Methods of Forming Joints in Portland Cement Concrete Pavement

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The types of joints used in concrete pavement are (a) construction joints, both longitudinal and transverse; (b) expansion joints, full pavement depth with a compressible filler; (c) longitudinal center joints, sometimes called "hinge" joints; and (d) contraction joints, transverse across paving lanes. Although a large variety of joint types and devices have been tried by highway departments and the several airfield construction agencies, there are currently only four basic methods of forming joints in concrete pavement: (a) hand-forming, hand-tooling; (b) sawing joints; (c) forming in the plastic concrete by some type of insert left in the pavement; and (d) placing preformed joint filler ahead of the concrete to form expansion joints.

A historical background, tracing the development of current jointing practices, is provided. Types and purposes of joints used in concrete pavement are described and the four basic methods of forming joints are discussed in sufficient detail to provide a basis for evaluation of each method.

•PROVIDING JOINTS in concrete pavement has been a major construction problem since the necessity for joints was first recognized. Engineers, materials producers and others have conducted much research to attempt to develop the strongest, smoothest riding, most durable joints that it is practicable to provide. Although a large variety of joint types and devices have been tried by highway departments and the several airfield construction agencies, there are currently only four basic methods of forming joints in concrete pavement: (a) hand-forming, hand-tooling; (b) sawing; (c) forming in the plastic concrete by some type of insert which is left in the pavement; (d) placing formed joint filler ahead of the concrete to form expansion joints.

HISTORICAL BACKGROUND

For a better understanding of current practices, it may be useful to trace briefly the evolution of joints in concrete pavement in the United States. The first portland cement concrete pavement of which there is an authentic record was placed in Bellefontaine, Ohio, in 1892. This construction, as all early pavements, involved the slow and laborious processes of mixing and placing the concrete by hand. The pavement was constructed in small slabs or blocks, 5 or 6 ft square. Joints consisted of the spaces left between slabs and were full depth on the order of expansion joints. Tarred paper was placed between the blocks to allow for expansion.

Construction of small slabs or blocks appears to have been the pattern of concrete pavements built before 1900. The comparatively wide joints at such short intervals were subjected to damage by the steel-tired wheels of the animal-drawn vehicles of the era. A variety of metal devices were contrived to protect the slab edges from such damage. Since there was no particular requirement for smooth pavements, some of these devices seem to have served their purpose with considerable success.

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The decade from 1900 to 1910 was a period of much experimentation in joint spacing and design. Joint damage by steel-tired wheels was still a matter of much concern. In efforts to overcome this problem experienced with very small slabs, the designers of concrete pavement approached the other extreme by building large slabs with widely spaced joints. During this period all joints were expansion joints at full pavement depth. A few examples will illustrate the widely divergent practices of the time:

1. In Toronto, Canada, in 1902, concrete pavement was built of slabs 20 ft square with $\frac{3}{4}$-in. expansion joints between the slabs. The joints were filled with a material referred to as "paving pitch."
2. In Richmond, Indiana, in 1903, a concrete pavement was placed in "large" slabs with 1-in. wide expansion joints.
3. In Washington, D. C., in 1906, a pavement was built in slabs 100 ft long with 1-in. wide joints filled with a bituminous material.

Reports indicate that these and other pavements of large slab dimensions exhibited uncontrolled cracking between the joints.

By 1910, recognition of the automobile as a practical means of transportation began to stimulate road construction. A quotation from the July 9, 1913, issue of Engineering and Contracting is illustrative of the jointing practices of that time:

> Practice exhibits a heterogeneous array of expansion joint details, spacings and arrangements. This is most true of transverse joint practice. The plan is general of placing joints between pavement edge and curb and, when railway tracks occupy the streets, of placing joints on each side of the tracks just outside the tie ends. There is no similar uniformity in transverse expansion joint practice. They are spaced 25, 30, 37½, 50, 60 and 100 feet apart and the most common spacings are perhaps 25 and 30 feet. Usually they are square across the roadway but various diagonal arrangements are employed. Structurally the differences are wide. Joints with metal guard plates, joints with rounded edges only, joints of all widths from ¼ to 1 inch, joints with fillers of a dozen characters are employed.

