# Joint Design for Concrete Highway and Street Pavements

INTRODUCTION ............................................................................................................. 2
EFFECT OF JOINT DESIGN AND SLAB SUPPORT ......................................................... 2
TRANSVERSE CONTRACTION JOINTS ........................................................................ 4
  Joint interval ............................................................................................................. 4
  Forming Contraction Joints ....................................................................................... 4
  Load Transfer .......................................................................................................... 5
  Aggregate Intertock .................................................................................................. 5
  Skewed Joints .......................................................................................................... 6
  Randomized Joints ................................................................................................... 6
  Stabilized Subbases ................................................................................................. 7
  Doweled Contraction Joints ...................................................................................... 9
  Contraction Joint Sealant Reservoir ....................................................................... 11
TRANSVERSE CONSTRUCTION JOINTS ................................................................... 12
TRANSVERSE EXPANSION JOINTS ......................................................................... 14
LONGITUDINAL JOINTS .............................................................................................. 14
SUMMARY .................................................................................................................. 17
REFERENCES ............................................................................................................ 17
INTRODUCTION

Jointing systems for concrete pavement are designed to ensure the structural capacity and riding quality of the pavement at the lowest annual cost. Joints control the transverse and longitudinal cracking that results from restrained contraction and the combined effects of restrained warping and traffic loads. They divide the pavement into practical construction increments, delineate traffic lanes, and accommodate slab movements. They also provide some load transfer between slabs.

Joint design has been developed from:
- Theoretical studies of concrete slab behavior \(^{(1,2,3,4)}\)
- Model and full-scale laboratory tests \(^{(5,6,7)}\)
- Experimental pavements subject to controlled vehicular traffic \(^{(11,9,10)}\)
- Performance of special experimental jointing projects \(^{(11)}\)

A careful study of the performance of pavements subject to the same traffic and similar environmental conditions as the proposed pavement is of great value and should be reflected in the design of slab dimensions and jointing details.

EFFECT OF JOINT DESIGN AND SLAB SUPPORT

Observing the slab behavior of unjointed plain pavements in service for many years can illustrate how joints are used to control cracking.

To attain adequate workability for placing and finishing concrete in highway pavements, 50% to 100% more mixing water is used than is needed to hydrate the cement. As the concrete consolidates and hardens, most of the excess water leaves the pavement and the concrete occupies somewhat less volume. Heat of hydration and pavement temperature normally peak a short time after final set. Temperature of the concrete declines due to both reduced hydration activity and lower air temperature during the first night of pavement life.

Contraction of the pavement from these sources is resisted by subgrade friction and tensile stresses are created. During the life of the unjointed plain pavement, these tensile stresses cause a transverse crack pattern like that shown in Fig. 1. Spacing of the initial cracks varies from about 40 to 150 ft. depending on concrete properties, point-to-point variations in subgrade friction, and climatic conditions during and after placement. The occurrence and interval of the early cracks is important. Their additional width and subsequent movement should be taken into consideration for proper joint sealing.

![Fig. 1. Initial cracking in unjointed pavement.](image)

After the concrete pavement hardens, there are stresses due to temperature and moisture gradients in the concrete. At and near the bottom of the pavement, daily changes in temperature and moisture content are small. The exposed top surface, however, undergoes fairly large daily variations in temperature and moisture content. At night the top of the pavement is usually cooler than the bottom, thus the top tends to contract and warp the slab edges upward. This tendency is resisted by the weight of the slab, creating tensile stresses in the top of the slab and compressive stresses in the bottom. During the day, the stress pattern is reversed.

Differences in moisture content between the top and bottom of a pavement produce similar but less severe stresses—lower moisture contents causing contraction and higher moisture contents causing expansion. The influence of

\* Superscript numbers designate references listed at the back of this publication.
restrained warping stresses on joint design is complicated because moisture and temperature differences often produce opposite effects. When the top of the slab is warmer than the bottom, causing the top to expand, the bottom of the slab will usually have a higher moisture content causing it to expand. Hence, the amount of restrained warping stress will be less than stress due to temperature differences alone.

Because of these opposing factors, and others, warping stresses computed from formulas that take account only of temperature gradients are higher than actual measured values. Warping stresses measured on one research project were only one-half the values computed on the basis of temperature.

When other calculations of stresses based on formulas that take account only of temperature gradient are compared to flexural strengths obtained at 8, 16, and 24 hours, indications are that there should be transverse cracks at spacings of 15 to 20 ft. or less during the first night of pavement life. Since this cracking does not normally happen, it is another demonstration that calculations based on temperature gradients alone do not produce values that agree with field experience.

In plain pavements with joint spacing of 15 to 25 ft., cracks do not generally form beneath all joints for a few weeks to several months after the pavement is opened to traffic. In pavements where distributed steel is used between joints spaced at 40 ft. or more, intermediate transverse cracks between joints may not develop for from several months to several years after the pavements are opened to traffic. When intermediate cracks do occur, they are spaced at about 15 to 25 ft. and they are the result of the combined effect of restrained warping and load stresses.

Since restrained warping is complex and repetitive loads compound the problem, plain pavement joint design is based on the performance of unjointed pavements. This performance shows that restrained warping in combination with loads will cause additional transverse cracks between the initial contraction cracks shown in Fig. 1 and that a longitudinal crack will form along the approximate centerline of pavements with two lanes of traffic. The resulting crack pattern is shown in Fig. 2. The interval between transverse cracks is normally about 15 to 30 ft., depending on factors such as shrinkage properties of the concrete, subbase and subgrade conditions, and climatic conditions.

In jointed pavements the joint interval is either designed to provide for each expected crack at 15- to 25-ft. intervals (plain slab design) or spaced at greater intervals with adequate distributed steel in each panel (reinforced slab design) to provide good performance at the intermediate cracks.

Some type of load transfer is required to minimize deflection at the joint and prevent faulting. (See the section, "Load Transfer.")

