of cracks.

In common practice filler is often applied to materials that properly fall in the category of sealers. Since this results in ambiguity, the more specific usage of these terms is recommended.

The term slab applies to the following:

Unreinforced Pavements. Any section of uncracked pavement lying between (a) two transverse joints, or (b) two transverse cracks, or (c) a transverse crack and a transverse joint.

Reinforced Pavements. Any section of pavement lying between two transverse joints, regardless of whether or not the pavement is cracked but provided that the reinforcing steel incorporated therein is capable of preventing the appreciable opening of any transverse cracks that may be present The term does not apply, however, to the unconventional, exceptionally long sections of pavement known as continuously reinforced, nor to any section of pavement that,by reason of changes in the widths of transverse cracks existing therein, does not undergo essentially the same amount of over-all expansion and contraction as an uncracked slab.

## REASONS FOR THE PROBLEM

In the final analysis, the filling and sealing problem originates from the fact that a concrete pavement is not a truly continuous structure. As is well known, all concrete pavements consist of a series of slabs or sections of pavement that are separated from one another by either transverse joints or transverse cracks, or a combination of transverse joints and transverse cracks, as the case may be. The joints or cracks are spaced at various intervals, but the interval rarely exceeds 100 ft.

There is, at present, no known practical way of constructing a section of pavement of considerable length in which the concrete itself will remain truly continuous, despite the installation of a large amount of reinforcing steel or the employment of prestressing. This is attributable to the relatively low tensile strength of concrete and the high tensile stresses to which an extensive section of pavement will sooner or later be subjected and which will result in the development of transverse cracks spaced at erratic intervals. Since these cracks have a number of objectionable features, it is the general practice to construct the pavement in a manner such that it will consist of a series of slabs of uniform length, which is accomplished by the introduction of transverse joints of one kind or another.

## PRIMARY CONSIDERATIONS

A proper approach to the filling-and-sealing problem requires first of all a knowledge of concrete pavements, especially as concerns their basic features and general behavior for the following reasons: (1) the problem has certain mechanical aspects which must be taken into account and (2) all of the filling and sealing materials presently available have very definite limitations. It is therefore appropriate to consider first the various elements of a concrete pavement.

## TRANSVERSE JOINTS

Basically, there are only three types of transverse joints: expansion joints, contraction joints, and hinge, or so-called warping joints. (in common practice the term "dummy joint" is often applied to contraction joints, and also to hinge joints. Since, as in the case of "filler", this leads to ambiguity, the more specific usage of these terms is also recommended.) The typical features of these joints are as follows:

### Expansion Joints

As the term implies, the primary function of an expansion joint is to provide space for the expansion of the pavement and to thereby prevent the development of compressive stresses of damaging magnitude. The typical features of this type of joint are shown in Figure 1.

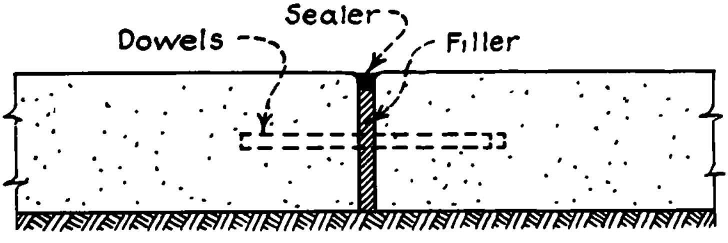


FIGURE I TYPICAL EXPANSION JOINT

It will be noted that the space between the slab ends contains a filler, which usually consists of a prefabricated strip of asphaltic material, or fiber board impregnated with asphalt, or granulated cork held together by a waterproof cementing agent and fabricated in the form of a strip, or a wooden board such as that of cypress, redwood, or other suitable decay-resistant lumber. Since these materials offer relatively little resistance to compression they, in effect, create expansion space. The filler has the following purposes: (1) By acting as a separator or bulkhead, it serves to divide the pavement into a series of slabs. (2) In view of its low resistance to compression, it permits the pavement to expand without undue restraint. (3) It tends to minimize the infiltration of water and solid materials, such as silt and sand, into the joint space. (4) By acting as a compressible gasket, it tends to counteract the damaging effect of whatever solid materials do infiltrate into the joint space.

Inasmuch as the concrete is deposited directly against both sides of the filler, the as-constructed width of the joint space is necessarily equivalent to the thickness of the filler.

As shown, the top of the joint space contains a sealer, which is usually composed of asphalt, or a mixture of asphalt and rubber. Sealers composed of tar are also used, but not nearly so extensively. In general, these materials are poured into the joint spaces after being liquefied by heating, there being a subsequent congealing of the material to the extent that it becomes a plastic semisolid. Those materials which contain rubber also possess a certain degree of elasticity.

There are, however, certain sealing materials which do not require heating, and which are known as the cold-poured types. These sealers, which are usually composed of rubber, or a mixture of rubber and asphalt, or other materials having the general characteristics of rubber, are either poured or extruded into the joint spaces at normal atmospheric temperatures, and, by a chemical reaction or other internal setting process, subsequently congeal to a plastic or elastic semisolid.

Since expansion joints are free to open as well as close, they also serve as contraction joints. Furthermore, since they permit of a certain amount of hinge action, they also serve in this respect as hinge joints. Consequently, in effect, an expansion joint is an all-purpose joint.

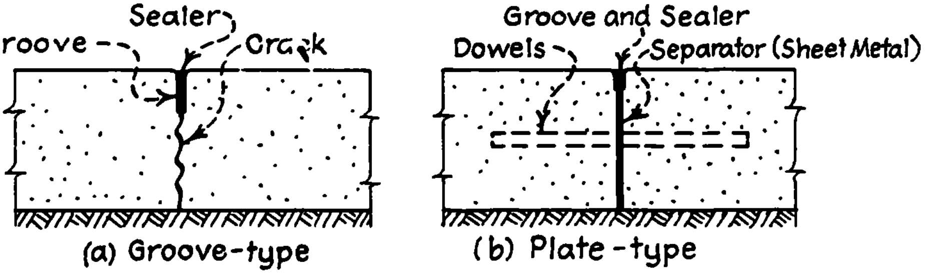
As indicated in Figure 1, it is the general practice to install a series of steel dowels or some form of load-transfer device at expansion joints. These dowels or devices have a dual function: (1) to transfer wheel loads across the joint space, in order that a load which is on or near the end of one slab is also supported to a considerable extent by the adjacent slab and (2) to maintain the slab ends at the same relative elevation and, especially, to prevent faulting, which is an occurrence wherein, under the action of heavy loads, one slab end becomes permanently depressed with respect to the other.

The devices also perform an important function from the standpoint of sealing, since if of adequate strength, they materially reduce differential deflection of the slab ends under the action of traffic. Any considerable differential deflection would obviously impose a serious strain on the sealing material.

## Contraction Joints

The primary function of a contraction joint is to permit the pavement to contract or shrink without excessive restraint and to thus prevent the development of excessive tensile stresses. Since contraction joints do not contain a compressible filler, they do not create expansion space. Eventually, however, there actually is the creation of a certain amount of expansion space at the contraction joints, which is due to the shrinkage of the concrete. Although the amount of shrinkage is a variable (depending largely upon the materials, amount of mixing water and the method of curing),some engineers estimate that in their particular localities the resulting space is sufficient to allow for about 20 deg. of increase in pavement temperature.

Basically, there are two types of contraction joints, namely: groove type and plate type, which are shown in Figure 2.



(a) Groove-type (b) Plate-type

**FIGURE 2 TYPICAL CONTRACTION JOINTS**

The typical features of a groove-type contraction joint are shown in Figure 2(a). This type of joint is usually created by the relatively simple procedure of forming a transverse groove in the upper part of the pavement while the concrete is still plastic, the groove subsequently being filled with a sealing material. Most of the contraction joints currently installed are of this type. The depth of the groove usually ranges from a quarter to a third of the thickness of the pavement. In some locations, however, it has been the practice to insert a strip of joint filler into the groove immediately after it is formed. A more recent development is the forming of the groove after the concrete has hardened, which is accomplished by means of a circular steel saw having diamond particles embedded in its periphery.

Because of the weakening in pavement section, there is sooner or later the formation of a crack below the groove. The configuration of the crack is usually so irregular that, so long as the opening of the joint is limited to a very small amount (perhaps not exceeding 0.04 in., there is a certain degree of interlocking of the slab ends, known as aggregate interlock. Since the interlocking tends to fulfill the same function as dowels, load-transfer devices are frequently omitted in connection with contraction joints of this design.

The typical features of a plate-type contraction joint are shown in Figure 2(b). This joint is created by erecting a separator or parting strip on the subgrade. The separator, which usually consists of sheet metal or some type of composition board, serves merely to divide the pavement into a series of slabs. Because of the absence of aggregate interlock it is the general practice to install a load-transfer device at contraction joints of this design.

In both types of contraction joints the groove serves as a reservoir for sealing material. There is, however, no uniform practice in regard to the width of the groove. On a nation-wide basis the width ranges from as little as 1/16 in. (created by installing tarpaper strips) to as much as 3/4 in., depending largely on personal preference.

Hinge Joints

The typical features of two types of hinge joints are shown in Figure 3.

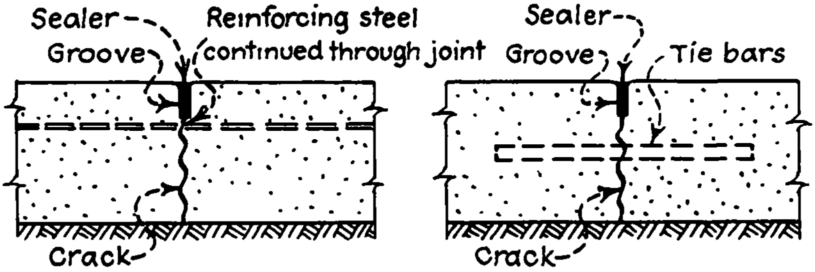


**FIGURE 3 TYPICAL HINGE JOINTS**

It will be noted that at this type of joint the ends of the adjacent slabs are connected together by means of reinforcing steel or tie bars. In consequence the joint undergoes practically no changes in width, and acts merely as a hinge. Inasmuch as their exclusive use would result in transverse cracking (being restrained from opening), hinge joints are installed only in conjunction with expansion or contraction joints. Actually, this type of joint is employed to only a limited extent. Since hinge joints remain at practically constant width, they are relatively easy to maintain sealed.

In addition, there are joints known as construction joints, which are installed between each day's work. These joints are, however, basically of the same type as those previously described, and may be either expansion joints, contraction joints, or hinge joints, depending upon the prevailing practice.