It was perhaps the indifferent success of this wide variety of joint spacings that led to the construction of concrete pavements without joints except at locations where construction was stopped. By 1915, several states were building such pavements and the practice was continued in some areas even during the 1930's.

Until about 1919, all transverse joints in concrete pavements were expansion joints with spacings from about 25 to 100 ft. In 1919, at least one project was built with a type of weakened plane contraction joint for crack control. This was done by setting a thin board on edge on the subgrade and placing concrete around it. This practice appears to have been followed for a while. The irregularity of the crack on the slab surface, however, and the difficulty of effectively sealing it, soon led to the formation of a groove on top of the pavement for the contraction joint. About this same time, use was first made of longitudinal joints to control cracking.

Most of the changes leading to the types of joints currently used in concrete pavements occurred between 1920 and 1930. These changes were influenced or brought about by research projects such as the test road at Pittsburg, California, the Bates test road in Illinois and tests by the U. S. Bureau of Public Roads at Arlington, Virginia. Important factors in the changes were the primary engineering objectives of obtaining improved joint design and better pavement performance at lower costs. This led to rapid mechanization of concrete paving methods at the same time that assembly-line techniques were being applied to automobile manufacturing to reduce costs. During this period of mechanization, practical methods were developed for construction of joints in concrete pavements.

By 1930, the principles of joint design for concrete pavement were generally understood and the basic types of required joints were in use. There was a misconception, since corrected, regarding the use of expansion joints, as well as a lack of knowledge of the effects of joint dimensions on the performance of sealing materials.

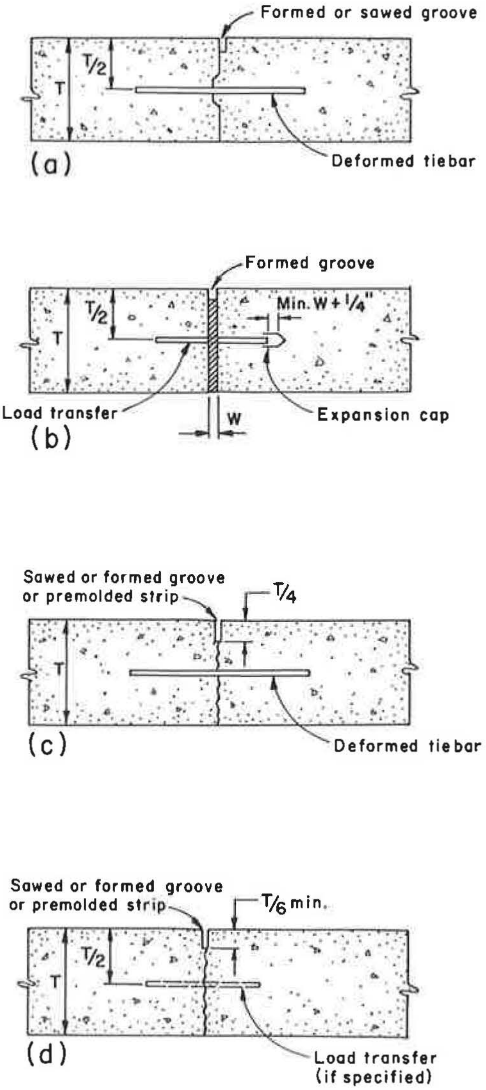

Figure 1. Basic types of concrete pavement joints: (a) construction joint, (b) expansion joint, (c) longitudinal center joint and (d) contraction joint.

TYPES OF JOINTS

Although the types of joints currently used in concrete pavement are generally well known, a brief review will perhaps help to prevent any misunderstanding of the following discussion of the methods of forming each type. The four types of joints (Fig. 1) used in concrete pavement are (a) construction joints, both longitudinal and transverse; (b) expansion joints which are full pavement depth with a compressible filler provided to permit the joint to close as the pavement expands; (c) longitudinal center joints, sometimes called "hinge joints," to relieve curling and warping stresses; (d) contraction joints in the transverse direction across paving lanes.