In plain pavements with 15 to 20 ft. joint spacing and narrow joint openings, load transfer across transverse joints provided by the interlocking action of aggregate particles at the face of the joint is adequate for projects carrying low volumes of trucks.

Skewed, randomized joints provide adequate joint performance and riding quality over a longer period of time and consistently superior pavement performance.

Use of a stabilized subbase, such as cement-treated subbase, is another way to improve performance of plain pavements with closely spaced aggregate interlock joints. Cement-treated subbase is a widely used, economical way of achieving an adequate structural section and providing an all-weather working platform for the paving contractor. However, the main function of stabilized subbases with respect to joint design is to reduce potential joint deflection. Dowels are required for additional load transfer to prevent faulting on plain pavements with granular subbases and 15 to 20 ft. joints when the two-way average truck traffic during the design life is estimated to be greater than about 300. This minimum average daily truck traffic may be increased if the subgrade consists of free-draining A-1, A-2, or A-3

* Trucks include single units with more than four tires and all combinations.
materials. Also, under certain climatic conditions where cement-treated subbases have been used, undoweled pavements have given acceptable performance under greater traffic. The need for dowel bars for a specific project should be determined by an evaluation of loading conditions, soil support, and performance of existing pavements under similar conditions. Untreated granular subbases, stabilized subbases, or dowels are not required on city streets and highways carrying light-to-moderate volumes of trucks. Where the volume of truck traffic and other conditions that cause mud-pumping are not present, subbases are not required for added support at aggregate interlock joints. For reinforced jointed pavements with longer joint spacings, dowels are required in all transverse joints because these joints are wider making load transfer by aggregate interlock ineffective. As with plain slab designs, stabilized subbases will further improve joint performance. Based on performance of reinforced jointed pavements, it is desirable to limit joint spacing to about 40 ft. For longer joint spacings, design of joint sealants and sealant reservoirs is much more critical than for short panels because of greater fluctuations in joint width.

Concrete pavement joints fall within two general classifications: transverse and longitudinal. They can be further classified as contraction, construction, and expansion joints. Discussion of each type follows:

**TRANSVERSE CONTRACTION JOINTS**

Of all the joints and joint locations in a concrete pavement, the spacing and dimensional design of transverse contraction joints is of most concern to the designer. Proper transverse joint design for both plain and reinforced pavements is essential to:

1. Determine the joint interval that will control cracks created by initial concrete shrinkage and restrained warping stress
2. Provide load transfer across joints to prevent faulting
3. Provide an adequate receptacle for a sealant that will exclude foreign materials damaging to the pavement or underlying components

**Joint interval**

To control cracking, the proper interval between contraction joints in plain pavements depends on shrinkage properties of the concrete, subbase or subgrade friction characteristics, slab thickness, and properties of the joint sealant. A maximum spacing of 20 ft. is recommended. Data from a large number of surveys, however, show substantial variations in joint spacing; therefore, local service records are the best guide for establishing a joint spacing that will effectively control transverse cracking. As mentioned, it is desirable to limit joint spacing of reinforced jointed pavements to about 40 ft. for best performance.

**Forming Contraction Joints**

Contraction joints can be constructed by sawing the hardened slab at the proper time or by placing an insert or groove in the slab surface while the concrete is plastic. To induce controlled crack formation, the weakened plane should be at least one-fourth of the slab depth. Inserts and grooving tools should be of minimum practical thickness so that excessive disturbance of the concrete is avoided. Sawed grooves can be made when the concrete strength is sufficient to enable the saw to cut through the concrete with a minimum of raveling or aggregate pullouts. The time of sawing is very important and usually ranges from between 4 hours after placing to over 8 hours, depending on weather conditions and other factors. All joints should be sawed in succession. If possible they should be sawed while the pavement is under compression to prevent the slab from cracking ahead of the saw. In cases where exceptionally hard aggregates are used, it may be more economical to form transverse contraction and longitudinal joints at the time of construction. A groove is made in the plastic concrete with a T-bar or other device that will form the groove in proper vertical and horizontal alignment. Preformed filler material should be inserted in the groove so that the top edge of the strip is flush with the pavement surface or slightly below. The surface of the pavement is then floated and checked with a straightedge. Preformed filler materials such as those specified in ASTM D994 (AASHTO M33), ASTM D1751 (AASHTO M213) and ASTM D2828 are used. After curing of the pavement, the top portion of the insert can be sawed out to form a sealant reservoir. When this is done, properties of the filler should be such that it will not gum up the saw blade, but it can be readily cut and disintegrated under the action of the saw. It is important that all preformed filler material be removed from the sides of the cut. On residential city streets with short joint spacing it is common practice to leave the preformed insert flush with the pavement surface.

* Pumping of concrete pavements as well as expansive subgrades and frost action are discussed in *Subgrades and Subbases for Concrete Pavements*, published by Portland Cement Association.
Sealing materials have been applied directly into 1/8- to 1/4-in.-wide contraction joints used with short joint spacing (Fig. 3). When a wider joint-sealant reservoir is needed, a double saw cut is recommended to widen the top of the joint, thus providing a better shape factor for the sealant material. This reservoir can be formed by making a second-stage cut no earlier than 72 hours after the concrete is placed or sawing simultaneously with the initial saw cut by placing blades of different sizes on the mandrel. Suggested reservoir dimensions, sealant properties, and application are discussed under “Contraction Joint Sealant Reservoir” below.

With short joint spacing, plastic tape inserts have also been used to control cracking in some areas. These joints are not sealed. To obtain best performance of plastic tape joints it is necessary to take the following steps:

Use plastic tape of about 13-mil thickness.
Place the tape by automatic machine vertically and no deeper than 1/8 in. below the pavement surface. Some tension is needed on the tape during installation.
Use tape with a width of at least 1/4 of the slab thickness.

If plastic tape joints are used in combination with tape inserts in the longitudinal joints, special care must be taken where the two tapes cross to prevent corner spalls. The transverse tape joints can be formed perpendicular to the longitudinal joint or they can be skewed. Tape for the longitudinal joint is placed first and then severed by an attachment on the transverse tape installer as it moves across the slab.

