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JOINTS IN PORTLAND CEMENT CONCRETE PAVEMENT

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JOINTS IN PORTLAND CEMENT CONCRETE PAVEMENT

Observations indicate that during years of service the first signs of pavement distress occur near joints. This is not unreasonable, for joints are points of weakness in the continuity of the pavement structure. What purpose then is served by joints? Joints are in effect designed or controlled cracks. At present it is impossible to build conventional pavements without cracking. But why is cracking inevitable? Concrete is a very durable material for pavement construction, but we must keep in mind its physical limitations for proper pavement design:

First, concrete is a brittle material; it cracks more readily than glass.

Second, concrete is a good material in compression, but a relatively poor material in tension, its tensile strength being only one-tenth of its compressive strength.

Third, concrete pavements are subject to wide variations in temperature and moisture, and thus the pavement is constantly undergoing elongation and contraction.

Pavements, if free to move without restraint, would lengthen due to increases in temperature or in moisture, and would contract due to decreases in temperature or moisture content. If the pavement were

not restrained tensile or compressive stresses would not result, but due to friction between the subgrade and the bottom of the slab, stresses do develop. Therefore, transverse joints are placed in the pavement to permit expansion and contraction to take place more readily.

Joint design in concrete pavement then is simply the matter of determining the following:

1. The type of joints to be used--expansion joints, contraction joints, or warping joints.
2. The spacing of these joints.
3. The structural features of the joint which will minimize the loss of supporting ability of the pavement at this point.

After approximately 50 years of building concrete pavements, one might expect that pavement designers would have answers to these three items and that there would be nothing further to argue about. However, this isn't the case. We will discuss these three items, in order, considering first the types of transverse joint.

Selection of Transverse Joint Type

Expansion joints, as the name implies, permit slab expansion (Fig. 1). They do this by means of two features, the 1-in. wide compressible joint filler, and the metal cap placed at the end of the dowel, which slides on the dowel and also allows 1-in. of slab expansion. The dowel, its function, and its design, will be discussed later. Incidentally, an expansion joint

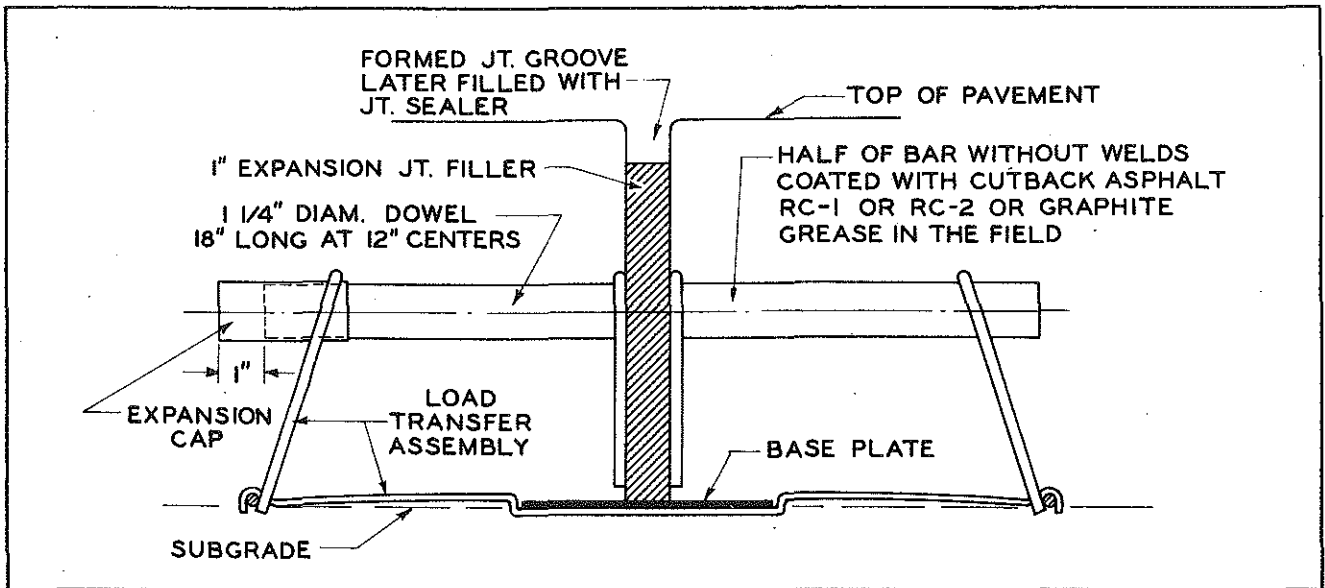


Figure 1. Expansion joint details.