## LONGITUDINAL JOINTS

In order to prevent longitudinal cracking, it is the general practice to divide the pavement longitudinally into lanes that are usually less than

15 ft. in width, the joints between the lanes being known as longitudinal joints. Several typical longitudinal joints are shown in Figure 4. In the case of the type shown in Figure 4(e) the groove is usually formed while the concrete is still plastic. A more-recent development, however, is the creation of the groove by means of sawing the pavement after the concrete has hardened.

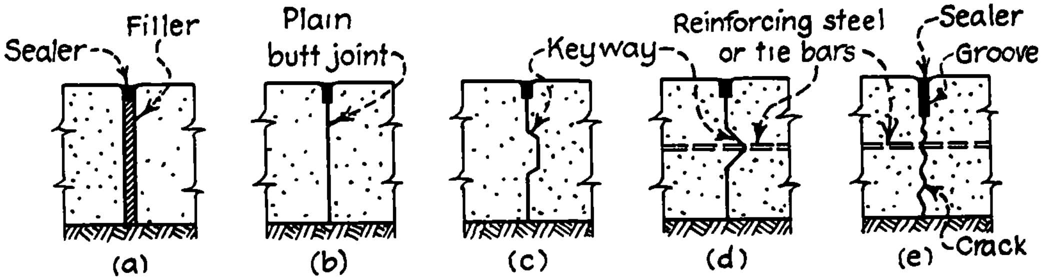


FIGURE 4 TYPICAL LONGITUDINAL JOINTS

Because of their relatively small changes in width, it is usually much easier to maintain these joints in a sealed condition than is the case with transverse joints, especially those types in which the lanes are held together by tie bars.

## VARIOUS JOINTING ARRANGEMENTS

Because the types of joints installed, and their spacing, have a very-important bearing on the filling-and-sealing problem, it is necessary to give consideration to the principal variations in pavement design, as related to joints, these being as follows:

1. Pavements which have no joints of any kind, except plain butt joints between the sections of pavement constructed from day to day. In general, this design was abandoned many years ago. All of these pavements necessarily have one thing in common: transverse cracks spaced at erratic intervals.

2. Pavements in which all of the joints are expansion joints. In general, these joints are spaced not less than 20 ft. nor more than 100 ft. apart. Most of the pavements of the 1920's and early 1930's were constructed in this manner. In recent years, with the exception of a few states, this design has been superseded by designs that include contraction joints.

3. Pavements which have expansion joints and contraction joints. This design was widely employed in the late 1930's and 1940's. Expansion joints at 120-ft. intervals, and intermediate contraction joints at intervals ranging from 15 ft. to 30 ft. is typical of this design. There has, however, been an increasing tendency to reduce the number of expansion joints—to the extent that at present, if installed at all, they are often spaced as much as 600 ft. apart.

4. Pavements in which all of the joints are contraction joints, with the exception of expansion joints immediately adjacent to bridges, and at other critical locations. Nationwide, the spacing of contraction joints ranges from as little as 10 ft. to as much as 100 ft., but generally ranges from 15 ft. to 40 ft. This design is currently employed very extensively,

5. Pavements which have expansion joints and hinge joints. Expansion joints at 100-ft. intervals and intermediate hinge joints at 25-ft. intervals is typical of this design. This, however, is a jointing arrangement which is not commonly employed.

## BASIC REASON FOR FILLING AND SEALING DIFFICULTIES

The basic reason why it is exceedingly difficult to maintain joints in a filled and sealed condition is the fact that, with the exception of those types which are prevented from opening, the joints undergo changes in width. These changes in width are, in fact, the very crux of the problem.

Actually, if it were not for their changes in width it would be a relatively simple matter to seal joints once and for all. It is therefore highly pertinent that consideration be given to the various factors which determine the amount of change.

### Effect of Temperature

As is well known, concrete expands or contracts, respectively, with an increase or decrease in its temperature. Although subject to some variation with different materials, the linear thermal coefficient of expansion of pavement concrete is on the order of 0.000005 per degree, Fahrenheit. As a practical example, a 100-ft. slab composed of concrete having this coefficient, and provided that it is free from external restraint other than the frictional resistance between itself and the subgrade upon which it rests, will increase approximately 0.3 in. in length if it undergoes a 50-deg. increase in temperature, and vice versa. To all intents and purposes, its change in length will be directly proportional to its change in temperature. (Incidentally, all calculated length-changes included hereinafter are based on a coefficient of 0.000005 per deg.)

### Effect of Moisture

Concrete tends to swell or shrink, respectively, with an increase or decrease in its moisture content. A change in moisture content will therefore effect a certain amount of change in the length of a slab. In those locations, however, where the amount of rainfall is distributed more or less uniformly throughout the year, and where there is a considerable range of change in temperature, the changes in slab length are due almost entirely to changes in temperature.

Of incidental interest is the fact that, since it is improbable that the concrete will ever again acquire a moisture content equivalent to that which it had at the time of construction, some of the shrinkage which takes place during the hardening period is permanent.

## Effect of Slab Length

It is one of the well-known basic principles of physics that, for any given change in temperature, the greater the length of a body the greater its over-all change in length—the change being directly proportional to its length. For all practical purposes this also holds true in the case of pavement slabs, provided that the slabs are of the conventional length and there is no restraint to their expansion and contraction other than normal subgrade friction.

Subgrade friction does, however, have some effect. By way of explanation, it is evident that as a slab expands and contracts it must necessarily move over the subgrade. Since between the slab and the subgrade there is frictional resistance to this movement, there is a certain amount of restraint to expansion and contraction. Consequently, a pavement slab undergoes a somewhat smaller change in length than would be the case if it were supported on a frictionless surface. However, for the conventional slab length, the difference is so slight as to be practically negligible.

For example, a 100-ft. slab supported on a frictionless surface would undergo a change in length of 0.30 in. if its temperature were to change 50 deg. But even if the coefficient of friction were as high as 2.0 (which is well above normal), the same slab supported on a subgrade surface would nevertheless undergo a length change of at least 0.28 in. Moreover, if the slab were only 50 ft. long, the reduction in length change due to subgrade friction would be only 0.005 in., at the most.

Actually, it is only in the case of slabs which are of very considerable length that the restraining effect of subgrade friction has any material effect on reducing the change in length. Consequently, for all practical purposes, at least up to 100 ft., the change in length may be considered to be directly proportional to the length of slab. It is thus seen that for any given change in temperature or moisture content, a 100-ft. slab will undergo practically five times as much change in length as a 20-ft. slab.

## Effect of Joint Spacing

For a pavement with joints and uncracked slabs, it is evident that slab length and joint spacing are essentially one and the same thing. It is also evident that any change in slab length is necessarily reflected in an equivalent amount of change of joint width. Consequently, in line with the case of slab length, the greater the joint spacing the greater the change in joint width. As in the case of slab length, and for all practical purposes within the limits of the conventional joint spacing, the direct proportionality also holds true. For example, joints spaced 100 ft. apart will normally undergo practically five times as much change in width as joints spaced only 20 ft. apart.

## Effect of Reinforcing Steel

The principal function of reinforcing steel is to prevent the opening of cracks. Consequently a cracked slab that contains an adequate amount of reinforcing steel will undergo essentially the same over-all changes in length as an uncracked slab. For this reason the occurrence of cracking in reinforced pavements neither increases nor decreases the amount of change in joint width to any significant extent. On the other hand, in the case of so-called plain, or unreinforced, pavements the situation is materially different, since there is an unrestrained opening of the cracks whenever the pavement contracts.

## Behavior of Unreinforced Pavements

Certain behavior patterns that apply to unreinforced pavements are worthy of note:

1. In the case of pavements without joint, the greater the distance between cracks the greater the crack opening. For example, cracks spaced 100 ft. apart open approximately five times as much as cracks spaced 20 ft. apart.

2. In the case of pavements with joints, the occurrence of cracking is reflected in a smaller amount of joint opening, which is compensated for by an opening of the cracks.

3. In the case of pavements with expansion joints, the occurrence of cracking results in a progressive closure of the expansion joints, which is accompanied by a progressive opening of the cracks. This process, which appears to be due principally to the infiltration of solid materials into the cracks when they are open in cold weather and which restricts their closure in hot weather, continues until the expansion joints resist further closure, at which point a state of equilibrium is reached.

It is of particular significance that the behavior pattern in Item 3 (above) applies also to those pavements which have expansion joints and contraction joints. Widespread experience with this jointing arrangement has shown that there is a progressive closure of the expansion joints, which is compensated for by a proportionate amount of increased opening of the contraction joints. Similar to pattern 3, this appears to be due principally to the infiltration of solid materials into the contraction joints and resulting resistance to their closure.

A typical example is found in the case of a pavement constructed with expansion joints at 100-ft. intervals and intermediate contraction joints at 20-ft. intervals. Assuming that 1-in. wood filler was installed in the expansion joints, these joints will eventually close to a width of approximately ½ in., at which point the filler will resist further compression. When this stage is reached, the intermediate contraction joints will be open, on the average, approximately 1/8 in. more than they would have been had the expansion joints been omitted.

## Effect of As-Constructed Temperature

It is apparent that a slab constructed during the hot weather of midsummer will normally have a much higher as-constructed temperature than one constructed on a relatively cold day in early spring or late fall. Consequently, the amount that a slab subsequently tends to become longer or shorter than it was at the time of its construction is a function of its as-constructed temperature. This is demonstrated by the following example:

Assume an unrestrained, 100-ft. slab having an as-constructed temperature of 100 F., and which subsequently attains maximum and minimum summer and winter temperatures, respectively, of 110 F. and 20 F. Because of its high as-constructed temperature, this slab will shorten a great deal more than it will lengthen. More specifically, it will be 0.48 in. shorter at 20 F., and only 0.06 in. longer at 110 F., than it was at the time of construction. Conversely, were this slab to have had an as-constructed temperature of 50 F., it would lengthen a great deal more than it would shorten, inasmuch as it would be 0.36 in. longer at 110 F. and only 0.18 in. shorter at 20 F.

Since it is the amount of change in slab length which determines the amount of change in joint width, it is thus seen that the as-constructed temperature of the pavement has a pronounced effect on the changes in joint width. With respect to certain jointing arrangements the effect is as follows:

1. Pavements having expansion joints only. If the as-constructed temperature is high, the joints will subsequently open a great deal more than they will close, and vice versa. Actually, many pavements of this design constructed in midsummer have such a high as-constructed temperature, especially those cured by the transparent membrane or the bituminous membrane method, that even during the hottest subsequent weather the expansion joints have a width that is somewhat greater than their as-constructed width. Under these particular conditions the joints are not called upon to act as expansion joints in the true sense of the word. This does not hold true, however, in the case of pavements in which there is the development of open cracks. In the case of low as-constructed temperatures, the expansion joints do, of course, close to less than their original width, that is, during subsequent hot weather.