![Fig. 3. Contraction joint.](Image)

**Load Transfer**

Load transfer across the transverse joint is developed by one of the following:

1. Aggregate interlock—the interlocking action of aggregate particles at the faces of the joint
2. Supplementing subgrade strength by the addition of a stabilized subbase
3. The addition of mechanical devices across the joint, such as dowel bars

When load transfer is adequate, load stresses and deflections at the joint are less than they are at a free edge. Faulting should be prevented to maintain pavement riding quality.

**Aggregate In tertock**

The irregular faces of the cracks that form below the groove or saw cleft provide adequate aggregate interlock for load transfer when short joint spacings are used and truck volume is not excessive. As load transfer effectiveness varies inversely with joint opening, the shortest practical slab length is desirable. Also, to maintain small joint openings, expansion joints are omitted except at fixed objects and unsymmetrical intersections.

Laboratory studies using the load application equipment shown in Fig. 4 have been made of the effectiveness of aggregate interlock as a load transfer method. The load interval and frequency simulated the interval and frequency occurring under field conditions. Splitting of the slab face and the subsequent joint opening were controlled by jacks. (Joint openings were kept between 0.015 and 0.085 in.) The studies showed that joint effectiveness or ability of one slab to transfer load to the adjacent slab—

- Decreased with increasing joint opening
- Improved with subbase strength
- Increased with the angularity of the coarse aggregate

\[
E = \frac{2d' \times 100}{d + d'}
\]

where \(d\) is the deflection of the loaded side of the joint and \(d'\) is the deflection of the adjacent side.

©Portland Cement Association 1975
Effectiveness data for 0.035-in. joint widths and 7- and 9-in. slabs on different types of support at the start of testing and after 1 million load applications are given in Table 1. Fig. 8 compares joint effectiveness and load applications for a 9-in. slab with a 0.065-in. joint opening.

Field measurements were made on actual pavements in service. The effectiveness of joints measured in the field was greater than those in the laboratory.\(^5\)

Fig. 4. Loading arrangement for load-transfer studies.

As mentioned, aggregate interlock alone will furnish enough load transfer to give good joint performance for lighter trafficked roads and streets. To ensure the best possible load transfer and the least loss in effectiveness of these joints due to traffic loads, joint intervals should be kept low—close to 15 ft.; foundation support should be reasonably uniform; and concrete aggregates should be sound and hard. There are many examples in many states of residential and collector city streets and lighter trafficked highways where the only load transfer across joints is by aggregate interlock. Where highway truck traffic is more than about 300 trucks per day in both directions,\(^*\) it is necessary to improve load transfer with the use of stabilized subbases or dowels, or both, to reduce deflections and prevent faulting.

**Skewed Joints**

Skewed transverse joints will improve joint performance and extend the life of plain pavements. A typical skew design is shown in Fig. 5. The joint is skewed sufficiently so that wheel loads of each axle cross the joint one at a time and the obtuse angle at the outside pavement edge is ahead of the joint in the direction of traffic because that corner receives the greatest impact from the sudden application of wheel loads. Skewed joints have these advantages:

1. Reduced deflection and stress at joints, thereby increasing the load-carrying capacity of the slab and extending pavement life
2. Less impact reaction in vehicles as they cross the joints, and hence a smoother ride if the joints have some roughness

Skewed joints with dowels are used in both plain and reinforced pavements.

Fig. 5. Skewed joints.

**Randomized Joints**

\(^*\) This minimum average daily truck traffic may be increased if the subgrade consists of free-draining A-1, A-2, or A-3 materials. Also, under certain climatic conditions where cement-treated subbases have been used, undoweled pavements have given acceptable performance under greater traffic.
A further refinement for improving performance of plain pavements is to use skewed joints at randomized or irregular spacings. The first design, developed in California, was for 13-19-18-12-ft. intervals. Randomized spacing patterns prevent rhythmic or resonant responses in vehicles moving at normal rural expressway speeds. Research at a motor vehicle proving ground indicated that slab spacing patterns of 7.5 ft. should be avoided. It is also essential to keep the maximum joint spacing small enough to control transverse cracking and to keep joint movement low. Other patterns that have been used include 9-10-13-14 ft. (Washington) and 17-23-22-16 (Georgia). Randomization and skewing of joints minimize the effect of any roughness at the joints. Thus randomization and skewing improve the riding qualities of pavements if the slabs have curled up at transverse joints or if some faulting has developed.

Skewed and randomized joints are recommended in all plain (not reinforced) pavements.

**Stabilized Subbases**

As mentioned, stabilized subbases are another way to improve the performance of plain and reinforced jointed pavements. Stabilized subbases reduce potential joint deflection, improve and maintain longer the effectiveness of the joint under repetitive loads, and provide an all-weather working platform for the paving contractor.

To serve these functions, cement-treated subbases are made with granular materials in AASHTO Soil Classification Groups A-1, A-2-4, A-2-5, and A-3. These materials contain not more than 35% passing the No. 200 sieve, have a plasticity index of 10 or less, and may be either pit-run or manufactured materials.

When cement-treated subbases meeting recommended standards are placed on low-strength subgrade, a marked increase in slab support, as measured by $k$ value, is obtained over that obtained with untreated granular subbases. This increase in support is valuable at joint areas. If plate bearing data from field test sections are not available, an estimate of the $k$ value of granular subbases and cement-treated granular subbases can be determined from Figs. 6 and 7. For example, the $k$ value of a 6-in. cement-treated subbase on a clay subgrade with a $k$ of 100 is 400 pci as compared to a $k$ of only 140 pci when an untreated granular subbase is used.

![Fig. 6. Effect of untreated granular subbase thickness on $k$ value.](image)

---

* Additional information on gradation requirements and laboratory tests for mix design are discussed in Subgrades and Subbases for Concrete Pavements, published by Portland Cement Association.