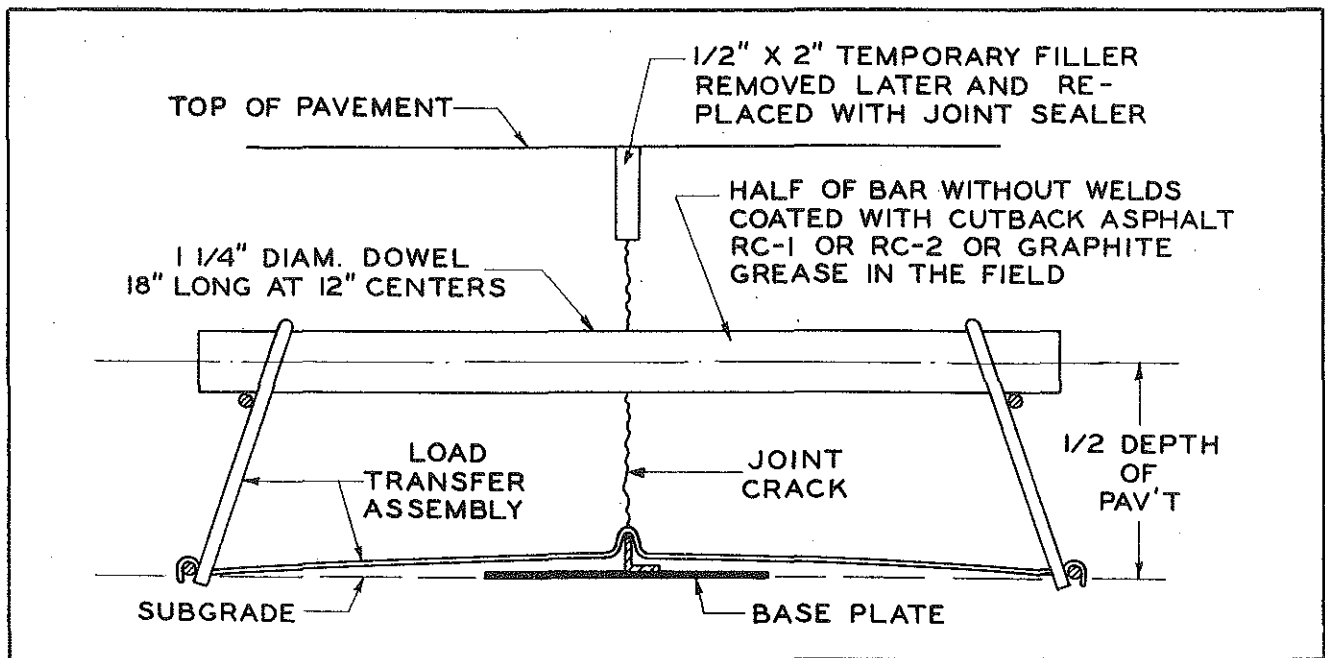


Figure 2. Contraction joint details.

Figure 3 (right). Two concrete design philosophies.

TWO CONCRETE DESIGN PHILOSOPHIES	
<p>PLAIN CONCRETE SLABS</p> <p>SHORT SLABS - 15 - 20 - 25 - 30' WITHOUT LOAD TRANSFER AT JOINTS.</p> <p>(GENERALLY MORE PREVALENT IN SOUTHERN STATES)</p>	<p>REINFORCED CONCRETE SLABS</p> <p>LONGER SLABS - GENERALLY 40 - 100 WITH LOAD TRANSFER AT JOINTS.</p> <p>(GENERALLY MORE PREVALENT IN NORTHERN STATES)</p>
<p>15 NORTHERN STATES</p> <p>1, PLAIN CONCRETE 2, BOTH PLAIN AND REINFORCED CONCRETE 12, REINFORCED CONCRETE</p>	

also permits the slabs to contract and thus also serves as a contraction joint.

Contraction joints permit slab contraction (Fig. 2). This is accomplished by establishing a smaller cross-section at the joint, called a plane of weakness joint. Then with temperature drop, tensile stresses are formed in the concrete pavement, the crack will develop at this location of reduced cross-section, and thus the contraction joint is formed.