2. Pavements having contraction joints only. If the as-constructed temperature is high, the joints will subsequently open more than if it is low. For instance, in the case of contraction joints at 20-ft. intervals and an as-constructed temperature of 100 F., a subsequent lowering in slab temperature to 20 F. will result in an average joint opening of 0.096 in. On the other hand, had the as-constructed temperature been 50 F., the lowering in temperature to 20 F. would have resulted in an average opening of only 0.036 in.

It is pertinent to note that since contraction joints do not create expansion space, a pavement of this design constructed in cool weather may be under compression during periods of high summer temperature. This will depend, however, upon whether or not the concrete has undergone sufficient shrinkage to compensate for the increase in temperature.

3. Pavements having expansion joints and contraction joints. The effect of as-constructed temperature on the amount of contraction joint opening depends upon the amount of expansion space that has been provided.

If the amount of space is such that there is no appreciable restraint to the expansion of the pavement, even a low as-constructed temperature will not, in the long run, effect a reduction in the contraction joint opening. In the case of the expansion joints, however, the lower the as-constructed temperature the more these joints will close during hot weather.

The behavior pattern of a pavement of this design is worthy of note. For example, assume a pavement constructed with 1-in. expansion joints at 100-ft. intervals and intermediate contraction joints at 25-ft. intervals. Assume, also, an as-constructed temperature of 50 F. followed by an increase to 100 F., which is then followed by a return to the original 50 F. With the increase to 100 F., and even though it consists of four individual 25-ft. slabs, the pavement between each expansion joint will expand as though it were a continuous 100-ft. slab. Neglecting, for simplicity, the effects of shrinkage and subgrade friction, the increase to 100 F. will result in the expansion joints being closed to a width of 0.70 in. Upon subsequent contraction, however, the 25-ft. slabs will not act collectively, but, on the contrary, will contract as individual units. In consequence, even though the pavement returns to its original temperature of 50 F., the expansion joints will not return to their original width, but will open to only 0.775 in., which is compensated for by an opening of the contraction joints.

It is thus seen that in the case of low-temperature construction of pavement of this design, the expansion joints remain permanently at less than their as-constructed width after the first cycle of hot weather expansion. It is also seen that during the expansion cycle there is a certain amount of re-positioning of the individual slabs in that they move towards the expansion joints, and that they do not return to their original positions during the subsequent contraction cycle.

## Effect of Climate

It is hardly necessary to point out that on a nation-wide basis there is a wide range of climatic differences. It is evident, for example, that the climate of Georgia differs vastly from the climate of Minnesota. Consequently the basic climatic conditions prevailing in any given location must be taken into account.

In addition to wide differences in the annual range of temperature change, there are wide differences in moisture conditions. Some of the western states, for example, experience prolonged periods of rainless weather during the summer. The indications are that the concrete undergoes a substantial loss in moisture content during these periods, which results in some shrinkage of the slabs. But since the maximum shrinkage exists during the periods of highest temperature, it appears that in these locations the actual midsummer expansion is somewhat less than would otherwise be induced by temperature alone. Moreover, prolonged periods of rainy weather during the winter presumably result in a high moisture content and swelling of the concrete, which tends to reduce the amount of contraction. It appears, therefore, that in these particular locations the over-all seasonal changes in joint width are significantly reduced by the effect of seasonal changes in moisture content. In other locations, however, as indicated previously, where the amount of rainfall is more or less uniform throughout the year, the changes in joint width are almost entirely a function of the amount of change in temperature.

Attention is directed to these nation-wide differences for three reasons: (1) to emphasize the fact that these differences do exist; (2) to suggest that it is highly desirable for each state, or at least each climatically similar region, to determine by precise measurement specifically how much over-all seasonal change in joint width occurs in the case of joints spaced at various intervals, especially since it is impossible to give proper consideration to the filling and sealing problem without this basic information; and (3) to point out that because of these climatic differences the performance of any given type of filler or sealing material may be susceptible to considerable variation. A sealing material that has proved entirely satisfactory in the southerly part of the country might, for example, prove entirely unsatisfactory in the northerly part.

These climatic differences, and other differences such as the jointing arrangement, as-constructed width of the joint space, coefficient of expansion of the concrete, and as-constructed temperature, necessarily require that due care be exercised in evaluating the merits of any particular joint material that has been used only within a limited geographical area.

## Effect of Infiltration

The amount of change in joint width is also a function of whether or not there is restraint to the normal behavior of the pavement. For example, in the case of many of the older pavements the joints are now partially or totally filled with infiltrated solid materials, such as silt or sand. Under these conditions, instead of there being a normal closure of the joints during warm weather, there is the development of compression in the pavement. During very hot weather the compressive stresses often attain a magnitude sufficient to cause serious damage. The infiltration of solid materials into the cracks in unreinforced pavements has, of course, a similar effect.

The question of whether or not the solid materials that infiltrate into joint and crack spaces are harmful to the pavement appears to depend upon the composition of these materials and their distribution in the spaces. If the materials are composed of very-finely divided particles, such as clay, they may squeeze out or spread over a considerable area when subjected to pressure. On the other hand, if they are of a granular composition and have high internal friction, such as clean sand, the indications are that they will neither squeeze out nor spread to any appreciable extent, regardless of how much pressure is applied to them.

The most-harmful condition occurs when these materials have accumulated in only a portion of the joint or crack space. This, in fact, is the usual condition. Most of these materials appear to enter at the pavement surface and, by the action of gravity, move downward and thus accumulate first in the lower portion of the joint or crack space. In addition, more of these materials tend to infiltrate into that portion of the joint or crack space which is in the vicinity of the shoulders than elsewhere.

There is also the possibility that under the action of traffic some of the subgrade material may be worked up, or be pumped up, into the joint or crack spaces. In any event, it is apparent that during an expansion cycle the entire expansive effort of the pavement is necessarily concentrated on these accumulations, the result being the development of high unit pressures. It consequently appears that these accumulations are to a large extent responsible for the occurrence of spalling, bottom rupturing, longitudinal cracking, buckling, and total shattering that often occurs at joints and cracks, the shattering being known as a blow-up.

That these infiltrated solid materials can be extremely harmful is readily apparent when the following factors are taken into account:

1. In response to daily and seasonal changes in temperature, the slabs are practically always in the process of either expanding or contracting. In consequence, the ends of the slabs at joints and cracks are practically always moving either towards or away from each other.

2. A tremendous amount of force is required to prevent the pavement from expanding. For example, a force of at least 500 tons is required to prevent a 40-ft. slab of 8-in. thickness and 10-ft. width from expanding 1/8 in., which is the amount it would normally expand for a temperature increase of about 50 F.

The ends of slabs at joints and cracks may therefore be compared to a pair of crusher jaws that are actuated by a very powerful force. Consequently, if there is high localized resistance to the closure of a joint or crack the concrete will in itself give way.

It is thus seen that due to the combined effects of the infiltration of solid materials into joints and cracks and the expansion and contraction of the slabs, the pavement can suffer serious damage. This, in fact, is one of the principal reasons why the filling-and-sealing problem is of such importance.

It is to be noted that thin layers of infiltrated material offer more resistance to compression than thick layers. Consequently, the narrower the joint space the more damaging these materials tend to be. There is also the possibility that the greater the change in joint width the more damaging the effects of infiltration.

## Effect of Growth

Some of the older pavements have undergone what is commonly known as "growth," which is the occurrence of abnormal expansion of the concrete. Under conditions of growth there is a progressive increase in slab length and, as a result, a loss of expansion space. In the course of time this leads to two things: (1) the development of compression in the pavement and (2) a reduction in the amount of change in joint width, which under extreme conditions, may become practically zero. For this reason, the joints in an older pavement which has undergone growth or in which the joints have become filled with solid material may be much less difficult to maintain in a sealed condition than is the case with a newer pavement.

## AMOUNT OF CHANGE IN JOINT WIDTH

Based on the results of a questionnaire sent by the Highway Research Board in January 1952 to all of the state highway departments in this country, only a very limited amount of precise data has thus far been developed in connection with joint-width changes. However, such information as was furnished by certain states, and pertinent comments submitted with this information, are as follows:

### California

We do not have a great deal of data throughout the state covering the seasonal change in joint width at contraction joints in concrete pavements. However, the values obtained on two experimental sections are as follows:

| Joint Spacing ft. | Minimum* Temperature F. | Maximum* Temperature F. | Joint Opening in. |
|---|---|---|---|
| 15 | 50 | 105 | 0.030 (Piru) |
| 15 | 35 | 120 | 0.060 (Vacaville) |

*Temperature midway between top and bottom of pavement.

### Connecticut

Tabulated below are the approximate over-all annual changes in joint width for various joint spacings, in reinforced pavements, observed between the years of 1949 and 1951.

| Location | Pave. Temp. Range F. | Joint Spacing ft. | Change in Width in. |
|---|---|---|---|
| A* | 20 to 100 | 93-100 | 0.30 |
| A | " | 109 | 0.40 |
| A | " | 118 | 0.48 |
| A | " | 127 | 0.50 |
| A | " | 136 | 0.60 |
| A | " | 145 | 0.56 |
| A | " | 154 | 0.63 |
| A | " | 154-163 | 0.66 |
| B** | 30 to 101 | 61 | 0.15 |
| C & D*** | " | 73 | 0.26 |

* Pavement in location A constructed in 1949. Gauge plugs installed at the time of construction.

** Pavement in location B was 15 years old at the time the gauge plugs were installed. The less than normal change in joint width recorded is apparently due to either infiltration or growth, or a combination of both.

***Pavements constructed in 1940 and 1941.

All of the above measurements apply to expansion joints.

(Based on supplemental correspondence, the indications are that, in Connecticut, the over-all annual changes in joint width for various joint spacings are essentially the same as shown hereinafter in the tabulation for New Jersey.)

## Iowa

No measurements have been made of the seasonal variation in the widths of joints in concrete pavements. Our data is limited to length changes in several concrete slabs, each 80 ft. long, 2 ft. wide and 6 in. thick. Length changes were measured by means of dial gauges mounted on concrete piers at each end of each slab. This work was done about 20 yr. ago. The observed movement checked the computed movement, assuming the following:

Thermal coefficient of concrete, 0.000006 per deg. F.
Coefficient of friction between concrete and earth, 2.0
Modulus of elasticity of concrete, 4,000,000 psi.

## Kansas

Measurements and recordings made on the Lawrence Experimental Concrete Pavement (constructed 1935 and 1936) indicated the following:

1. The thermal coefficient of expansion ranged from 0.0000034 to 0.0000044.

2. The over-all seasonal change in pavement temperature ranged from 20 F. to 120 F., approximately.

## Massachusetts

During the fall of 1951, gauge plugs were installed at six series of expansion joints in concrete pavements in the Boston area. Preliminary results indicate that the joints between 57-ft. slabs appear to open about 0.1 in. for a 30-deg. change in temperature.