** Westergaard’s modulus of subgrade reaction, $k$, is equal to the load in pounds per square inch on a loaded area (usually a 30in-diameter plate) divided by the deflection in inches for that load or the total load in pounds divided by the total volume displaced in cubic inches. $k$ values are expressed in pounds per square inch per inch (psi/in.) or as pounds per cubic inch (pci). Details of equipment and procedures are given in ASTM D 1195 and D 1196. $k$ values from the nonrepetitive plate-load test (ASTM D 1196) are commonly used for pavement design purposes.
Increased subgrade support provides better joint performance. Joint efficiency for aggregate interlock and other joint types on both untreated and cement-treated subbases has been studied in the laboratory.\(^5,6,7\) Aggregate interlock effectiveness was measured by comparing deflections at the loaded and unloaded edges of joints in full-scale test slabs (Fig. 4).\(^7\) Deflections were measured at the start of each test series and again after various repetitions of 9-kip loads had been applied to simulate a wheel load moving over the joint at 30 mph.

Table 1 shows joint effectiveness values for a 0.035-in. wide joint on clay subgrade, untreated granular subbase, and cement-treated subbase. It can be seen that cement-treated subbase adds considerably to joint performance.

Fig. 8 shows that the loss of load transfer effectiveness of cement-treated subbases occurs at a slow rate and even after one million load applications the joint effectiveness remains at a value over 50%. The relative performance of cement-treated and untreated granular subbases indicates that a cement-treated subbase will provide a greater degree of load transfer throughout the pavement service life.

The data in Table 1 and Fig. 8 are relevant to pavements carrying large volumes of trucks. Hence, the test results should not be construed as showing that subbases, untreated or cement treated, are required on city streets and highways carrying light-to-moderate truck traffic. Where the volume of truck traffic is not enough to cause mudpumping, a subbase is not required for added support at aggregate interlock joints.

<table>
<thead>
<tr>
<th>Slab depth, in.</th>
<th>Slab support</th>
<th>Joint effectiveness(^1) at 0.035-in. joint width, %</th>
<th>Initial</th>
<th>After 1 million loads</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Subgrade</td>
<td>89</td>
<td>90</td>
<td>5</td>
</tr>
<tr>
<td>9</td>
<td>Subgrade</td>
<td>89</td>
<td>93</td>
<td>29</td>
</tr>
<tr>
<td>7</td>
<td>Granular subbase</td>
<td>145</td>
<td>88</td>
<td>9</td>
</tr>
<tr>
<td>9</td>
<td>Granular subbase</td>
<td>145</td>
<td>96</td>
<td>52</td>
</tr>
<tr>
<td>9</td>
<td>Cement-treated</td>
<td>145</td>
<td>98</td>
<td>77</td>
</tr>
</tbody>
</table>

\(^1\) Joint effectiveness is determined by \(E = \frac{2d}{(d + d')} \times 100\), where \(d\) is deflection of the loaded side of the joint and \(d'\) is deflection of the adjacent side.
Dowelled Contraction Joints

As discussed, dowels can be used to supplement the load transfer produced by aggregate interlock and stabilized subbases. Placed at middepth in the slab, they resist shear as loads cross the joint and thus help to reduce deflections and stresses at the joint. The dowels should be plain round bars equivalent to ASTM A615 or CSA G30.12. Before delivery to the jobsite, at least one-half of each bar should be covered with one coat of lead or tar paint. Dowels should be able to move longitudinally in their slot to allow free joint movement from expansion or contraction of the concrete and to improve joint effectiveness. Recommended dowel dimension and spacings are given in Table 2. Diameters and embedments are based on research reported by Teller and Cashell of the Federal Highway Administration.

Table 2. Dowel Size

<table>
<thead>
<tr>
<th>Slab depth, in.</th>
<th>Dowel diameter, in.</th>
<th>Dowel embedment, in.</th>
<th>Total dowel length, in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>5/8</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>6</td>
<td>3/4</td>
<td>6</td>
<td>14</td>
</tr>
<tr>
<td>7</td>
<td>7/8</td>
<td>6</td>
<td>14</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>6</td>
<td>14</td>
</tr>
<tr>
<td>9</td>
<td>1-1/8</td>
<td>7</td>
<td>16</td>
</tr>
<tr>
<td>10</td>
<td>1-1/4</td>
<td>7-1/2</td>
<td>18</td>
</tr>
<tr>
<td>11</td>
<td>1-3/8</td>
<td>8</td>
<td>18</td>
</tr>
<tr>
<td>12</td>
<td>1-1/2</td>
<td>9</td>
<td>20</td>
</tr>
</tbody>
</table>

1 All dowels spaced at 12-in. centers.
2 On each side of joint.
3 Allowance made for joint openings and for minor errors in positioning dowels.

In reinforced pavements with distributed steel (meshdowel design), the joints are usually spaced too far apart for any benefit from aggregate interlock. Therefore, load transfer at these joints is provided by the subbase and dowels (Fig. 10). The integrity and serviceability of the intermediate random cracks in reinforced slabs is provided by distributed steel. The distributed steel is designed to keep intermediate cracks from opening, thus ensuring aggregate interlock and preventing infiltration at the crack. Since dowels are designed to slip and permit slab movement in the longitudinal direction, they must be properly aligned parallel to pavement surface and centerline.

* Patented or proprietary load-transfer devices are available and may be used instead of dowels. Some have merit if properly installed at correct spacings. This information sheet is confined to dowels made of smooth round steel bars.
** Formulas for computing distributed steel and tables giving sizes and spacing of steel are given in Distributed Steel for Concrete Pavements, published by Portland Cement Association.
Corrosion of steel dowels has occurred in some areas where salt and calcium chloride deicers are used. Corrosion, accelerated by penetration of deicer brine to the dowels, can cause dowel seizure and prevent movement at the joint. This can result in blowups and spalling at the locked joint, intermediate cracks, or adjoining joints since a locked joint creates a slab twice as long as was designed and intermediate cracks may occur. Failure of the reinforcing can occur at the intermediate cracks because of the high tensile stress in the steel. Also, joint openings at other joints will be larger than anticipated.