Construction Joints

Construction joints are transverse header joints, installed wherever paving is interrupted, or longitudinal construction joints between lanes of multiple-lane pavement. Their purpose is to divide large pavement areas into convenient size for paving. Longitudinal construction joints are usually provided with deformed tie bars or tie bolts to prevent horizontal movement and with keyways or tongues and grooves built into slab edges to provide load transfer between lanes.

Transverse construction joints may serve as contraction joints if their location coincides with that of planned transverse contraction joints. If it is to be a contraction joint, a butt-type joint is formed by the header or transverse form and dowels are used for load transfer across the joint. Transverse construction joints not occuring at planned joint locations are generally tongue-and-groove joints provided with tie bars to prevent movement.

Expansion Joints

Expansion joints are usually transverse joints used to relieve expansion stresses in the concrete by providing a space where the concrete can expand if necessary. An expansion joint is created by inserting a non-extruding, compressible material as a filler between two slabs. The material should have sufficient strength to resist horizontal slab movement partially but permit such movement before crushing or buckling stresses develop in the concrete. A groove above the expansion filler is provided to receive joint sealing material.

Very few pavements are now built with regularly spaced expansion joints. Tests and experience have shown that closely spaced contraction joints provide adequate space for pavement expansion under normal conditions. Expansion joints are still used adjacent to bridges and other fixed structures in the pavement and at certain intersections.

Longitudinal Center Joints

Longitudinal center joints are generally provided in highway and street pavements other than those built in narrow lanes by the method known as "lane-at-a-time" construction. These center joints are intended to relieve the transverse stresses which develop from wheel loads and slab curling or warping due to moisture and temperature differential in the pavement. Longitudinal center joints are frequently referred to as hinge joints. They are not intended to open and close and tie bars are usually provided to prevent such movement.

Contraction Joints

Contraction joints are transverse joints used to relieve tensile stresses created by pavement contraction as the concrete cools and loses moisture. Contraction joints also relieve longitudinal stresses due to loads and curling and warping. They control the location of transverse cracking if properly spaced. Depending on spacing and other design considerations, these joints may or may not be provided with dowels for load transfer.

METHODS OF FORMING JOINTS

Hand-Formed Joints

The earliest method of forming joints in the surface of concrete pavement was by workmen using hand tools. Although this was in keeping with the hand methods of mixing and placing concrete in the early days, the practice of hand-forming and hand-tooling of joints extended well into the modern period of highly mechanized paving operations. Until about the mid-1950's, more joints were provided by hand methods than by any other means.

Limitations. —Although many miles of completely acceptable concrete pavements were built with hand-formed joints, the limitations of this method have become apparent in recent years. A critical limiting factor is the scarcity of skilled workmen. With the great expansion of concrete paving operations in highway and airport construction, workmen with adequate experience in the forming and tooling of joints have become spread too thin to produce dependable results on every project. Another factor is the speed with which modern paving equipment can place concrete. It is comparatively commonplace for a modern paving train to place a mile or more of 24-ft wide concrete pavement in one day. It would be a formidable task for a crew of finishers to provide joints in such a large expanse of paving by hand methods.

Hand-formed dummy groove joints (contraction and longitudinal center joints) have objectionable features which are probably inherent in the method. They are frequently of irregular width. They are often the source of bumps or depressions that cause pavement roughness. Concrete along the joints may be overworked with resultant poor durability. One of the major sources of trouble in dummy groove joints formed by hand methods has resulted from the template used to maintain the groove in the plastic concrete. Workmen may leave the template in place so long that the partially hardened concrete is fractured horizontally as the plate is lifted out. The thin layer of concrete above the horizontal crack may spall off under traffic, thus creating a serious maintenance problem.

Acceptable Uses of Hand-Forming. —Hand-tooling is the generally accepted method of finishing expansion joints and has provided completely satisfactory joints when properly accomplished. Expansion joints require that the expansion filler be installed ahead of the placing of concrete. It must be installed vertically and staked securely to the subgrade. Since most plans call for the expansion filler to be recessed $\frac{3}{4}$ to 1 in. below the pavement surface, some type of installation guide or cap is normally used in construction. This is generally a metal channel which fits over the filler and maintains it in a straight line across the paving lane. The cap is normally raised partially to permit edging of the concrete on both sides of the filler with a wide-flanged double edger, after which the cap is removed. The formed groove should be as wide as the filler and completely clear with no concrete bridging above the filler or at either end. The finished expansion joint should be checked with a straightedge to make certain no depression or hump has been created during the edging and finishing operations.