(Based on the foregoing observation, the indications are that joint-width changes in Massachusetts are essentially the same as shown in the tabulation for New Jersey.)

## Michigan

The results of measured joint-width changes on three test roads in Michigan are as follows:

TABLE 1

M-43 West of Grand Ledge
(8-inch uniform pavement)

| | Type of Construction | | Contraction Joint Opening | |
|---|---|---|---|---|
| Slab Length | Expansion Joint Spacing | Reinforcing Steel | 1st season 70 F. to 40 F.* | Subsequent Maximum 85 F. to 33 F |
| ft. | ft. | lb. per 100 sq. ft. | in. | in. |
| 100 | None | 86 | 0.19 | 0.25 |
| 50 | None | None | 0.08 | 0.12 |
| 100 | 400 | 86 | 0.08 | 0.28 |

## TABLE 2

US-27 South of St. Johns
(8-inch uniform pavement)
(New project)

| | Type of Construction | | Contraction Joint Opening | |
|---|---|---|---|---|
| Slab Length | Expansion Joint Spacing | Reinforcing Steel | 1st season 83 F. to 34 F.* | |
| ft. | ft. | lb. per 100 sq. ft. | in. | |
| 99 | 400 | 78 | 0.24 | ( 9" unif. pvmt.) |
| 99 | 400 | 78 | 0.29 | (10" " " ) |
| 99 | 400 | 78 | 0.28 | (11" " " ) |
| 99 | 400 | 78 | 0.31 | (12" " " ) |

*Temperatures at which readings were taken.

## TABLE 3

M-115 Test Road West of Clare
(9-7-9 pavement)

| | Type of Construction | | Contraction Joint Opening | |
|---|---|---|---|---|
| Slab Length | Expansion Joint Spacing | Reinforcing Steel | 1st season 75 F. to 25 F.* | Subsequent Maximum 75 F. to 25 F. |
| ft. | ft. | lb. per 100 sq. ft. | in. | in. |
| 60 | 120 | 60 | 0.27 | 0.22 |
| 60 | 240 | 60 | 0.27 | 0.20 |
| 60 | 480 | 60 | 0.24 | 0.20 |
| 60 | 900 | 60 | 0.27 | 0.21 |
| 60 | 1800 | 60 | 0.25 | 0.21 |
| 60 | 2700 | 60 | 0.22 | 0.18 |
| 30 | 120 | 37 | 0.16 | 0.10 |
| 30 | 240 | 37 | 0.17 | 0.10 |
| 30 | 480 | 37 | 0.14 | 0.10 |
| 30 | 900 | 37 | 0.13 | 0.08 |
| 30 | 1800 | 37 | 0.10 | 0.07 |
| 30 | 2700 | 37 | 0.14 | 0.09 |
| 20 | 120 | None | 0.13 | 0.08 |
| 20 | 240 | None | 0.13 | 0.09 |
| 20 | 480 | None | 0.13 | 0.08 |
| 20 | 900 | None | 0.11 | 0.07 |
| 20 | 1800 | None | 0.12 | 0.07 |
| 20 | 2700 | None | 0.13 | 0.09 |
| 10 | 120 | None | 0.09 | 0.03 |
| 10 | 240 | None | 0.05 | 0.05 |
| 10 | 480 | None | 0.06 | 0.03 |
| 10 | 900 | None | 0.06 | 0.03 |
| 10 | 1800 | None | 0.04 | 0.03 |
| 10 | 2700 | None | 0.04 | 0.03 |

## Minnesota

From 1940 to 1944, inclusive, extensive measurements were taken on a large experimental project on Highway 60, between Worthington and Brewster. The measured average contraction joint openings for a pavement temperature of 25 F. are as follows:

| Joint Spacing<br>ft. | Average Joint Opening<br>in. |
|---|---|
| 15 | 0.045 |
| 20 | 0.060 |
| 25 | 0.075 |
| 30 | 0.090 |

The possible maximum temperature variation of the pavement on this project is, approximately, from 110 E in the summer to -20 F. in the winter. Under average conditions, pavement temperatures above 80 F. will not affect the joint openings, since the joints are completely closed at approximately this temperature. Any increase in temperature above 80 F. is reflected in the development of compressive stresses in the pavement.

When the subgrade is frozen it resists the normal contraction of the slabs. With a temperature of less than 25 F. the contraction of the pavement has been found to be approximately one half its normal rate. With the low temperatures, cracks form in the subgrade and shoulders, with the result that the joints at such subgrade and shoulder cracks open in an amount corresponding to the cracks in the subgrade and shoulders. It has been observed that during extremely cold weather some of the joints coincident with these cracks have been open as much as ½ in.

## Missouri

Measurements taken on an investigational concrete pavement project indicated the following approximate average joint openings when the pavement temperature was 30 F:

| Joint Spacing<br>ft. | Joint Opening<br>in. |
|---|---|
| 25 | 0.07 |
| 60 | 0.15 |

## North Carolina

During the period from 1947 to 1951, gauge plugs were installed in 24 projects. The measured over-all annual changes in width of contraction joints spaced at 30-ft. intervals are as follows:

### Mountainous Country

| County | Project | Change in Jt. Width Openings<br>in. | Installation<br>date | Age<br>mo. |
|---|---|---|---|---|
| Buncombe | 9085* | 0.10 | 8-9 -50 | 17 |
| Catawba | 6246 | 0.07 | 11-12-48 | 37 |

## Hilly Country

| County | Project | Change in Jt. Width Openings in. | Installation date | Age mo. |
|---|---|---|---|---|
| Guilford | 5325 | 0.16 | 8-10-49 | 29 |
| " | 5355A | 0.09 | 12-21-48 | 36 |
| " | 5355B | 0.08 | 11-18-48 | 37 |
| Forsyth | 7408 | 0.12 | 5-23-50 | 20 |
| Davidson | 5283A | 0.11 | 7-26-48 | 41 |
| " | 5283B | 0.10 | 8-24-48 | 40 |
| " | 5285 | 0.14 | 5-11-51 | 8 |
| Mecklenburg | 6558 | 0.08 | 11-10-48 | 26 |
| Durham-Orange | 4602 | 0.11 | 6-14-48 | 42 |
| Durham | 4119 | 0.15 | 7-13-51 | 6 |
| Union-Anson | 6973A | 0.10 | 9-23-47 | 51 |
| " | 6973B | 0.11 | 9-23-47 | 51 |
| Chatham | 4075 | 0.16 | 7-17-49 | 30 |
| " | 4078* | 0.11 | 10-18-50 | 15 |
| **Coastal Plain** | | | | |
| Wake | 4875 | 0.07 | 10-31-47 | 50 |
| " | 4793 | 0.11 | 9-2 -49 | 28 |
| Sampson | 2739 | 0.10 | 9-26-47 | 51 |
| Cumberland | 3392 | 0.12 | 7-19-48 | 41 |
| Washington | 1972A | 0.11 | 4-21-49 | 33 |
| " | 1972B | 0.10 | 5-16-49 | 32 |
| Wilson | 2957 | 0.13 | 4-20-48 | 44 |
| Pasquotank | 1734* | 0.12 | 8-16-50 | 17 |

*Continuous-recording thermometers installed in these projects.

For the average annual weather cycle, the pavement temperatures recorded midway between the top and bottom surfaces of the pavement are as follows:

| County | Minimum F. | Maximum F. | Maximum Change F. |
|---|---|---|---|
| Buncombe | 27 | 104 | 77 |
| Chatham | 23 | 111 | 88 |
| Pasquotank | 34 | 108 | 74 |

The gauge plugs were installed in these pavements at the time of construction, and the original measurements were taken on the same day--just as soon as the concrete had hardened sufficiently to hold the plugs securely in position and before any cracking below the contraction joint grooves.

(Referring to the foregoing tabulations, it is of interest to note that, in general, the amount of joint opening is noticeably less in the case of the pavements constructed during the cooler months than for those constructed during the warmer months--the effects of the as-constructed temperature of the pavement being quite apparent.)

## Wisconsin

In 1939 and 1940, some studies were made on four different pavement projects of the movement of concrete pavements at expansion and contraction joints. Brass plugs were inserted in the pavement, one on each side of the joint, 6 in. apart. Measurements were taken under different temperature conditions using a strain gauge made of Invar, and having a dial reading 0.001 in.

These measurements indicated that the change in joint width of expansion joints spaced at 30-ft. intervals was 0.0156 in. per 10-deg. change in temperature. At expansion joints spaced 100 ft. apart this change was 0.03 in., while at the intermediate contraction joints at 25-ft. intervals the change was 0.0125 in. per 10-deg. temperature change.

Lacking precise data, the over-all change in slab temperature between the hottest weather in the summer and the coldest weather in the winter can only be approximated. However, the annual average (air) temperature in Wisconsin ranges from 39 F. in the north to 44 F. in the southern part of the state. Extreme temperatures of 110 F. above zero and 54 F. below zero are a matter of record.

While such extremes may be of short duration, there are times when the periods of hot weather are prolonged sufficiently that, with the absorbed heat, the pavement temperature may reach about 120 F. Similarly, there are prolonged periods of subzero weather during which the pavement temperature may drop to about -20 F., giving an over-all range of about 140 deg. It is questioned, however, whether the changes in slab length are as great as this temperature range would indicate. It is believed that in many cases, after freezing has penetrated into the subgrade, the pavement is frozen solidly to the subgrade; thereby restraining further movement, with a tendency to inhibit it entirely.

## New Jersey

During the past 10 yr., gauge plugs have been installed at a great many joints spaced at intervals ranging from 14 ft. to 187 ft. The following designs of pavement are involved: (1) pavements having expansion joints only, (2) pavements having contraction joints only, and (3) pavements having expansion and contraction joints.

The plugs were installed at the time of construction and the original measurements were generally taken just as soon as the concrete had hardened sufficiently to hold the plugs securely in position (on the same day of construction) in order to determine the amount that subsequent joint widths differ from the as-constructed widths. Precise measurements have been taken at frequent intervals by means of an Invar gauge. The more significant observations and results are as follows:

1. For the average annual weather cycle, the pavement temperature, as recorded midway between the top and bottom surfaces, ranges from a minimum of 20 F. in midwinter to a maximum of 110 F. in midsummer.

2. The approximate overall annual changes in joint width for various joint spacings are as shown in the following tabulation:

Approximate Over-All Annual Changes in Joint Width--New Jersey

| Joint Spacing<br>ft. | Change in Width<br>in. |
|---|---|
| 15 | 0.07 |
| 20 | 0.09 |
| 30 | 0.14 |
| 50 | 0.23 |
| 100 | 0.46 |

The foregoing changes apply to practically all pavements in New Jersey, regardless of the jointing arrangement, the only exceptions are those relatively few pavements constructed during the cooler seasons which, at the same time, have no expansion joints.

