NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE

19

DESIGN, CONSTRUCTION, AND MAINTENANCE OF PCC PAVEMENT JOINTS

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE **19**

DESIGN, CONSTRUCTION, AND MAINTENANCE OF PCC PAVEMENT JOINTS

RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION
OF STATE HIGHWAY OFFICIALS IN COOPERATION
WITH THE FEDERAL HIGHWAY ADMINISTRATION

AREAS OF INTEREST:
- PAVEMENT DESIGN
- CONSTRUCTION
- GENERAL MATERIALS
- MAINTENANCE, GENERAL

HIGHWAY RESEARCH BOARD
DIVISION OF ENGINEERING NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING 1973

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Highway Research Board of the National Academy of Sciences-National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectvity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway departments and by committees of AASHO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are responsibilities of the Academy and its Highway Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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PREFACE

There exists a vast storehouse of information relating to nearly every subject of concern to highway administrators and engineers. Much of it resulted from research and much from successful application of the engineering ideas of men faced with problems in their day-to-day work. Because there has been a lack of systematic means for bringing such useful information together and making it available to the entire highway fraternity, the American Association of State Highway Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Highway Research Board to undertake a continuing project to search out and synthesize the useful knowledge from all possible sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series attempts to report on the various practices without in fact making specific recommendations as would be found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available concerning those measures found to be the most successful in resolving specific problems. The extent to which they are utilized in this fashion will quite logically be tempered by the breadth of the user's knowledge in the particular problem area.

FOREWORD

By Staff
Highway Research Board

This report should be of special interest to design, materials, construction, and maintenance engineers responsible for portland cement concrete (PCC) pavement joints. Information is offered on current joint practices, as well as on continuing research trends and needs for PCC pavement joints.

Administrators, engineers, and researchers are faced continually with many highway problems on which much information already exists either in documented form or in terms of undocumented experience and practice. Unfortunately, this information often is fragmented, scattered, and unevaluated. As a consequence, full information on what has been learned about a problem frequently is not assembled in seeking a solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem. In an effort to resolve this situation, a continuing NCHRP project, carried out by the Highway Research Board as the research agency, has the objective of synthesizing and reporting on common highway problems—a synthesis being identified as a composition or combination of separate parts or elements so as to form a whole greater than the sum of the separate parts. Reports from this endeavor constitute an NCHRP report series that collects and assembles the various forms of information into single concise documents pertaining to specific highway problems or sets of closely related problems. This is the nineteenth report in the series.

The first concrete pavement of record in the United States (at Bellefontaine, Ohio, begun in 1891) utilized jointing, but apparently only as a construction convenience. Expansion joints were used as early as 1903 in a Richmond, Ind., pavement, and in a 1906 Washington, D.C., pavement incorporating 100-ft (30.5m) slabs with 1-in. (25m) joint widths. One of the earliest uses of planned contraction joints was in a West Virginia pavement in 1919. Load transfer dowels evidently were first used in a pavement near Newport News, Va., in 1918.

Even with a background of experience dating back over three-quarters of a century, and an unusually strong background of research, joint maintenance continues to be a preponderant part of total pavement maintenance. The recognition of the importance of base support and the increased use of stabilized bases in recent years, together with other significant advances, have been helpful, but the development of a totally satisfactory joint remains to be accomplished.

This report of the Highway Research Board records current design, construction, and maintenance practices for PCC pavement joints, and indicates the scope of present and future research. It also discusses these practices from the standpoint of improved pavement performance, more effective construction and maintenance techniques, and achieving rational design methods.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from many highway departments and agencies responsible for highway planning, design, construction, operations, and maintenance. A topic advisory panel of experts in the subject area was established to guide the researchers in organizing and evaluating the collected data, and to review the final synthesis report.

As a follow-up, the Board will attempt to evaluate the effectiveness of this synthesis after it has been in the hands of its users for a period of time. Meanwhile, the search for better methods is a continuing activity and should not be diminished. An updating of this document is ultimately intended so as to reflect improvements that may be discovered through research and practice.

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ACKNOWLEDGMENTS

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Information on current practice was provided by many highway agencies. Their cooperation and assistance were most helpful.

DESIGN, CONSTRUCTION, AND MAINTENANCE OF PCC PAVEMENT JOINTS

SUMMARY

Joints are placed in concrete pavements to control cracking and accommodate movements caused by changes in temperature and moisture, and to facilitate construction. Jointing practice has evolved from simple butt joints to complex designs with load transfer assemblies and sealant reservoirs that preserve joint function through a range of conditions.

All joints alleviate warping stresses. Those designed exclusively for that purpose, such as center-line joints, are of the weakened-plane type, with the adjoining slabs usually tied together with steel. Those allowing longitudinal contraction as well as warping relief are contraction joints. Those permitting longitudinal expansion in addition to contraction and warping relief are expansion joints. Special joints permitting large movements are used at bridge approaches. Changes in joint width depend on pavement design, environment, restraint, and other factors.

Joint design involves knowledge of road use and traffic; pavement type; load transfer requirement; subgrade support; environment, including temperature extremes and freeze-thaw cycles; soil type and frost susceptibility; aggregate characteristics; and sealant properties. Under favorable conditions (little movement, short slabs, good support, good drainage) plain concrete pavements may be used with weakened-plane contraction joints made with transverse plastic inserts and without dowels. Under severe conditions, with heavy traffic and with reinforced pavement, doweled contraction joints are required with reservoirs and sealants that are designed to be compatible with the longitudinal movement. Special jointing systems may be required at bridges.

Construction of pavement joints varies greatly in difficulty and cost. Mechanical placement of plastic inserts in longitudinal center-line joints is simple and cheap. Sawed contraction joints in plain pavements are relatively simple to build and are not difficult to seal. Contraction joints in reinforced pavements require the operations of preparing and staking the dowel basket (or mechanically implanting the dowels), marking the dowel location outside the area of disturbance, grooving or sawing to the required depth and reservoir width, cleaning the groove, placing the seal, and protecting the joint from infiltration during early traffic. Expansion joint load transfer units require addition of a compressible filler and appropriately placed expansion caps on the dowels, and hand finishing of the groove. Most exacting is the preparation and placement of special bridge approach joints, which sometimes require sleeper slabs and anchor lugs.

Placing of the joint sealant is an operation requiring meticulous care and thorough cleaning of the recess and groove. Poured sealants must be deposited to proper depths without air or moisture entrapment. Preformed sealants must be tailored to the correct width and placed mechanically to avoid detrimental elongation.

Problems at joints are related to magnitude of movement, load transfer mechanisms, base support, moisture and frost environment, compatibility of design

and materials, presence of incompressible particles, use of deicing salts, and adequacy of slab thickness for current traffic. Common types of distress are raveling, spalling, faulting, pumping, and blowups.

Maintenance of joints includes the preventive operations of removing sources of contamination, cleaning joints of old seals and infiltrated particles, and resealing. Remedial operations include correcting poor slab support, stabilizing moisture-susceptible soils, correcting drainage and removing sources of excess water, and repairing spalls. Maintenance also includes reconstruction activities following blowups, and replacement of "frozen" joints as well as those joints destroyed by frost action and pumping.

Research is needed to improve joint design, construction, and maintenance. Suggestions include the development of new paving types, such as a modification of continuously reinforced pavement with controlled cracking (elastic joints), and pavements that can be held in mild compression by improved prestressing techniques. More effort should be expended on joint seal development. Concepts of preassembled joints should be explored. Rapid means of removal and replacement of concrete should be developed. There is need for rapidly setting concretes that can minimize expressway maintenance delays.

Details of design, construction, and maintenance of concrete pavements are included in the many references in this report and in Appendix A. This report is intended to stimulate paving engineers to reexamine their prevailing practices, to reassess the compatibility of their designs with location and environment, and to use good design, construction, and preventive maintenance to obtain improved joint performance.

CHAPTER ONE

EVOLUTION OF JOINTING

The section of street at Bellefontaine, Ohio, paved in 1891 is the first portland cement concrete pavement of record in the United States. It must be assumed that the jointing was a construction convenience rather than a planned spacing for temperature effects. Pavements laid in Toronto in 1902 were 20-ft (6.1 m)* squares with ¾-in. (19 mm) wide joints filled with "paving pitch." "Large" slabs were placed in Richmond, Ind., in 1904, with 1-in. (25 mm) wide joints; subsequent reports mention temperature cracking.

One early record mentions that 100-ft (30.5 m) slabs were built on a 1906 Washington, D.C., project, with 1-in. (25 mm) joint widths. By 1913, joint spacings ranged from 25 ft (7.6 m) to 100 ft. Although the slabs were predominantly rectangular, some joints were skewed. Joint widths varied from ¼ to 1 in. (6 to 25 mm) and many filler materials were used. In 1914, the American Concrete Institute (ACI) recommended that slabs be not more than 35 ft (10.7 m) long, that joints be not less than ¼ in. nor greater than ⅜ in. (10 mm) wide, and that joint edges be protected by steel (*1*).

Until 1914, joints were built with the thought that concrete would expand as temperatures increased, and that some relief or expansion space should be provided to prevent the buildup of high compressive stresses. However, engineers then learned that the first slab volume changes were contractions, and, therefore, expansion space at all joints was unnecessary.

The first use of a weakened-plane contraction joint was reported in 1919 on a West Virginia project. A thin board, one-half the slab depth, was positioned on the subgrade to reduce the section. A controlled crack occurred over the board as the concrete temperature dropped at night from its high value due to early hydration. Later, this technique was rejected because of erratic cracks at the surface. In-

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* SI equivalents are conversion of U.S. customary units in accordance with "Metric Practice Guide," ASTM E 380-70.

stead, deep grooves were formed in the top surface of the concrete and then filled with mastic to "seal" the crack.

As wider pavements were built it was observed that two-lane slabs developed meandering longitudinal cracks in the central area. About 1920, longitudinal center-line joints were introduced in pavements 20 ft (6.1 m) or more in width, and later the existence of warping stresses sufficient to crack the slabs was theorized by Westergaard (*2*). Soon tie bars were placed across center-line joints to prevent lane separation.

INTRODUCTION OF LOAD TRANSFER DEVICES

There is no reported use of special designs or techniques for joint construction prior to 1918, when load transfer dowels were used on a pavement near Newport News, Va. Only four ¾-in. (19 mm) dowels across a ⅜-in. (10 mm) joint were used for a 20-ft (6.1 m) wide pavement. Other states began experimenting with devices for transferring loads across joints and many proprietary devices were developed. These devices, as well as dowels, were tested by several agencies and reports were published by Michigan, New York, Texas, Illinois, and others (*1, 3*).

Laboratory analyses of dowel performance were made by Friberg (*4*) and by Finney and Fremont (*5*). Field application indicated deficiencies in the sizes then recommended, and subsequent tests by Teller and Cashell (*6*) in 1958 indicated the need for dowel diameters to be one-eighth of the pavement thickness.

TEST ROADS AND PAVEMENT SLABS

Three major investigations conducted during the 1920's and 1930's had great influence on concrete pavement design and jointing practice. These were the Pittsburg test in California (*7*), the Bates tests in Illinois (*8*), and the Bureau of Public Roads (BPR) tests at Arlington, Va. (*9*). The first two were road tests in which pavements of several designs were constructed in large loops and traversed by trucks of known weights. The Arlington test was a scientifically designed experiment with slabs that were subjected to static loads applied at specific locations.

The Pittsburg test was designed primarily to examine the need for steel reinforcement in concrete pavements. Slabs of several designs were separated by full-depth joints. The Bates test was considerably broader in scope and the slabs were instrumented to observe the effects of load intensity and location on slab deflection at the joints. The Arlington tests included slab deflection and strain measurements on the concrete at many locations. Joints of several designs were evaluated. A later investigation by Sutherland and Cashell (*10*) resulted in formulas for assessing joint effectiveness.

COOPERATIVE ROAD TESTS

About 1940, a cooperative study to investigate concrete pavement design was initiated by six states (California, Kentucky, Michigan, Minnesota, Missouri, Oregon) and the Bureau of Public Roads. The reports (*11, 12*) revealed the influence of climate and traffic on joint behavior. The joints studied were of several types and were spaced at various distances. The spacing of full-depth expansion joints was a major variable, as was the intermediate spacing of several types of contraction joints. In addition, some sections were designed without expansion space. Also, in some reinforced pavement slabs grooves were formed in the concrete above the distributed steel to provide a tied (dummy) joint that relieved warping stresses but did not permit horizontal width changes. Michigan reported the following significant facts (*13*):

> 1. The seasonal movements of the expansion joints indicate that a considerable expansion and subsequent permanent displacement of the slab ends takes place during the first year after construction, using at least 50 percent of the space originally provided.
> 2. Subsequent to the first year's movement the section ends oscillate with seasonal temperature changes, the amplitude of these seasonal movements gradually diminishes with time, and a slow, progressive permanent displacement takes place. Eventually the joint filler may become compressed to the state that no further longitudinal movement can occur.
> 3. Contraction joint spacing has considerable influence upon the amplitude of expansion joint movement.
> 4. All contraction joints acquire a small permanent opening, which increases with time. The degree of joint movement and amount of residual opening is more pronounced as the distance between contraction joints is increased.
> 5. The movement of contraction joints is greater near the expansion joints than it is near the center of the sections.
> 6. Dummy joints react similarly to contraction joints, but to a much smaller degree.
> 7. In sections of pavement longer than 1,800 ft without expansion joints, there is a point of zero longitudinal movement approximately 700 to 900 ft from the ends of the section. Consequently, the central portions of such sections at elevated temperatures will be under restraint similar to that of continuous slabs in which no expansion joints have been provided.

Concluding statements indicated that (1) adequate load transfer is essential; (2) grooving and sealing is superior to bituminous fiber inserts; (3) continuous plate assemblies are conducive to severe spalling; (4) thickened edges were not superior to uniform sections; and (5) commercial hot-poured asphalt-rubber compounds were better than other poured materials for seal durability.

A summary of the 10-year reports (*14*) shows progressive closure of expansion joints, with the greatest movement occurring in the early years (Fig. 1). Correspondingly, contraction joints opened, although where the expansion joints were eliminated or widely spaced there was little tendency for the contraction joints to open progressively. The study had great influence on the decisions of highway departments to eliminate expansion joints from their designs.

SEALANT RESEARCH

After the joint is designed and built, its preservation as a working component of the pavement is important. Sealing is the means by which preservation is attempted. The history of joint seal development parallels that of joint design. It was recognized early that some kind of deformable

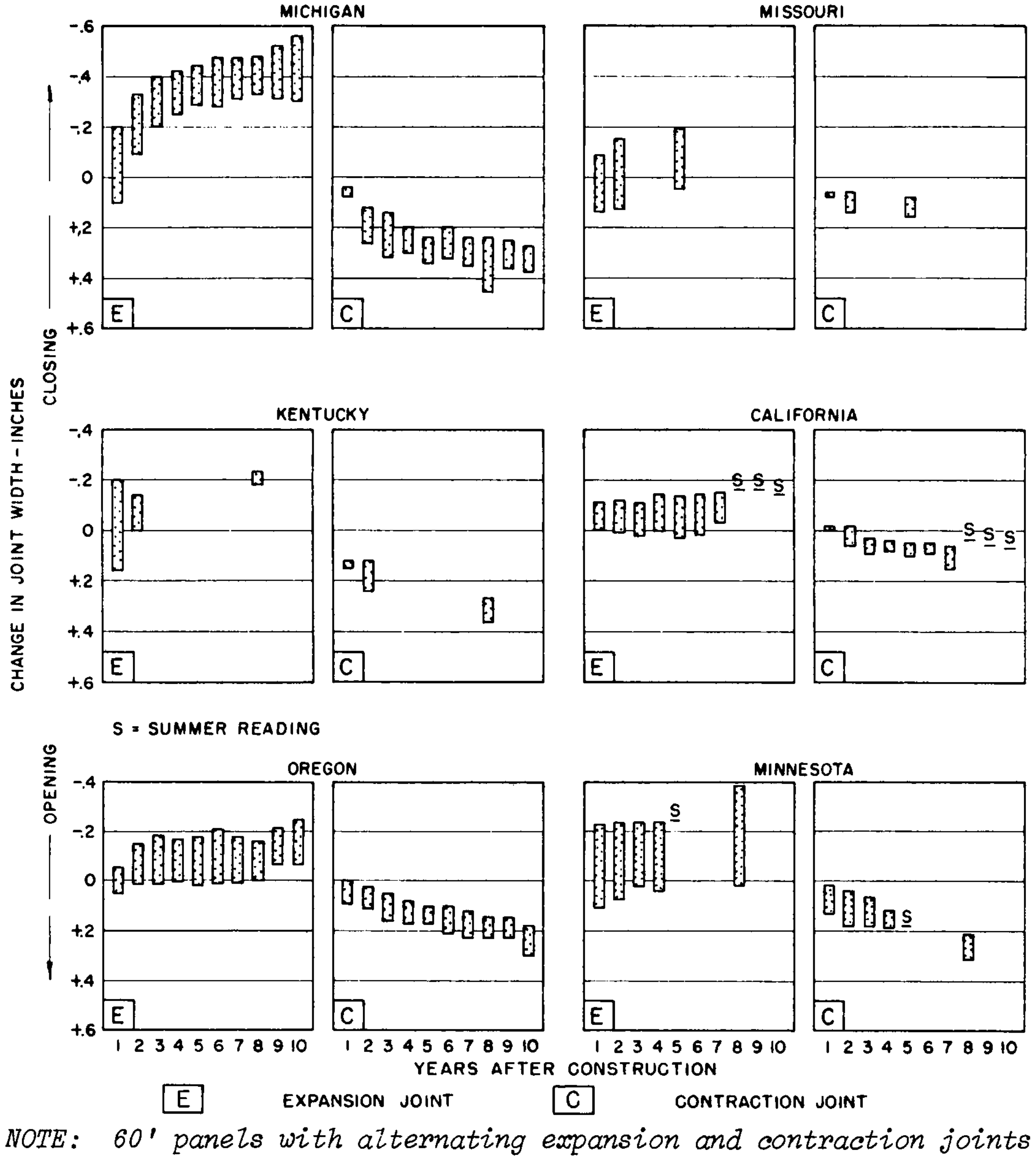


Figure 1. Annual and progressive changes in the width of expansion and contraction joints, reinforced sections (14, *Fig. 3*).

material should fill the joints and cracks in concrete pavements to prevent infiltration of water and dirt. However, little thought was given to the application of the seal until the cracks and joints opened in the fall, when maintenance crews with the familiar tar kettles poured tar into the cracks. As coal tar can be melted with direct heat and is relatively insensitive to overheating, it seemed to be an ideal crack filling material. However, its ductility is lost in cold weather, and so the tar seal becomes brittle and ineffective when the crack width is greatest.

Asphalt was tried as a seal because it retained some ductility at low temperatures. However, this material flowed at high temperatures and also fell short of the extensibility requirements in areas of low temperatures. A mixture of natural rubber latex and asphalt was conceived and was a distinct improvement. This sealant was less sensitive to temperature, had improved ductility at lower temperatures, and had better adhesion and cohesion properties. In the short-slab sections of the cooperative research studies (*12*), this seal performed favorably.

World War II depleted the supply of natural rubber, so a compromise seal using reclaimed rubber was substituted. This proved to be inferior to the natural latex-asphalt seal, but was used as an expedient for a number of years. Later, it was modified by the addition of synthetic latex, to give the product now in common use.

The boom in plastics had its impact on joint seals. In attempts to find new markets for their products, entrepreneurs proposed a large number of materials for sealing joints. These included elastomers of all types, most of which, because of the short pot life of the product, required the mixing of two components at the job site. Some exhibited good adhesion and cohesion characteristics, but few survived the rigors of winter joint movement. The need for clean joint faces and a product that remained ductile at winter temperatures and resilient at summer temperatures was difficult to satisfy at acceptable prices.

Sealant failures, even those occurring in carefully controlled field experiments, have not necessarily been caused by the material. Poor joint designs (too narrow, too deep, too large a movement, hydraulic pressures, etc.) may have subjected the sealants to demands that were impossible for any sealant to meet.

The influence of shape of the sealant reservoir was examined by Tons (*15*). He found that some materials with good extensibility that heretofore had failed when installed in narrow grooves because they were stressed above their extensibility limits, could be used safely with an optimum reservoir shape. Figure 2 shows this concept.