Transverse joints in concrete pavements as currently constructed in almost all states are either expansion or contraction joints. Since concrete performs well in compression, field testing and research have shown over the years that expansion joints generally are not necessary in concrete pavements. For example, the Michigan Test Road constructed in 1940 in cooperation with the Bureau of Public Roads was one of the research projects which demonstrated that expansion joints are not necessary. Most states now use expansion joints only at special locations near bridges or railroad tracks or intersecting streets, where some displacement due to slab expansion might cause structural damage. However, six states are still using them elsewhere than at such special locations, four of these at approximately 600-ft spacings, and two at spacings less than 100 ft. One state (Mississippi) is using expansion joints without contraction joints at a 78-ft spacing. Except for the special

locations mentioned previously, the remaining 43 states are using contraction joints exclusively as transverse joints.

Among these latter 43 states, however, there are two basically different approaches to joint design. They involve 1) plain or unreinforced slabs, and 2) reinforced slabs. The spacing of contraction joints is quite dependent upon which type of slab is selected.

Approximately 60 percent of the states are constructing reinforced concrete pavements only, 30 percent are constructing plain or non-reinforced pavements, and 10 percent are constructing both plain and reinforced concrete pavements. Plain concrete pavements are generally built in short slabs to minimize cracking, and load transfer devices are generally omitted at transverse joints. Reinforced pavements have longer slabs, although slab lengths vary considerably throughout the states, and load transfer is almost always used.

Transverse Joint Spacing

Fig. 3 shows that plain concrete slabs in 15-, 20-, 25-, and 30-ft lengths, most often without load transfer, are generally more prevalent in the southern states. Reinforced concrete slabs varying from 40 to 100 ft in length, with load transfer, are more prevalent in northern states. Of 15 northern states, 12 are constructing reinforced pavement slabs, 1 plain slabs, and 2 both plain and reinforced slabs. Fig. 4 illustrates a study of contraction joint spacing practice in 28 states

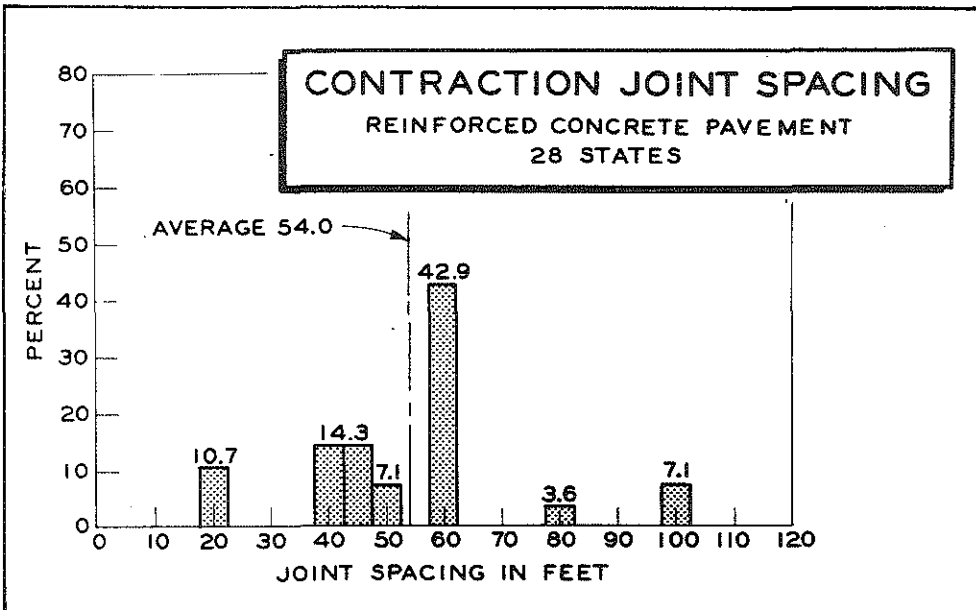


Figure 4 (left). Frequency distribution of contraction joint spacing.