### Calculated Joint-Width Changes

It should be borne in mind that the average winter and summer pavement temperatures cannot be used as a basis for calculating the over-all seasonal changes in joint width, because the difference between the averages is much smaller than the difference between the actual minimum and maximum temperatures. For example, the maximum summer pavement temperature is much higher than the average summer temperature, and the minimum winter temperature is substantially lower than the average winter temperature. Since joint fillers and sealers are obliged to function throughout the entire range of over-all change in joint width, from minimum width to maximum width, it is necessary to deal in terms of the extremes.

## JOINT MATERIALS

In giving consideration to the various kinds of filling and sealing materials it is necessary to bear in mind that since joints have depth as well as width they necessarily have volume, which naturally varies with changes in width. Fundamentally, therefore, the problem is one of effectively filling and sealing a space that undergoes changes both in width and in volume. As will be shown later, the effect of volume-change is of particular significance in connection with those materials which, in certain respects, have the properties of a liquid.

### Joint Fillers

The conditions under which joint fillers are obliged to function are variable and, under certain conditions, unpredictable. It will be recalled, for example, that in the case of a pavement having expansion joints in association with contraction joints there is a progressive permanent closure of the expansion joints. Since the amount of change in expansion-joint width is unpredictable under these particular conditions, the following discussion pertaining to the behavior of joint fillers should be considered to apply primarily to pavements in which the changes in width are predictable and essentially the same from year to year, as is the case, for example, with a reinforced pavement having expansion joints at 60-ft. intervals and no intermediate contraction joints.

The primary function of a joint filler is, of course, to fill the joint space, and to thus prevent the entrance of water and solid materials. The ideal filler would therefore consist of a material that is capable of varying in thickness in precisely the same amount that the joint space varies in width. Such a filler would function as shown diagrammatically in Figure 5. Note that the filler has undergone a change both in thickness and in volume.

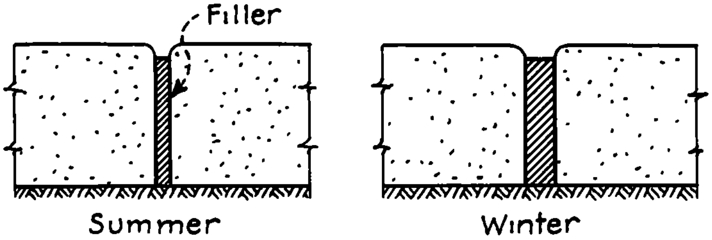


FIGURE 5 PERFORMANCE OF IDEAL JOINT FILLER

It is significant to observe that if a filler were available that would actually function in this manner there would be no need for sealing materials, at least in so far as expansion joints are concerned.

As a practical example of how much the ideal filler would actually have to change in thickness, the experience in New Jersey has been that expansion joints spaced at 78-ft. intervals undergo an over-all annual change in width of approximately 3/8 in., that is, in connection with reinforced pavements in which all of the joints are expansion joints.

Unfortunately, all of the various materials thus far employed as joint fillers have in common a serious deficiency in that they fail to recover to anywhere near their original thickness after being compressed a substantial amount and maintained in this condition for an extended period. There are, of course, a number of materials that will recover to practically their original thickness, provided they are only momentarily compressed. But joint fillers in actual service are usually maintained in a state of compression for several months at a time, that is, during the summer when the pavement is in an expanded condition. Consequently, the worth of any particular joint filler is largely determined by the amount of its recovery after a prolonged period of compression. It needs to be appreciated, however, that it is problematical whether there actually is any known material suitable for use as a joint filler which, at the same time, is entirely free from this basis deficiency. It appears that such a material is still to be discovered or developed.

In addition, it should be borne in mind that even if a filler were to be discovered or developed which would actually recover to 100 percent of its original thickness, and which would retain this capacity, certain installation procedures would have to be developed in order to utilize the filler to the best advantage. As previously pointed out, in the conventional method of construction the concrete is deposited directly against both sides of the filler and, in consequence, the as-constructed width of the joint space is equivalent to the thickness of the filler. It is apparent, however, that upon the arrival of colder weather there is a contraction of the pavement and an opening of the joint, at which time the joint space has a width that is greater than the thickness of the filler.

Under these conditions it is evident that unless the filler has the capacity to exceed its installed thickness, or is in some way installed in a state of compression and subsequently released, it cannot completely fill the joint space during cold weather. This deficiency is common to all of the conventional fillers, and is illustrated in Figure 6.

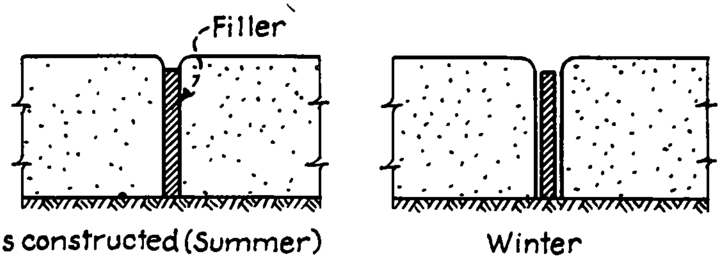


**FIGURE 6 PERFORMANCE OF CONVENTIONAL JOINT FILLER**

A typical example is found in the case of a pavement having expansion joints at 60-ft. intervals and an as-constructed temperature of 100 F. Even neglecting the effect of shrinkage, if the pavement temperature lowers to 20 F. in midwinter the joint spaces will be more than ¼ in. wider than the fillers are thick.

Importance of Recovery

It is evident that if a filler is maintained in a state of compression during the summer months, and then fails to recover in thickness when the joint opens in cold weather, a vacant space must necessarily be created. In itself, the space is of no particular significance. But the infiltration of water and solid materials into the space can be detrimental.

It is also evident that the filling of the vacant space with infiltrated solid materials while the joint is open during the winter will result in a further compression of the filler during the following summer. Consequently, owing to the combined effects of opening and closing of the joints, failure to recover, and the infiltration of solid materials, the conventional filler usually undergoes a progressive reduction in thickness. This process continues until the filler finally resists any further compression.

As a general rule, by the action of gravity, the infiltrated solid materials move downwards and accumulate first in the lower portion of the joint space. In consequence, it is usually the lower portion of the filler that first undergoes compression, and which first becomes compressed to the point of refusal. This process is shown diagrammatically in Figure 7.

As shown, this can result in a shattering of the lower portion of the pavement at the joint.

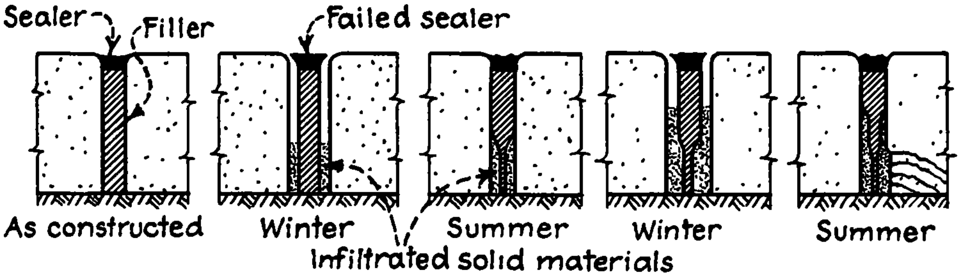


**FIGURE 7 PROGRESSIVE COMPRESSION OF TYPICAL FILLER**

It is to be noted that if the filler were able to do no more than retain an appreciable amount of recovery it would at least do two things. First, by reason of its recovery it would limit the amount of solid material that could infiltrate into the joint. Second, by continuing to act as a compressible gasket it would prevent the development of excessive resistance to joint closure. The manner in which this filler would function is shown diagrammatically in Figure 8.

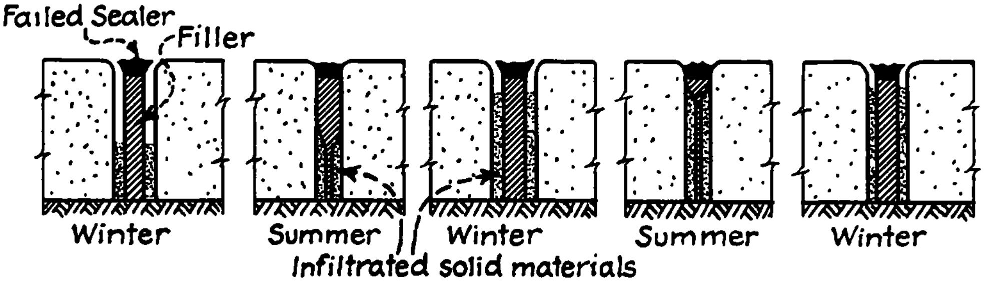


**FIGURE 8 BEHAVIOR OF RECOVERABLE FILLER**

## VARIOUS TYPES OF JOINT FILLERS

In years past, many different materials of a compressible nature have been used as joint fillers, none having proved entirely satisfactory. The fillers which are commonly used at present, and their general characteristics, are as follows:

### Premoulded Bituminous Filler

The most-common type of filler employed during the earlier years of concrete pavement construction, and still employed to some extent, is that which is known as premoulded bituminous joint filler. It is composed primarily of asphalt. In order to effect some degree of rigidity, the asphalt contains a small amount of felt or other inert material. This filler is manufactured in strips of various thicknesses, faced on each side with paper, and, in effect, is an asphalt board.

This type of filler has several undesirable characteristics. First, since asphalt is basically a liquid, it is practically incompressible within itself. When confined between two surfaces and subjected to pressure, as in a joint space, it extrudes rather than actually compresses. Consequently this filler is compressible only in effect. Second, after being "compressed" it will by no means recover to its original thickness. It stays put, so to speak. Third, when it extrudes from a joint space it will push the sealer out of the joint space and collect on the pavement surface and cause both an unsightly appearance and a bump.

One can readily visualize the behavior of this type of filler. When the joint closes, a portion of the filler necessarily extrudes. Then, when the joint opens, the filler remains in a compressed condition, and a vacancy is created. Solid materials then infiltrate into the vacancy. Upon subsequent closure of the joint these materials displace and cause a further extrusion of the filler. With repetitions of this cycle a progressive interchange takes place--solid material going in, and filler coming out. In the course of time, it is by no means uncommon for fillers of this type to completely vacate the joint space, and to be replaced with solid foreign material.

In view of this behavior it is apparent that any material which possesses the properties of a liquid, or which is susceptible to extrusion, cannot fulfill the requirements of a satisfactory joint filler.

