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*Abridgment*

# Pavement Design Features and Their Effect on Joint-Seal Performance

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**The effect of the design parameters of pavement on the long-term performance of joint-sealing materials is studied. The work is a compilation of the work of many researchers in the field of pavement joint sealing. The design features considered are type and size of joint, type of subbase, length of slab, slab thickness, type of load-transfer device, temperature and moisture range, and the material properties of the concrete in the pavement. The effect of each of these features is considered in some detail, and recommendations are made based on the results of past research. No attempt is made to evaluate the merits of the various types of joint-sealing materials.**

The joints in rigid pavements are usually sealed to prevent the intrusion of water, incompressible solids, and chemical deicing solutions. The intrusion of these materials could have a detrimental effect on the joint and the pavement system and result in faulting, spalling, blowups, and other distresses common to rigid pavements.

The sealing material must accommodate the repetitive movement between pavement joints while maintaining its integrity. It is the design features of the pavement that determine how much movement the sealant must accommodate.

The movement of a pavement slab is a function of many variables. The most prominent of these factors are type and size of joint, length of slab, slab thickness, type of subgrade, type of load-transfer device, temperature, moisture, material properties, and type and volume of traffic. Joints are introduced into the pavement because the free movement of the pavement is restrained and this induces stresses that cause cracking. The joints are designed and spaced to control cracking.

In order to design the joint properly, one must know the magnitude and direction of movement in the pavement. A slab between joints can move horizontally because of a change in temperature and moisture, or it can curl because of a difference in temperature between the top and bottom of the slab. The horizontal movement of the slab is resisted by the friction between slab and subbase, which induces stresses in the slab. These stresses are shear stresses, accompanied by either tension or compression, depending on the direction of movement. Flexural stresses are induced in the slab under traffic loads. These stresses are greatly increased when the slab lifts off its base as a result of temperature or moisture gradient.

Another type of movement that may occur is differential settlement caused by the subbase or subgrade.

## TYPE OF JOINTS

### Longitudinal Joints

Longitudinal joints can be located between lanes or between the edge of the pavement and the shoulder. They are used to restrict the lateral and vertical movement of the joint and to relieve the warping stresses induced in the pavement by the temperature and moisture differentials between the top and bottom surfaces of the slab.

Tie bars that are usually 12.7 or 15.9 mm (0.5 or 0.625 in) in diameter are used in all states as well as in Europe (1, 2). They are effective in holding the slabs in contact and in the same vertical plane. Aggregate interlock provides the load transfer across the joint. When the lanes are constructed separately, a longitudinal construction joint is used.

The longitudinal edge-shoulder joint is relatively new in concrete pavements but has been receiving a great deal of attention and study in the past few years. A 1975 highway survey (3) shows a great deal of distress at this joint when asphalt shoulders are used, including a drop-off from the edge of the pavement that can be as great as 5.1 cm (2 in).

Proper sealing of longitudinal joints is not a major problem. If the joints are tied (all center joints and some edge joints), there is very little demand on the performance of the sealant. Consequently, the movement is rather small and the joint can be sealed by using hot-poured materials. Premolded seals can also be used if the joint is sawed. If, however, the joint is not tied—as, for example, when an asphalt shoulder is used—the horizontal and vertical movement becomes large. In such an instance, a low-modulus silicone sealant may be more effective (4).

### Transverse Contraction Joints

Contraction joints are designed to control random cracking attributable to warping, frictional stresses, load stresses, shrinkage, and thermal and moisture changes by providing a weakened plane in the concrete slab where the crack occurs. Unfortunately, not all joints crack when they are supposed to, and sometimes they are sealed before cracking. Tension in the sealant results when the joint is finally relieved. The first joints to crack tend to open wide, since they have to accommodate the movement of more than one slab. If they are sealed at this stage, the sealant tends to become highly compressed and even extruded in hot weather.