Hand-forming has been generally adequate for providing a groove for sealing both transverse and longitudinal construction joints, although sawing is generally considered more economical, is frequently used for this purpose, and may provide a smoother joint. Since construction joints will generally have tie bars to prevent movement, a shallow and comparatively narrow groove provides a sufficient reservoir for the joint sealer. Unless the reservoir is to be sawed, both sides of the joint should be edged during finishing operations. The groove for the joint sealer should be formed during the edging of the second slab or paving lane. Generally, a groove approximately $\frac{3}{4}$ in. deep and $\frac{3}{8}$ in. wide will be adequate for this purpose.

Sawed Joints

The practice of sawing joints in concrete pavement started about 1950 and became widespread in a relatively short time. The acceptance of this new method coincided very closely with the development of more efficient machines for placing and finishing concrete and the consequent speedup of paving operations. Use of the improved equipment to its full capacity became possible when joint forming was eliminated from the hand-finishing operations.

The early sawing operations were hampered by the limitations of the available sawing equipment. A brief quotation from an article by Robert Janowitz in the June 1959 issue of Roads and Streets will sum up the equipment improvement made in the first ten years of sawing operations:

> In the short span of ten years, many changes have taken place in concrete sawing. The early, low-powered, hand-pushed saws have given way to larger and more powerful self-propelled machines. The life of diamond blades has been extended greatly with the advent of tungsten-carbide bonds. Low cost, silicon carbide type abrasive blades can be used to cut green concrete in many places and have slashed cutting cost dramatically.

Application of Sawing.—Sawing has been successfully used for forming all types of joints in concrete pavement. Even expansion joints are sawed in England, though they are generally formed by hand in this country. The simpler and comparatively non-critical uses of sawing are for forming grooves at the top of construction joints and sawing longitudinal center joints. Since these joints are subject to little, if any, movement, the saw cuts can be of minimum width to permit effective sealing. Usually, a $\frac{3}{16}$-in. width has been found appropriate for this purpose.

Longitudinal construction joints can be grooved for sealing by sawing along the joint to a depth of $\frac{3}{4}$ to 1 in. or as provided by specifications. Sealing can follow closely after sawing and cleaning of the joints, a procedure that eliminates the necessity of a second cleaning before sealing. Transverse construction joints can be sawed in the same manner when they are tied, non-working joints. When the transverse construction joints are to function as contraction joints, the joint width provided should be the same as for other contraction joints.

Longitudinal center joints function similarly to contraction joints except that there is little movement in opening and closing of the joint. Experience has indicated that the sawing of the groove for these joints can be delayed until the concrete has hardened. It must be done before the pavement is opened to traffic—including construction traffic. To control cracking effectively, longitudinal center joints should have a minimum depth of one-fourth the slab thickness. They need have only the width required for sealing, approximately $\frac{3}{16}$ in.

Sawing has been used very successfully in providing longitudinal center joints. Because of the depth required, concrete saws operating in tandem have proved advantageous for sawing these joints. Sawing may be done with diamond or abrasive blades, using the most economical method for the particular aggregate. Usually the center joint can be flushed out, dried and sealed immediately after sawing, eliminating a second cleaning.

Sawing of contraction joints is the most critical operation performed in this method of joint forming. A quotation from the Navy specifications on joints indicates many of the factors to be considered in sawing contraction joints:

> The time of sawing shall be varied, depending on existing and anticipated weather condtions, and shall be such as to prevent uncontrolled cracking of the pavement. Sawing of the joints shall commence as soon as the concrete has hardened sufficiently to permit cutting the concrete without chipping, spalling, or tearing. If early sawing is the cause for under-cutting or washing of the concrete and the action is sufficiently deep to cause structural weakness or excessive cleaning difficulty, the sawing operations shall be delayed and resumed when directed. The sawing operation shall be carried on both during the day and at night as required regardless of weather conditions.