### Asphalt-Impregnated-Fiber Filler

The asphalt-impregnated-fiber fillers were developed primarily because of the excessive amount of extrusion associated with the premoulded bituminous fillers. These fillers are composed mainly of fibrous materials that are usually derived from wood or sugar cane, and are similar in structure to the cellular materials which, in the form of sheets, are used for insulating purposes. The function of the asphalt impregnation is to render the filler waterproof and decay-resistant. The asphalt quantity is limited, however, so that no appreciable amount of it squeezes out when the filler is compressed.

These fillers, being of low structural strength, offer little resistance to compression. Because of their air-cell content, they may be compressed a considerable amount without extruding.

### Cork Fillers

There are two types of cork fillers, namely: regular and self-expanding, both of which consist of granulated cork particles cemented together. As in the case of the asphalt-impregnated-fiber fillers, the cork fillers offer little resistance to compression, and may be compressed a considerable amount without extruding. From the standpoint of decay resistance, cork fillers are very durable.

The self-expanding cork fillers were developed in order to make available a type of filler that has the capacity to attain a thickness greater than its installed thickness. In the manufacturing process, these fillers are precompressed to approximately two thirds of their original thickness. Since contact with moisture would cause them to recover, at least to some extent, they are then coated with a waterproofing agent and wrapped in heavy waxed paper, the latter being removed at the time of installation. For some indefinite period after installation, the waterproofing coating prevents the absorption of moisture. This coating eventually breaks down, however, and there is then the absorption of moisture and a tendency to swell.

### Cork-Asphalt Filler

This type of filler consists of granulated cork particles in combination with asphalt. In view of these constituents, this would appear to be a durable filler. It has been reported, however, that certain fillers of this type, despite having passed the standard laboratory extrusion test, have undergone an undesirable amount of extrusion in actual service. This has apparently been due to either an excess asphalt content or to the asphalt having approached a fluid state during periods of high pavement temperature, or both.

### Wood Fillers

Wood fillers are usually in the form of ordinary boards, with or without preservative treatment. Care is exercised in their selection, however, in order to avoid the use of lumber having excessively large knots or other objectionable structural defects. Because of their natural decay-resistance and freedom from knots, the most commonly used wood fillers have consisted of either cypress, redwood, or western red cedar.

Some wood fillers have been fabricated such that the grain direction is vertical in the joint space, which is accomplished by sawing the lumber into short pieces and attaching the pieces together, edge to edge. The primary purpose of this form of fabrication is to prevent extrusion, which might otherwise occur as a result of compression or swelling.

A limited amount of investigational work has been done to determine the possibilities of precompressed wood. More particularly, it has been found that most woods may be compressed to approximately 50 percent of their original thickness without serious structural damage, provided that transverse spreading is prevented during compression, and that if kept dry the wood will remain indefinitely at a thickness not exceeding 65 percent of its original thickness. When soaked in water, however, the compressed wood will swell to at least 94 percent of its original thickness, and some woods will swell to more than 100 percent. It has also been found that even after repeated cycles of compression, and prolonged periods of compression, the wood will nevertheless retain a considerable part of its capacity to swell when in contact with water. There are, however, in addition to high cost, a number of difficulties associated with the practical application of precompressed wood which, for the time being at least, seem to preclude its use as a joint filler.

Based on reports, wood fillers appear to be the best available, which may be due to their greater capacity to recover. Because of their considerable resistance to compression, they may also be of structural benefit to the pavement.

In the use of wood fillers it needs to be appreciated that, with the absorption of moisture, wood is susceptible to swelling a rather large amount, and that to restrain swelling requires considerable force. Consequently, in the edging of joints having wood filler, it is of the utmost importance that the space above the filler be so formed as to have a width at least equivalent to the thickness of the filler (preferably somewhat greater), and that the space be centered directly over the filler, otherwise any subsequent swelling of the wood is almost certain to result in spalling. It is also desirable to prevent premature swelling, which may be accomplished by a liberal application of tar or asphalt paint.

## Glass-Fiber Filler

Of more recent development is a filler composed of glass fibers and asphalt. This filler is manufactured in strips of various thicknesses faced on both sides with paper. Its resistance to compression is low. Since the asphalt content is limited, it appears to be practically free from extrusion. Being composed primarily of nonperishable materials, it would seem to be durable.

## Solution to the Filler Problem

The solution to the filler problem may require one of the following procedures: (1) the development of an expansible filler, of enduring expansibility, that may be installed in a precompressed condition; (2) the creation of the joint space by means other than the permanent filler, and the subsequent filling of the space with a precompressed expansible filler; (3) the introduction of an additional strip of filler, precompressed and of an expansible nature, when the joint spaces are at or near their maximum width during cold weather.

There are, however, certain practical problems to be solved and economic factors to be taken into consideration in all of these procedures. And there are undoubtedly other lines of approach. For example, the fact that concrete pavements are capable of withstanding considerable compressive stress might possibly be used to good advantage in solving the problem.

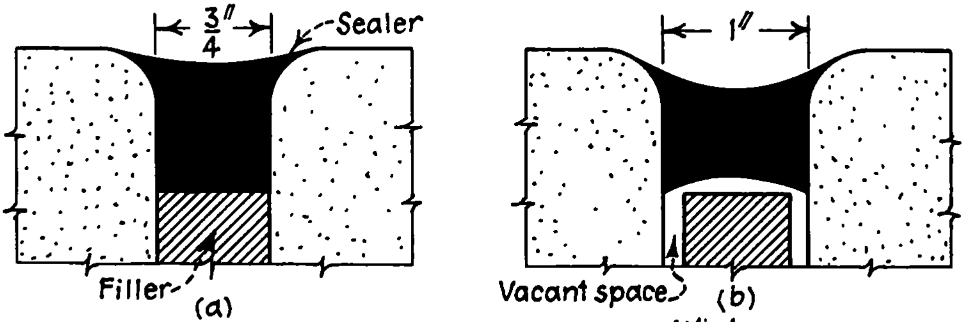
Continued serious effort to solve the filler problem is fully warranted, if only for the following reasons: (1) in the interest of preserving the pavement and (2) in view of the vast amount of time, effort and money that is now being spent on the endless and only partly effective procedure of sealing (pouring) joints.

If and when a joint filler of reasonable cost is developed that has the capacity to completely fill the joint space at all times the so-called pouring of joints will be a thing of the past.

## JOINT SEALERS

As previously defined, joint sealers are those materials of a liquid or semiliquid nature that are poured into joint spaces for the purpose of excluding water and solid foreign materials. It is particularly important to bear in mind that, in common with liquids, these materials are practically incompressible within themselves and are incapable of changing in volume to any significant extent. Consequently, sealing materials are capable only of changing in shape.

In conjunction with an expansion joint, a first-class sealer would function essentially as shown in Figure 9. For purposes of illustration, the following conditions have been assumed: (1) a 3/4-in. filler, (2) a 60-ft. joint spacing, (3) an as-constructed pavement temperature of 90 F., and (4) a minimum winter pavement temperature of 20 F.



(a) As constructed (Summer)

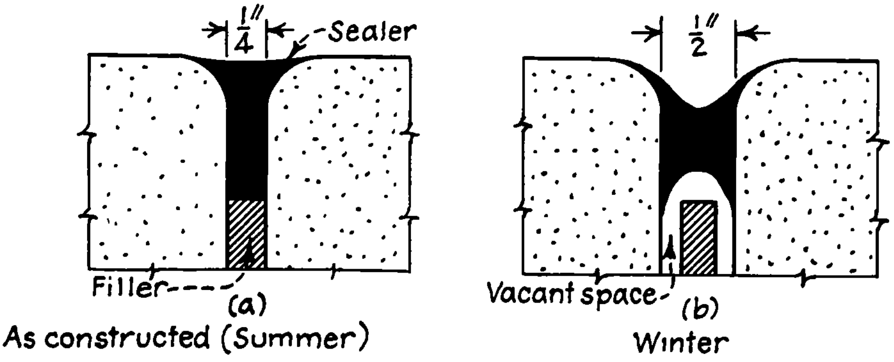
(b) Winter

FIGURE 9 EXPANSION JOINT WITH $\frac{3}{4}$" FILLER

It will be noted that: (1) With the increase in joint width from 3/4 in. to 1 in., the sealer has been obliged to undergo a stretch of 33 percent. (2) Since the sealer is of constant volume, the cross-sectional area of the sealer is necessarily the same for both the summer and winter conditions. (3) In effect, the sealer is merely a membrane across the top of the joint space. (4) During the winter, the filler does not completely fill the joint space, there being a total of ¼ in. of vacant space between the filler and the slab ends. At the ends of the joint, water and foreign materials are free to infiltrate into this space.

The upper portion of an expansion joint is also shown in Figure 10, but in this instance the filler is only ¼ in. thick. All of the other conditions are assumed to be the same as in the preceding example. The purpose of this figure is to demonstrate the importance of the as-constructed width of the joint space.

It will be noted that, for exactly the same amount of joint opening as in the preceding example, the sealer has in this instance been obliged to undergo a stretch of 100 percent. Carrying this a step farther, had the as-constructed width of the joint space been only 1/8 in. the sealer would have had to stretch 200 percent.



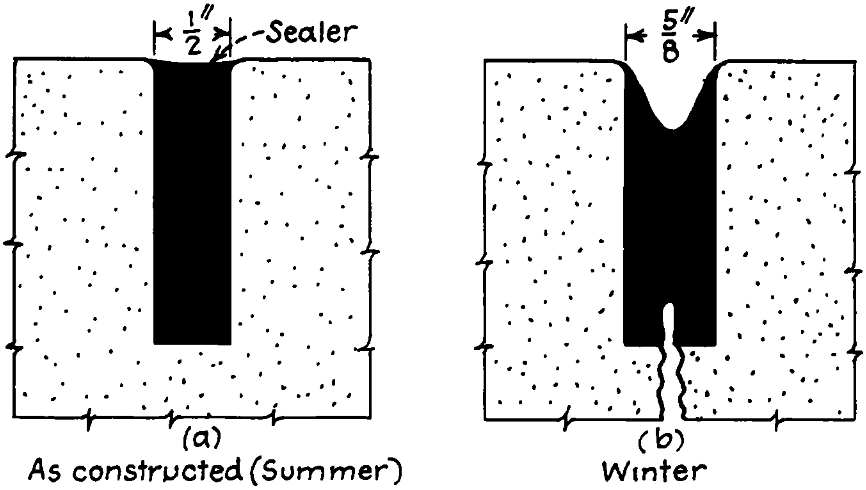
(a) As constructed (Summer)

(b) Winter

FIGURE 10 EXPANSION JOINT WITH $\frac{1}{4}$" FILLER

It is thus seen that the narrower the joint space the greater the strain on the sealing material and the more likely the sealer is to fail. It is therefore erroneous to assume that the narrower the space the easier it is to maintain in a sealed condition. Actually, within reasonable limits, it is just the other way around.