To overcome the requirement that sealants must remain tightly sealed to the joint faces by high adhesive forces, the industry began to experiment with premolded strips of styrene, urethane, polychloroprene, and other synthetic rubbers that could be inserted into the reservoirs and remain under compression. Probably the most popular of the preforms were the compartmented neoprene strips. One of the pioneering states in research on preformed seals was New York. They found that preformed compression seals appeared to give the best over-all service for sawed transverse (*16*) and longitudinal (*17*) joints.

CURRENT STATUS OF AMERICAN PRACTICE

A survey of current concrete pavement practice (Appendix B) shows that few states build expansion joints except at structures. Almost all transverse joints are of weakened-plane types, with sawed grooves, formed grooves, or insert strips in the upper area of the slab. In most cases the grooves are sealed with hot-poured elastic material, although the acceptance of preformed seals seems to be increasing. Dowels or similar load transfer mechanisms are used by almost all agencies.

Longitudinal grooves for center-line crack control are usually sawed. A number of states permit use of plastic insert strips as alternates and a few states specify this method. Almost all longitudinal joints are tied. Joints at the lane edges are more often keyed than butted.

Contraction joint spacing in plain pavement ranges from 12 to 30 ft (2.7 to 9.1 m) in repeat pattern designs. Spacings in reinforced pavements range from 25 (for gravel aggregates) to 100 ft (7.6 to 30 m). Several agencies now specify a "random" spacing of joints; i.e., a repeated pattern of three or four different spacings, such as 13, 19, 18 and 12 ft. (4.0, 5.8, 5.5, and 3.7 m), frequently in conjunction with a skewed joint.

It is generally recognized that the performance of a joint is dependent on base support. Many agencies are now using cement- or bituminous-treated bases to support concrete pavement.

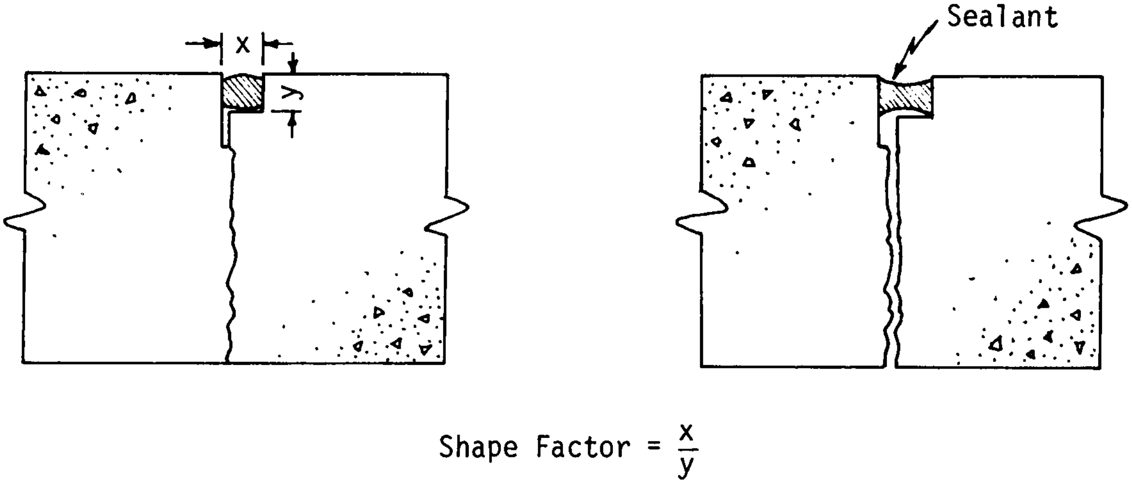


Figure 2. Concept of shape factor and effect on sealant elongation.

CHAPTER TWO

JOINT FUNCTIONS

A joint in a concrete pavement is an engineered cleavage to facilitate construction or to limit stresses due to environment to acceptable values. Without joints for stress control, unsightly random cracks develop. The unpredictability of these cracks in both location and size makes maintenance difficult. Planned jointing minimizes random cracking and permits sufficient width control and reservoir design so that the joints may be sealed against ingress of water and small solid particles.

Although control joints are necessary in conventional pavements to make the material compatible with the environment, they are detrimental in that they form boundaries. Load stresses are greater at boundaries than at interior locations, and the discontinuities require special treatments to enable loads to be transferred to adjacent slabs.

TYPES OF JOINTS

Pavement joints may be designated as expansion, contraction, construction, warping, or edge joints according to their construction and function. (Some variations of these names are: center-line, control, night, dummy groove, and hinge). All joints fall within two general classifications: transverse and longitudinal.

Transverse Joints

Transverse joints include (a) expansion joints (provide expansion space, permit slab contraction, and relieve warping stresses); (b) contraction joints (permit slab contraction and relieve warping); (c) construction joints (to facilitate construction; may be designed as either contraction or expansion joints); and (d) warping joints (restrain horizontal movement but relieve warping stresses).

Expansion Joints

Expansion joints are those that provide space for slab expansion or anticipated progressive horizontal movement (Fig. 3a). Such movement may result from a gradual shoving of an adjacent slab due to infiltration of other joints and cracks while they are open during the cold season, or from some unusual condition that causes abnormal growth or lengthening of the concrete. Usually, these joints are infrequent and are placed at structures and intersections to accommodate the movement. The common expansion joint is identified by the compressible filler material installed full depth between the slabs. In a few cases they are spaced at more frequent intervals (about 600 ft; 180 m) in the main-line pavement when concrete is placed in late fall or early spring and it is anticipated that ambient temperatures plus the heat of hydration following construction may not cause the slabs to attain lengths as great as those expected during hot summer weather.

Bridge approach joints are special forms of expansion joints that allow greater movement. They are either modifications of usual expansion joints or they incorporate special devices. A common practice is to use a wide section of asphaltic concrete before the bridge. One method of doing this is shown in Appendix C. Another practice is a series of several short slabs separated by expansion joints of the common main-line type. Another practice uses a slab with anchor lugs in the subgrade (Fig. 3d). When the total movement is absorbed in a single joint, special techniques may be used, such as the wide-flange joint (Fig. 3d), which is more often used in CRCP.

Contraction Joints

Contraction joints are designed cleavages spaced to inhibit intermediate random cracking due to slab shortening (Fig. 3b). Under normal warm-weather construction conditions the pavement slab attains its greatest length soon after placement because of high early-hydration temperatures. As ambient temperatures decline and hydration heat diminishes, the resulting contraction, combined with some drying shrinkage, causes slabs to shorten significantly at early ages. Contraction joints are designed and spaced to permit this movement, thus reducing frictional drag stresses induced in the concrete to tolerable values. They usually are built by weakening the cross section, either by grooving the fresh mix, embedding an insert strip, or sawing a groove as soon as the concrete has attained sufficient strength to allow cutting without raveling.

Construction Joints

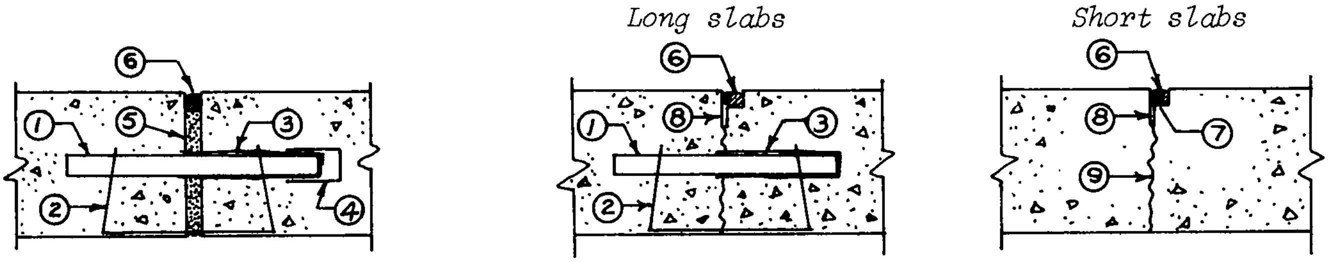
Transverse construction joints are built when it is necessary to halt construction, such as at the end of a day's work. Often, transverse construction joints fall at planned locations for expansion or contraction joints and are built to conform with the specifications for those joints.

Warping Joints

Transverse warping joints, built between contraction joints in reinforced slabs by placing inserts or cutting grooves above the distributed steel, are used in some states. However, the most common form of warping joint is the longitudinal joint between two lanes constructed at the same time (see following section).

Longitudinal Joints

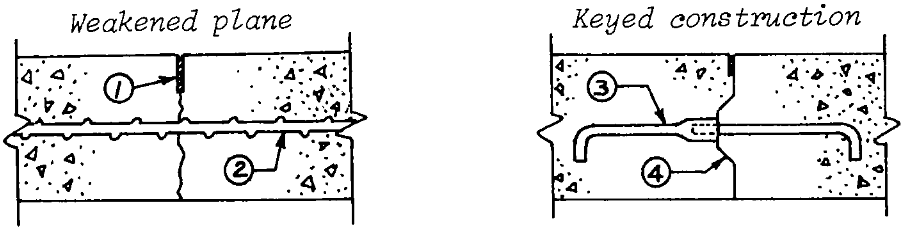
Longitudinal joints are located between lanes or at the edge of the pavement, and are either weakened-plane (warping) joints or construction joints. Both types restrict lateral movement (assuming tie bars are used) and relieve warping stresses.


(a) Expansion Joint

(b) Contraction Joints

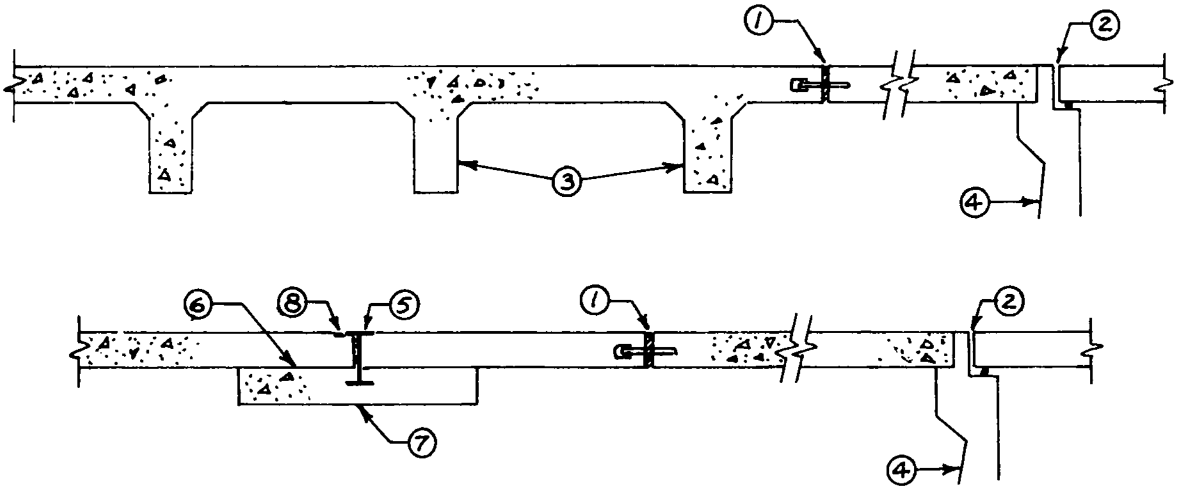
1. *Dowel*
2. *Basket*
3. *Coating*
4. *Expansion cap*
5. *Filler board*
6. *Seal*
7. *Stop strip*
8. *Groove*
9. *Interlocking aggregate*

(c) Between-Lane Joints



1. *Groove with sealant or insert*
2. *Deformed steel tie*
3. *Threaded insert tie (or bent re-bar)*
4. *Molded key and keyway*

(d) Bridge Approach Joints



1. *One or more conventional expansion joints*
2. *Bridge joint*
3. *Reinforced transverse beams*
4. *Bridge abutment*
5. *Wide flange beam or proprietary device*
6. *Friction reducer (plastic, asphalt, etc.)*
7. *Sleeper slab*
8. *Seal*

Figure 3. Joint types.

Center-Line Joints

Warping joints are used at the center line of two-lane pavement cast in a single operation to reduce stresses that attempt to make the concrete slab deviate from its initial plane. Temperature differentials between the top and bottom surfaces of slabs produce such stresses, as do moisture differentials. These stresses, in combination with vehicle loads, cause pavements over 16 ft (4.9 m) wide to develop an off-center longitudinal crack if a joint is not provided. Erratic crack patterns and displacements may be caused also by subgrade movement due to moisture or frost swell and loads that deflect slabs temporarily from their neutral planes where inadequate foundations exist. The weakened planes are usually constructed either by inserting a parting strip vertically into the fresh mix or by sawing a groove of specified depth after the concrete has hardened. Unless transverse steel extends continuously across the pavement joint, tie bars usually are used to restrain movement.

Construction joints are used to join adjacent pavement lanes that are constructed separately. These are full-depth joints with abutting smooth faces or with formed keys and keyways. Movement is usually restrained by tie bars.

Edge Joints

Edge joints, relatively new in concrete pavements, are the longitudinal joints between the pavement and a concrete shoulder. Tie bars are sometimes used to prevent separation and to preserve the seal that prevents surface water from infiltrating beneath the pavement edge.

"MOVEMENTS" OR CHANGES IN JOINT WIDTHS

Although joints are designed for several purposes, a common function for all joints is the reduction of warping and curling stresses. Whether the slabs actually separate or simply hinge at a joint, a moment discontinuity exists and bending stresses are relieved. The basic difference in joint types is the nature of the provision for horizontal movement.

Tied joints (such as warping, center-line, and most longitudinal joints) are designed to prevent joint opening. Consequently, if load transfer is adequate and little relative vertical movement develops, they make minor demands on sealants.

Contraction joints allow limited openings, with magnitude dependent on the environment and slab lengths. Poured sealants for these joints are subjected to high adhesive and cohesive tensions, whereas preformed seals must continue to expand and press against the joint faces with sufficient compression to withstand displacement by traffic.

Expansion joints, and bridge approach joints, cycle in both expansion and contraction during early pavement life. Movements are relatively large and joint seals are difficult to maintain. One joint used to separate roadway pavement from bridge structures is shown in Appendix C.

The cooperative study report (*12*) gives many data on joint width change, both seasonal and daily. From the

TABLE 1

JOINT MOVEMENTS[a]

JOINT TYPE AND SPACING	DAILY MOVEMENT (IN./°F)	(MM/°C)	SEASONAL MOVEMENT (IN.)	(MM)	10-YEAR JOINT CLOSURE (IN.)	(MM)
Dummy at 30 ft (9 m) between contr. jts. at 60 ft (18 m)	<0.001	<0.05	0.001 to 0.008	0.025 to 0.20	—	—
Contraction at 30 ft (9 m) RCP	0.002	0.09	0.025 to 0.10	0.6 to 2.5	—	—
Contraction at 60 ft (18 m) between exp. jts. at 120 ft (37 m)	0.002 to 0.005	0.09 to 0.23	0.10	2.5	—	—
Contraction at 60 ft (18 m) between exp. jts. at 240 ft (73 m)	—	—	0.15	3.8	—	—
Expansion at 120 ft (37 m) with contr. jts. at 60 ft (18 m) and dummy jts. at 30 ft (9 m) 1-in. (25 mm) exp. space	0.003 to 0.004	0.14 to 0.18	—	—	0.55[b] 0.3[c]	14[b] 7.6[c]
Expansion at 240 ft (73 m) with contr. jts. at 30 ft (9 m) and dummy jts. at 15 ft (4.6 m) 1-in. (25 mm) exp. space	0.001 to 0.002	0.05 to 0.09	—	—	0.8[b] 0.6[c]	20[b] 15[c]

[a] From Ref. *13*. [b] Maximum. [c] Residual.

Michigan data (*13*) it is noted that "dummy joints," which are tied warping joints midway between contraction joints, had small daily and seasonal movements (Table 1). Closure was not complete and movements cycled about values that increased with age and, with a few exceptions, reached values of 0.035 in. (8.9 mm) after 10 years.

Contraction joint movements were dependent on slab length, distance between expansion joints, and location with respect to expansion joint (Table 1). The 60-ft (18 m) contraction joints between 120-ft (37 m) expansion joints had a residual opening of about 0.35 in. (8.9 mm) after 10 years. For the same slab length between expansion joints spaced 240 ft (73 m) or more, the 10-year residuals were about 0.10 to 0.15 in. (2.5 to 3.8 mm).

Expansion joint movement depended on total pavement joint spacing; when expansion joint spacing was doubled, and dummy and contraction spacing was halved, daily expansion joint movements were reduced substantially (Table 1). The largest seasonal and progressive movements occurred at expansion joints with the greatest spacing (Table 1). Extreme expansion joint closures were found in the sections with 2,700-ft (823 m) expansion joint spacings, where total closure of a 3-in. (76 mm) joint reached almost 2.4 in. (61 mm) and residuals were about 2.2 in. (56 mm).

Thus, warping joints tend to widen slightly with time, contraction joints tend to widen more and the increase in width is greater with greater spacing, while expansion joints tend to close progressively in magnitudes also related to spacing.

CHAPTER THREE

JOINT DESIGN

A number of factors must be considered when a joint is designed. These include joint function (see Chapter Two), anticipated movement, load transfer, slab support, pavement type and thickness, cracking beneath the groove, sealants, and traffic.

Because the costs of transverse joints are reduced as provision for movement is reduced, it is advantageous to design a joint only for the appropriate function and with provisions for the minimum necessary movement.

ANTICIPATED MOVEMENT

Factors determining the width changes in transverse joints are temperature, slab length, moisture environment, expansive characteristics of the concrete, particle size and stability of base and shoulder materials, and freeze-thaw cycles. Also, there is mutual interaction between expansion and contraction joints, so that the residual openings of contraction joints increase when expansion joints relieve horizontal restraint.

Temperature Ranges

Temperature ranges vary greatly throughout the United States and Canada. Daily air temperature ranges of 60° F (33° C) may be experienced in spring and fall in some states and seasonal ranges may be as great as 130° F (72° C). Actual pavement temperature is a function of wind, precipitation, air temperature, solar radiation, and the thermal properties of the pavement. One report (*23*) calculated the seasonal differences in pavement temperatures for the continental U.S., based on average conditions in the States, and expressed them as shown in Figure 4. In general, the figure shows temperature differences that are much greater than those commonly used for design and, as such, are probably conservative. For local conditions, the exact thermal difference can be measured on adjacent pavements or calculated by the procedure recommended by Barber (*24*).

The Michigan data from the cooperative study (*13*) showed daily width changes in contraction joints at 60-ft (18 m) spacing to be up to 0.005 in. per °F (0.23 mm/°C) (see Table 1), so a 60° F change in temperature would result in a width change of 0.30 in. (7.6 mm). This design incorporated expansion joints at 120-ft (37 m) spacing and contraction joint movement was unusually large. Movements for contraction joints at 30-ft (9 m) spacings were about one-half of this amount.

Short-slab joint movements were significantly smaller. In the Michigan sections with 20-ft (6 m) slabs and with expansion joint spacings greater than 900 ft (274 m), daily contraction joint movements seldom exceeded 0.001 in. per °F (0.05 mm/°C) and seasonal movements were about 0.05 in., cycling about residuals from 0.05 to 0.08 in. (1.3 to 2.0 mm).

Because of subgrade and end restraints, joint width changes are less than would be predicted by mathematical use of the coefficient of expansion (Fig. 5). However, there are unpredictable variations from joint to joint and provision for ample movement must be provided to assure control of those joints developing unusual openings.