Stainless-steel-clad dowels have been used for a number of years in at least one state to protect against corrosion in areas adjacent to the ocean and subject to the action of salt water or salt-laden atmosphere. These dowels are corrosion-resistant and do not require greasing on the job to prevent bond with the concrete. Laboratory studies have been made to identify low-cost dowel coatings that will prevent corrosion while inhibiting bond with the concrete. Suggested specifications for coated dowel bars have been developed based on these and other studies.

Coated dowel bars have been used in many projects and their performance to date has been good. Their use promotes good joint performance in harsh environments. Some coated dowel bars are free sliding, which eliminates the need for applying lubricants in the field to reduce friction.

When dowels are used it is essential to adequately consolidate the plastic concrete around and beneath them. The traditional method of placing dowels to ensure their stability has been by means of fabricated-steel supporting units or baskets. These units must be sturdy and so placed that the dowels are properly aligned and parallel to the centerline. Skewed assemblies are used with skewed doweled joints.

Several states and other countries have used a vibratory dowel placer that eliminates the need for a supporting unit. A survey of projects in several states showed that the performance was excellent in nearly all instances and the alignment of the dowels was equal or superior to those placed on baskets.
As mentioned, proper dowel alignment is important, but a reasonable tolerance is permissible. One study has shown that a maximum vertical or oblique misalignment of 1/4 in. and a horizontal misalignment of 3/4 in. appear to be tolerable. A Federal Highway Administration Notice recommends: "Dowels shall be parallel to the centerline and surface of the slab. Tolerance of this placement shall be with ±1/4 in. per 18-in. dowel."

**Contraction Joint Sealant Reservoir**

Joint movement in pavements is influenced by factors such as volume change characteristics of the concrete, slab temperature range, friction between the slab and subbase or subgrade, and slab length. It is not easy to predict this movement, and because of the variables involved, actual movements often do not agree with calculated values and are not uniform at all joints. Because of subgrade and end restraints, changes in joint width are less than would be predicted by mathematical use of a coefficient of expansion.\(^{(16)}\)

The sealant used in the joints must be capable of withstanding repeated extension and compression as the pavement expands and contracts with temperature and moisture changes. Sealants can be classified as field-molded and preformed. Field-molded sealants are those applied in liquid or semiliquid form that then assume the shape of the sealant reservoir. Preformed sealants are shaped during manufacture.

In order to maintain an effective field-molded seal, the sealant reservoir must have the proper shape factor (depth-to-width ratio). Within the practical limitations of minimum joint depth, the reservoir should be as nearly square as possible. This means that a sealant reservoir normally must be formed by increasing the width and reducing the depth of the top portion of the joint to hold the sealant. For narrow joints with close joint spacing, the reservoir can be formed by inserting a cord or other material to a predetermined depth to define the reservoir. This method minimizes the amount of joint sealant required. The same cord can be used to cure the joint faces and keep out foreign material by placing it at the pavement surface when the joint is formed and then embedding it deeper when the joint is sealed. The part of the total slab movement that extends or compresses the sealant also increases or decreases the width of the joint after the sealant is installed. The closer the sealant installation temperature is to the mean annual pavement temperature, the less will be the strain on the sealant in service. However, since the tension condition as the joint opens from a reduction in temperature is the most critical in sealant behavior, joint sealants installed somewhat below the mean temperature can be expected to perform best.\(^{(17)}\)

Table 3 lists suggested depths and widths for sealant reservoirs in transverse joints. These are for field-molded sealants, such as those meeting current AASHTO, ASTM, and federal specifications. AASHTO M 173, ASTM D1190, and Federal Specifications SS-S-001401 include hot-applied thermoplastic asphalt-rubber compounds. Upgraded rubberasphalt sealants as well as polymer-type, hot-poured elastomeric sealants meeting upgraded requirements of SS-S-1401 are also available. Cold-poured, thermosetting, chemically curing elastomers, usually of two components that are mixed on the project, generally meet ASTM D1850. These include polysulfide and eurethane sealants. The allowable ranges of extension and compression can be found in Reference 17.

In general, sealant reservoir dimensions similar to those in Table 3 are indicated based on joint performance. Reservoir dimensions for a particular project should reflect sealant properties and field performance of sealants and pavements similar to the project being designed. Liquid sealant manufacturers generally publish aids for selecting reservoir dimensions to suit their product.

**Table 3. Contraction Joint Reservoir - Dimensions for Field-Molded (Poured) Sealants**

<table>
<thead>
<tr>
<th>Joint spacing, ft.</th>
<th>Sealing reservoir shape</th>
<th>Width, in.</th>
<th>Depth, in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 or less</td>
<td>1/4</td>
<td>1/2 minimum</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>3/8</td>
<td>1/2 minimum</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>1/2</td>
<td>1/2 minimum</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>5/8</td>
<td>5/8</td>
<td></td>
</tr>
</tbody>
</table>

Prior to sealing, the joint surfaces must be clean and free of curing compound, residue, laitance, and any other foreign material. Cleaning can be done by water or compressed air, wire brushing, sandblasting, or high-pressure-water blast, depending on the joint surface condition and sealant manufacturer's recommendations. Proper cleaning is essential in order to obtain a joint surface that will not impair bond or adhesion with the field-molded sealant. The surfaces should be dry when the sealant is placed. With field-molded sealants a stiff self-adhering strip, coated paper, or metal foil is apphed to the bottom of the sealant space to break the bond between the sealant and bottom of the reservoir (Fig. 11). The bond breaker also supports the sealant so that it does not sag into the joint. Frequently, a cord or rope is used as a bond breaker in the reservoir. In that case, the reservoir must be deeper by an amount equal to the cord diameter so the proper shape factor is maintained for the sealant. The joints should be filled to 1/4 in. below flush with the pavement surface ± 1/16 in.
Preformed seals are compartmentalized or cellular elastomeric devices that function between the joint faces in a compressed condition at all times. The preformed compression seals must remain compressed approximately 15% at maximum joint opening to maintain sufficient contact pressure for a good joint seal and to resist displacement, and generally not more than 55% at maximum closing of the pavement joint to prevent overcompression. Required widths for preformed seals take into account the specified compression range, installation temperature, width of the formed opening, and expected slab movement.