This is also true in the case of contraction joints. Figure 11, for example, shows a groove-type contraction joint in which the as-constructed width of the groove is ½ in., and which, after being sealed, opens 1/8 in. Although it is very problematical as to just what shape the sealer would assume when the joint opens, it nevertheless appears probable that it would be more or less as shown in drawing Figure 11 (a), which is based on the assumption that there is no bond failure at any point. But it is at least certain that its cross-sectional area would be exactly the same as in Figure 11 (b), which is the case in these drawings.

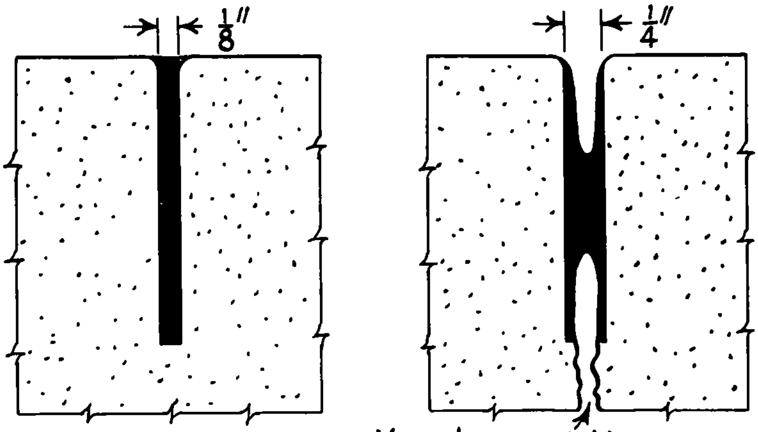


(a) As constructed (Summer)

(b) Winter

FIGURE 11 CONTRACTION JOINT WITH $\frac{1}{2}$" GROOVE

If, on the other hand, the as-constructed width of the groove had been only 1/8 in., the situation for the same amount of joint opening would probably have been something on the order of that shown in Figure 12 (b). In this case also, the sealers in (a) and (b) have the same cross-sectional area.



(a) As constructed (Summer)

Vacant space (b) Winter.

FIGURE 12 CONTRACTION JOINT WITH $\frac{1}{8}$ GROOVE

It will be noted that the sealer shown in Figure 12 (b) has not only been very materially stretched and changed in shape, but that, in addition, 50 percent of the groove necessarily has no sealer in it whatever. Actually, this is merely a typical case of a sealing material of constant volume doing its best to fill and seal a space that is 100 percent larger than itself. The preceding examples will serve to emphasize the need for the development of sealers (and fillers) that are capable of changing in volume in conformity with the changes in joint width.

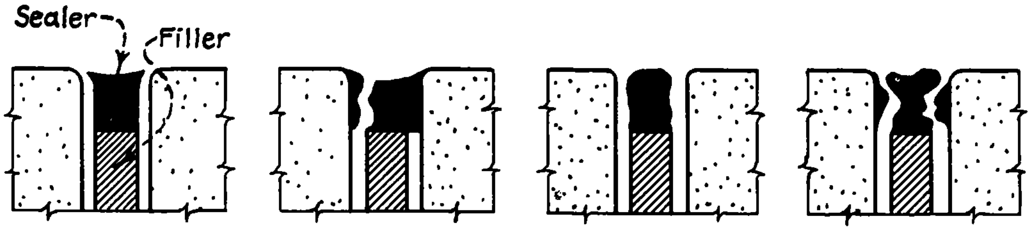
From the standpoint of appearance and riding qualities, there is much to be said in favor of narrow joints. But if there is to be any expectation whatever of effective sealing, the joint space must have sufficient width to accommodate the required amount of sealer. There should, in fact, be a proper relationship between: (1)the amount of change in joint width, (2) the capabilities of the sealing material, and (3) the width of the joint space.

It is therefore apparent that part of the responsibility for effective sealing rests with the engineer. If, in his design, he specifies joint spaces that are altogether too narrow in terms of their change in width, he will find that there is simply no known sealing material that will perform satisfactorily.

It is of incidental interest to note that the conventional method of sawing joints results in a groove of essentially the same dimensions as that shown in Figure 12(a). In recognition of the fact that the space may be too narrow to accommodate the necessary amount of sealing material and in view of the difficulties experienced in filling grooves of such limited width, it has been the practice in certain locations to increase the width of the upper portion of the groove. This has been accomplished by the employment of two saw blades, of different diameters, placed side by side and used simultaneously. It has also been reported that power-driven grinding equipment has been developed, and is now available, for the same purpose.

## Failure of Sealing Materials

The most common forms of sealer failure are shown in Figure 13. Some of the factors which contribute to the failure of sealing materials are as follows:



Bond failure

Separation

Bond failure and drawing together by skin tension

General disintegration

FIGURE 13 TYPICAL FORMS OF SEALER FAILURE

1. Under climatic conditions typical of the northerly part of the United States, joint sealers, being in association with the upper surface of the pavement, are obliged to function under temperatures that range from about 10 F. (or lower) in midwinter to about 140 F. (or higher) in midsummer. Unless it remains in a fairly stable condition, the sealer may either drain out of the joint space in warm weather (due to the transverse slope of the pavement) or be excessively brittle in cold weather, or both. Of necessity, sealing materials are exposed directly to heat, cold, sunlight, rain, sleet, snow, ice, freezing and thawing, oil and grease drippings, and the action of traffic.

2. During the melting process prior to their application, sealing materials are often subjected to excessive or prolonged heating. This usually damages the material to the extent that it fails to perform satisfactorily.

3. If the concrete is moist or covered with a film of dirt, laitance or other foreign matter at the time the sealer is placed, its bond with the concrete may be very poor. There is also the possibility that moisture absorbed by the concrete after the placement of the sealer may be a cause of bond failure.

4. For curing purposes, bituminous or resinous materials are sometimes sprayed on pavement surfaces immediately after the finishing operations are completed. Films of these materials adhering to the sides of joint spaces often interfere with the attainment of adequate bond.

5. As often occurs in the case of undowelled joints, any excessive differential deflection of the slab ends under the action of traffic will have a tendency to tear the sealer loose, or to shatter it if it is brittle during cold weather.

6. If the filler is composed of materials that are susceptible to extrusion, the sealer will be pushed out of the joint space during pavement expansion.

7. In the case of the older pavements, the upper portions of the joint spaces often contain foreign matter and remnants of old, debilitated sealing materials. Unless removed, these materials may seriously interfere with the effective bonding of new sealers.

8. In the case of joints that are pumping and faulted, the upward ejection of the entrapped water or mud during the passage of heavy loads tends to force the sealer out of the joint spaces.

In the preceding comments pertaining to the premoulded bituminous type of filler, it was pointed out that, by a process of interchange, the infiltration of solid materials often results in complete extrusion of the filler. The progressive extrusion of sealing materials and their replacement with solid materials, by the same process, is of common occurrence, especially in connection with contraction joints.

## VARIOUS TYPES OF SEALERS

### Asphalt and Tar Sealers

The sealing material most commonly employed, both past and present, is composed of asphalt—a small amount of mineral filler or other inert substances being added to render the asphalt less fluid. Sealers composed of tar have also been used, but to a lesser extent. It is necessary to heat these materials to cause them to pour readily. They are, however, damaged by excessive or prolonged heating.

### Thermoplastic Sealers

In recent years, sealers composed principally of a mixture of asphalt and rubber have been developed. Those types which require heating are known as "thermoplastic sealers." Reports differ as to their performance. It is nevertheless the general opinion that these sealers are superior to the ordinary asphalt and tar sealers.

The experience has been that the thermoplastic sealers require rigidly controlled heating, otherwise they are likely to be seriously damaged. For this reason, special heating equipment has been developed, the use of which is essential to the protection and satisfactory performance of these materials.

### Cold-Poured Sealers

Over a period of years, many sealers have been developed which do not require heating—these being known as the "cold-poured" types. In general, these sealers consist of rubber, or a mixture of asphalt and rubber, or other materials which have the characteristics of rubber.

As compared with the asphalt, tar, and thermoplastic sealers, the cold-poured sealers have been used to only a limited extent, and mostly on an experimental basis. Consequently, little is known in regard to the performance of the more recent types. It is known, however, that some of the earlier types (and possibly all) failed in bond after a very short period of service.

## CRACK SEALERS

It is customary to employ essentially the same kind of materials for the sealing of cracks as are used for the sealing of joints. It is doubtful, however, whether these materials actually penetrate into the cracks to any appreciable extent, that is, with the exception of those cracks which are open rather large amounts. It is probable that, in general, these materials merely cover up the cracks, particularly the narrow cracks in reinforced pavements. The complete filling of narrow cracks with anything other than a material that is very fluid even at normal temperatures is probably a practical impossibility, and may not be worth the effort.

In view of the difficulty of sealing cracks, machines have been developed, and are on the market, which cut grooves in the pavement surface, coincident with the cracks. These grooves, which have appreciable width and depth, serve as reservoirs for the retention of the sealing materials.

## TESTING OF JOINT FILLERS

In the testing of joint fillers, it is the usual practice to place a 4- by 4-in. sample of the filler between metal plates and, at the rate of approximately 0.05 in. per min., compress it to 50 percent of its original thickness, the load being released immediately after the compression has been completed. This operation is repeated three times. After the released specimen is permitted to recover for 1 hr., its thickness is measured in order to determine the amount of recovery.

It will be noted that in this test the specimen is maintained in a state of compression for only a very short period. As previously pointed out, however, joint fillers in actual service are often maintained in a state of compression for weeks at a time. Moreover, tests have shown that many fillers which have a high degree of recovery after being only momentarily compressed will have practically no recovery if maintained in a prolonged state of compression. There furthermore appear to be instances where, for example, a given Filler A, after momentary compression, might have less recovery than Filler B, but that after prolonged compression the reverse is the case.

It is therefore apparent that the results of momentary compression are not necessarily indicative of the long-term performance of any given filler nor of the relative merits of different fillers. Consequently it appears advisable to supplement the above test with a test in which the specimens are subjected to prolonged compression and, at the same time, maintained in an environment that most nearly simulates the actual conditions in a joint space.

## TESTING OF JOINT SEALERS

One phase in the usual testing of joint sealers that appears to warrant further consideration is the pouring of a quantity of the sealer between two mortar blocks and, at a temperature of approximately 0 F., pulling the blocks apart at a given rate in an extension machine. The mortar blocks are 1 by 2 by 3 in. in size, and are placed with their larger surfaces 1 in. apart at the time the sealing material is poured between them. To prevent the lateral escape of the sealer, bulkheads are placed between the blocks, near their ends—the dimensions of the congealed sealer being 2 by 2 in. by 1 in. thick. As a general rule, the blocks are pulled ½ in. farther apart than they were originally, that is, the sealer is extended 50 percent beyond its original thickness.