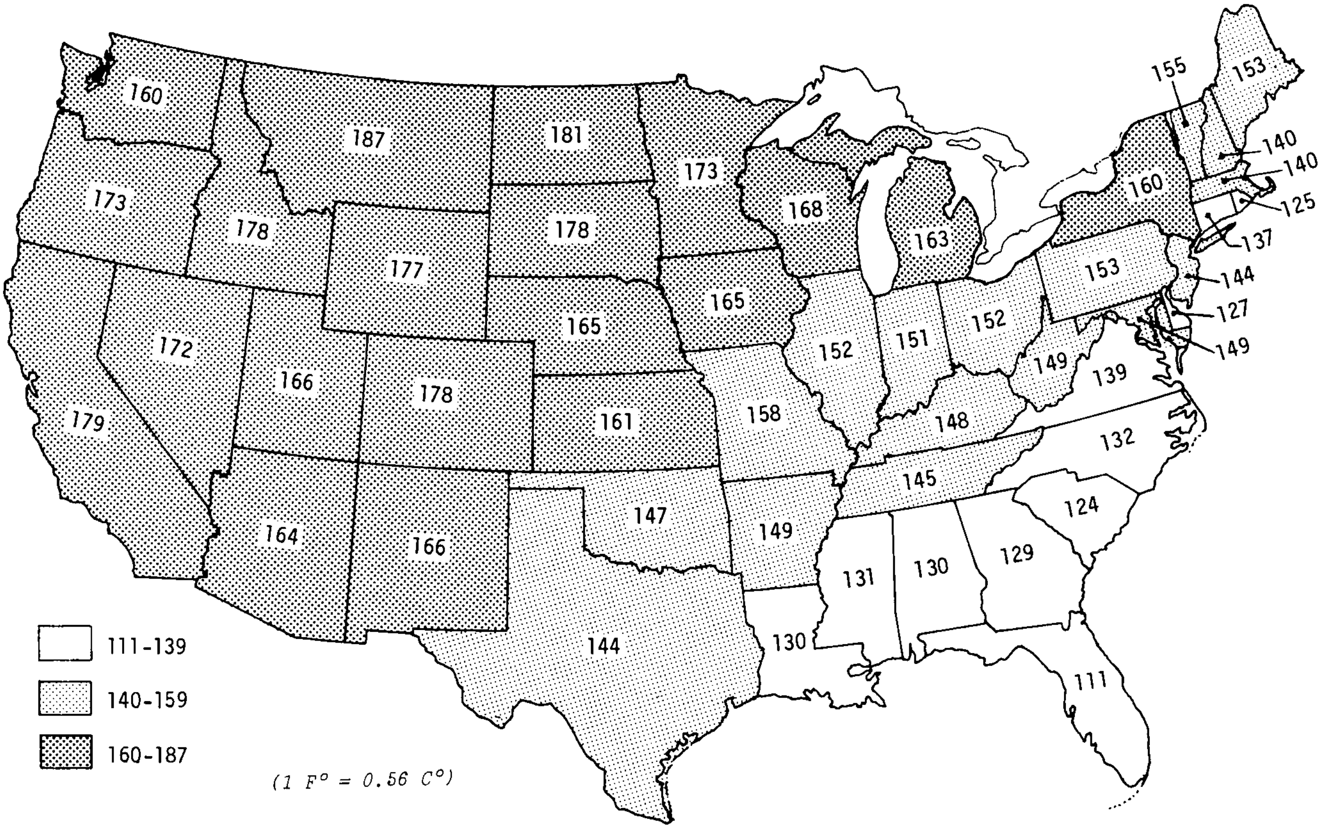


Figure 4. Calculated maximum seasonal temperature differences (°F) in concrete pavement (after Pachuta and Smith, 23).

Slab Length

Slab length was noted to be a prime factor in the amount of joint movement. This is important in joint design because of the effect on load transfer mechanisms, sealant type and retention, and use of reinforcement. If other factors determine that a reinforced design is to be used, economics suggests that the slabs be as long as tolerable to minimize the number of load transfer assemblies required, but short enough to allow the joints to be properly sealed.

If the design is plain concrete, joints can be spaced 20 ft (6 m) or less apart to utilize aggregate interlock for load transfer. Experience as well as laboratory tests show that load transfer by aggregate interlock becomes ineffective at openings of 0.035 to 0.04 in. (0.9 to 1.0 mm). To assure openings below the limit, slab lengths in plain concrete must be based on environment and material factors.

Moisture

Moisture in the concrete is an important element in the behavior of concrete pavements. Unfortunately, moisture content in pavements is difficult to measure as an entity and its effects depend greatly on the characteristics of the aggregates, the fresh concrete proportions of the ingredients, and the environment. A slab on grade never dries out entirely; its bottom remains wet, while the upper surface shrinks and expands with changes in the surface moisture content. In one experiment the slab experienced an overall shrinkage of between 50 and 100×10^{-6} in./in. during the late summer after being cast. During the following wet winter it expanded to between 0 and $+50 \times 10^{-6}$ in./in., thus producing a maximum annual cyclic range of 150×10^{-6} in./in. (*25*).

This general magnitude of shrinkage and expansion from moisture is probably typical of most slabs on grade, but may not hold true for concrete containing porous or soft nondurable aggregates. These values can be compared to the thermal expansion, which is about 500×10^{-6} for a 100° F (56° C) temperature range. The moisture content also affects the coefficient of thermal expansion, the modulus of elasticity, and the strength of the concrete. Although few good data are available on the effects of moisture in slabs on grade, many data do exist on laboratory specimens. Laboratory tests on concrete from the AASHO Road Test indicated that adding 0.5 percent moisture to dry specimens produces the same unit increases in length that occur with a temperature increase of about 35° F (18° C) (*26*). However, it is difficult to relate this to field performance. The field moisture content is not easy to ascertain and thermal effects confound the analysis.

Another effect of moisture is to create warping in the slabs and cause the slab ends to lift upward. This creates a permanent condition in the slab with uplift as much as $\frac{1}{16}$ to $\frac{1}{8}$ in. (1.6 to 3.2 mm) independent of cyclic temperature curl.

Thermal Expansion

Expansion characteristics of the concrete are important in anticipating joint width changes. It has commonly been assumed that ordinary concrete will expand about 5 to 6×10^{-6} in./in./°F (9 to 11×10^{-6} mm/mm/°C) increase in temperature. Fortunately, the coefficient of thermal expansion for steel is in the same range and no shape distortion is experienced in reinforced concrete slabs due to the presence of steel under ordinary conditions. Because of subgrade restraint, a practical calculation for anticipated joint movement for either plain or reinforced slabs can be made by modifying the expansion coefficient figure to 4×10^{-6}/°F (7×10^{-6}/°C) to compensate for restraint.

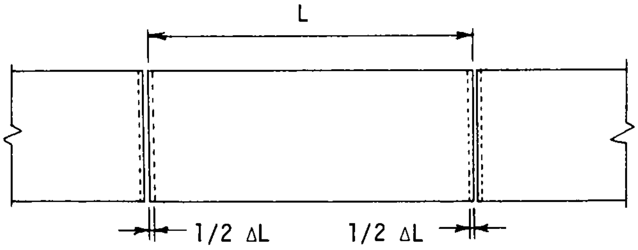
Aggregates affect the thermal expansion of concrete. The 1972 joint survey (Appendix B) shows that Kentucky uses 25-ft (7.6 m) joint spacing when gravel aggregates are used, but permits 50-ft (15 m) spacing with limestone aggregate concrete. Michigan has shown that aggregates with a greater amount of soft and nondurable material contribute to pavement blowups, but in this case large expansion may be coupled with deteriorated joint faces that cannot withstand high stresses.

Europeans have experimented with cements with low heat of hydration that reduce the initial volume of slabs of fresh concrete. So-called "expansive" cements also have been tried in some pavements. Although the thermal coefficient does not change significantly, the fresh concrete tends to expand if kept wet for the first three days. It then tends to cycle with temperature changes about a length greater than that for a similar slab of Type I or IA cement. Reports on the effectiveness of this material are conflicting.

Particle Size

Particle sizes of base and shoulder materials are significant because these materials can infiltrate pavement joints and cause loss of expansion space. California studies of plain pavements on cement-treated bases indicated that material under the approach slab migrated from the shoulder. In the AASHO Road Test the thin underdesigned slabs pumped base material both at edges and through joints. Short longitudinal "crow foot" cracks that appeared on some older pavements at infiltrated joints were thought to be caused by high shear stresses due to incompressibles in the infiltrated material.

Many concrete pavements are built on cement-stabilized or bituminous-stabilized bases and some pavements are flanked with concrete or bituminous shoulders. Where the edge joints are kept sealed, the ingress of surface water and debris is restricted, with the result that joint infiltration is reduced significantly, hence providing better-performing joints.



L = 30 ft = 360 in (9144 mm)

Curing Temperature = 80°F (27°C)
Winter Low = -20°F (-29°C)
ΔT = 100°F (56°C)

Coefficient of expansion:

$\alpha = 5 \times 10^{-6}$ in/in/°F (9×10^{-6} mm/mm/°C)

$\Delta L = (\Delta T)\ (\alpha)\ (L)$

$\Delta L = (100)\ (5 \times 10^{-6})\ (360)$ in

$= (56)\ (9 \times 10^{-6})\ (9144)$ mm

$\Delta L = 0.18$ in (4.6 mm)

[Note: Compare to actual seasonal movement of 30 ft slab in Table 1]

Figure 5. Mathematical prediction of seasonal joint movement.

Freeze-Thaw Cycles

Freeze-thaw cycling is currently the standard method of distinguishing good from bad concrete in the laboratory. Similarly, in pavements, freezing and thawing can be detrimental to substandard concrete. Joint faces subjected to large amounts of deicing salts are prone to deteriorate. Thus, it is not surprising that joint problems are more prevalent in regions of many freeze-thaw cycles than in other areas. Unfortunately, good aggregates are becoming scarce in some areas and unavailable in others. Producers have been required to use beneficiation procedures to reduce the occurrence of detrimental materials in freeze-thaw areas. However, there are many areas of the U.S. that have few freeze-thaw cycles and can build roads with concrete of a quality not as high as that necessary in the northern states and Canada. In cold regions, top quality concrete and effective joint seals are essential.

Expansion Relief

Expansion relief has been shown to be a serious problem. Protection to prevent damage and avoid displacement must be provided at bridges, at intersections with other concrete roads, and at railways. Also, relief must be provided to prevent blowups, particularly where concrete was placed during cold weather. A dilemma appears when it is recalled that contraction joints get wider as expansion relief is offered.

Relief cannot be provided with an open joint because it would soon be filled with solids. To resist this infiltration, compressible inserts are used. These are usually ¾ to 1 in. (19 to 25 mm) thick, 1 in. less than the pavement depth, and made of asphalt-impregnated fibers. Other methods are sometimes used at bridges (see Fig. 3d and Appendix C).

It appears that expansion relief as built into a new pavement has a limited life. When slabs contract, infiltration space is provided. When they expand, the infiltrated material is compressed and permanently occupies some of the space. Recurrence of this action eventually uses all of the relief provided and new relief must be constructed. Several states have found it necessary to saw one or more new expansion joints near bridges.

LOAD TRANSFER

Vertical slab alignment is preserved by the use of some means of load transfer. The purpose is to provide shear transfer when axles move across the joint. The load transfer mechanism retards faulting from frost action in the subgrade, moisture swell of certain soils in arid regions, and loss of support due to pumping. However, the design is primarily to transfer load.

Aggregate Interlock

Aggregate interlock is the simplest means of load transfer —the protrusions in one fractured face mesh with the recesses in the other. Studies by the Portland Cement Association (PCA) indicate that early fracture and the occurrence of many "pull-outs" of aggregate from the mortar offers better interlock than delayed cracking with fractured aggregates. Aggregate angularity is advantageous and the area of the fractured face is significant. There must be some compromise between the depth of groove or saw cut to assure early cracking and a depth that produces the greatest practical interlocking area. Experience has shown this compromise depth to be about $d/4$. The practice of sawing alternate joints early to allay random cracking and returning to saw remaining joints at a later date is not conducive to good aggregate interlock in either the joints with delayed sawing or the joints sawed earlier (which will often have larger openings).

Aggregate interlock is lost after joints widen to 0.035 to 0.04 in. (0.9 to 1.0 mm). As effectiveness varies inversely as the joint width, the shortest practical slab length is desirable.

One of the incidental findings of the PCA tests was that moderate infiltration of surface fines into the joint increases the effectiveness of load transfer. However, the total closure due to the infiltration in many joints has been shown to be detrimental because it exhausts space provided for expansion.

Field studies indicate that heavy truck traffic accelerates deterioration of aggregate interlock joints. The PCA tests showed this to be the result of abrasion due to the impact of aggregate and socket and scrubbing of the faces.

Dowels and Proprietary Devices

Dowels and proprietary devices are used for load transfer across joints in concrete pavements. The 1972 survey (Appendix B) showed a variety of diameters and lengths of round dowels in use today. Dowels are commonly ⅛ of the pavement thickness in diameter, 18 in. (460 mm) long, and are usually spaced on 12-in. (300 mm) centers.

Dowels provide shear transfer, but offer little resistance to bending. Shear transfer decreases slightly with minor joint openings, and loss of effectiveness becomes significant at openings greater than 1 in. (25 mm). At these larger gaps between joint faces the dowels tend to bend.

Dowels in expansion joints are coated one-half their length and capped on the coated end to assure room for joint closure (see Fig. 3a). In contraction joints the dowels are usually coated full length, but end caps are omitted as the joint does not provide expansion space. Coatings vary, but ideally they serve the dual purpose of inhibiting corrosion and reducing friction so the dowel can slip freely.

Corrosion and misalignment are factors that are detrimental to doweled joint performance. The use of deicing salts causes corrosion that may eventually cause dowels to "freeze," be reduced in section, or break.

Methods of reducing corrosion and extending dowel life include (a) pretreatment with a plastic coating and (b) use of stainless steel or some other noncorrosive material. A number of states use inhibiting paints, which are of dubious value (*18*). New Jersey uses stainless-steel sleeves, and dowels precoated with plastic (polyethylene, epoxies, nylon, etc.) are being introduced.

Misalignment can reduce joint movement and, if severe, can cause spalling and, eventually, joint failure. To avoid misalignment, dowels are held firmly in prefabricated baskets or placed by machine. It is essential that the baskets be rigid to resist displacement when the wet concrete mix is placed. Paving contracts should include specifications on dowel preparation, placement, alignment, and for location tolerances on joint grooves. If dowels are to be placed by machine, requirements should be established to limit surface reworking where dowels are vibrated into the mix.

Proprietary devices are basically short dowels in rigid supports. Individual bar alignment is less critical, but precise groove location is essential.

SKEWED AND RANDOMLY SPACED JOINTS

Several states are presently using skewed joints. They were originally tried in 1932, but have only been widely used since 1951. Normally, the design is such that the joints are skewed approximately 2 ft (0.6 m) in 12 ft (3.7 m). The skew results from a counterclockwise rotation of the transverse contraction joint so that the impact of the wheel crossing the joint falls on the obtuse angle formed by the skewed joint and the longitudinal edge of the pavement. Skewed, undoweled joints have their primary advantage over treated bases; otherwise faulting can become a problem.

The advantages of the skew are that it reduces stresses in the impacted corner and helps reduce the corner cracking that used to be prevalent with older narrow pavements. The impact is also reduced by causing the wheel axles to be more gradually applied to the leave slab rather than to have the entire axle load "fall" onto the leave slab, as is the case with perpendicular joints.

The skew also provides a slightly smaller distance between the joint faces, which aids the aggregate interlock. Over-all, the skewed joints provide a smoother ride to the traveling public.

At least one state is using skewed joints with reinforced slabs and dowels. However, because the dowels must be placed parallel to the center line, alignment of the dowels is difficult. The state uses skewed baskets to alleviate the problem. The use of skewed joints with adequate dowels is an overrefinement that probably is not necessary because adequate dowels effectively eliminate faulting.

Skewed joints are often constructed in conjunction with randomized joint spacings, such as a repeated pattern of slab lengths of 13, 19, 18, and 12 ft (4.0, 5.8, 5.5, and 3.7 m). This random spacing breaks up the resonance that can be created by some vehicles when uniform 15-ft (4.6 m) joint spacings are used.

SLAB SUPPORT

The strength of the foundation is significant to joint design because slab deflection increases with reduced support. Firm foundation support, such as is provided by treated bases, reduces slab deflections. Relative vertical movement and increased abrasion of adjacent joint faces is greater where conditions favorable to faulting or pumping exist. If the leave slab has insufficient support and undersized dowels, the impact on the dowels tends to produce oval-shaped sockets. This results in looseness that is conducive to still greater impacts and higher concrete stresses beneath the dowels and may eventually cause joint failures.

When treated bases are used, vertical movements of slab edges and corners due to warping may increase slightly; however, load-deflection studies have shown that the deflection curve becomes abruptly flatter when the load puts a warped slab in contact with the base. This firm restraint to further deflection is a deterrent to load transfer deterioration. It seems significant that Western states have been employing cement-treated bases and aggregate interlock joints with success, whereas such joints have not proved durable in other areas where untreated bases were used.

PAVEMENT THICKNESS AND TRAFFIC

An indirect factor in joint design is pavement thickness. If thin pavements are built for light loads and traffic volumes, it is prudent to design these with appropriate joints and bases. Usually pavements of 6-in. (150 mm) or less depth are jointed with weakened-plane joints without dowels. As discussed in the sections on aggregate interlock, these joints must be closely spaced; consequently, the pavement can be built without reinforcement.

Thicker pavements, built for greater loads and high traffic frequencies, require joints with dowels or other load transfer units. Exceptions have been noted in low-frost and arid regions. The contributions of dowels to joint performance in pavements with heavy loads were apparent in the results of the AASHO Road Test. There, in spite of excessive pumping on underdesigned slabs, both reinforced and plain, most joints remained in good condition.

LONGITUDINAL JOINTS

The center-line or lane-dividing joint between lanes cast in the same operation is a weakened-plane joint with aggregate interlock load transfer (Fig. 3c). It usually is restrained from lateral movement by tie bars of ½- or ⅝-in. (13 or 16 mm) diameter, 24 to 48 in. (610 to 1,220 mm) long and spaced at 18 to 48 in. (460 to 1,220 mm). A common system for 8-in. (200 mm) thick pavement consists of ½-in. by 30-in. bars at 30-in. (760 mm) spacings. Because tie bars are designed to preclude slippage between the bars and the concrete, tie bar alignment is not a consideration.

The groove to weaken the plane is usually sawed to a depth of at least one-fourth the pavement thickness. Lesser depths do not always produce controlled cracking. A more recent procedure for weakening the plane is mechanical insertion of a plastic strip. Various thicknesses have been used, but a 10-mil (0.25 mm) thickness is common. The metal and fiber inserts used by some states are being discontinued.

Longitudinal construction joints between lanes constructed separately, and at the edge of the pavement to provide for additional lanes, may be butt or keyed joints. Usually, pavements of 8-in. (200 mm) or greater thickness are cast with a female keyway containing bent tie bars or threaded inserts (Fig. 6), although they can be built with the male keyway. The keyway shape was the result of experiments by the U.S. Corps of Engineers (*19*). To complete the joint, bent bars are straightened or sections are threaded into the inserts prior to the next pour. The joint groove may be formed in the new concrete or sawed at a later date.

A keyed joint is effective only if it remains tightly closed, because the taper magnifies the effects of the opening. Experience with keyed joints in thin pavements has led to abandonment of this practice in slabs of 6 in. (150 mm) or less thickness. There is insufficient material in the upper lip of the keyway to withstand the stresses imposed by loads and environment. For these thin slabs, butt joints are more satisfactory.

Edge Joints

Edge joints are modifications of lane-separation or longitudinal construction joints. Some concrete pavements have

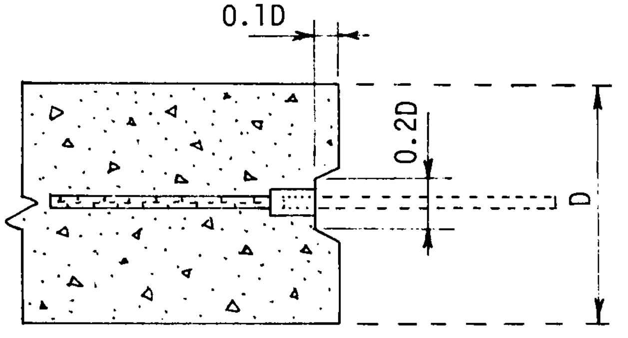


Figure 6. Keyed longitudinal construction joint.

been built with concrete shoulders cast in the same pass as the traffic lane. In this case the edge joint is a weakened-plane joint. If tied, the bar size can be reduced or the spacings can be greater than those used for mainline slab joints.

When the shoulders are cast after completion of the mainline paving, the edge joints are butt-type construction joints and should be tied. The bar spacings are greater than for traffic lane joints.

BRIDGE APPROACH JOINTS

There is a great range of practice in bridge approach joint design (Appendix B). Some states use a single ¾-in. (19 mm) expansion joint on each side of the bridge, others use two or three ¾- or 1-in. (19 or 25 mm) joints with intermediate 20- to 80-ft (6 to 24 m) slabs. Several require 4-ft (1.2 m) gaps of bituminous concrete in addition to multiple expansion joints. Others use a single 4-in. (100 mm) expansion joint of special design. One state requires 50 ft (15 m) of bituminous pavement on each approach to the structure.