Since transverse contraction joints relieve tensile stresses which develop during early hardening and cooling, while the concrete is relatively weak, the reduction in cross-section does not have to be as great as in longitudinal center joints. Experience has shown that a depth of groove equal to one-sixth of the slab thickness or the diameter of the maximum size aggregate, whichever is greater, will generally control transverse cracking.

The exact time of sawing contraction joints depends on the type of aggregate, curing method, cement factor and weather. Generally all joints should be sawed in succession as soon as is possible without damaging the surface of the pavement. A slight amount of raveling should be permissible since it gives the operator a good gage of his timing. If there is no raveling at all, the concrete is probably too hard and cracks may develop ahead of the saw.

In some areas where very hard coarse aggregates are used, the cost of sawing joints may be prohibitive. A procedure to minimize the difficulty of sawing hard aggregates has been successfully used on a few projects. This consisted of vibrating a T-bar into the plastic concrete at the proper joint location. The vibrated T-bar laterally displaced the coarse aggregate from the saw-cut location and minimized the hard particles encountered by the saw after the concrete had hardened. Although this procedure may assist in sawing hard aggregates, it also adds an additional piece of mechanized equipment to the paving train and may increase the manpower requirement.

The sawing of contraction joints in concrete containing very hard aggregates, and particularly natural gravel, may produce a condition adjacent to the joints which is unfavorable to the durability of concrete. As the saw strikes the particles of hard aggregate, a vibration may be created by the saw action and aggregate resistance. This vibration may be severe enough to break the bond between the sawed stone fractions and the surrounding mortar. Since the concrete has hardened sufficiently that bond will not be reestablished, the damage is permanent. Some of the raveling and spalling of concrete occurring along sawed joints is probably due to this type of damage during sawing.

The width of sawed contraction joints will depend on the joint interval or length of slabs. Egons Tons and others have demonstrated that the dimensions of joints have a critical effect on the performance of joint sealers. This effect is covered by the term "shape factor." A joint width of 1/4 in. is generally adequate for the relatively short contraction joint intervals generally used in unreinforced concrete pavement. At the longer joint intervals usually specified when distributed steel is used in the concrete, wider contraction joints will be required. The general practice in sawing wide contraction joints is to use two passes of the saw to complete the joint. The first saw cut is narrow and to full joint depth. The second pass may be made with two saw blades separated by a spacer of proper thickness. The wider second cut is only of sufficient depth to accomodate the joint sealer material. Figure 2 illustrates two types of sawed contraction joints.

Advantages of Sawed Joints.--The sawing of joints has permitted the construction of much smoother concrete pavement than was possible when all joints were hand-formed.

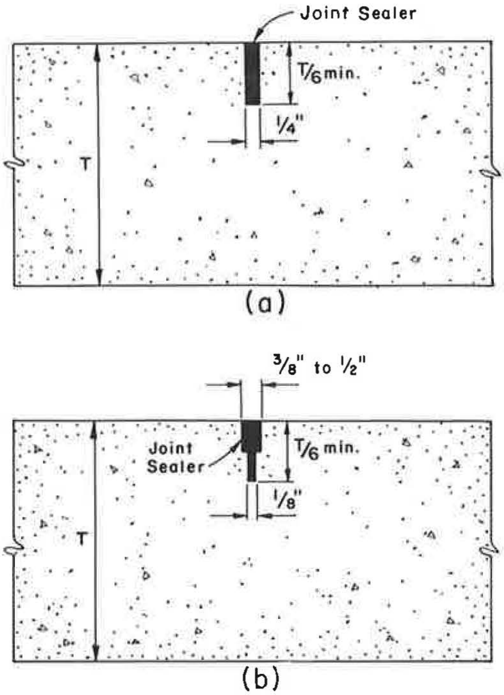

Figure 2. Sawed contraction joints in concrete pavement: (a) short joint intervals, and (b) long joint intervals.

Joint sawing has contributed to greater production of concrete pavement with less manpower which has resulted in overall economy. It has also helped to eliminate the overworking of concrete along joints with its consequent lack of durability.