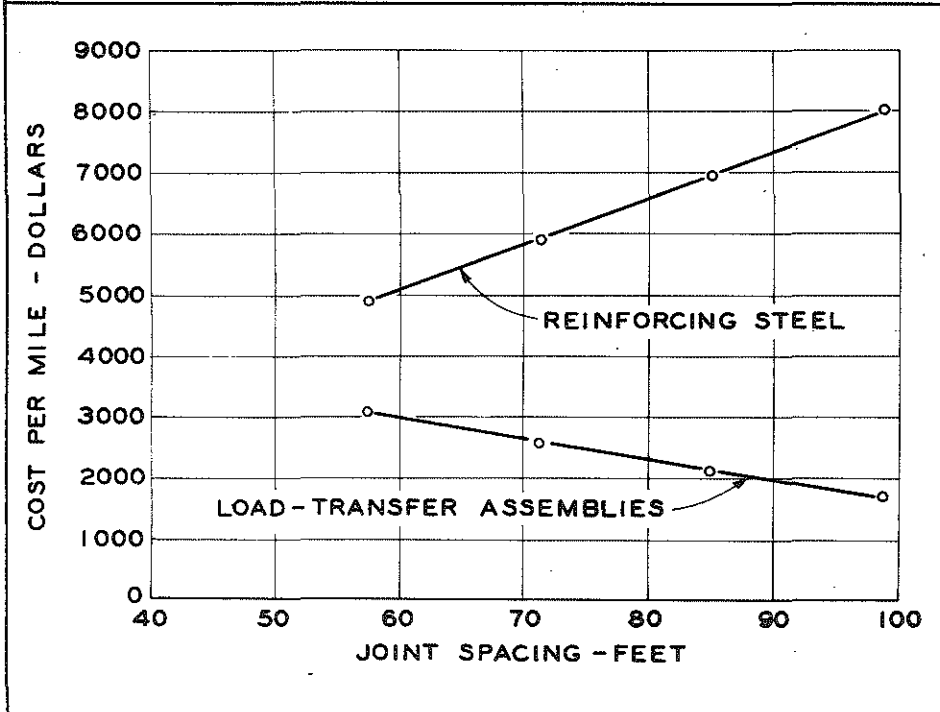


Figure 5 (bottom left). Effect of joint spacing on cost of steel.

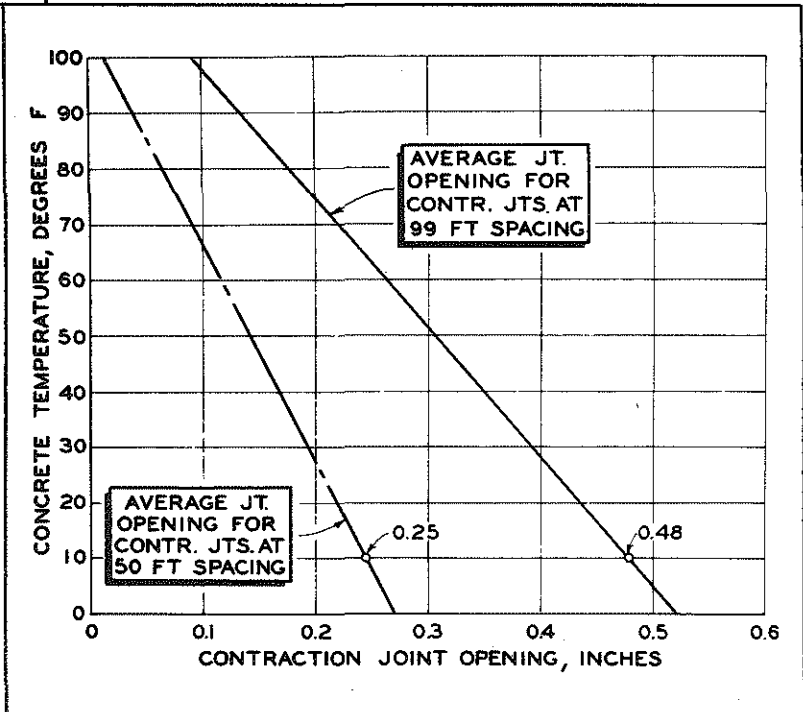


Figure 6 (bottom right). Effect of temperature on contraction joint opening for two joint spacings.

constructing reinforced concrete pavements, indicating a range of from 20 to 100 ft, with a majority near 60 ft and the average at 54 ft.

Greater slab lengths have certain advantages:

1. A joint is a point of structural weakness in the pavement--the fewer per mile the better.
2. Less hand work and thus greater construction efficiency is achieved when fewer joints are installed.
3. Longer slabs require fewer load transfer assemblies per mile.
4. They also generally produce a pavement surface with better riding quality.