Anchor lugs have been provided to restrain end movement of the mainline pavement. Long sections of pavement without expansion relief and continuously reinforced pavements benefit from these restraints; however, all movement is not eliminated. The anchor lugs are transverse beams about 2 ft (0.6 m) wide and 3 to 4 ft (0.9 to 1.2 m) deep, tied with reinforcement to the last slab or end of CRCP section before expansion relief (see Fig. 3d). If multiple lugs are used, they are spaced to permit full utilization without shearing the soil. Common anchor lug spacings are 15 to 17 ft (4.6 to 5.2 m).

The design of bridge approach joints is not standardized. It can only be suggested that, unless experience dictates otherwise, multiples of conventional expansion joints on each side of the bridge are generally satisfactory and produce little pavement roughness. The 4-in. (100 mm) special joints require sleeper slabs and expensive sealants, and to date must be considered as experimental. Gaps filled with bituminous materials require constant rebuilding when placed between concrete slabs, and often produce a bump when traversed by a vehicle.

The bituminous gap in the bridge approach design is a sure method of preventing thrust against the bridge; however, it should be noted that adjacent pavement joints may open and cause loss of pavement integrity. With pavements and structures under constant observation by maintenance workers, the chances of thrust development by exhausting expansion relief before detection are remote.

SEALANTS AND RESERVOIRS

In most states, all joints that are not formed with plastic or other permanent inserts are sealed. The designer must specify sealants and provide reservoirs that assure compatibility with design, environment, and joint function.

Factors to consider in the selection of poured sealants are:

- Adhesion to the joint faces.
- Cohesion throughout the temperature range experienced.
- Preservation of ductility at low temperatures.
- Resilience or resistance to infiltration at high-temperature ranges.
- Extension through which the material will retain the desirable properties.
- Durability under weather and traffic.
- Health hazards to workers.
- Pot life during installation.
- Operation latitudes (i.e., limitations on heating for hot-poured applications and mixing requirements in two-component elastomers).

Important features for preformed sealants are material durability, resilience, and compressibility limits as affected by physical structure. Of greater importance is the need to retain the sealants in compression to prevent them from being forced into the joint or pulled out. Adhesives for this purpose are ineffectual.

Selection of a sealant is determined by a combination of cost, past experience, slab length, and joint movement.

Cost

The materials of lowest cost are hot-poured sealants. Most of those in use meet AASHO Specification M 173, ASTM Specification D 1190, or Federal Specification SS-S-164. They are asphalt-rubber compounds that make effective seals for a few years in joints with small movements and in mild environments. Extensibility of this joint material is limited at low temperatures.

Cold-poured elastomers, usually of two components that are mixed on site, are required or permitted in some states. These materials usually meet ASTM Specification D 1850 or Federal Specification SS-S-1596. They are costlier than hot-poured materials, but have greater extensibility under adverse conditions.

Preformed sealants are being accepted by a number of highway agencies. They are precompressed at installation, are not subjected to adhesive stresses at the joint face, and are not subjected to cohesive tension. Most are compartmented neoprene strips with cells designed to resist permanent sticking (seizing) when precompressed and to assist lateral expansion as required to fill the joint space (Fig. 7). Standard specifications for these materials are AASHO M 220 and ASTM D 1056. Initial cost of preformed sealants is greater than for others, but cost per year of service in northern states is comparable to that for other seals.

The effect of cost and past use on sealant selection is indicated by the survey response (Appendix B). Of the states and provinces replying, 41 used hot-poured sealants, 11 permitted cold-applied materials, 4 required preformed sealants, and 13 permitted their use. It is significant that the states and provinces requiring preformed seals are Michigan, New York, Ontario, and Nova Scotia, all in regions of severe winter exposure.

Joint Movement

Joint movement affects sealant selection because of the demands on extensibility. Joints with very small movements, such as center-line joints, longitudinal construction joints, edge joints, and transverse warping joints, can be sealed with hot-poured materials. When these materials are used in transverse contraction joints, the reservoir must be wide enough to keep extension of the sealant within its capabilities (usually less than 20 percent).

Joint movement, reservoir width, and extensibility requirement are related, as demonstrated in this illustration: A plain concrete pavement with 20-ft (6.1 m) slabs is built at 70° F (21° C). Weakened-plane joints are formed with ⅜-in. (9.5 mm) grooves and sealed. The following winter, temperatures drop to 10° F (—12° C). Using 4×10^{-6} in./in./°F (7.2×10^{-6}/°C) for thermal contraction on a restraining subgrade, the slab shortened 0.0576 in. (1.46 mm). Thus, the seal was extended 0.0576/0.375 (1.46/9.5) or 15 percent. If the sealant reservoir had been ⅝ in. (15.9 mm), the extension would have been 9 percent, which is a reasonable figure for a hot-poured seal at 10° F. If the temperature drop had been only 40° F (22° C), the sealant in a ⅜-in. groove would have extended about 10 percent. This is within the capabilities of a hot-poured seal at 30° F (—1° C) so the ⅜-in. groove would have sufficed.

Another illustration suggests the difficulties in sealing transverse joints between long slabs. With a ¾-in. (19 mm) wide reservoir between 60-ft (18 m) slabs, a 24 percent extensibility would be required of the sealant for a 60° F (33° C) temperature drop (say from 70° to 10° F) (21° to —12° C). Thus, a hot-poured seal would not be suitable, and this design would require cold-poured elastomers or preformed seals. If a preformed seal were used, a groove ⅝ in. (16 mm) wide could be fitted with a 1-in. wide strip, thus compressing the seal 37.5 percent. This would maintain a minimum lateral compression of 20 percent at 10° F, the usual prescribed working limit for this seal.

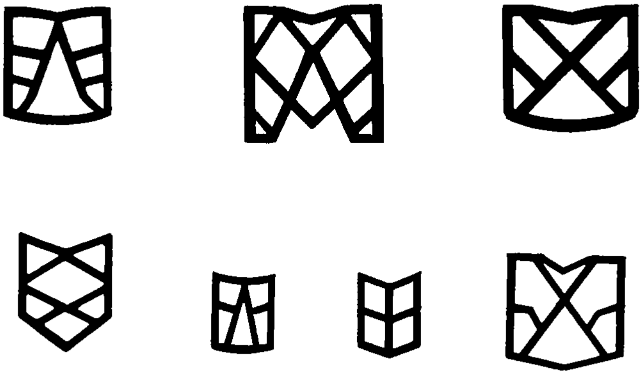


Figure 7. Cross sections of preformed joint seals.

CHAPTER FOUR

JOINT CONSTRUCTION

Proper construction of joints is essential to good durability and functioning. Some construction concepts are mentioned in the discussions of joint problems and joint design. Details of good practice are discussed here, as well as the results of carelessness.

TRANSVERSE JOINTS

Weakened-Plane Joints

A weakened-plane joint is simply a joint created by weakening the cross section of the pavement. Generally, one of three methods is used to create the weakness: (1) an insert is placed in the surface of the pavement, or (2) a groove is formed in the surface of the wet concrete, or (3) a saw cut is made shortly after the concrete has set.

Regardless of the method used to weaken the cross section, it is important that the insert or groove be located over the center line of the dowel assembly, if dowels are used. This requires that these positions be marked clearly on the side forms or that stakes or flags be placed where they cannot be disturbed by the slip-form paver or other equipment. This is especially true if the dowels are short or proprietary devices are employed.

Inserts

When the weakness is created by the insertion of a thin plastic strip, the strip is placed automatically by a machine following the finisher or slip-form paver (Fig. 8). The float then passes over the surface and the embedded strip is undisturbed. An alternate to the machine is placement by vibrating a full-width or lane-width bar into the concrete. The plastic strip is folded over the edge of the bar, which is then positioned by workmen, and the assembly is vibrated into the wet concrete. The bar is then withdrawn, leaving the plastic embedded. Transverse joints of this type sometimes exhibit raveling of the edges under traffic.

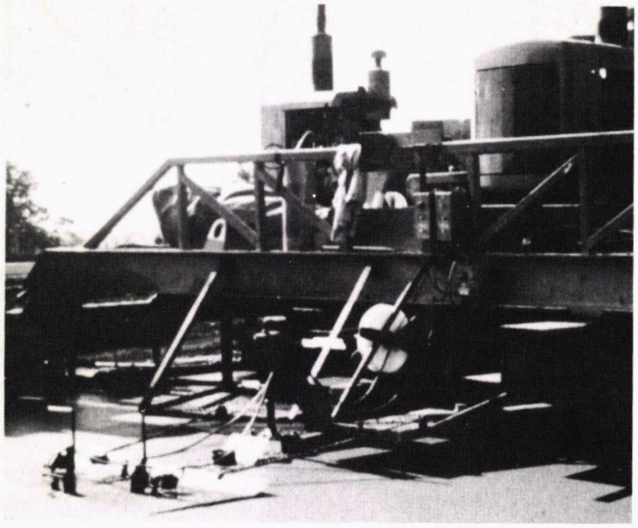


Figure 8. Machine placing plastic insert for transverse joint.

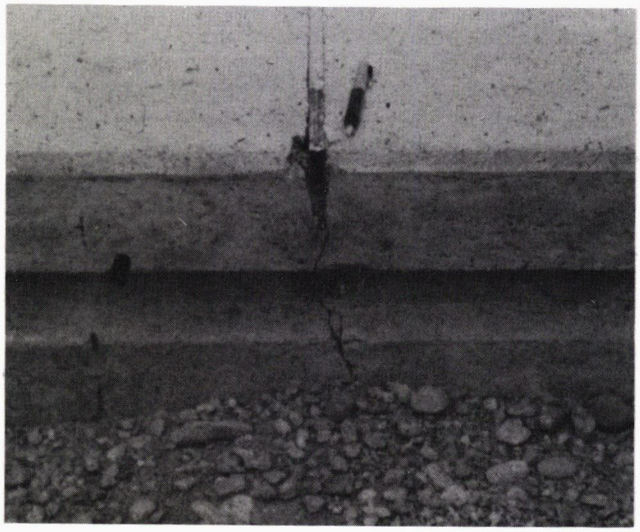


Figure 9. Metal insert.

Figure 10. Insertion of strips in transverse joint.

Metal or rigid inserts are placed in a similar manner. In some cases, it may be necessary to part the wet concrete with guides and trowels or with grooving bars prior to placement of the insert (Figs. 9 and 10). Rigid inserts are likely to tilt when disturbed by finishing equipment; it is essential that no part of the insert protrude above the pavement surface. The metal inserts have shown poor performance when used with long slabs in northern climates.

Sometimes metal or fiber inserts are installed with provision for sealant above the insert. In other cases, expanded polyurethane or other material is inserted in the wet concrete and, after the concrete has set, is either sawed or routed to permit seal installation.

Formed Grooves

Although not generally used, grooves in the wet concrete can be made by vibrating or working a T-shaped grooving bar into the mix. The bar should have a tapered web to permit withdrawal and should be embedded full depth to the flange. It should also be coated with form oil or other appropriate parting material. After the concrete has stiffened sufficiently to prevent flow, the grooving bar is withdrawn and the groove is edged. Some edging is desirable, even though the joint appears to be well formed, because of the tendency to disturb the edges when the bar is withdrawn. However, this hand work often produces rough-riding joints.

Sawed Grooves

Sawed grooves (Fig. 11) are made after the concrete has attained sufficient strength to enable the saw to cut through the aggregates and produce a minimum of aggregate pullouts. The time of sawing is critical; it may be as soon as 4 hours after casting on a warm windy day, or exceed 8 hours under other conditions. Experienced personnel are necessary to determine the proper time to saw.

The cuts are made with a single blade or a gang saw. Blades with cemented abrasives are preferred to diamond blades for these early cuts. If temperatures are rising, the blades may be set to cut full depth; but if sawing is delayed until temperatures are falling, random cracking may develop from the end of the partially completed cut to the pavement edge. Making two passes, with the first cut at half depth, is advantageous in retarding this type of cracking.

Sometimes, because equipment or labor is not available for optimum cutting, every second or third joint is cut early. The remainder are sawed later. This practice may forestall random crack development, but it has the disadvantage that cracks at the early-cut grooves open wider than those sawed later. As indicated previously, this is detrimental to effective aggregate interlock and causes joint sealing problems because of the nonuniformity of movement. It may be desirable to resaw the joint with a wider cut immediately prior to sealing. This will usually provide a joint of uniform width.

Finally, the top of the sawed groove must be widened to accommodate the seal and beveled slightly to reduce raveling. Reservoir widths vary with design, but depths are usually 1 in. (25 mm). The reservoir may be sawed simultaneously with the groove cut by spacing blades of different sizes on the mandrel or it may be sawed or routed later. Early reservoir sawing may have a cost advantage, but it slows the progress of groove cutting. Also, the green concrete may exhibit more aggregate pullouts.

Load Transfer Dowels

Contraction Joints

Load transfer dowels for contraction joints were discussed in Chapter Three. A number of styles of supporting baskets are available, and most meet requirements for rigidity. Usually the gripping and slipping ends of dowels alternate. Therefore, the construction must be examined to ascertain if there is a distinction, so that the coating treatment can be applied correctly. Baskets must be spaced accurately to conform to lengths of reinforcement fabric being used on the project and firmly staked to prevent displacement (Fig. 12). A surcharge of fresh concrete on the dowel assembly contributes to stability.

Placement of contraction joint dowels by a mechanical placer (Fig. 13) eliminates some of the problems with baskets. When the placer follows the finisher, surface disturbances clearly indicate where the dowels were placed (Fig. 14); thus, a check on location is provided. Sometimes hand floating is necessary to reduce these disturbances so they cannot be seen after passage of the tube or final float.

Expansion Joints

Load transfer dowel assemblies for expansion joints usually differ from contraction joint assemblies in that a ¾- to 1-in. (19 to 25 mm) asphalt-impregnated compressible fiberboard or other suitable material is attached vertically at mid-length, and the greased ends of the dowels are capped with devices that provide space for dowel movement at least equal to the filler board thickness (Fig. 3a). The board extends from the base to a line about 1 in. below the surface. The board is capped with a shaped metal strip that allows the finisher or slip-form paver to pass over the joint without disturbance. Before the concrete has set, the cap is removed and the joint is edged to form a reservoir for the sealant. This is a hand operation, performed from a contractor's bridge. Edging should be done with a minimum amount of working and, if preformed seals are specified, the reservoir walls must be left straight and true. This requirement has inspired some experimental work in removing the concrete over the filler by sawing.

Transverse Construction Joints

Transverse construction joints can be built to function as either contraction or expansion joints. The pour is terminated at a header that is adapted to suit the needs of the joint specified on the plans for that location. If no joint is indicated within 15 to 20 ft (4.6 to 6.1 m), and long reinforced slabs are being built, some provision must be made to have continuity of reinforcement when the header is removed and the new concrete is placed. If the planned joint location is close, dowels are inserted through the header. Before the next pour, the header is removed and the dowels are checked for alignment. If the plans call for a contraction joint, the dowels are greased and new concrete is placed. If an expansion joint is specified, a filler strip is installed and the dowels are capped in addition to being greased. Subsequent joint spacing to meet planned

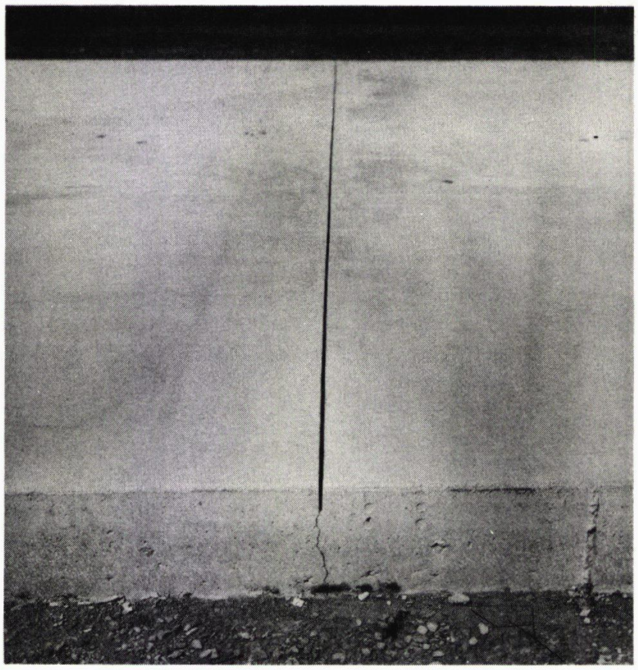


Figure 11. Typical sawed contraction joint between short slabs, before sealing.

Figure 12. Dowel assembly being checked.

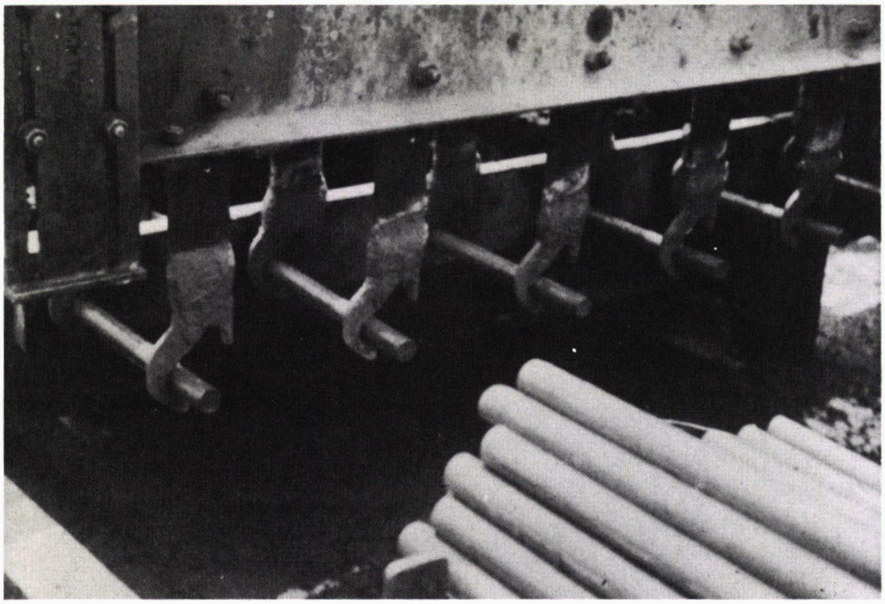


Figure 13. Dowel placer.

stationing may be specified in the plans or left to the discretion of the project engineer.

Past experience indicates that construction joints can be a major source of problems. Poor dowel alignment, inadequate concrete vibration, and pavement surface finishing irregularities are the most common errors. The "night" side of the joint may contain poor-quality concrete that has been carried along in front of the paver. In some cases, the first batches of concrete placed at the joint when construction resumes are of questionable quality.

LONGITUDINAL JOINTS

Weakened-Plane Center-Line Joints

Weakened-plane center-line joints in multilane pavements are tied with deformed bars that are usually forced into the concrete surface by a rotating drum-like device (Fig. 15). The placer may follow a second spreader or slip-form paver; hence, the bars would be above the reinforcing steel. Or the placer might be on the first spreader in two-course construction or on the single spreader when a mesh depressor is used; thus, the bars would be below the reinforce-

Figure 14. Surface disturbance behind placer.

ment. This method has a decided cost advantage over the old method of tying the bars to chairs on the subgrade or to reinforcing mats. It also assures good alignment and accurate depth because there is no subsequent disturbance.

The longitudinal joint plane is weakened, usually by mechanical insertion of a plastic strip into the fresh concrete or by sawing the hardened concrete (Fig. 16). The plastic strips must be carefully placed to prevent protrusion or burial. Occasionally, metal or fiber inserts are forced manually into grooves plowed into the mix by a grooving wheel. Early sawing of longitudinal joints is recommended, particularly in late fall paving, because the rapid temperature drop can create a critical thermal gradient while concrete strength is low, thus causing off-center longitudinal cracking. Evidence indicates that inserts may not be as effective as sawed grooves in defining planes of weakness; hence, a greater depth may be necessary.

Longitudinal Construction Joints

Longitudinal construction joints in pavements with 8 in. (200 mm) or greater thicknesses often incorporate molded keys. The keyway is formed in the first pour, either by attaching a deformed plate or a key strip to the side form, or by shaping the edge of extruded slip-form concrete with a device on the sliding form. Some states do not use a keyway, and a few also do not use ties.

Experience has shown that wood key shapes attached to side forms are unsatisfactory because they absorb water from the concrete and swell. This produces upward thrust on the lip of the keyway and may cause early cracking. Also, the green concrete is in jeopardy when prying devices are used to extract the wood molds.

When pavements are placed between forms, tie bars are bent and placed so the longitudinal portion lies in the keyway (Fig. 17a), or two-piece threaded devices are used and the female portion is installed perpendicular to the keyway (Fig. 17b). In reinforced pavements these ties and sections can be wired to the steel mats.