Joint Inserts

The use of inserts for forming joints in plastic concrete is not new. Various devices and materials have been tried, some dating back almost to the time when joints were first used. A great many of these were found impractical or ineffective and were discontinued. Nevertheless, the principle of forming joints by use of inserts has persisted and some types are currently in use.

This report does not attempt an exhaustive review of the types of inserts that were tried and discontinued. Rather, the discussion is confined to the principal types used currently. It may be that some are omitted that are equal in importance to those discussed. The main purpose here is to explore the principle and its possibilities. The four types discussed may be seen in concrete pavements in various parts of the country.

Bituminous Ribbon Joints.—The use of preformed bituminous ribbon inserts started in the 1930's. The material consists of felt, $1/16$ or $1/8$ in. thick, impregnated with asphalt. Cut to proper dimensions for joint depth, the material is installed in the plastic concrete by special machines devised for the purpose.

When properly installed, ribbon joints have proved successful for longitudinal center joints and for contraction joints spaced at short intervals. Where the material was installed vertically, in a straight line and flush with the pavement surface, it has shown good performance over a long period of time. No edging, grooving nor sealing of the joint is required because the preformed ribbon serves as a complete and permanent joint filler.

A number of poor installations of ribbon joints have been reported and observed. The material has been installed on a slant, in wavy lines and at a depth below the surface of the pavement. Each of these faults contributed to pavement defects along the joints. The slanted material caused spalling, wavy alignment failed to control cracking and the buried ribbon caused spalling above it on the surface of the slab.

Deformed Metal Plate.--This patented device came into use in the early 1950's. It consisted of a galvanized iron plate with horizontal deformations or corrugations and was used for the dual purpose of forming the joint and providing mechanical interlock. The plates were pressed into the plastic concrete by a machine especially modified for the purpose. The plates were of proper width for installation $1/2$ in. below the surface and $1/2$ in. from the bottom of the slab. The slab surface was finished above the joint without grooving or sealing. Pavements built with this joint have not shown a good performance record. Extensive raveling and spalling along the joints have been reported. Use of this device appears to have been discontinued.

Sawed-Out Inserts.--This type of insert (Fig. 3) has been used for several years, though its use became more widespread in the middle 1950's. The inserts may be made of corrugated paraffin-treated paper, resin-impregnated fiber strips or premolded bituminous strips similar to expansion joint fillers. Boards of cane fiber and

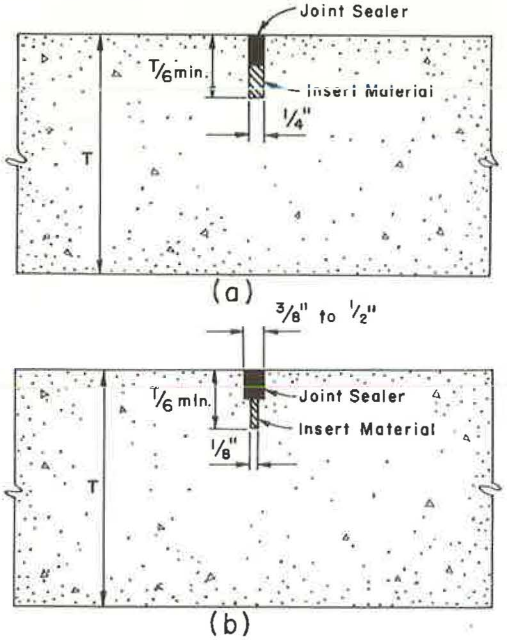

Figure 3. Sawed-out insert joints: (a) short contraction joint intervals, and (b) long contraction joint intervals.

a low asphalt content have also been successfully used.

The insert material is cut into strips of proper width to provide the specified joint depth. These strips are inserted in a groove formed by vibrating a T-bar into the plastic concrete behind the last mechanical finishing equipment. The insert is placed in the groove slightly below the surface and the surface over the joint is finished with a scraping straightedge. A crack will develop below the surface as the concrete hardens since it provides a plane of weakness. A fine crack will also develop above the insert which serves as a guide for the saw operator.