Certain disadvantages of longer slabs must also be considered:

1. A greater weight of reinforcing steel is required per unit of pavement area.
2. The reduction in expenditure on load transfer assemblies with longer slabs is offset by increased cost for pavement reinforcement, according to prices analyzed in a study last year and shown in Fig. 5.
3. Longer slabs also involve the very difficult problem of proper sealing of transverse joints, for the opening of a contraction joint with temperature variation is proportional to slab length, and the elasticity, adhesion, and cohesion of the joint sealing material are severely tested when longer slabs are used.

Fig. 6 is a statistical analysis of the average measured joint opening of 99-ft slabs as compared to 50-ft slabs for various temperatures. Note that at 10 F, average joint openings are 0.48 and 0.25 in. (approximately 2 to 1) for 99- and 50-ft joint spacings, respectively.

Transverse Joint Details

We have covered two aspects of transverse joint design, selection of the type of joint and its spacing. The third and last item is to determine those details of the joint which will permit it to function properly with a minimum of maintenance.

The first and most important of these details is the use of a load transfer device across the joint. The purpose of this device, which most often is a steel dowel, is to help reduce pavement deflection by distributing the load at a joint corner to both sides of the joint, thus obtaining a wider area of support from the subgrade beneath the slab (Fig. 7). Properly designed doweling systems will transfer 40 percent or more of the load across the joint and will prevent faulting of the two slab edges forming the joint. Joint faulting is generally the first and primary cause for deterioration of short-slab pavements constructed without reinforcement or load transfer devices. Under heavy traffic conditions this joint faulting leads to a rough, unbearable ride after five to ten years.

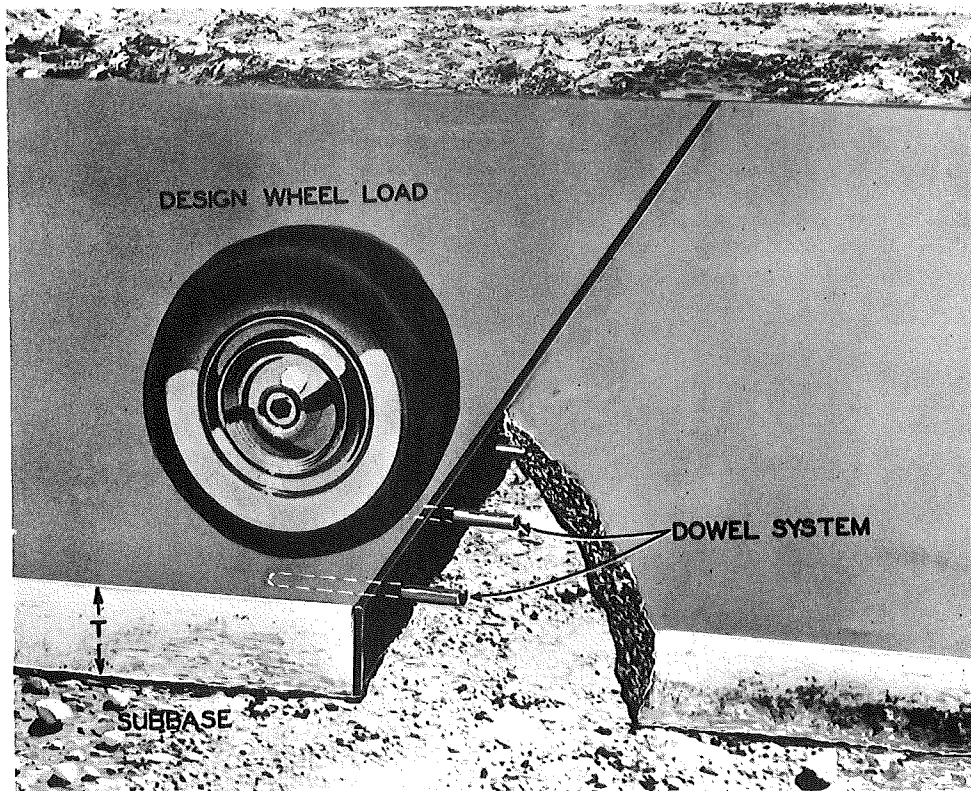
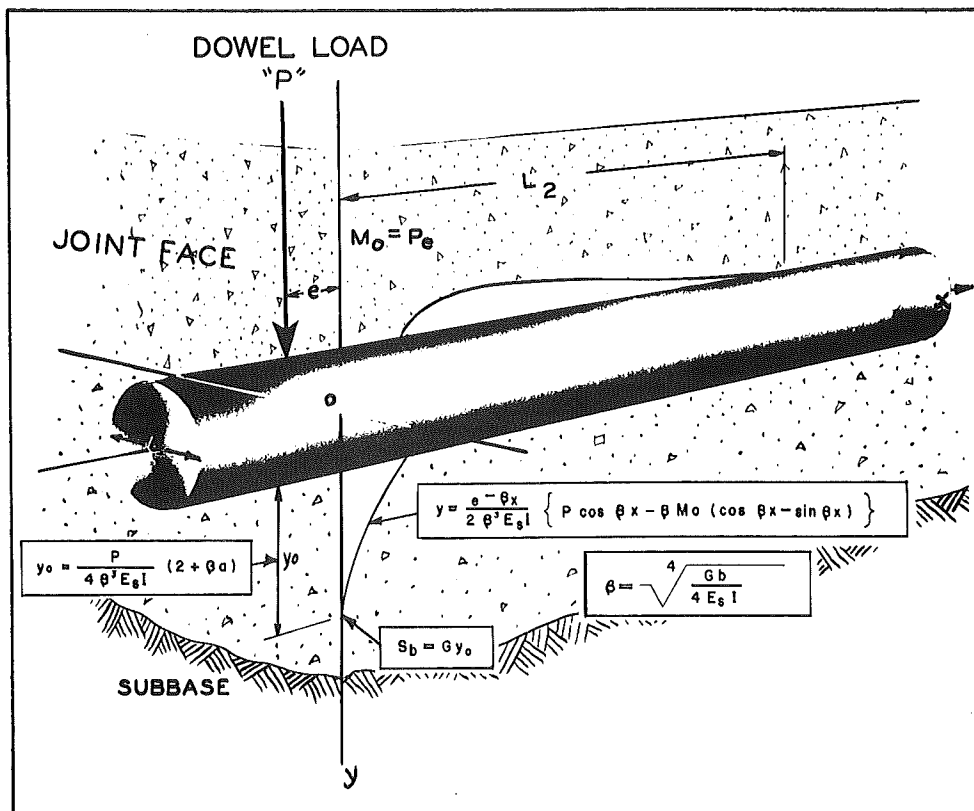