Methods of installing ties in keyways formed by slip-form pavers are still experimental. It is beneficial to insert the tie or half-tie into the joint face before it is left free standing. Some contractors are attempting this with innovative attachments. Others pneumatically drive the bar into the fresh mix through a slot in the trailing forms. In a good mix the slight edge and surface disturbance does not appear to be objectionable.

SEALING

Hot-Poured Sealants

Hot-poured sealants are usually mastics of asphalt filled with latex, butyl, or reclaimed rubber, all of which lose their elastic properties when overheated. Thus, the heating kettle is a "double boiler," in which the heat distributing material may be sand or oil. Directions for use suggest slow heating and then rigid control of temperatures between specified limits. Initial heating to reach pouring temperature requires several hours, and the kettles are fired at night for morning use.

Before placement the groove and reservoir must be prepared by thoroughly cleaning out all debris. Sometimes an air blast is sufficient to remove dust and other particles, but if there has been an appreciable delay between cutting and sealing, some more positive technique (such as wire brushing) must precede the air blast. Sand blasting is not recommended, because the sand particles penetrate the crack below the groove and fill the space needed later for temperature closure. After cleaning, a paper or plastic tape or cord is laid in the bottom of the recess to prevent the sealant from penetrating the bottom of the groove and also to destroy bond between the sealant and the bottom of the reservoir (Fig. 18a). This not only provides for sealant economy but also assures best sealant performance by allowing necking from the bottom, as well as the top, when the sealant is stretched.

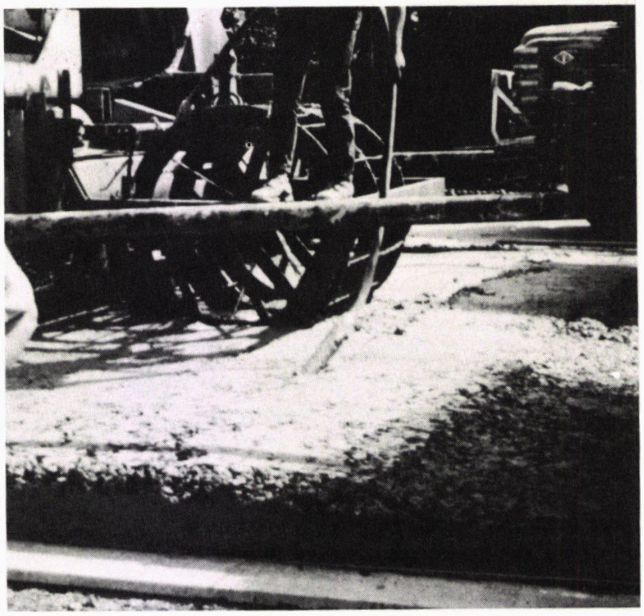


Figure 15. Placing tie bars by rotating drum.

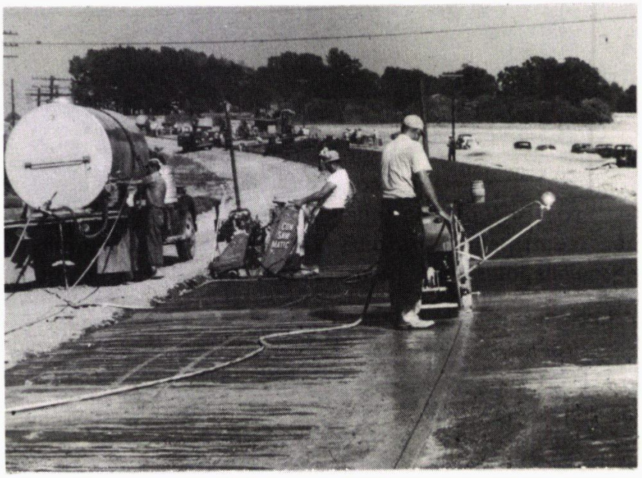


Figure 16. Sawing transverse and center-line joints.

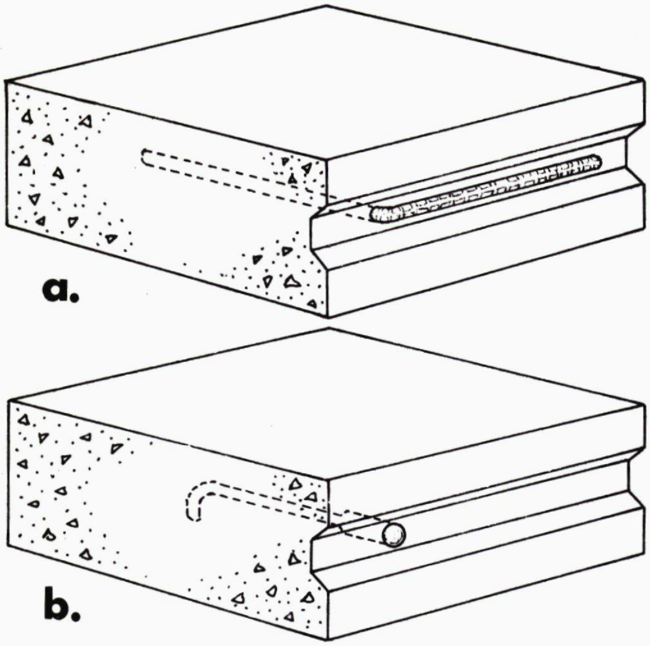


Figure 17. Tie bars.

Figure 19. Application of two-component sealant.

In narrow grooves, such as those in center-line joints, there is no groove shoulder defining the bottom of the reservoir. Either the groove is completely filled or a rope of jute or other material is inserted into the groove to a predetermined depth to define the reservoir (Fig. 18b).

Hot-poured sealants are injected into the prepared reservoirs through nozzles shaped to penetrate into the space and to fill the reservoir from bottom to top. Some skill and experience are necessary on the part of the operator to insert the correct amount of sealant. In hot weather, when joints are closed, the freshly poured hot sealant should bulge up slightly without being above the pavement surface (Fig. 18c). In cold weather the top of the fresh sealant should be slightly below the pavement surface (Fig. 18d). To prevent tracking and loss of sealant due to traffic, the sealed joint should be covered with paper tape if traffic is permitted soon after sealing.

Cold-Poured Sealants

Cold-poured sealants are the polymers generated by mixing two components at the site. Some of these are polyurethanes, polysulfides, and modified epoxies. The basic resin is supplied in one container and the activator or hardener in another. They may be mixed in a paddle mixer and distributed in much the same manner as hot-poured seals or, preferably, they may be fed from separate sources to a mixing nozzle (Fig. 19).

Advantages of polymers (such as increased extensibility, reduced temperature sensitivity, and good adhesive and cohesive strength) are offset somewhat by higher material cost, short pot life, and difficulties in cleaning equipment. Whereas the asphalt-type kettle and hoses may be cleaned by kerosene or similar petroleum-base solvent, the solvents for polymers are usually expensive, toxic, and ineffective after the product has aged. Thus, installation of cold-

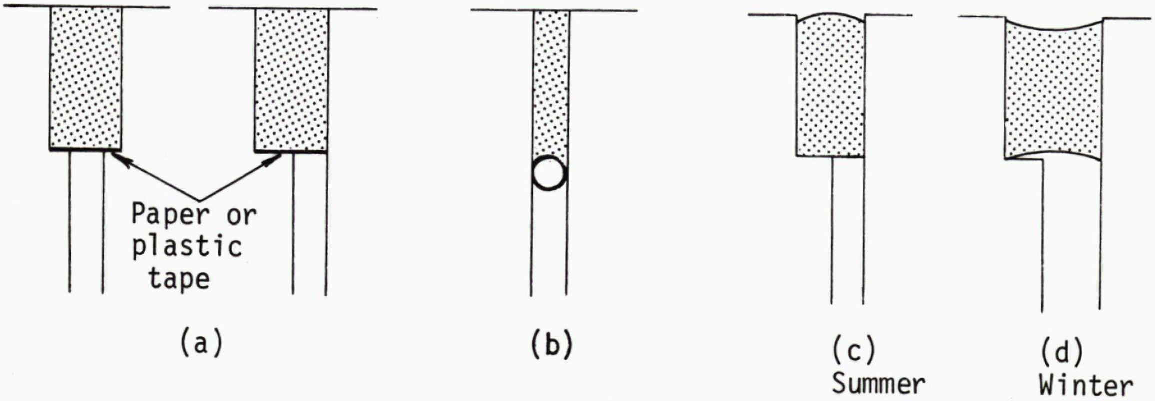


Figure 18. Hot-poured sealant installation.

poured material is not a job for inexperienced labor and is usually contracted to specialists.

Preparation of reservoirs for cold-poured sealants is the same as for hot-pours, with the added stipulation that the concrete surface be dry. Hot-poured materials may also trap bubbles of air or steam from damp reservoir walls, but usually these work to the surface and the residual heat tends to remove unwanted moisture. However, the chemical heat of cold-poured materials may not be sufficient to remove the moisture film and poor adhesion will result. A final application of protective tape over the joint is sometimes necessary with cold-poured material because the curing process is slow and tackiness persists for some time.

Preformed Seals

Preformed seals must be selected to fit each reservoir, or the slab length and reservoir must be designed to fit the seal. If the maximum compressibility limit is exceeded the cells will be locked or, if minimum allowable compression is not maintained, the seal will become loose. The reservoir for these seals must have smooth straight walls to conform with the molded shape; thus, sawing produces the best reservoir. A small bevel at the pavement surface reduces raveling. Again, thorough cleaning is necessary.

Immediately before installation of the seal strip, the walls of the reservoir are coated with a temporary lubricant that later serves as an adhesive. The strip is then precompressed and inserted by a machine or special tools (Fig. 20). Hand installation is unsatisfactory because of the tendency to reduce the seal section by elongation rather than by compression. It is usually specified that elongation at insertion cannot exceed 5 percent.

The techniques of joint construction, grooving, and installation of sealants have improved with the introduction of new materials. This has been stimulated in part by the awareness of a need for a seal rather than a filler. An understanding of the material, its limitations, application hazards, and necessity for clean grooves and reservoirs is essential to good performance, and these conditions are best achieved by specialists. Unskilled labor cannot be expected to appreciate the problems or make good installations.

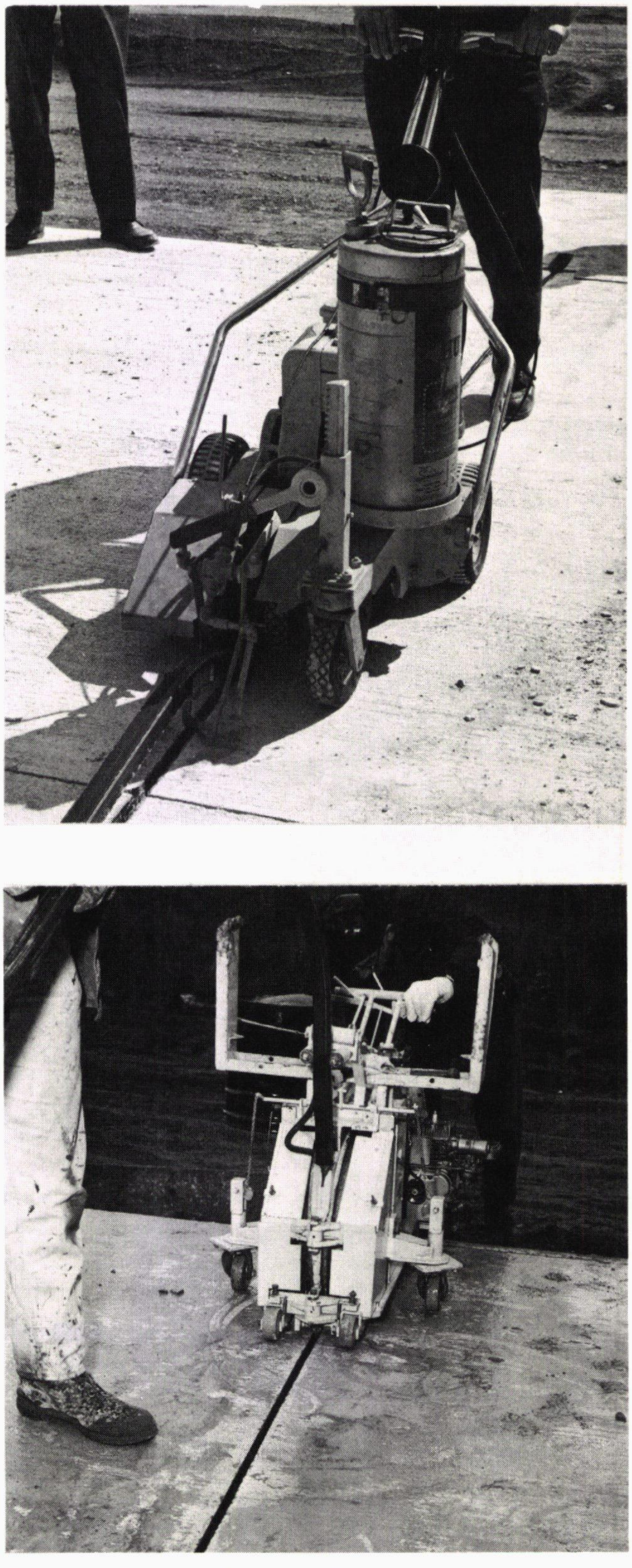


Figure 20. Placing preformed seals.

CHAPTER FIVE

JOINT PROBLEMS AND MAINTENANCE

Although joints are introduced in conventional pavements to provide crack control, some of the problems associated with discontinuities continue to exist, and other problems may result from pavement use, joint design, and construction methods.

The greatest portion of concrete pavement maintenance is joint maintenance. Some of the principal causes of distress that require remedial action are:

- Poor slab support.
- Soil movements.
- Excess water.
- Particle infiltration.
- Faulty load transfer performance.
- Overloads on the pavement.
- Sealant failures.
- Incompatibility of spacing, reservoir, and materials.
- Disintegrated or "rotted" joint faces.

Interaction may cause effects to accumulate and produce rapid deterioration. Many of these conditions can be alleviated or distress can be retarded by preventive maintenance. If, however, problems develop, it will be necessary to restore damaged joints to a functioning condition through various repair methods.

PREVENTIVE MAINTENANCE

Operations to prolong joint life without major repairs include removal of sand and soil that might infiltrate the joint from the pavement surface, restoration of shoulder material and grade to maintain water control at pavement edges, and replacement of seals that have been disturbed by traffic and snow removal.

Seal replacement too often is done by labor that does not appreciate the joint function and simply fills the joint groove with a sealing compound. If cleaning is specified, it is limited by these crews to the removal of particles that can be dislodged by an air blast.

Resealing is, in fact, just as important as initial sealing and all specifications for initial sealing should be observed. When an undamaged joint is to be resealed, the old seal is completely removed, the reservoir is thoroughly cleaned by wire brush and solvent if necessary, the groove is inspected for incompressibles and cleaned as deeply as possible, and then given a final air sweep. The new seal is then applied in the same manner as for initial construction.

JOINT PROBLEMS

When problems occur at joints it is necessary to determine the cause (or causes) and then to effect a repair. The following information, as well as additional information contained in *NCHRP Synthesis 9* (*20*), is not given in detail because each agency has developed methods that are best suited to its operations and labor. Skills are required in maintenance as in any other branch of highway service, and it is difficult to generalize on skills. Most states have maintenance manuals that include details for materials and procedures for all except catastrophic damage. The remarks of this chapter are basic and serve to suggest reasons for the various operations rather than to give explicit details.

Raveling

Raveling is an irregular tearing of the concrete at a groove or saw-cut (Fig. 21a) and is usually not serious except at joints where preformed sealants are to be installed. Raveling is detrimental to a smooth ride and may be a forerunner of more severe deterioration because of weak concrete in the joint area.

Cause and Prevention

Raveling may be the result of early sawing or untimely removal of grooving bars when the grooves are formed in the plastic mix. Methods of prevention include: (1) hardened concrete should not be sawed until the saw cuts through the aggregate rather than tearing it out of the matrix; (2) forming bars should be tapered and oiled to permit easy removal; (3) the groove and adjoining surface should be brushed clean to remove all hard particles and concrete drippings that can harden in the groove when the wet mix is tooled.

Repairs

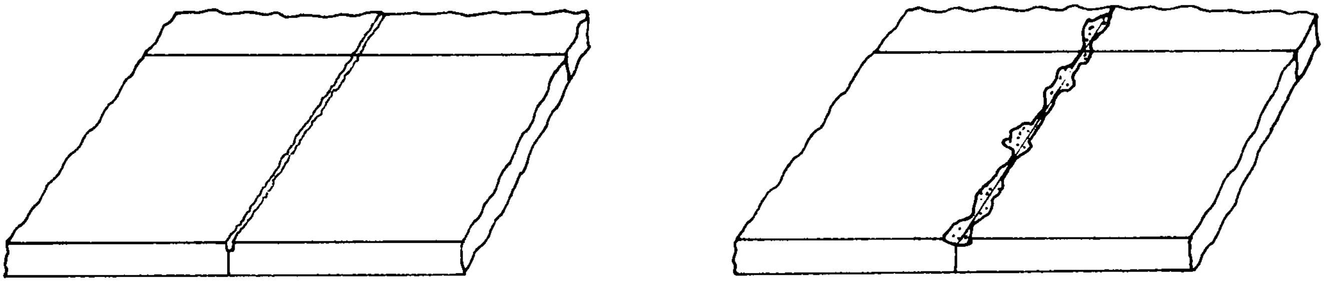
Repairs to a raveled joint, if necessary for sealant installation, can be made with special bonding or epoxy mortar mixes.

Spalling

Spalling occurs when portions of the pavement at the joint edges are dislodged by some stress-producing action (Fig. 21b). Spalls contribute to sealant failure and pavement roughness and may forecast serious damage, such as blowups. Extensive spalling may negate the use of preformed sealants, which need good contact faces.

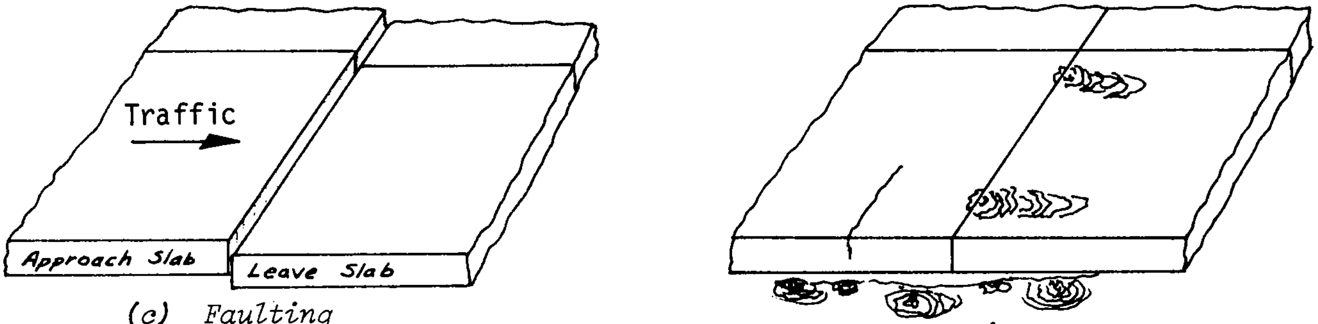
Causes and Prevention

Spalling is caused by infiltration into the joint of hard particles of high resistance to compressibility, often called incompressibles. These particles resist joint closure during warm weather and produce horizontal shear stresses that can exceed the concrete shear strength. Spalls in pavements with short slabs usually are relatively small, especially in



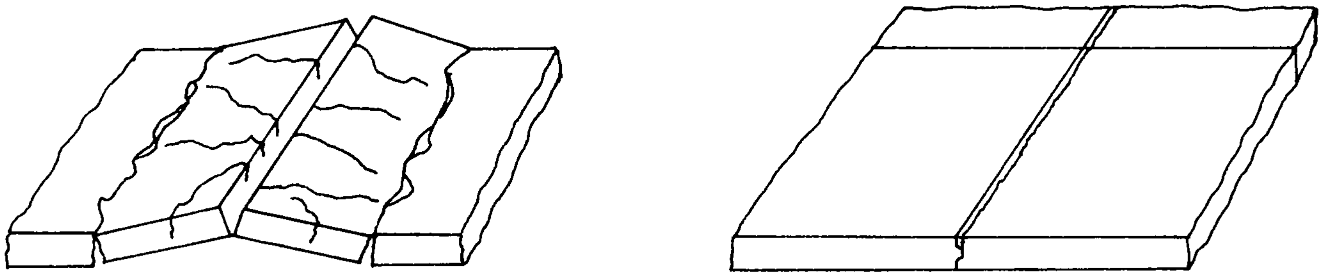
(a) Raveling

(b) Spalling



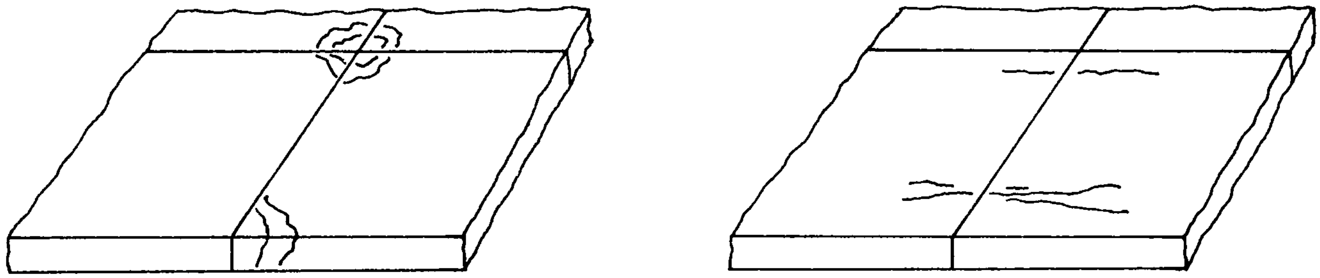
(c) Faulting

(d) Pumping



(e) Blowup (buckling)

(f) Keyway Failure



(g) Corner Breaks

(h) Compression Cracks

Figure 21. Distress at joints.

pavements of recent construction. In older pavements, or those with long slabs, larger spalls may occur due to excessive movement and infiltration or due to malfunctioning of load transfer devices. Spalls also may be caused by poorly designed inserts, by joint fillers containing incompressibles, or by direct contact between joint faces by particles of hardened concrete that were not removed.