The joint and seal widths given in Table 4 are suitable for many preformed sealants. The dimensions should be interpreted in relation to local environmental conditions and the service record of joints under similar service conditions. For specific products, seal size recommendations and availability can be obtained from the manufacturer or supplier.

Table 4. Joint and Sealant Width for Preformed Compression Seals

<table>
<thead>
<tr>
<th>Joint spacing, ft.</th>
<th>Joint width, in.</th>
<th>Sealant width, in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 or less</td>
<td>1/4</td>
<td>7/16</td>
</tr>
<tr>
<td>30</td>
<td>3/8</td>
<td>5/8</td>
</tr>
<tr>
<td>40</td>
<td>7/16</td>
<td>3/4</td>
</tr>
<tr>
<td>50</td>
<td>1/2</td>
<td>7/8</td>
</tr>
</tbody>
</table>

Standard specifications for preformed sealants are AASHTO M 220 and ASTM D 2628.

**TRANVERSE CONSTRUCTION JOINTS**

Transverse construction joints are necessary for planned interruptions such as at the end of each day's run, at leave-outs for bridges and intersections, and where emergency interruptions suspend operations for 30 minutes or more.

Fig. 12 shows typical details for planned and emergency construction joints where one or more abutting lanes of a roadway are constructed separately from the adjoining lanes. Planned construction joints, such as used at the end of a day's run, are installed at normal joint locations. They are butt-type joints with dowels since there is no aggregate interlock to provide load transfer. Dowel size and spacing are the same as given in Table 2. To perform properly, the dowel ends extending through the butt joint must be lubricated before paving is resumed if they were not precoated to prevent corrosion and excessive bond.
If an emergency construction joint occurs at or near the location of a planned contraction joint, a butt-type joint with dowels is recommended. If the emergency construction joint occurs in the middle third of the normal joint interval, a keyed joint with tiebars should be used as in Fig. 12. This is necessary to prevent opening of the joint, causing sympathetic cracking in the adjacent lane. Either deformed bars or tiebolts can be used to tie the emergency joint together. Tiebar dimensions and spacings are given in Table 5. (Tiebars are also discussed under "Longitudinal Joints.")

Fig. 12 also shows typical transverse construction joint details for full-width paving. Since both planned and emergency construction joints extend across all lanes being paved, it is not necessary to install tied keyway joints for emergency stoppages between normally spaced transverse joints. Load transfer is needed, however, and tied keyway joints are often used because doweled butt joints are more costly. The keyway provides the load transfer and the deformed tiebar or tiebolt keeps the joint closed to ensure joint effectiveness.

Table 5. Tiebar Dimensions

<table>
<thead>
<tr>
<th>Slab depth</th>
<th>Tiebar sizes</th>
<th>12.5 ft. or less</th>
<th>16 ft.</th>
<th>25 ft.</th>
<th>30 ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>in.</td>
<td>in.</td>
<td>in.</td>
<td>in.</td>
<td>in.</td>
<td>in.</td>
</tr>
<tr>
<td>5</td>
<td>1/2X30</td>
<td>30</td>
<td>30</td>
<td>25</td>
<td>21</td>
</tr>
<tr>
<td>5-1/2</td>
<td>1/2X30</td>
<td>30</td>
<td>30</td>
<td>23</td>
<td>19</td>
</tr>
<tr>
<td>6</td>
<td>1/2X30</td>
<td>30</td>
<td>30</td>
<td>21</td>
<td>17</td>
</tr>
<tr>
<td>6-1/2</td>
<td>1/2X30</td>
<td>30</td>
<td>30</td>
<td>19</td>
<td>16</td>
</tr>
<tr>
<td>7</td>
<td>1/2X30</td>
<td>30</td>
<td>28</td>
<td>18</td>
<td>15</td>
</tr>
<tr>
<td>7-1/2</td>
<td>1/2X30</td>
<td>30</td>
<td>26</td>
<td>17</td>
<td>14</td>
</tr>
<tr>
<td>8</td>
<td>1/2X30</td>
<td>30</td>
<td>25</td>
<td>16</td>
<td>13</td>
</tr>
<tr>
<td>8-1/2</td>
<td>1/2X30</td>
<td>30</td>
<td>23</td>
<td>15</td>
<td>12</td>
</tr>
<tr>
<td>9</td>
<td>5/8X30</td>
<td>30</td>
<td>30</td>
<td>22</td>
<td>18</td>
</tr>
<tr>
<td>9-1/2</td>
<td>5/8X30</td>
<td>30</td>
<td>30</td>
<td>20</td>
<td>17</td>
</tr>
<tr>
<td>10</td>
<td>5/8X30</td>
<td>30</td>
<td>30</td>
<td>19</td>
<td>16</td>
</tr>
<tr>
<td>10-1/2</td>
<td>5/8X30</td>
<td>30</td>
<td>29</td>
<td>18</td>
<td>15</td>
</tr>
<tr>
<td>11</td>
<td>5/8X30</td>
<td>30</td>
<td>28</td>
<td>18</td>
<td>15</td>
</tr>
<tr>
<td>11-1/2</td>
<td>5/8X30</td>
<td>30</td>
<td>27</td>
<td>17</td>
<td>14</td>
</tr>
<tr>
<td>12</td>
<td>5/8X30</td>
<td>30</td>
<td>25</td>
<td>16</td>
<td>13</td>
</tr>
</tbody>
</table>

Transverse construction joints falling at planned locations for contraction or expansion joints are built and sealed to conform with the specifications for those joints. As shown in Fig. 12, the initial cut at the location of a planned contraction joint need only be 1 in. deep. A 1-in.-deep saw cut is also made and sealed for the emergency (tied and keyed) joint but a square sealant shape factor is not needed (Fig. 12).
TRANSVERSE EXPANSION JOINTS

When transverse contraction joints are closely spaced as previously outlined, expansion joints are not required except under special conditions. Surveys of projects in service and experimental projects\(^\text{1}\) show that expansion joints are required only at fixed objects and unsymmetrical intersections provided that:

1. The pavement is constructed of materials that have normal expansion characteristics.
2. The pavement is divided into relatively short panels by contraction joints spaced to control transverse cracking.
3. The contraction joints are properly maintained to prevent infiltration of incompressible materials.
4. The pavement is constructed during periods when the ambient temperatures are well above freezing.