Besides horizontal movement caused by a change in temperature and moisture, the slab tends to curl because of differences in temperature and moisture between the top and bottom of the slab. The ends tend to lift up when the surface of the pavement is cooler than the bottom. The slab assumes a reverse curl when the surface is warmer than the bottom. The pavement is constantly under fatigue loading caused by traffic. When the top surface of the pavement is cooler than the bottom and the pavement ends are curled upward, traffic loads depressing the slab ends accentuate the fatigue-loading situation. Consequently, the sealant in a transverse joint is subjected to high adhesive and cohesive tensions as well as shearing stresses. The magnitudes of these stresses are dependent on the environment, the length of span, and other factors.

The type of sealant and the dimensions of the joint are designed to correspond to the expected movement in the pavement. Shearing stresses should be considered in the design of the seals. Faulting induces shear-type stresses in the sealant section. In field-molded sealants, this displacement increases the tensile stresses and in some instances doubles the strain on a joint sealant. According to Thornton (4),

> Preformed open cell seals cannot normally accommodate faulting in excess of 3.2 mm [0.125 in] without slipping on the joint face. They are not designed for a shearing type movement and the greater the degree of compression, the less the shearing movement that can be accommodated.

Sealant failures can generally be attributed not to deficiencies in the seal material but to poor joint designs (too narrow, too deep, or with too large a movement), which subject the sealants to excessive stresses (1).

## SIZE OF JOINT

In discussing the size of the joint, we should differentiate between field-molded and preformed seals. Tons (5), in his theoretical study of rectangular field-molded seals, showed that the greater the minimum width and the shallower the sealant in a joint, the less is the strain in the sealant.

Preformed seals are precompressed and inserted into the joint in the compressed state. As they attempt to return to normal shape, they exert a force against the joint wall, thus forming an effective seal. The seal must be exactly sized for its joint opening. The recommended working range of the preformed seal was suggested to be 30 percent of its initial width with a minimum 20 percent compression (1, 6).

According to the 1975 survey of practice (3), joints in concrete pavements are formed mainly by sawing. The width of the joint in reinforced and doweled pavements varies from 3.2 to 19.1 mm (0.125-0.75 in) with no correlation between width and slab length; the depth varies from 5.1 to 8.3 cm (2-3.25 in). The depth of the joint in plain concrete pavements is D/4, and the width varies from 3.2 to 9.6 mm (0.125-0.375 in). Obviously, more attention should be paid to the dimension of the joint.

## SLAB LENGTH

The opening and closing of a joint, and thus the stresses in the seal, are a direct function of the length of the slab between the joints. Long slabs result in larger openings than short slabs. It is prudent to use shorter slabs for the following reasons:

1. Because the joint will be narrower, incompressibles will slide more easily over it rather than getting embedded in the sealant.
2. There will be less movement and, therefore, smaller stresses in the sealant.
3. Continuity between adjacent spans will be improved, and this will result in an increase in load transfer through aggregate interlock.
4. Joint performance will be improved and spalling and blowups reduced (3).
5. Intermediate transverse cracks will be minimized or even eliminated.

Joint spacing in plain pavements in different states varies from 4.6 to 9.2 m (15-30 ft). Plain pavements with a joint spacing greater than 6.1 m (20 ft) show a marked loss in aggregate interlock, which increases the risk of faulting. These longer slabs also tend to develop midslab cracks. Since the cracks are not restrained by reinforcement, they tend to widen and spall more easily. Several states use a random repeated spacing of skewed joints: 4, 5.8, 5.5, 3.7 m (13, 19, 18, 12 ft).

For reinforced pavements, joint spacing varies from 9.1 to 24.4 m (30-80 ft). The percentage of reinforcement increases with an increase in joint spacing, but there is a net saving in the costs associated with the elimination of some of the joints. The optimal spacing, based on a 1975 survey of average cost of mesh reinforcement, dowels, and sawing and sealing the joints, is 12.1-15.2 m (40-50 ft). Although 12.1-15.2 m is the optimal spacing from a first-cost point of view, it might not be so in the long run. Slabs longer than 6.1 m (20 ft) crack. The cracks, while generally held tight by the reinforcement, tend to spall earlier than the joints. Pavements that have properly designed thicknesses and 4.6- to 6.1-m (15- to 20-ft) long slabs do not crack transversely between joints (3).