Joint damage from spalling can be reduced by good design and construction practice. Design must assure contraction joint faces of sufficient area to withstand the compressive forces and must provide adequate load transfer. The concrete must be of proper strength with durable aggregates. If inserts are used, they must be correctly installed to prevent the bridging of incompressibles, including hardened concrete particles, across the joint. Plastic and compressible inserts are less conducive to spalling than metal. Care must be taken to prevent infiltration of hard particles from the road surface and shoulder by effective sealing.

Maintenance and Repair

Prevention or delay of spalling is accomplished by good preventive maintenance. Material in the reservoir or groove can be removed by plowing out the seal and routing or resawing the groove. The crack beneath the groove is difficult if not impossible to clean. After spalls have occurred, remedial work becomes more expensive.

As a stopgap measure, bituminous patches are used to repair spalled joints (Fig. 22). More permanent repair consists of replacing the dislodged material with new portland cement concrete or mortar, or by an epoxy or polymer-based mortar. The old concrete surface is cleaned and etched, and a coating of mortar of the material used is applied. A thin strip of wood or metal, coated with bond-breaking material or lined with plastic, is placed in the joint groove to form a reservoir, and the new mix is tamped onto the old surface and against the form. The surface is struck off carefully and textured to conform to the surrounding concrete. When portland cement concrete is used, some agencies report advantages in retempering before final finish. Wet curing is important. When epoxies or latex additives to concrete mortars are used, no water cure is necessary, although latex mortars require a waterproof covering for a minimum of 48 hours to prevent shrinkage cracks.

Figure 22. Spalled joint patched with bituminous material.

Epoxy mortars have the advantage of short cure times and, except in cold weather, traffic may be allowed on the pavement in 4 to 6 hours after repairs. These materials, as well as those containing latex additives, are slightly more difficult to work with than portland cement mortars because they adhere to the tools and cannot be cleaned by water.

Faulting

Faulting is a type of joint deterioration produced by traffic. It is identified by the "step-off" developed from the "approach" slab to the "leave" slab (Fig. 21c).

Causes and Prevention

As a load crosses the joint, a downward thrust is applied suddenly to the leave slab as compared to the more gradual rate of application on the approach slab. Studies by the Portland Cement Association (PCA) showed that the impact of the leave slab may tend to consolidate or densify the supporting material unless it is treated to resist densification. It was noted in California (*21*) that there was particle movement counter to the direction of traffic when water collected below the concrete, even though the bases were stabilized with cement. Eventually, the leave slab elevation is lower than that of the approach slab.

Incidental causes of faulting are numerous and range from material weakness to overloading of the pavement. Supporting soil may be moisture sensitive and have reduced support capacity at high moisture contents. This may be caused by compaction deficiencies or nonuniform stabilization. Pavement thickness may be inadequate because traffic has exceeded expectations and deflections at joints have become too large. Pavement warping and poor drainage may have permitted ingress of shoulder or base material under slab ends. Load transfer devices may be deficient or have failed, or joint openings may be great enough to void the effectiveness of aggregate interlock in plain pavements.

Minor faulting may be tolerable, but faults exceeding 1/16 in. (1.6 mm) usually produce enough noise from the tire impact to be detected audibly. If conditions causing initial faulting persist, the elevation differences usually increase. Severe faulting causes joint seals to fail because the joint faces move vertically, subjecting the seal to a rotating action. Sealant failure allows water and particle ingress to aggravate the conditions, and excessive faulting may result in early corner cracking and slab failures.

A number of precautions have been identified in design and construction to reduce the probability of faulting. Subgrade conditions must be analyzed and support properly designed. Slab thickness must be sufficient for future needs and reliable load transfer methods must be used. Sealants and reservoirs must be compatible with pavement environment and use. The joints must be well constructed, with load transfer units properly installed. Actual slab support must meet the design requirements and satisfy construction specifications.

Maintenance and Repair

Maintenance operations to correct faulting include slabjacking, grinding (bump cutting), restoration of sealant, and foundation moisture (drainage) control. Measures to preserve the pavement, short of reconstruction, are load limitations; traffic reduction by the addition of extra lanes; or, in some cases, construction of concrete or stabilized shoulders.

If the cause of the faulting is poor slab support, the effects may be ameliorated, at least temporarily, by slabjacking. Methods and materials for the operation vary with circumstances. In essence, holes are drilled or bored in the depressed slab at frequent intervals inward from the edges and a slurry (a designed mix of cement and sand, or fine limestone and water) or a suitable bituminous mixture is forced under pressure beneath the slab until it emerges at the edge or an adjacent hole. The injection hole is then plugged and the treatment is repeated in the next hole. This continues, with repeats as necessary to restore elevation. If sufficient pressure cannot be maintained to accomplish full restoration, the operation may be repeated at a later time. This may require redrilling through the first treatment. Slabjacking, however, can completely freeze joints if the grout is permitted to fill the groove or the crack.

If the condition cannot be checked by slabjacking, an end failure of the slab will result. Reconstruction should include removal of the base and subgrade that has failed to support the slab, redesign of drainage to remove the source of water, replacement of suitable subgrade and base, replacement of load transfer assembly if used, and placement of the new concrete. Continuity must be restored in the reinforcement, if used, and the joint function must be analyzed in order to install the proper type and appropriate reservoir and seal.

Pumping

Pumping is a phenomenon that may sometimes be a cause of faulting or sometimes be aggravated by faulting. When the fine particles of a pavement foundation or shoulder are carried by infiltrated water, and traffic produces a large number of deflections sufficient to cause the material to be ejected onto the pavement or shoulder surface, the process is called pumping (Fig. 21d). Pumping is not limited to joint areas but may be found also at slab edges. "Blowing" is another term sometimes used, but blow holes may exist without evidence of particle extrusion.

Causes and Prevention

Pumping occurs when traffic produces cycles of alternating high positive and negative pressure on free water over a saturated base or subgrade. At joints the same action that produces faulting may produce pumping. At edges the material put into suspension by negative pressure is blown out between the slab edge and the shoulder by the following positive pressure.

Pumping indicates that something is amiss in the pavement system. It becomes serious when the volume of displaced material is such that large areas of slabs are left unsupported. This is conducive to increasing deflections and ultimate failure. Joint pumping is detrimental to joint life because it causes particles to collect between the joint faces. It can also exert sufficient pressure to loosen the joint seal. The infiltrated, unsealed joint, poorly supported, then becomes a likely point for slab failure.

Methods of assuring good pavement life without pumping are very similar to methods used to prevent faulting. Emphasis on high-quality bases and good drainage can reduce pumping to a rare occurrence. When proper slab thickness and support are provided, deflection is minimal, water is prevented from entering between the slab and the base, and pumping cannot occur.

Maintenance and Repair

Maintenance to reduce pumping on pavements consists of removing the source of water infiltration, restoring the support by slabjacking, and cleaning and resealing joints.

The remedy for water infiltration is to try to eliminate the source of water, or the line of ingress of water into the joint, and to provide means to carry the water away so rapidly that damage is minimal. If the base is drainable, impermeable shoulder material should be replaced by an open-graded material to permit lateral drainage, and side ditches should be deepened to accept the water. Alternates are the installation of lateral and longitudinal drains. If the leave slab is depressed, it can be slabjacked to elevation (see "Faulting") and the joint then cleaned and resealed. If there is no faulting and the base is impermeable, an undersealing treatment with asphalt may protect against erosion.

Severe cases of pumping may require reconstruction of the joint (see "Faulting").

Blowups

Blowups occasionally occur at joints in concrete pavements when high temperatures and moisture in the concrete produce excessive expansion. The weakest joint of a series offers stress relief to the compression built up in the pavement by shattering or by buckling upward (Fig. 21e). This may occur gradually or suddenly and the failed areas may vary greatly in size and severity.

Cause and Prevention

Longitudinal thrust builds up in the pavement because infiltrated material occupies the space at contraction joints created by the shrinkage and contraction of the slabs. The horizontal compressive thrust becomes eccentric because of some inadequacy in the joint face (such as soft or nondurable aggregates) or salt deterioration due to the application of deicers.

Although many studies have been made of blowups, most have been concerned with correlating the number of observed blowups with environmental conditions, the number and types of joints in the pavement, and the lengths of pavement between blowups. Little is known in a quantitative way about stresses at the time of blowup, the moisture content of the concrete, the amount of debris in the joints, the strength of the concrete and its condition at the joints, and the effects of various bases, drainage designs, shoulders, slab thicknesses, and joint sealants.

Qualitatively it has been observed that:

- Most blowups occur during the spring or early summer after a significant hot spell combined with recent rain, and usually occur late in the afternoon.
- Although blowups do occur in growing concrete caused by chemical reactions (such as an alkali-aggregate reaction), the extent of such growth is not very prevalent across the United States. Most blowups occur in chemically stable concrete where physical lengthening is caused by debris infiltration at the cracks and joints.
- A pavement incorporating all expansion joints does not suffer blowups. Pavements containing intermixed expansion and contraction joints are very susceptible to blowups. Blowups seldom occur where joint spacings are less than 20 ft (6 m) (with no intermediate expansion joints), even where joints are not sealed.
- Blowups almost never occur in new pavements. If the pavement is susceptible to blowups, they begin to occur after 3 to 5 years of age.
- Blowups occur at various frequencies; the maximum observed is about one blowup per mile per year (0.6 per km per year).
- Blowups usually occur at joints or cracks in the pavement and the concrete at the blowup appears to be weak or deteriorated at that point.

These observations fit a logical pattern when they are considered in light of the following:

- Pavements with long slabs have greater joint openings than do those with short slabs. A 100-ft (30 m) slab will have a joint opening of approximately ¾ in. (19 mm) and it is difficult to maintain effective seals. Areas where deicing grit is used have a copious supply of material available to fill the joints. Most of these areas also use long slabs.
- Good drainage and chemically stabilized bases and shoulders restrict the amount of loose materials that can infiltrate joints. Slab ends deflect more on soft bases and produce pumping action that forces debris upward into the joints.
- Saturation can reduce the compressive strength of concrete from 20 to 40 percent.
- Joints are particularly susceptible to being the focal point for blowups because:
    (a) Often, poor concrete is placed at joints during construction.
    (b) Salts, moisture, and infiltration debris can cause concrete deterioration.
    (c) Because of the saw cuts only about 80 percent of the depth of the concrete is in contact.
    (d) Warping/curling and loads can cause spalling at the top or bottom to further reduce the effective cross section.
    (e) Excessive faulting and deflections at joints can also reduce the area of the faces in contact.
- During a cold winter much debris can infiltrate the open joints. Subsequent warming in the spring can cause expansion and blowups. Once the pavement has blown up, it has relieved itself. If no exceedingly warm weather follows, no subsequent blowups will occur that summer. However, the cycle begins again the following winter.
- Once a pavement blows up and relieves itself the adjacent joints open wider, thus funneling more material into the joints, which causes more subsequent blowups. The occurrence of the first blowup portends a continuing problem.

Design and construction techniques to reduce the frequency of buckled joints include a consideration of climate and environment, good base and shoulder design, proper joint spacing to keep movement to a minimum, good joint design with adequate and properly installed load transfer units, proper sealant reservoir design and selection and application of sealant, sufficient joint face area to withstand high compressive stresses, selection of sound aggregates for the concrete, and care in obtaining quality concrete at the joint.

Maintenance and Repair

The preventive maintenance techniques mentioned under "Spalling" will also help to prevent blowups. In addition, before a blowup occurs, temporary relief to high compressive stresses can be provided by sawing a gap in the concrete and filling it with bituminous concrete or a preformed compressible material. Reinforced pavements more than five years old, built with aggregates that may absorb moisture and expand, or soft aggregates that may deteriorate under chloride applications, are prone to expand abnormally under conditions of high temperature and moisture. They should be under surveillance during these circumstances, and if joint widths attain closure limits, new relief should be provided. This is best done at night during brief periods of falling temperatures to avoid difficulties and hazards caused by the thrust of the pavement against the saw blade and the concrete to be removed.

Blowup repair is necessarily a reconstruction operation, because the pavement in the joint must be replaced. Saw cuts are made in good concrete on either side of the displaced joint. The disrupted material is removed, with no disturbance to the base, and replaced with new concrete. In reinforced pavements construction joint techniques are used to tie the new concrete to the old reinforced material. The replacement joint should be doweled and built to new joint specifications. It may be an expansion joint with the traditional filler for expansion space, or a contraction joint if expansion space already has been provided at some nearby location.

Experience in Michigan with precast concrete sections has been good (*22*). These slabs are built 1 in. (25 mm) thinner than the existing pavement and are bedded in place (Fig. 23). When desired, load transfer is obtained by drilling the old pavement and inserting 1¼ by 9-in. (32 × 230 mm) dowels into these holes. After positioning the new slab the dowels are pulled into contact with and welded to a steel plate cast in the precast slab. Slotted filler strips cover the dowels and seals are applied over the filler. Michigan has also had success using a fast-setting concrete for a cast-in-place repair. A 9-bag mix (500 kg of cement/m^3 of concrete) with 2 to 4 lb of calcium chloride per bag (21 to 43 gr per kg of cement) is used and the pavement is closed to traffic for only 8 hours.

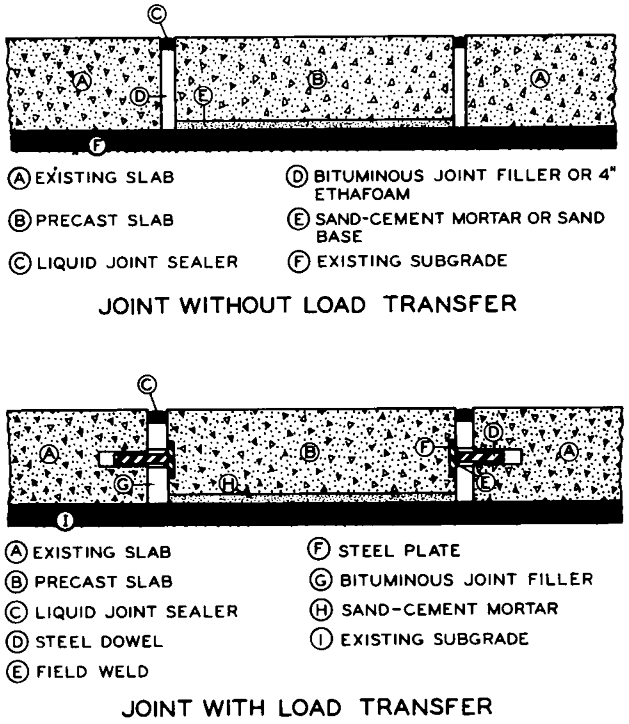


Figure 23. Precast slabs for joint repair (Michigan).

Soil Movements

Soil movements from moisture swells in silts and clays, or from frost heave, produce bumps in the surface. Temporary swell treatments are injections of limewater in the arid moisture-sensitive soils to achieve a partial stabilization, and chloride applications in frost-sensitive areas. In arid regions, roadside vegetation has been found to contribute to pavement undulations and its removal is beneficial.

Frost action is usually controlled by drainage. Removal of freezable water by shoulder treatment and drains can reduce the effect. A more effective remedy is by reconstruction and consists of removal of the frost pocket and replacement of this material by soil of the type surrounding the pocket and compacting it to the same moisture-density conditions.

Sealant Failures

Sealant failures often are the result of incompatibility of spacing, reservoir, and materials. Maintenance can do little about spacing, but sealants can be replaced with materials that can conform to the movement or reservoirs can be widened to provide a good shape factor. If preformed seals are selected for replacement, reservoir walls must be inspected and repaired if necessary to assure intimate contact between sealant and concrete across the full width of the pavement. Techniques for repair are those used for repairing spalls.

Frozen Joints

Frozen joints are frequently caused by dowels that corrode and "freeze" in place instead of slipping as intended. Misaligned dowels and reinforcing steel that inadvertently crosses the joint are other causes of frozen joints. The problem can be prevented by using dowels that are cut without lips or burrs, well-coated with lubricant, and accurately positioned. Where corrosion of dowels is a problem, special noncorroding materials or coatings should be used.

Frozen joints due to misaligned or corroded dowels may or may not require replacement. If slabs are short and the adjacent joints are functioning properly, there may be no serious difficulty with a frozen joint. However, the large movements in adjacent joints in long slabs may be conducive to early failures. Temporary relief may be provided by sawing through the dowels in the frozen joint, but load transfer is destroyed and it is likely that eventual reconstruction will be required.

Other Problems

Problems, such as slab separation and keyway failures, occur in some longitudinal joints. Separation has been found on roads built a lane at a time with no tie bars spanning the construction joint. In some instances where keys and keyways were used for preservation of vertical alignment, separation produced a looseness at the key and heavy loads running along the joint caused upper lip failure of the keyway (Fig. 21f). This failure is more probable in thin pavements—6 in. (150 mm) or less in depth—and is evidenced by a crack roughly paralleling the joint. Eventually the concrete above the key breaks out.

Occasionally, pumping occurs through longitudinal joints and when metal inserts are used, or plastic inserts are poorly installed, there may be raveling or spalling. Also, on thin pavements, the intersection of longitudinal and transverse joints is a likely location for problems. Fine line cracks a few inches from the joints may be "D" cracks that result from moisture or freezing action on the poor aggregates in the concrete. Sometimes joint grooves or saw cuts are not located directly over load transfer units.

Corrections for these conditions are self-evident. Keys should not be used in thin slabs and longitudinal joints should be tied. Longitudinal joint grooves should be properly sawed, cleaned, and sealed. Metal inserts that stay in place should be avoided; plastic inserts should be installed carefully. Load transfer units should be placed carefully, groove locations should be well marked, and the concrete mix should be placed without disturbing the unit and be well consolidated. Reinforcement should be placed accurately and lapped.

Maintenance of longitudinal joints usually requires removing all loose materials and filling and sealing. If pumping is serious, slabjacking or undersealing is necessary.

CHAPTER SIX

RESEARCH

CURRENT RESEARCH

Several agencies are currently engaged in research into PCC pavement joints. Some of these are identified in Table 2. It is readily acknowledged that this is not a comprehensive list and that productive research and evaluation studies may be in initial or continuing stages in many highway agencies, universities, and other research-oriented agencies.

NEEDED RESEARCH

Although much effort has been expended toward the development of satisfactory joints and seals in concrete pavements, no ultimate design has been achieved. Many worthwhile contributions have been made, and it is believed that the problem is understood; but it remains to develop a satisfactory, maintenance-free joint.