Fig. 13 shows a typical expansion joint. Filler materials are specified in ASTM D994 (AASHTO M33) and D1751 (M213). The filler is commonly placed 3/4 to 1 in. below the slab surface to allow space for sealing material. The space above is temporarily fitted with a cap to allow the finisher or slipform paver to pass over the joint without disturbance. Before the concrete has set, the cap is removed and the joint edged. On some city streets the filler is placed flush with the pavement surface or slightly below and not sealed.

Steel dowels are the most widely used type of load transfer. In transverse expansion joints, one end of each dowel is equipped with a cap into which the dowel can move as the concrete expands. The cap must be long enough to cover 2 in. of the dowel, with one closed end and with a suitable stop to hold the end of the cap at least 1 in. from the end of the dowel bar at the time of concrete placement. The cap must fit the dowel bar tightly and the closed end must be watertight. The half of the dowel with the capped end must be coated to prevent bond and permit horizontal movement. In areas where dowel corrosion is causing problems, new construction should include corrosion-resistant dowels as discussed in the section "Doweled Contraction Joints."

LONGITUDINAL JOINTS

Longitudinal joints control irregular longitudinal cracks that would otherwise occur, as shown in Fig. 2. Such cracks normally develop from the combined effects of load and restrained warping after pavements are subjected to traffic. Under certain conditions, such as rapidly dropping air temperature during the first night, longitudinal cracks may occur early. In such cases, early formation of the longitudinal joint is required.

The following criteria are useful guides for the spacing of longitudinal joints:

1. On both two-lane and multilane highway pavements, a spacing of 10 to 13 ft. serves the dual purpose of crack control and lane delineation. Longitudinal joints on arterial streets should also be spaced to provide traffic- and parking-lane delineation. On these streets it is customary to allow 10 to 12 ft. for each travel lane and 10 to 12 ft. for parking that can also be used as a travel or turning lane.

2. Longitudinal joints are not required for crack control on one-way ramps where the slab width is 18 ft. or less.\(^1\) Two types of longitudinal centerline or lane-dividing joints in current use are shown in Fig. 14. The intermediate longitudinal joint shown at the bottom of Fig. 14 is used where two or more lanes are paved at a time. With slipform paving two-, three-, or four-lane pavements can be placed in one pass. This type of joint can be sawed or formed by inserting and leaving in a plastic tape (such as polyester or polyethylene) or a premolded insert while the concrete is plastic. If the joint is sawed, a sealant is placed in it. Either the groove is completely filled or a cord or other material is inserted first to reduce the amount of sealant required. The keyed joint shown at the top of Fig. 14 is used for lane-at-

\(^1\) Normal ramp width is 16 ft. with increases to about 18 ft. on short-radius curves.
concrete information
PORTLAND CEMENT ASSOCIATION

a-time construction, for multilane pavements where the full width is not paved in one pass, and for ramp connections to mainline pavements.

Both types of longitudinal joints are hinged joints that depend on a key (tongue and groove) or aggregate interlock to maintain structural capacity and serviceability. On most highway pavements, the joints are restrained from lateral movement by deformed steel bars (tiebars or tiebolts).

Details of longitudinal construction joints formed at the edge of each construction lane or series of lanes are illustrated in Fig. 15. The keyed joints can be extruded with a slipform paver or made with a shaped metal strip attached to the forms. When adjacent lanes are placed, the new concrete will form the key portion of the joint. In slipform construction, deformed tiebars or tiebolts are inserted before the supports are removed from the side of the concrete.

It is important to use the keyway dimensions shown at the top of Fig. 15. Larger keys reduce the strength of the joint and may result in keyway failures. The key must be located at middepth of slab to ensure maximum strength.

A keyway can be constructed along the outside edges of the pavement to provide for lane additions at a later date. One half of a tiebolt can be installed to permit tying the added lanes.
Tiebars are designed to overcome the resistance of subgrade or subbase to horizontal movement when the slab is contracting. This resistance is developed over the distance between the tied joint and the nearest free edge. The required cross-sectional area of tiebar per foot length of joint is given by the following formula:

\[ A = \frac{bC_fh}{12f_s} \]  
(Formula 1)

in which

- \( A \) = cross-sectional area of steel required per foot length of joint, square inches
- \( b \) = distance between joint and the nearest untied joint or free edge, feet
- \( C_f \) = coefficient of subgrade (or subbase) resistance to slab movement, usually taken at 1.5
- \( w \) = weight of concrete, pounds per cubic foot (150 lb. per cubic foot for normal-weight concrete)
- \( h \) = slab thickness, inches
- \( f_s \) = allowable working stress in steel, psi (usually taken as approximately 2/3 of the yield strength)

Tiebars should be long enough so that anchorage on each side of the joint will develop the allowable working strength of the tiebar. In addition, an allowance of about 3 in. should be made for inaccurate centering of the tiebar. Expressed as a formula, this becomes

\[ f_s \times d_b = \frac{1}{2} \frac{L_t}{350} \]  
(Formula 2)

where

- \( L_t \) = length of tiebar, inches
- \( f_s \) = allowable working stress in steel, psi (same as in Formula 1)
- \( d_b \) = diameter of tiebar, inches

Recommended tiebar dimensions are given in Table 5. For standardization, tiebars for lane widths of 12.5 ft. or less (spacing of 12.5 ft. in Table 5) are based on a constant length and spacing of 30 in. To further simplify construction procedures it is desirable to use the same size and length of tiebars. To this end, the spacings of tiebars given in Table 5 are based on standardized tiebar sizes. The tiebar dimensions given in Table 5 satisfy Formulas 1 and 2 when the following factors are used:

- \( C_f = 1.5 \)
- \( w = 150 \) lb. per cubic foot
- \( f_s = 25,000 \) psi

Since there is probably a limit to the width of pavement that can be tied together beyond which excessive shrinkage stresses will cause early highway pavement cracking, it is recommended that no more than four lanes (approximately 50 ft.) be tied.