If bituminous impregnated strips are used, only the top ½ to 1 in. need be removed for joint sealing, leaving the remainder of the insert as partial filler. Width of the groove should be at least the width of the insert and can be provided as wide as required to provide a proper shape factor for the joint sealer.

This type of insert joint has been used by some highway departments and on military and civil airport pavements. Both the Navy and Army Corps of Engineers permit its use. The joint acts as a positive crack control from the time the

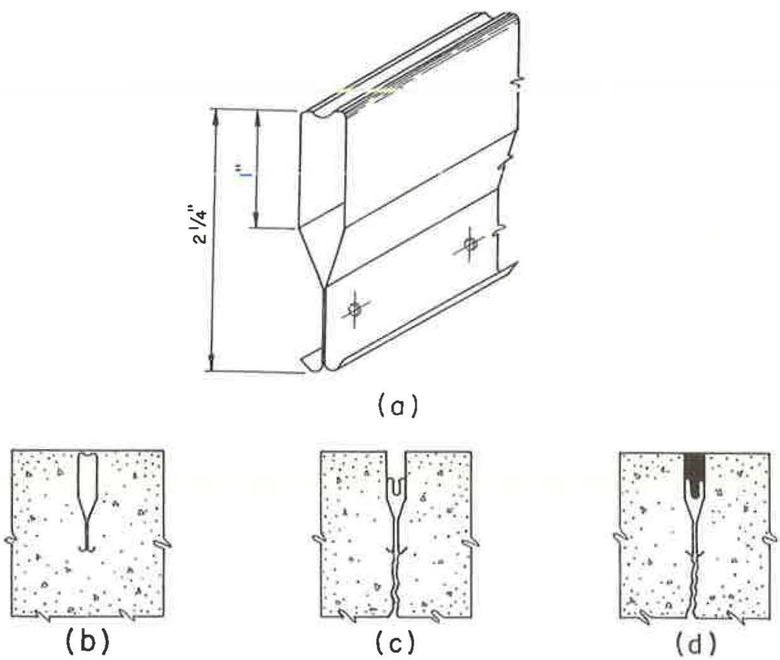

Figure 4. Tubular metal joint insert: (a) cross-section of $2\frac{1}{4}$-in. insert, (b) as installed, (c) after crimping, and (d) after sealing.

concrete is placed and sawing can be delayed until after all pavement is completed. Joint sealing can follow immediately after sawing and cleaning the joints.

Tubular Metal Joint Inserts.--The tubular metal joint insert is a comparatively recent innovation and its use has spread rapidly. The tubular device is fabricated from 30-gage galvanized steel to provide joint depths of 2, 2¼ or 3 in. with section lengths up to 13 ft. Sections of the material may be fitted together to provide a continuous length for use in longitudinal center joints. The shape of the device is illustrated in Figure 4.

The tubular insert may be inserted by hand into a groove vibrated into the plastic concrete or it may be installed mechanically with specially designed equipment. Styrofoam plugs are placed in open ends of the device to prevent the entry of mortar. The insert is installed so that its top is flush with or slightly below the surface of the concrete. After the concrete has hardened but before traffic is allowed on the pavement, the metal tube is crimped down to form a reservoir for joint sealer. This is done by a machine equipped with a wheel that enters the joint and crimps the tube to the proper depth. The ⅜-in. wide void created by crimping the metal tube is rectangular at the top and pointed at the bottom. The specified sealer should be applied immediately after the tube is crimped to prevent the entry of dirt or debris. Figure 4 shows a sequence of the device as installed, crimped and sealed.

This insert has been in use by some state highway departments since 1958. It has been used in highway pavements in several states and in airport pavements. It is included in the U. S. Army Corps of Engineers design criteria for airfield pavements. Joints formed by the tubular insert have a short service record at this time. Performance has been variable. The device appears to function better in pavements with short contraction-joint intervals than it does at longer spacings; joint spalling has occurred on pavements with the tubular insert installed at 60- to 100-ft intervals.

CONCLUSIONS

It appears that each of the methods of joint forming favorably commented on are adequate when used properly and under the proper conditions. Competent engineering judgment should provide the proper method or combination of methods required in a specific situation.

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