The frustrations with the assignment have led engineers to search for alternates to joints in pavements. Such research led to the development of continuously reinforced pavement, which substitutes closely spaced and tightly closed random cracks for the less frequent joints with greater movement. A modification of CRCP now being explored is the elastic joint concept, in which frequent stress raisers in the subgrade induce controlled cracks transversely across the concrete in areas of unbonded steel. The width of the crack opening is governed by the unbonded length, steel content, and crack spacing. Ideally, the cracks should be held to such narrow widths that maintenance is not required. This concept needs further research.

Another development spurred by problems with pavement joints is the prestressed concrete pavement. This has merit in that the prestressed length of pavement is always in compression and cracks are not induced. This concept, in fact, utilizes concrete to its best advantage because of its high compressive strength. However, when precompression of the concrete is attained through tension strands or rods, the cost of the steel is appreciable. When compression jacking against anchors or abutments is the prestressing method, the pavement stresses are continually changing and there is danger of complete loss of prestress on one hand and high stresses conducive to buckling on the other hand. These concepts need further research.

In both of these instances, pavements must be built in finite lengths and must be interrupted by bridges and intersecting roads. This requires that provision be made at the ends of these lengths to absorb the thrusts and movements that occur. Thus, the joint problem reoccurs; bridge approach joints in pavements are still experimental. Much more research is needed in this area.

It is unlikely that conventional pavements will be replaced by sophisticated designs for some time. Therefore, additional effort must be expended to continue to improve joints in plain and reinforced pavements. In the last 50 years, some of the best minds in the paving area have applied themselves to this problem. The result today is an aggregate-interlocked joint for plain pavements with short slabs, and dowel joints for pavements with longer slabs. As indicated elsewhere in this report, there are still problems with the performance of both.

Recently, some attempts have been made to develop preassembled joints containing all components, including the seal. It is appreciated that much joint trouble stems from construction deficiencies and that the preassembled joint may overcome this difficulty. Furthermore, in such a joint the sealant can be heat-bonded to the joint walls if they are metal and sealant adhering problems can be minimized. These assemblies can be provided with limiting devices on the movement to assure that seals are not broken. When slab movements are excessive, multiple units can be installed. The concept should be subjected to thorough research.

Until better devices are discovered, it is likely that load transfer assemblies will utilize solid round steel dowels. Some advances have been made in reducing corrosion by use of noncorrosive alloys and by plastic coating. However, it is still necessary to align a dozen or so dowels in each lane rather precisely and hold them in position during the paving operation. The dowel placer attempts to overcome this problem by vibrating the dowel to position in the spread or finished concrete. However, as in most instances,

TABLE 2

SUMMARY OF KNOWN RESEARCH ACTIVITIES RELATED TO PCC PAVEMENT JOINTS[a]

RESEARCH PROJECT TITLE	RESEARCH AGENCY	HRIP NO.[b]
Rigid Pavement Design—Joint Spacing	Florida Department of Transportation	25 080996
Performance of Experimental PCC Pavement Sections	California Division of Highways	25 091281
Rigid Pavement Joints and Sealants Study	Georgia Dept. of Transportation, Office of Materials and Tests	25 206912
Development of an Improved Contraction Joint for Portland Cement Concrete Pavements	Cincinnati University	25 220667
Structural Performance of Load Transfer Devices	Federal Highway Administration	26 017549
Rigid Pavement Investigations—Growth Characteristics and Blowups, and Performance of Transverse Joints and Joint Sealing Materials	Maryland State Dept. of Transportation, Bur. of Research	26 213988
Pavement Faulting Study	Georgia Dept. of Transportation, Office of Materials and Tests	26 219889
Development of Procedures for Replacing Joints in Concrete Pavements	Michigan Department of State Highways	40 221062
Preformed Elastomeric Pavement Joint Sealing Systems—Field Evaluation Phase (NCHRP Project 4-9, Phase II)	Utah State Highway Department	
Improved Pavement-Shoulder Joint Design (NCHRP Project 14-3)	Georgia Institute of Technology	
Resealing Rigid Pavement Joints	New York Department of Transportation	34 228505

[a] As of June 1973. [b] Acquisition number assigned by the Highway Research Information Service of the Highway Research Board; HRIP = publication entitled *Highway Research in Progress* (current issue).

solutions to one problem cause other problems and the dowel placer is still subject to maladjustment and misuse.

Dowels should not be considered the ultimate in load transfer devices. Some other concept and a noncorrosive material that provides a good balance between shear in the elements and shear in the concrete is needed. This mechanism should minimize the opportunities for error in installation without causing a weakness in the joint area. It should provide freedom of horizontal movement and be capable of sealing to prevent water and particle infiltration. Research is needed in this area.

In spite of the great amount of research that has been done on joint sealants, an ideal sealant has not been developed. Joint movement is limiting the workable lengths of pavement slabs. Where plain pavements are built, the slab length is determined by the crack pattern for that concrete and base, and if these slabs are sufficiently short and reservoirs are adequate, sealants can cope with the joint movement. However, longer slabs containing reinforcing steel are limited in length because poured sealants have insufficient extensibility and preformed sealants are limited in their compressibility range. A number of midwestern states have built reinforced slabs about 100 ft (30 m) in length for some years because economic studies based on cost of steel and joint construction have shown this to be their lowest cost pavement. However, joint sealing problems and blowups have caused them to reduce these lengths. It should be possible to develop a seal for joints between 100-ft slabs and research should be encouraged to that end.

Durability of joint seals is extremely important. It has been suggested that hot-poured seals have had a service life of about two years. These authorities also suggest a similar service life for cold-poured materials. Estimated life of preformed materials is five to ten years. Part of this limited life is due to faulty installation, improper design, or excessive spacing. However, a large part is also due to lack of material durability. In certain areas of the U.S., and in Canada, winters are very cold and summers are hot. These extremes impose a hostile environment on seals and produce deterioration. The ideal seal has not been produced and further research is needed on seal durability.

Recent advances have been made in the properties of portland cement. Cements have been developed that produce concretes that expand during early hydration. Although this expansion ceases after a few days, the final length of a slab made of expansive concrete is greater than that of a similar slab using type I cement. Also, low-heat cements have been used in some European countries in an attempt to reduce slab cracking. It is suggested that joints in pavements of expansive-cement concrete and low-heat-cement concrete may be slightly different from those in standard-cement concrete pavements. If new cements are to be tried in concrete pavements, volume change characteristics must be known to properly design the joints.

Joint replacement has always been tedious and expensive. There is a need for new equipment capable of cutting and removing old concrete and lifting new units into place. Experience in Michigan with precast replacements has shown these to be practical, but preparation of the old area and material handling must be improved. This is another area of needed research.

Traffic demands on urban expressways are such that lanes can be closed for only a very limited time without causing serious delays. To facilitate maintenance operations such as joint repair or replacement, it is desirable to use materials that can cure rapidly. Polymer cements are much too expensive for extensive replacement and it is essential that cheaper, rapid-setting cements be developed. Recent research at the Portland Cement Association Laboratories indicates that such products are possible. Research is needed to insure that these materials are permanent and durable.

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APPENDIX A

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APPENDIX B

SURVEY OF CONCRETE PAVEMENT JOINT PRACTICES IN THE UNITED STATES AND CANADA

Data for the tabulation were obtained in the winter of 1971-72 by requesting appropriate officials to update pertinent portions of the Portland Cement Association publication IS 0011.10. An asterisk (*) indicates either that there were no changes since 1969 or a revision was not received.

It is realized that states may use several specifications for the same item due to variations in conditions at the time of construction or repair. Presumably the data given apply most frequently. Where more than one number is shown in a cell, these numbers apply in the same order as slab depths, slab lengths, or pavement types if they are offset by commas. Dashes between numbers indicate a range.

When a number was not definitive, letters or reference digits enclosed in parentheses were placed in pertinent locations. In other cases descriptive words or abbreviations indicate the exclusive area of use or the applicable specification. Abbreviations used are:

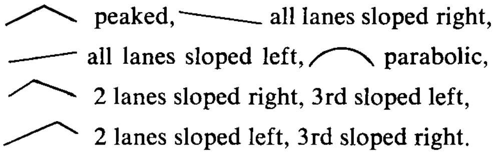
P	plain concrete pavement.
R/C	conventionally reinforced concrete.
CRC	continuously reinforced concrete.
mod.	modification.
Exp't'l	experimental.
rpt	repeat.
Var	variable.

Other symbols are as follows:

A	as shown on plans
E	as directed by engineer
d	concrete depth or thickness
u	untreated aggregate
o	untied
ct	cement-treated or soil-cement
ac	asphalt-treated or bituminous base
lt	lime-treated
m	mils (0.001 in.)
pl	plastic strip
rc	in rock cut
s	secondary roads
st	stabilized

Occasionally a number enclosed in parentheses could be mistaken for a slab length or some other characteristic. This is unfortunate; but attempts at other types of designation also led to confusion. Thus, it is cautioned that the only significance in a parenthesized number is the note to which it refers. These notes are as follows:

(*1*) Transverse surface profile:



(*2*) Width uniform except as indicated.
(*3*) Untreated aggregate or stabilized base.
(*4*) Excluding plastic strip inserts.
(*5*) Same as mainline pavement.
(*6*) Insert sawed to provide reservoir or to remove.
(*7*) Metal plate or preformed plank or fiber.
(*8*) Also no subbase.
(*9*) Untreated aggregate on 6-in. stabilized subgrade.
(*10*) Option, 16-ga. metal, ⅝-in. top clearance, no seal.
(*11*) Center 6 ft rounded.
(*12*) ac used over ct or lt soil.
(*13*) Keyed for two or more paving operations.
(*14*) Only with gravel-aggregate concrete.
(*15*) 2 in. for cold-applied seal, 1 in. for preformed.
(*16*) R/C = d/4 + ¼, P = d/4 except 9-in. @ 2½-in. depth.
(*17*) R/C @ 33 ft, P > 8 @ 32 ft, P ≤ 8 @ 48 ft.
(*18*) Normally ac.
(*19*) Only outer lanes.
(*20*) Rural 15 ft, urban 19 ft.
(*21*) 18-ga. deformed metal.
(*22*) Tie bars ⅝ × 30 @ 30 in. used infrequently.
(*23*) Material must not be disturbed by operations.
(*24*) Tie bars ⅝ × 48 @ 40 in. for R/C; ½ × 30 @ Var. for CRC.
(*25*) Actual thickness based on support.
(*26*) Interstate repeats 15-13-17.
(*27*) Either 4 in. wide on base or 2 in. on sleeper and lugs.
(*28*) Hot asphalt with mineral filler.
(*29*) 12 WF 58.
(*30*) Repeat pattern 13-19-18-12.
(*31*) Used only where roadway is sanded.
(*32*) Spaced 15 ft when max. aggregate size is ¾ in.
(*33*) Wide ac pressure relief provided.
(*34*) Repeat pattern 17-23-22-16.
(*35*) Top ¾ in. widened to ½ in.
(*36*) Used only in adjacent three slabs each side of bridge.
(*37*) 4 lugs, 2 ft wide × 3 ft deep @ 15 ft, CRC only.
(*38*) Repeat pattern 13-18-17-12.
(*39*) Used only as alternate.
(*40*) Not used in P.
(*41*) Only CRC: 2-in. doweled expansion joint and 3 lugs, 2 ft wide × 4 ft deep @ 20 ft.
(*42*) 2¼ in. for weakened plane or ⅝ in. over metal plate.
(*43*) 2 lugs, 2 ft wide × 3 ft deep @ 15 ft.
(*44*) Gravel-aggregate concrete, 25 ft; limestone, 50 ft.
(*45*) First joint 50 ft from bridge.
(*46*) Winter season (Sept. 15 to Apr. 15) 355 ft.
(*47*) Expansion joints used rather than contraction.
(*48*) First joint 20 ft from bridge.
(*49*) 4 lugs, 2 ft wide × 3 ft deep @ 17 ft.
(*50*) 1 in. for 8 R/C, 1¼ in. for 9 and 10 R/C.
(*51*) 45 lb for 8 R/C, 54 lb for 9 and 10 R/C.
(*52*) 10 ga × 5½ in. sheet metal, or ½ in. × 2½ to 2¾ in. wood strip.
(*53*) Malleable iron two-component load transfer device.
(*54*) Catalytically blown asphalt.
(*55*) In CRC: ¾ in. joints @ 0, 20, 60; 4 lugs, 2 ft × 4 ft @ 40 ft.
(*56*) Steel, ⅛ in. thick, full depth.
(*57*) New shapes and seals being explored.
(*58*) Repeat pattern 19-25-24-18, and ramp slabs 25 ft.
(*59*) P: 2 joints @ 25 ft; CRC: 3 joints @ 50 ft.
(*60*) Insert completely removed, sawed to ⅜ in.
(*61*) Gravel-aggregate concrete 18 ft, stone 25 ft.
(*62*) Hot-poured sealant only for maintenance.
(*63*) P: 4 ft joint on sleeper and 5 joints ¾ in. wide @ 20 ft. CRC: 3 joints 1 in. wide @ 40 ft and 6 lugs 2 ft × 3 ft @ 15 ft.
(*64*) R/C: rural 80 ft, urban 40 ft.

SI equivalents: 1 in. = 25.4 mm
1 ft = 0.3048 m
1 lb = 0.4536 kg
1 ft^2 = 0.0929 m^2

State (Prov.)	FREEWAYS, EXPRESSWAYS, INTERSTATE									
	Concrete Pavement				Pavement Base material & depth, in.				Shoulder Base	
	Mainline		Ramps							
	Depth in.	Crown *(1)*	Depth in.	Width ft. *(2)*	ct	Other stab.	u	Depth in.	ct	Flex. *(3)*
Ala	8, 9, 10	∧	*(5)*	Var	✓	✓	✓	6	✓	✓
Alta*										
Ariz	9	╲	9	Var	5		3	8		✓
Ark*	9, 10	╲	8	15	✓		✓	6	✓	✓
Cal	7.8-9.6	╲			4.8-5.4	6-9 lt	6	11.4		✓
Colo*	8	╲	8	Var	✓	✓	✓	4		✓
Conn	9	∧	9	24			✓	6-10, 18 rc		✓
Del	9-10	╲ ∧	8-10	Var	4		8	12	✓	u
DC	10	╲	9, 10	Var			✓	Var		✓
Fla*	9	╲ ∧	9	16		✓		12		✓
Ga	9, 10	╲	8, 9	16-20	5	1 ac		6	✓	
Ida	8	╲			✓			4		✓
Ill	8-10	∧	8-10	14-16	✓	✓		4		✓
Ind	9-10	∧	8-10	16		✓	✓	4, 6		✓
Iowa	8-10	∧	6-10	16, Var	✓	ac	✓	4		✓, st
Kan	9	∧	9	18		*(9)*	✓	4		✓
Ky	10	*(11)*	10	18			✓	6, 5 rc		✓
La	8, 10	╲	9	15	✓	ac *(12)*		6	✓	
Me*	8	∧					✓	9-15		✓
Man*	6, 8	∧	6, 8	Var			✓	A		✓
Md	9	╲	9	Var			✓	6		✓
Mass	9	∧	9	Var			✓	12		✓
Mich	9-10	╲ ∧	9	16			✓	14		✓
Minn	8-10	∧	8, 9	16			✓	3-6		✓
Miss	8, 9	∧	8, 9	16, Var	✓	4 ac		6	✓	ac
Mo	8-10	∧	8, 9	18, Var			✓	4	✓	✓
Mont	8	*(11)*	8	Var	✓	ac		5		✓
Neb	8-10	╲ ∧	8	16	✓		✓	4		✓
Nev	8, 9	╲	8	12-24	✓			4-6		✓
NJ	8-10	∧	8-10 *(18)*	Var			✓	Var		✓
NM	8, 9	∧	8, 9	Var	✓			4	✓	✓
NY	9	╲	9 *(18)*	Var			✓	12		✓
NC	9, 10	╲	9	Var			✓	4		✓
ND	8	∧	9	14, Var		ac		2		✓
NS*										
Ohio	8 CRC, 9, 10 R/C	— ∧	9	Var	4	3 ac, 4 lt	6			✓
Okla	8 CRC, 9 other	╲	8, 9	*(20)*		✓		4-6	✓	
Ont*	9	∧	9	Var	✓	✓		6 min		✓
Ore	8	╲	8	Var	✓	ac	✓	6-14		✓
Pa	9, 10	╲	8-10	Var			✓	Var		✓
Que*	9	∧ ∧	9	12	✓	✓	✓	Var	✓	✓
RI	8	∧					✓	12		✓
SC	8-1/2 CRC, 9, 10 other	∧	8-10	Var. A	✓	✓	✓	Var	✓	✓
SD	8, 9	╲ ∧	8, 9	18	✓	✓	✓	2-5		✓
Tenn	9 rural, 10 urban	╲	9 rur, 10 urb	Var	✓	✓	✓	6		✓
Tex	8 CRC, 10 other	╲	6, 8, 10	Var	✓	ac		4-8		✓
Utah	9, 10	╲	9, 10	A	4		4	8		✓
Vt	8	∧	A	A			✓	A		✓
Va	8 CRC	A	9 P	Var	✓			6	✓	✓
Wash	9	╲	A	14		✓	✓	6 min		✓
W.Va	8 CRC, 8, 9 other	╲	9	Var	✓	✓	✓	6 st		✓
Wis	8-10	∧	9	15		✓	✓	6-9		✓
Wyo	8-9 *(25)*	╲	8	16	✓		✓	4&6		✓

2-LANE PRIMARY					SECONDARY ROADS						
Concrete Pavement		Base (Subbase)			Concrete Pavement		Base (Subbase)				
Depth in.	Crown	ct	Other stab.	u	Depth in.	Crown	ct	Other stab.	u	None	State (Prov.)
8, 9	︿	✓	✓	✓							Ala
6-8	︿	✓		✓							Alta*
8	︿	5		3	8	︿			✓		Ariz
9	︿			✓							Ark*
7.2-9	—	4.8-5.4	6-9 1t	6	6.6-7.8	—	✓	1t	✓		Cal
8	—	✓	✓	✓							Colo*
8	︿			✓							Conn
8, 9	︿	✓		✓	8	︿			✓	✓	Del
10	⌒			✓	8	⌒			✓		DC
8, 9	︿		✓								Fla*
8	︿⌒	✓			6, 7	︿⌒	✓				Ga
8	—	✓									Ida
8-10	︿	✓	✓		6-10	︿			✓	d<8	Ill
9	︿		✓	✓	9	︿			✓		Ind
6-10	︿⌒	✓	ac	(8)	6-8	︿⌒				✓	Iowa
9	︿		(9)	✓	9	︿			✓	✓	Kan
8, 9	- - (11)			✓	8	- - (11)			✓		Ky
8, 9	︿	✓		✓	8	︿	✓		✓		La
8	︿			✓	8	︿			✓		Me*
6, 8	︿			✓	6-8	︿			✓		Man*
9	︿			✓	9	︿			✓		Md
											Mass
9	︿			✓	8, 9	︿			✓		Mich
7-9	︿			✓	6-8	︿			✓		Minn
8, 9	︿	✓	ac								Miss
8-10	︿			✓	7, 8	︿			✓		Mo
8	(11)	✓			8	(11)	✓				Mont
7.5-10	︿	✓		✓	6-7	︿				✓	Neb
											Nev
8-10	︿			✓	8, 9	︿			✓		NJ
8, 9	A	✓			8, 9	A	✓				NM
9	︿			✓	9	︿		✓	✓		NY
8, 9	︿			✓	A	︿			✓		NC
8, 9	︿		1t	✓							ND
8	︿			✓							NS*
8 P, CRC, 8, 9 R/C	︿			✓	7-9	︿			✓	✓	Ohio
8, 9	⌒		✓		7, 8	⌒		✓			Okla
8, 9	︿	✓	✓		7, 8	︿	✓	✓	✓		Ont*
											Ore
8-10	︿			✓	8-10	︿			✓		Pa
9	︿⌒	✓	✓	✓							Que*
8	︿			✓	8	︿			✓		RI
											SC
7, 8	︿	✓	✓	✓							SD
9	—	✓	✓	✓	10 urb	—	✓	✓	✓	✓	Tenn
8 CRC, 10 other	︿	✓	ac		8 CRC, 10 other	︿	✓	ac			Tex
9, 10	—	4		4	(18)						Utah
8	︿			✓	8	︿			✓		Vt
8 P	A	✓			5-7	A			✓	✓	Va
7.8	︿			✓	7.8	︿			✓		Wash
9	︿	✓	✓	✓	9	︿	✓	✓	✓		W.Va
9	︿		✓	✓	9	︿			✓		Wis
7.5, 8	︿	✓		✓	7.5	︿			✓		Wyo