Tiebars or tiebolts are not required at longitudinal joints in city street pavements where materials placed in back of curbs provide the restraint needed to keep longitudinal joints closed without ties.

---

* Tiebars should be deformed steel bars conforming to ASTM A615, A616, or A617; CSA G 30.12, G30.13, or G30.8. Deformed billet steel bars (A 615) grade 40; CSA G30.12 grade 40 are normally specified if the bars are to be bent and later straightened during construction.

** For transverse emergency construction joints, this is the nearest regularly spaced transverse joint where movement can occur.

*** The maximum working stress for the bond in deformed bars is generally taken as 0.10 of the compressive strength of the concrete, up to a maximum of 350 psi. It is permissible to use this maximum value in the design of tiebars because paving concrete should have a compressive strength in excess of 3,500 psi.

---

# The resistance coefficient, \( C_f \) is sometimes referred to as the coefficient of friction between the slab and subbase (or subgrade). The situation is more complex than pure sliding friction since shearing forces in the subbase or subgrade and warped slabs may be involved in the resistance. For subgrades and granular subbases, coefficients of resistance range from 1 to 2 depending on type of material and moisture conditions. Coefficients for stabilized subbases are likely to be slightly greater. Research indicates that the coefficient also varies with respect to slab length and thickness. A coefficient of 1.5 is commonly used for design.

## The maximum working stress for the bond in deformed bars is generally taken as 0.10 of the compressive strength of the concrete, up to a maximum of 350 psi. It is permissible to use this maximum value in the design of tiebars because paving concrete should have a compressive strength in excess of 3,500 psi.
As previously discussed, intermediate longitudinal joints are surface-grooved by sawing or by impressing a plastic tape or premolded insert. It is essential to make the depth of weakened-plane longitudinal joints at least 1/4 the slab depth plus 1/2 in., otherwise longitudinal cracking may not be controlled. It is important to check joint depth frequently while sawing is underway and to make allowance for blade wear. It is equally important to check the depth of formed grooves and premolded inserts. The width of sawed longitudinal joints is commonly 1/8 to 1/4 in. Sawing may be done before the end of the curing period or shortly thereafter, but early enough to control cracking. Joints should be sawed before any equipment or vehicles are allowed on the pavement. After sawing, the joints should be flushed out, dried, and sealed to eliminate a second cleaning. Joints sawed with dry cutting blades can be cleaned with compressed air. In narrow longitudinal grooves such as those in centerline joints, there is no groove shoulder defining the bottom of the sealant reservoir. The groove can be completely filled with sealant material or a rope, cord, or other material can be inserted in the groove first to reduce the amount of sealant required. Because longitudinal joints are tied to prevent opening, a square shape factor is not essential in longitudinal joints. When plastic tape is used for both longitudinal and transverse joints, the material in the longitudinal joint should permit hinging of the joint and should be of a type that can be severed with little displacement when transverse plastic tapes are subsequently placed. If displacement of the longitudinal tape from placing of the transverse tape is considered a problem, the longitudinal joints can be sawed. The inserts must not bond to or react with the concrete and must be noncorrodible. The longitudinal tape must be installed vertically by an automatic machine to a depth of 1/4 the slab thickness plus 1/2 in. It should be installed flush with the slab surface to a maximum of 1/8 in. below the slab surface.

**SUMMARY**

The objectives of joint design are to develop a jointing system that will control cracking, provide adequate load transfer across the joints so that concrete pavements will continue to be smooth riding for the full design life, and to provide a sealant reservoir that will minimize infiltration into the joint. These objectives are best accomplished for an individual project by using the following basic principles with consideration of the performance of concrete highway and street pavements subjected to similar traffic and environmental conditions:

1. In plain pavements with 15- to 20-ft. joint spacing, adequate load transfer is provided by aggregate interlock when the volume of trucks is low. In reinforced pavements with longer joint spacing, dowels are required in all transverse joints.
2. The use of skewed and randomized joints improves joint performance and is recommended for all plain (not reinforced) pavements.
3. Where the volume of truck traffic and other conditions that cause mud-pumping occur, granular subbases are required. Stabilized granular subbases, such as cement-treated subbases, improve joint performance of plain and reinforced pavements.
4. Under certain conditions of heavy traffic, dowels are used in plain pavements to supplement the load transfer provided by aggregate interlock and stabilized subbases. In reinforced pavements with longer joint spacing, load transfer is provided by subbases and dowels.
5. Transverse expansion joints are required only at fixed objects and unsymmetrical intersections.
6. A longitudinal joint spacing of 10 to 13 ft. serves the dual purpose of crack control and lane delineation on highways.
7. Joint sealants capable of withstanding repeated extension and compression compatible with joint spacing and proper sealant reservoir dimensions are required to provide an adequately sealed joint.

**REFERENCES**

concrete information

PORTLAND CEMENT ASSOCIATION


This publication is based on the facts, tests, and authorities stated herein. It is intended for the use of professional personnel competent to evaluate the significance and limitations of the reported findings and who will accept responsibility for the application of the material it contains. Obviously, the Portland Cement Association disclaims any and all responsibility for application of the stated principles or for the accuracy of any of the sources other than work performed or information developed by the Association.