It is important to bear in mind that in this test the sealing material, because of its limited dimensions, accommodates itself to this stretching action by becoming concave on all four of its exposed surfaces. In a joint space,on the other hand, because the length of the sealer in the direction parallel with the joint is usually 10 ft. or more, the sealer is obliged to accommodate itself by becoming concave on only its top and bottom surfaces. Consequently, in the case of a joint, any given amount of joint opening will impose a greater strain on the sealing material than the same amount of pulling apart of the mortar blocks. It is therefore apparent that even though a given sealer may withstand an extension of 50 percent between a pair of mortar blocks, it may not necessarily withstand the same amount of extension in a joint space. For this reason, it appears desirable to determine the proper relationship between the mortar-block test and the opening of joints in actual service.

Also warranting consideration is the preparation of the mortar blocks. For reasons of creating the same conditions for all of the materials being tested, the usual practice is to grind that surface of the block with which the sealing material comes into contact. In addition, prior to introducing the sealing material between them, the blocks are usually oven-dried to a constant weight at a temperature of about 225 F., and their ground surfaces are thoroughly cleaned of film or powder by vigorous brushing.

It is evident that under actual field conditions the faces of the joint are rarely in a condition comparable to that of the mortar blocks. Since the presence of dirt, laitance, moisture or other foreign matter on the joint faces is known to interfere seriously with the attainment of satisfactory bond, there is good cause to question whether the results obtained from the use of ground, cleaned, oven-dried blocks are reliably indicative of the performance of any given material in actual service. It would therefore appear desirable to supplement this test with one that more nearly simulates the true conditions.

## MECHANICAL SEALING DEVICES

In view of the limitations and generally unsatisfactory performance of filling and sealing materials, numerous attempts have been made to solve the sealing problem by means of mechanical devices of one kind or another, the more important of which are as follows:

### Sheet-Metal Flashing

Although now rarely installed, sheet-metal flashing has been the most-commonly used form of mechanical sealing device. The metal itself usually consists of either copper, brass or galvanized steel. Two typical designs are shown in Figure 14.

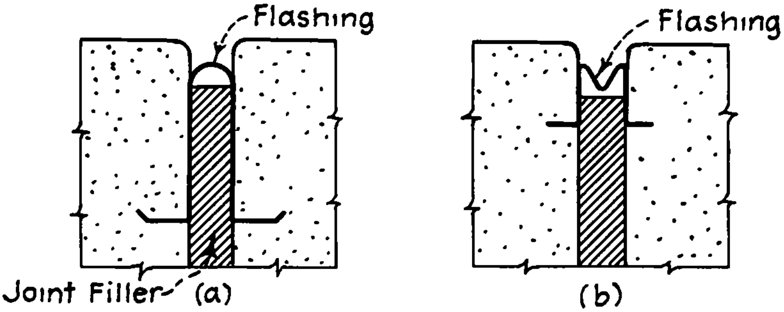


**FIGURE 14 TYPICAL SHEET METAL FLASHINGS**

In most instances the flashing has extended only across the top of the joint space. Since this obviously does not prevent the entrance of water and foreign materials at the ends of the joint, some designs have included vertical strips of flashing at the ends.

In general, sheet-metal flashings have proved unsatisfactory, for the following reasons: (1) With changes in joint width there is necessarily a bending of the flashing. If repeatedly bent beyond its elastic limit, which is usually the case, it sooner or later fails by cracking. (2) The progressive infiltration of solid material into the joint space, acting in conjunction with the changes in joint width, tends to result in a progressive deformation of the flashing. (3) If of steel, and even though galvanized, the flashing usually fails by rusting within a few years.

In addition to their limited value, past experience has shown that certain flashings can cause considerable damage to the pavement. To illustrate, Figure 15 shows the manner in which a particular type of flashing has resulted in serious spalling.

Figure 15(a) shows the flashing as installed. Figure 15(b) shows the ultimate shape of the flashing, which results from the combined effects of infiltration and the changes in joint width. Figure 15(c) shows the serious surface spalling which occurs during an expansion cycle. It will be noted that the flashing traps the infiltrated material in the upper portion of the joint space. Moreover, that during an expansion cycle the entire expansive effort of the pavement is concentrated on this entrapped material.

In instances of this kind it is not at all unusual for the spalling to extend 18 in. or more from the joint.

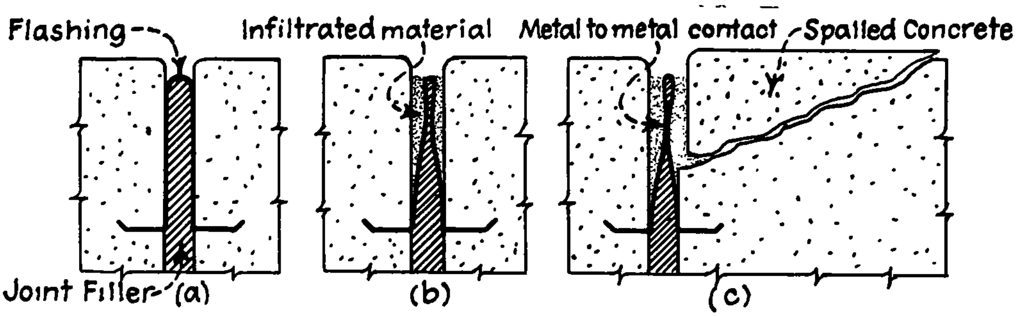


FIGURE 15 FLASHING DEFORMATION AND SPALLING

It cannot be overemphasized that the use of flashings involves considerable risk. Especially to be avoided is their installation in narrow joints, since the thin layers of infiltrated material that accumulate on each side of the flashing will very likely prove to be practically incompressible. In addition, the greater the change in joint width the greater the risk of spalling. Past experience has also shown that supplemental sealing of the joints with the conventional type of joint sealer is no guarantee whatever against the infiltration of solid material.

Preformed Rubber Flashings

A more recent development is a flashing composed of synthetic rubber (neoprene). In cross-section, these are similar to the sheet-metal flashings previously described, and are intended to serve the same purpose. A typical flashing of this type intended for use at contraction joints is shown in Figure 16.

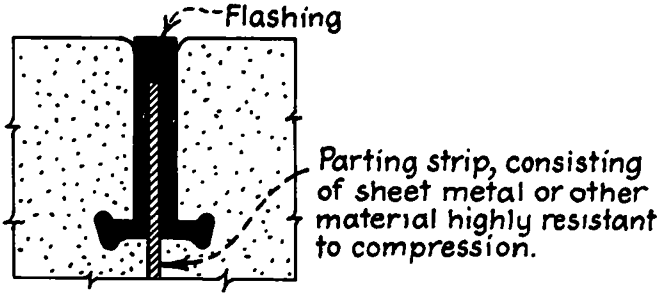


FIGURE 16 PREFORMED RUBBER FLASHING
(Contraction joint)

Offhand it would appear that this type of flashing has considerable merit. However, a number of test installations in various parts of the country have shown that these flashings have resulted in very serious spalling at an early date. Whether or not the spalling has been due to infiltration or other causes remains unknown.

In view of these experiences, it is evident that extreme caution needs to be exercised in the use of any kind of flashing, regardless of its apparent merits, and no matter how harmless it may appear to be.

### Miscellaneous Devices

Certain other mechanical sealing devices, which have either been merely suggested or used to only a very limited extent, are as follows:

1. Structural steel sections, such as angles, Z-bars, or channels, so positioned as to be overlapping and to slide on one another with changes in joint width.

2. A flat, steel plate covering the joint space and centered thereon, the plate to rest on shelves formed in the pavement surface at the ends of the slabs, and to be secured by means of bolts.

3. Two U-shaped and mutually engaging sections of sheet metal, in combination with coil springs.

4. A section of rubber tubing, hose, or similar hollow resilient material, forced into the joint space in a somewhat flattened condition.

5. A membrane of rubber or waterproof fabric spanning the joint space, attached by one means or another to the ends of the slabs.

6. A section of sponge rubber or other resilient material containing a high percentage of air voids, forced into the joint space in a compressed condition.

7. A strip of sheet metal, or bituminized fabric, centered on the joint, positioned on the subgrade, and extending upward along the outside edges of the pavement. The purpose of this trip is to prevent water and foreign materials from entering the joint space from the bottom and ends, the top of the joint being sealed in the conventional manner. The strip is also intended to prevent subgrade material from being pumped up through the joint space.

## SUMMARY OF BASIC FACTORS

The more-important basic factors related to the filling and sealing problem may be summarized as follows:

1. The difficulty of maintaining joints in a filled-and-sealed condition is due primarily to the fact that with changes in slab temperature and moisture content the joints undergo changes in width. This also applies in the case of cracks in unreinforced pavements. In addition, the greater the change in joint width the greater the difficulty.

2. Other conditions being the same, and within certain limits, the greater the joint spacing the greater the change in joint width. For the conventional joint spacings, and for all practical purposes, the amount of change in joint width is directly proportional to the joint spacing.

3. Even for the same spacing, the amount of over-all seasonal change in joint width is not the same in all parts of the county, since the change is also dependent on other factors such as over-all seasonal range of temperature change, amount and distribution of rainfall, coefficient of thermal expansion of the concrete, and the temperature at the time of construction (if expansion joints are omitted or spaced at distant intervals).

4. For any given change in joint width, the narrower the joint space the greater the strain on the sealing material and the more likely the material is to fail.

5. The principal deficiency of all known joint fillers is their failure to recover in thickness after extended periods of compression.

6. The principal deficiency of the conventional sealing material is that it is basically a liquid. Consequently it is practically incompressible within itself, of practically constant volume, and susceptible only to a change in shape. Since, with a change in width, the joint space also changes in volume, this type of material has very definite limitations.

7. For any sealing material to prove satisfactory there must be a proper relationship between the capabilities of the sealer, the over-all change in joint width, and the width of the joint space. No known sealing material will perform satisfactorily if, in terms of the over-all change in joint width, the joint space is too narrow. This also holds true if, for any given width of joint space, the over-all change in width is excessive.

8. The performance of any given sealing material in one part of the country is not necessarily indicative of its probable performance elsewhere, since among other things, climate is a very-important determining factor.

The Highway Research Board is organized under the auspices of the Division of Engineering and Industrial Research of the National Research Council to provide a clearinghouse for highway research activities and information. The National Research Council is the operating agency of the National Academy of Sciences, a private organization of eminent American scientists chartered in 1863 (under a special act of Congress) to "investigate, examine, experiment, and report on any subject of science or art."