Figure 7. Design condition for load transfer at a joint.

Figure 8. Free body diagram of a dowel.



A free body diagram of a dowel and the equations used in dowel design are shown in Fig. 8. These equations are developed on the basis of the theory of an elastic beam on an elastic foundation and are used to determine the proper dowel size and length to provide wheel load transfer across the joint without excessive bending stress in the dowel or excessive bearing stress between the concrete and the steel dowel. The Department from 1939 to 1944 conducted extensive laboratory testing of dowels and other load transfer devices and was one of the first states to evaluate their load transfer efficiency quantitatively.

Since the joint must be free to open with slab contraction, it is very important that the dowel be properly aligned vertically and horizontally across the joint. Any misalignment will cause binding and tensile stress in the slab and will lead to slab cracking.

Other details of joint design are shown in the cross-sectional view of a contraction joint (Fig. 2):

1. The dowel is centered over the joint crack and an assembly is used to support the dowels in their correct location during construction.
2. One end of the dowel is coated with a lubricating grease to break the bond and thus reduce friction between the concrete and the dowel, permitting slab contraction.
3. A base plate is used beneath the joint to prevent subbase material from working up into the open crack during periods of slab contraction.

Material in the crack opening would prevent later slab expansion and closing of the joint.

4. A joint groove is formed above the center of the load transfer assembly, establishing a plane of weakness to insure that the crack forms at the proper location. Later the temporary forming strip is removed and the joint seal is placed in this groove.

5. The joint seal functions to prevent infiltration of sand and small stones into the joint, which would eventually clog the joint and prevent it from closing under slab expansion.

Longitudinal Joints

In addition to transverse joints in concrete pavements, we also have longitudinal joints, sometimes called centerline joints in two-lane construction. What is the purpose of a longitudinal joint? The first concrete pavements built did not have longitudinal joints. However, as pavement widths increased it was noted in the 1920's that pavement approximately 16 ft or wider developed random longitudinal cracking. Thus, the center longitudinal joint was used as a matter of expediency to form a controlled crack and prevent irregular longitudinal cracking.