## SLAB THICKNESS

The design for the thickness of a concrete pavement is based either on serviceability criteria or on allowable stresses. For primary roads, a slab thickness of 22.9 or 25.4 cm (9 or 10 in) is generally required for reinforced and doweled pavements; 22.9 cm or more for doweled, plain pavements; and 20.3-33 cm (8-13 in) for plain, undoweled pavements. Increased slab thickness reduces deflections and improves the performance of the pavement.

When the surface of the pavement is cooler than the bottom, the slab tends to dish upward at the end to a degree determined by slab length. Truck traffic that passes over a typical contraction joint when the slabs are dished upward causes a repetitive vertical movement that creates a great potential for fatigue failure of a sealant. The vertical movement in a 22.9-cm undoweled slab with short joint spacing is small. It is at maximum when the truck is moving at a slow speed close to the edge of the pavement (7-9). A thicker slab would reduce deflections, but dowel bars on a stabilized base would achieve the same result more cost-effectively.

## TYPE OF SUBBASE

Three types of subbase are now generally used in highway construction: granular, cement stabilized, and asphalt stabilized. Stabilized subbases are, of course, more expensive, but they are stronger and more erosion resistant. They reduce pavement deflection and the migration of fines under the pavement. No matter what type of subbase is used, a well-drained subgrade must be included as part of the overall system.

Besides a reduction in the vertical deflection of the edge of the pavement, cement-treated subbases help to maintain more uniform joint openings as a result of high friction values between the subbase and the slab (10-12).

The erosion of the subbase is a factor that contributes to most of the distresses that occur at a joint. The top of the joint is normally sealed to prevent the intrusion of water and foreign material from the surface of the pavement. The bottom of the joint and the vertical edge are not sealed and therefore provide access for intrusion of material from the subbase and the shoulder. Gravity keeps the material intruding from the subbase at the bottom of the joint. This material prevents the joint from closing and thus induces shear stresses that cause spalling of the bottom and edge of the pavement. Blowup of the pavement could result if the spalling at the bottom of the joint becomes excessive.

A seven-year study of a pavement in Ohio indicates that bottom spalling is not a function of the type of subbase but of joint spacing. Compared with pavement sections that have 12.2-m (40-ft) spacing of joints, sections of pavement with 6.4-m (21-ft) spacing stand out as a group because of the mildness of spalling that occurs at the bottom irrespective of whether the subbase is granular or stabilized.

Spalling at the bottom of the contraction joints is a much more serious problem than surface spalling. The manner of construction of the normal contraction joint leaves a jagged edge at the bottom of the pavement that is much more conducive to spalling than the straight, sawed edges at the top of the pavement.

There may be a lesson to be learned from history. Submerged plane contraction joints were tried more than 25 years ago but were discontinued because they left a jagged crack in the pavement surface that spalled easily and was difficult to seal. The present method of contraction-joint construction may well be creating exactly the same problem in reverse—i.e., simply putting the spalling at the bottom of the pavement where it can't be seen. It is well worth considering using both the submerged plane contraction joint and the sawed joint at the surface. This design is used in the United Kingdom.

Faulting is another distress common in pavements. It is a function of repetitive heavy-truck loading and free water under the slab as well as the type of subbase. As NCHRP Report 56 (10) states, "Unless the conditions causing faulting are corrected, elevation differences between adjacent slabs usually become progressively greater. This contributes to the failure of joint seals through shearing action as joint faces move vertically."

Faulting is more common in undoweled pavements because dowels reduce live-load deflections. Stabilized bases provide more protection against faulting than granular bases because of less deflection of the pavement and less loose material that could be pumped under the approach slab.

## TYPE OF LOAD-TRANSFER DEVICE

Although various types of load-transfer devices have been used throughout the world, the round steel dowel has become the predominant method of load transfer. Two major problems remain, however: misalignment and corrosion.

Bryden (13) showed that a 12.7-mm (0.5-in) misalignment of one dowel caused cracking of the test slab.

Dowel corrosion causes a swelling of the bar and can be severe enough to freeze the joint. Frozen joints can be identified because the adjacent slabs usually develop one midslab crack. This will be a working crack, and evidence of corroded reinforcement will usually be noted.