Fig. 9 illustrates the need for longitudinal joints in order to reduce transverse warping and prevent longitudinal cracks. As temperature varies during each day the upper surface of the pavement becomes colder than the bottom surface. Generally this occurs at night, and as a result

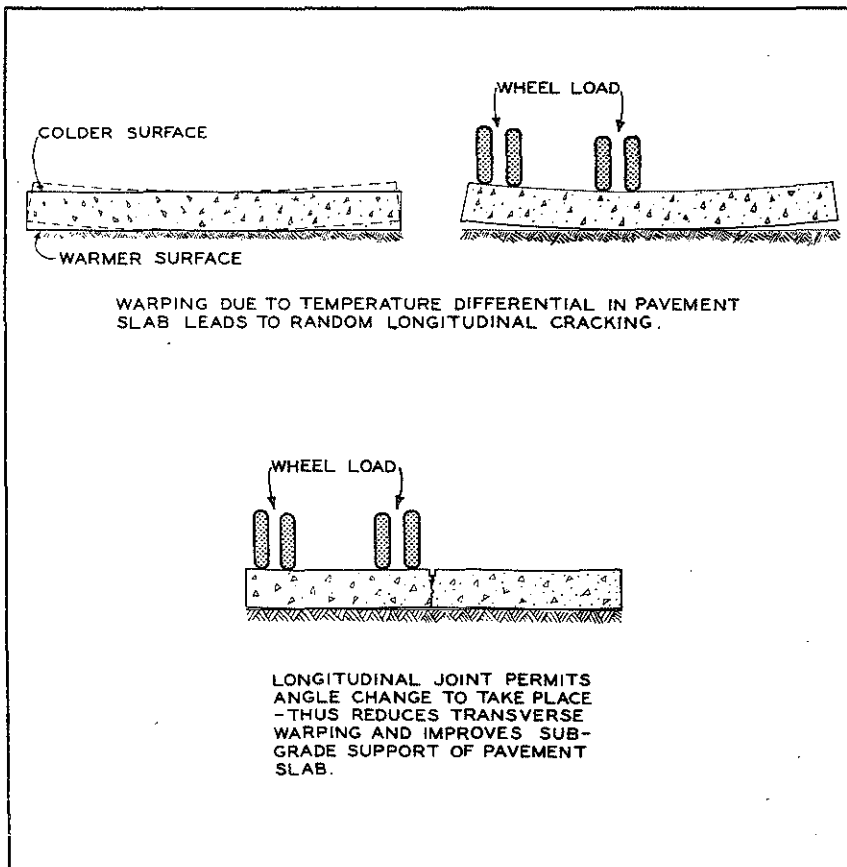


Figure 9. Longitudinal joint reduces transverse warping stress.

Figure 11 (right). Longitudinal bulkhead construction joint.

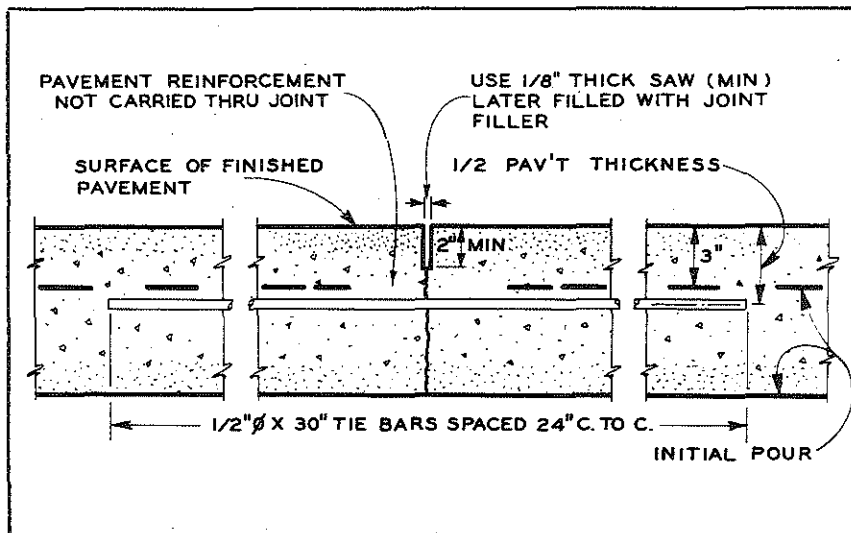
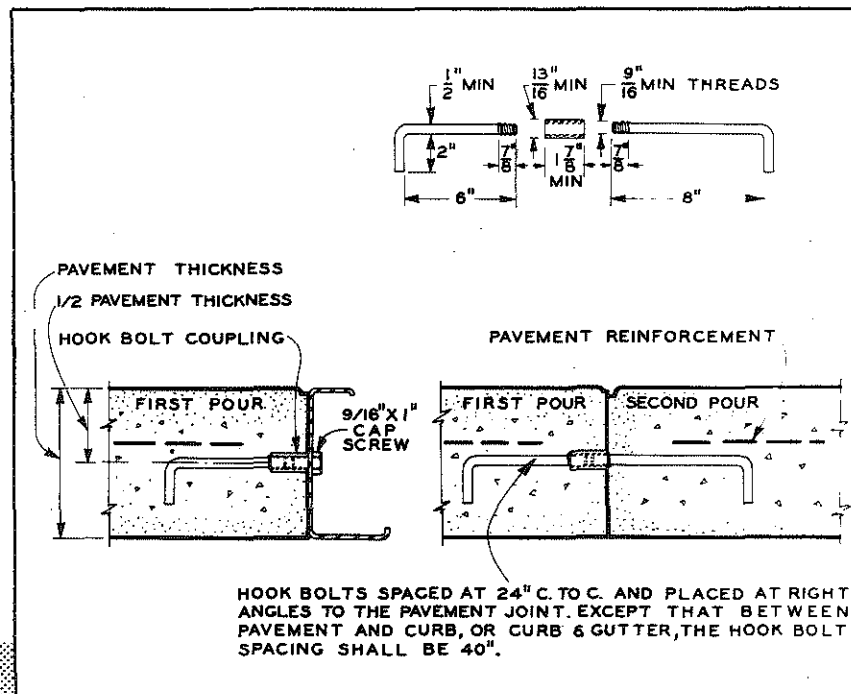


Figure 10. Longitudinal lane tie joint.



the pavement warps as shown. Wheel loads passing along the unsupported outer shoulder edge which is warped upward cause sufficient tensile stress to form longitudinal cracks. With a longitudinal joint this warping is reduced because a hinge permitting angle change is introduced and the pavement thus receives better support from the subgrade. This type of joint which reduces warping stresses is called a hinge or warping joint.

The controlled crack or joint is formed in a manner similar to the contraction joint (Fig. 10) by establishing a plane of weakness at the appropriate location. For this joint the plane is established by sawing an 1/8-in. wide groove to a depth of 2 in. Subsequently, a crack forms at this location. The tie bar shown, a 1/2-in. diam bar 30 in. in length, serves a different purpose than the dowel for transverse joints. The tie bar functions, as its name implies, to hold the two slabs together. Size and spacing of the tie bars are determined so that they can resist the tensile forces tending to separate the slabs. The tie bar does not function as a load transfer device, as the dowel does. In holding the slabs together in intimate contact, it permits load transfer across the joint by means of aggregate interlock. The jagged faces of the crack when held tightly together are adequate for transferring loads from one slab to the other, should a wheel load occur along the edge of the joint.

Reinforcing steel in pavement slabs has the same function as the tie bar for longitudinal joints. If random transverse cracks develop, the

reinforcing steel holds the faces of the crack together, permitting load transfer across the crack and thus preventing faulting at the crack. When short slabs are used (20 ft or less), if cracks form in the plain or unreinforced slabs, they stay fairly well closed since very little expansion or contraction takes place in such short slab lengths. Thus, reinforcing steel to hold these cracks together is less essential than for longer slabs.

Another type of tie bar, called a hook bolt, is used for pavements with more than two lanes where all lanes are not poured at the same time (Fig. 11). One part is embedded in the first pour or lane at the time of construction. Before the second pour the other part of the hook bolt is threaded into the coupling and then after the second pour the slabs are tied together.

Jointless Pavements

In spite of the diversity of design opinions concerning joint spacing and joint details, all designers agree that conventional pavements must have joints. However, two pavement designs, the continuously reinforced and the prestressed, solve joint problems by eliminating the joint. Continuously reinforced pavement eliminates joints in exchange for closely spaced fine cracks. The ends of the pavement may be restrained from movement by anchors cast into the subgrade. However, this type of pavement requires approximately three times as much reinforcing steel as conventional pavements. Prestressed pavements attempt to eliminate

joints and cracking by introducing a compression force to counterbalance tension stresses due to temperature and moisture changes. Currently, the mileage of continuously reinforced pavement is increasing, but prestressed concrete pavements are still confined chiefly to short experimental sections.

Summary

In summary, joint construction practice through 50 years of concrete pavement construction has been a continuing series of research experiments seeking as our ultimate goal a method of preventing or controlling pavement cracking while minimizing other undesirable features of joint construction.