Various corrosion-resistant coatings, such as Monel, nickel, and stainless steel, have been used with different degrees of success. Metallic coatings, however, are expensive. Most recent experience has been with plastic-coated dowels (8, 13, 14). Plastic coatings naturally vary on different experimental projects. One such coating is a two-layer coating of 0.1 mm (4 mils) of asphalt covered by 0.4 mm (17 mils) of polyethylene. The plastic-coated dowels show promise of excellent long-term performance.

## TEMPERATURE AND MOISTURE EFFECTS

Temperature is widely believed to be the primary factor that affects joint movement. There are actually four separate temperatures to be considered: air, pavement surface, midslab, and subgrade. However, since the moisture content of the pavement also affects slab movement, both temperature and moisture effects should be considered. Both are believed to have an effect on the curling of pavements as well as on longitudinal movements.

Several studies (6-8, 13, 15-18) have been conducted on the relation between temperature and longitudinal movement. Only a few studies take into account the effects of both temperature and moisture. Lang (15) has given an excellent summary of these factors. He recorded temperatures at six places in a 17.8-cm (7-in) slab and at five places in the subgrade and made moisture measurements at midslab and at three places in the subgrade.

Allen (19), in his work on pavement curl, concluded that the primary factor affecting curl was swell or shrinkage of the subgrade rather than temperature or moisture gradients throughout the slab.

However, the curl of pavements as measured by the deflection of slab ends has been reported by several states (8, 15). South Carolina has reported that, in the morning when the top of the slab was cool, deflections were five to six times as great as deflections on the same joints in the afternoon. New York and Ohio have reported the same conclusion.

In summary, however, even though engineers in every state are aware of moisture effects and the existence of pavement curl, the majority of states use the temperature range only as the design factor in determining slab length and the size of joint openings.

## PROPERTIES OF PAVEMENT MATERIALS

The thermal-expansion characteristics of concrete are important in anticipating changes in joint width. Concrete made with aggregates that are high in quartz or chert content exhibits more movement than concrete made of most limestones.

However, in joint resealing, joint spalling may be the major consideration. Joint spalling is affected not only by the coefficient of expansion but also by the tensile strength of the concrete. Tensile strength depends on the type of aggregate, the permeability and strength of the paste, and the pore and void characteristics of the mix.

Pavement growth also causes difficulties with resealing. Relief joints have to be cut in the pavement to prevent blowups or excessive pavement translation. Louisiana investigators (18) have concluded that, in their area, pavement growth is related mainly to incompressibles in the joint. However, expansive aggregates are used in some parts of the country. In New York State, it was found many years ago that combining certain aggregates with high-alkali cements resulted in the formation of a gel around the aggregate particles, which caused the pavement to expand.

## CONCLUSIONS

There is a wealth of information available on the various pavement design features that affect joint-seal performance. Because different designs are used in various states, it becomes difficult to draw concise conclusions. Several facts, however, do stand out.

1. Most states have had the best performance from pavement in which only contraction joints are used. Skewed joints are being used successfully in many areas.
2. Joint size can be related to slab length and temperature range.
3. Slab lengths are progressively shortening because of the presence of midslab cracks in the longer slabs. Midslab cracks are usually not seen in slabs 6.4 m (21 ft) or less in length.
4. Although many different types of load-transfer devices have been tried, the standard dowel is still the most commonly used and is quite successful. Plastic-coated dowels have performed well in preventing dowel corrosion.
5. Treated subbases have been effective in reducing pavement curl and midslab cracking in longer slabs.
6. Although the effect of moisture is acknowledged, it is generally ignored in design. The design of slab length is based on temperature range.
7. Material properties have a marked effect on the service life of a pavement. Angular aggregates give better aggregate interlock. The tensile and shear strength of the aggregate and paste affect the amount of spalling in the pavement.

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# Pavement Restoration Measures to Precede Joint Resealing

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**Various methods of rehabilitating jointed concrete pavement are discussed, based on the experience of the Georgia Department of Transportation. Special emphasis is given to techniques that may be required before joints are resealed. The measures discussed are stabilizing moving**