State (Prov.)	TRANSVERSE JOINTS										
	Construction Joints				Contraction Joints						
	Type				Spacing ft.		Type				
	Keyed	Butt	Tied	Dowels	Plain	R/C	Skew	Saw	Form	Insert	Perm. Insert
Ala	✓			✓	20	57.5		✓		✓	✓ *(6)*
Alta*		✓		✓	20		✓	✓	✓		
Ariz		✓	✓		15 *(26)*		✓	✓		✓	20 m, pl
Ark*		✓		✓		45		✓	✓	✓	*(6)*
Cal	✓		✓		*(30)*		✓	✓		✓	20 m, pl
Colo*		✓			*(30) (32)*		✓	✓			
Conn		✓		✓		40			✓	✓	metal
Del		✓		✓		45		✓			
DC			✓		15	A				✓	*(7)*
Fla*		✓		✓	20					✓	*(6)*
Ga		✓		✓	*(34)*		✓	✓			
Ida	✓		✓		*(38)*		✓	✓		✓	20 m, pl
Ill		✓	s	✓	20 s	100		✓			
Ind	✓		✓			40		✓			
Iowa		✓		✓	20, 40 s			✓			
Kan	✓			✓		61.5		✓	✓	✓	metal
Ky	✓		✓			25, 50 *(44)*		✓			
La		✓	✓	✓	20	58.5			✓	✓	
Me*					A	A					
Man*	✓				16	20	✓	✓		✓	fiber
Md	*(13)*	✓	✓	✓		40		✓	*(14)*		
Mass		✓	✓			40		✓			
Mich		✓		✓		71.17		✓			
Minn	✓		✓		20	27	P	✓	@ 80'	✓	
Miss		✓		✓		*(47)*					
Mo	✓		✓		30	61.5		✓			
Mont	✓		✓		*(30)*		✓	✓			
Neb	P, 6-7.5	✓		8-10	15	46.5	P, 6-7.5				
Nev	✓		✓		*(30)*		✓	✓			
NJ			✓		15-20	*(47)*			✓	✓	*(52)*
NM	✓		✓		15-20		✓	✓			
NY		✓		✓		60.8		✓	✓		
NC		✓		✓	30			✓			
ND	✓	✓	✓	✓	15-20		P	✓	✓		
NS*		✓		✓		56		✓			
Ohio		✓		✓	17	40 max	P	✓			
Okla		✓		✓	15		Exp't'l	✓	✓		
Ont*		✓		✓	*(30)*		✓	✓			
Ore		✓	✓	✓	15-60	61.5		✓			✓
Pa		✓		✓		46.5		✓	✓	✓	*(56)*
Que*		✓		✓		60		✓			
RI		✓		✓		40		✓	✓		
SC		✓		✓	*(58)*		✓	✓		*(6)*	metal
SD		✓	✓		20		P	✓	✓	*(60)*	
Tenn		✓		✓	*(61)*		✓	✓	✓	*(6)*	*(7)*
Tex			CRC		15	60		✓	✓		redw'd
Utah	✓			*(38)*			✓	✓			
Vt		✓		✓	A	A		✓	✓	✓	*(7)*
Va		✓		✓	20	40		✓	✓	*(6)*	
Wash		✓		✓	A-Rpt		✓	✓		✓	✓
W.Va		✓	CRC	R/C		61.5		✓	✓		A
Wis		✓		✓		*(64)*		✓			
Wyo	✓		✓		*(30)*		✓	✓	✓	*(6)*	

TRANSVERSE JOINTS									State (Prov.)
Contraction Joints					Expansion Joint Spacing ft.	Sealants Specified			
Dimensions		Dowels				Hot poured elastic	Cold applied	Preformed elastic	
Width in. *(4)*	Depth in.	Dia. in.	Length in.	Spacing in.					
1/4, 3/8	d/4	d/8	18	12		M-173			Ala
1/4 max	d/4 - d/5	A	A	A	A				Alta*
3/16 *(4)*	2					M-173		M-220	Ariz
1/4 - 3/8	d/4	1	18	15		*(28)*			Ark*
1/4 max	2					*(31)*		*(31)*	Cal
1/8	2	1-1/4	12	12		M-173			Colo
3/8	3	1-1/8	18	12	A	M-173			Conn
3/16	d/4 + 1/4	1-1/4	18	12		M-173		M-220	Del
1/4	d/3	A	A	12	30	SS-S-164	SS-S 156, 159		DC
3/8	2-1/2	1	18	12		M-173			Fla*
3/16 *(35)*	1-1/2 - 2-1/4	1-1/4 *(36)*	18	15		SS-S-1401A			Ga
1/4 *(4)*	2							*(39)*	Ida
1/8 min	2-3/4, 1-1/2 s	1-1/4 *(40)*	18	12		D-1190	D-1850		Ill
1/8	d/4	1-1/4	18	12		M-173	D-1850		Ind
1/8 min	d/4 min	1-1/4	18	12		M-173			Iowa
3/8	*(42)*	1-1/4	18	12		Kan		✓	Kan
1/8 - 1/4	2	d/8	18	12		D-1190			Ky
7/16	2-3	1	24	12				Neopr.	La
A	A	A	A	A		A	A	A	Me*
1/4	1, 2	A	A	A		Man			Man*
1/4 ± 1/16	*(15)*	1-1/4	18	12	600	D-1190	D-1850	Md	Md
3/8	2-1/4	1-1/8	16	12		SS-S-164			Mass
1/2	2-1/2	1, 1-1/4	18	12	*(46)*			Mich	Mich
3/8	1-5/8, 2-1/2	1 - 1-1/4	18	12		M-173 mod		Minn	Minn
					63-3/4	M-173			Miss
3/8	d/4	1 - 1-1/4	18	12		D-1190			Mo
1/8 - 3/8	d/4	1	18	12		SS-S-164			Mont
1/8 - 3/16	d/4	*(50)*	18	12		M-173			Neb
1/8 - 1/4	2					✓		✓	Nev
(52)	*(52)*				78.17	NJ			NJ
1/4	2	A	A	A		M-173	D-1850, SS-S-1596		NM
5/8	2	*(53)*	*(53)*					NY	NY
3/8 ± 1/16	d/4 + 1/4	d/8	2d - 2	12		M-173		M-220	NC
3/8 max	2-3/4	1-1/4	18	12		D-1190 mod		A	ND
1/4	1-1/2	1-1/2	12	12				Ont	NS*
1/4 ± 1/16	d/5	d/8	18	12		M-173	Ohio	Ohio	Ohio
3/8	d/4	1 - 1-1/4	24	12		M-173	Okla	*(54)*	Okla
3/8	2-1/2	1-1/4	18	12				Ont	Ont*
1/8 - 1/4	2	1	18	12		M-173		M-153, M-213	Ore
3/8 *(57)*	d/4	1-1/4	18	12		SS-S-164			Pa
1/4	2-1/4	1-1/4	18	12		D-1190		Que	Que*
1/4	2	1	18	12		RI			RI
1/4	2-1/4	1-1/4	18	14		M-173			SC
1/4, 3/8	2, 2-1/4					A		✓	SD
1/4	2-3	1-1/4	15	12		A	A	A	Tenn
1/2 - 3/4	d/4	1-1/4	22	12		Tex	Tex	Tex	Tex
1/8 - 1/4	2-1/4	5/8	30	48		SS-S-164			Utah
1/4 min	d/5	A	A	A	A	M-173, SS-S-164	SS-S-159b	A	Vt
3/8	d/4	1-1/4	18	12		M-173 *(62)*	D-1850	D-1056	Va
1/8 - 1/4	1-1/2					M-173	D-1850		Wash
1/4	d/4	1-1/4	19	12		M-173		A	W.Va
1/4 min	2	1 - 1-1/4	18	12		D-1190			Wis
1/8 - 3/16	2					M-173		A	Wyo

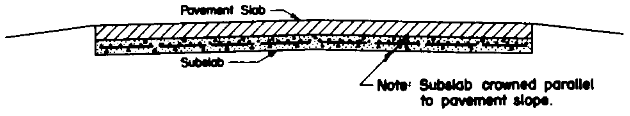
State (Prov.)	LONGITUDINAL JOINTS											
	Construction			Control				Dimensions		Tie Bars		
	Keyed	Butt	Tied	Sawed	Formed	Insert	Perm. Insert	Width in. *(4)*	Depth in.	Dia. in.	Length in.	Spacing in.
Ala	✓		✓	✓		✓		1/4	d/4	1/2, 5/8	30	18-26
Alta*	✓		✓	✓				1/4	d/4	A	A	A
Ariz		✓	✓, 0	✓		✓	6 m, pl	3/16	2	1/2	24	30
Ark*	✓		✓	✓	✓	✓	*(6)*	1/4	2-3/16	1/2	48	30
Cal		✓		✓		✓	4 m, pl	1/4	2			
Colo*	✓		✓			✓	10 m, pl		2	3/8	36	36
Conn	✓		✓	✓		✓	Iron	3/8	2 - 2-3/4	1/2 - 5/8	30	30
Del		✓	✓	✓				3/16	d/4 + 1/4	5/8	48	40
DC	✓					✓	*(7)*	1/4	d/3	1/2	36	A
Fla*	✓		✓	✓		*(6)*		3/8	2-1/2	1/2	24	31, 35
Ga	✓		✓	✓				1/4 - 5/16	1-5/8 - 2-3/4	1/2	30	30
Ida				✓		✓	10 m, pl	1/4	2 - 2-1/4			
Ill	✓		✓	✓		✓	10 m, pl	1/8	2-3/4, 1-1/2 s	5/8, 1/2 s	30	30
Ind	✓		✓	✓				1/8	d/4	5/8	36	36
Iowa	✓		✓	✓				1/8	d/4 min	1/2	36	30
Kan	✓		✓	✓	✓	✓	10 m, pl *(10)*	1/4	2-1/2 min	1/2	24	30
Ky	✓		✓	✓				1/8 - 1/4	d/4 + 1/4	1/2	30	30
La			✓		✓	✓	pl	7/16	2-3	1/2	24	24
Me*								A	A	A	A	A
Man*	✓		✓	✓	✓			1/4	d/4	5/8	36	30
Md	*(13)*		✓	✓	*(14)*			1/4 ± 1/16	*(15)*	5/8	48	48
Mass	✓		✓	✓				1/4	2-1/2	5/8	30	48
Mich		✓	✓	✓				1/8 min	2-1/2 min	1/2	30	40
Minn	✓	✓	✓	✓				1/8	2-3	1/2, 5/8	30	36
Miss			✓			✓	8 m, pl	1/4	2	1/2	30	30
Mo	✓		✓	✓				1/8 min	d/4	5/8	30	30
Mont	✓		✓	✓		✓	10 m, pl	1/8 - 3/8	d/4	1/2	24	30
Neb	✓		✓				✓	1/8 - 3/16	*(16)*	5/8	30	*(17)*
Nev		✓	✓	✓				1/8 - 1/4	2	1/2	22	30
NJ	✓		*(19)*	✓				1/4	2-1/4 - 2-3/4	5/8	36	48
NM	✓		✓	✓				1/4	2	1/2	30	30
NY			✓	✓	✓			5/16	2	5/8	15	40
NC		✓	✓	✓				3/8 ± 1/16	d/4 + 1/4	1/2, 5/8	30	30
ND	✓		✓	✓	✓	E	pl	1/8	2-1/2	5/8	30	48
NS*				✓				1/4	1-1/2	5/8	30	30
Ohio	✓		✓	✓			12 m, pl	1/8	d/3	5/8	30	30
Okla	✓	✓	A	✓	✓	✓	*(21)*	3/8 - 1/2	1-1/2 - 2	1/2	30	30
Ont*	✓		✓	✓				1/4	2-1/2	5/8	30	30
Ore		✓		✓			✓	1/8 - 1/4	2	*(22)*		
Pa	✓		✓	✓				3/8	d/4 + 1/4	5/8	48	50
Que*	✓		✓	✓				1/4	2-1/4	9/16	24	30
RI		✓	✓	✓				1/4	2	1/2	20	30
SC	✓		✓	✓		✓	metal	1/4	2-1/2	1/2	30	30
SD	✓		✓	✓		✓	pl	1/8	d/4	5/8	30	48
Tenn	✓			✓	✓	✓	metal, fiber	1/4	d/4	1/2	24	30
Tex			✓	✓	✓			1/8 - 1/4	d/4	1/2	30	24-36
Utah	✓			✓				1/8 - 1/4	2-1/4	5/8	30	48
Vt	A	A	A	✓	✓			1/8 min	d/4	A	A	A
Va		✓	✓	✓	✓	*(6)*	pl	3/8	d/3	5/8	30	40
Wash		✓	✓	✓		✓	*(23)*	1/8 - 1/4	2	1/2	24	36
W.Va	✓		✓	✓	✓		✓	1/4	d/4	*(24)*		
Wis			✓	✓	✓			1/8 min	1-1/2	1/2	24	36
Wyo	✓		✓	✓		✓	8 m, pl	1/8 - 3/16	2	1/2	24	30

SPECIAL ITEMS								State (Prov.)
Reinforcement Steel		Bridge Approach						
		Expansion Joints					Anchor Lugs	
R/C lb/100 sq.ft.	CRC Long. % of sect.	No.	Width in.	Spacing ft.	Dowels	Sleeper		
54	0.6	3	1	80	✓	✓	A	Ala
A	A	A	A	A	A	A	A	Alta*
		1	(27)			✓	✓	Ariz
59	0.6	1	4			✓	(29)	Ark*
		1	3/4					Cal
		3	3/4	20	✓			Colo*
52		1	3/4 (33)	40	✓			Conn
54	0.6	1	3/4	20		✓		Del
50-61		Var	Var	Var	✓		Var	DC
		1	48 (33)	100		✓		Fla*
	0.6	3	3/4	30	(36)		(37)	Ga
		1	1-3/8			✓		Ida
78	0.6-0.7	1	4		(41)		(41)	Ill
54	0.6	2	48 (33)	20.5		✓		Ind
	0.6-0.65	3	3-4	15 P, 80 CRC		CRC		Iowa
61		2	3/4	33	✓	✓	(43)	Kan
36 @ 25', 60 @ 50'	0.6	3	1	25 (45)	✓			Ky
74	0.6	1	3/4	20	✓	✓		La
A		A	A	A	A	A	A	Me*
69	A	A	A	A	A	A	A	Man*
54	0.62		(33)			CRC		Md
45, 65			(33)					Mass
76, 83	0.7	3	1-1/4	29.5, 15.5	✓		CRC	Mich
30		3	1-3/8 - 2	31	✓			Minn
78	0.585	4	1	40 (48)	✓		(49)	Miss
61		2	2	30, 61.5		Agg.		Mo
		1	3/4		✓			Mont
(51)	0.65	1	@ 4, 2 @ 2	25		✓		Neb
		1	1-1/2					Nev
80		5	1	23.58	✓			NJ
		2	1	20	✓			NM
63		3	1 (33)	61	✓			NY
A	0.6	4	1	A	✓			NC
	0.6	3	1	39.5				ND
74		A	A	A	A	A		NS*
54	0.6	2	1	40	✓			Ohio
	0.612	3	1-1/2	60	✓			Okla
		1	3/4	Var	✓			Ont*
61-113	0.6	1	3/4	20			(55)	Ore
A	A	1	1					Pa
69		2	3/4	100	✓			Que*
65		1	3/4					RI
	0.61	(59)	1	(59)	✓	✓	CRC	SC
	0.6	1	4	15		✓		SD
		2	1/2	24				Tenn
66-91	0.5, 0.6	1	1-1/2			✓	(49)	Tex
		1	3/4	10.5 min				Utah
A		A	A	A	A	A	A	Vt
61	0.6	3, 6	(63)	20, 40	✓	(63)	(63)	Va
		1	1/2		✓			Wash
61	bar 0.65, wire 0.59	3	3/4 (33)	61.5	✓	(29)		W.Va
69	0.61	4	3/4	40	✓			Wis
		2	3/4	15	✓			Wyo

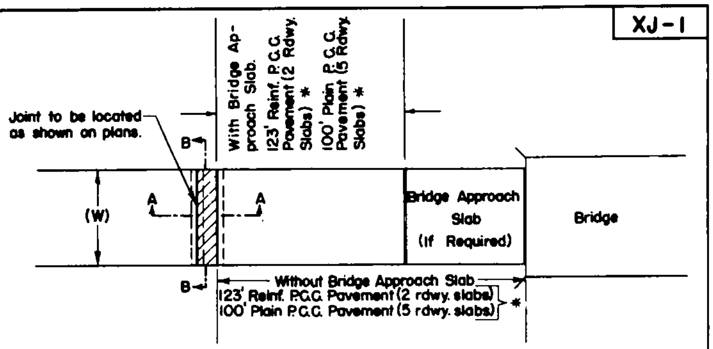
APPENDIX C

BRIDGE APPROACH EXPANSION JOINT

XJ-1

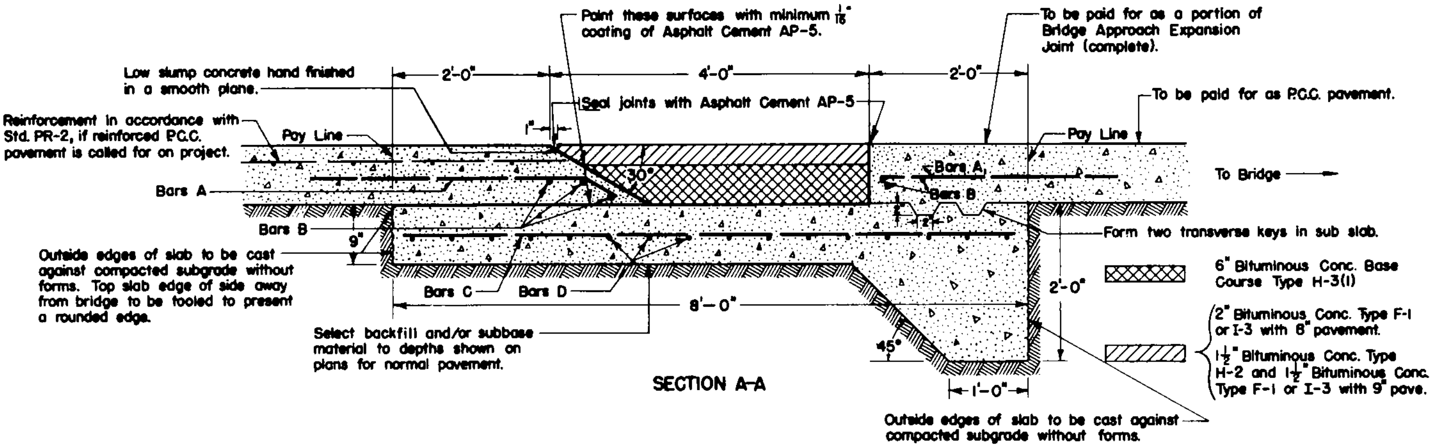


SECTION B-B



PLAN

* Denotes desirable values



SECTION A-A

NOTES

Basis of payment to be linear feet of transverse measure (W), of the complete joint including subslab, bituminous material, portion of pavement slab over the subslab between the pay lines shown in Section A-A; and all additional excavation.

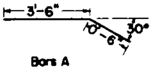
Concrete in subslab to be Class A (AE).

Bars A, A1, & B to be placed as shown whether plain or reinforced P.C.C. pavement is used.

Portions of Bars A and A1 which are outside of the indicated pay lines are to be included in price bid for complete joint.

SCHEDULE OF REINFORCING STEEL

MARK	SIZE	SPACING C-C	LENGTH	NO. REQ'D.	WEIGHT/FT. TRANSVERSE MEASURE LBS.
A	5	12"	4'-0"	(W)	4.172
A1	5	12"	3'-0"	(W)	3.129
B	5	6"	W-4"	5	5.215
C	4	6"	7'-8"	(W)(2)	10.240
D	4	6"	W-4"	16	10.688



Bars A

APPROXIMATE QUANTITIES PER FOOT OF TRANSVERSE MEASURE

	MAIN LINE PAVEMENT DEPTH	
	8"	9"
Cu. Yds. Class A(AE) Conc.	.30	.30
Lbs. Reinforcing Steel	33.44	33.44
Tons Bit. Conc. H-3(I)	.16	.15
Tons Bit. Conc. H-2	—	.05
Tons Bit. Conc. F-I or I-3	.06	.04
Sq. Yds. P.C.C. Pave. **	.51	.52

** Note: Beveled portion of pavement slab has been converted to equivalent design depth of main line pavement.

REVISED	
4-15-64	

BRIDGE APPROACH EXPANSION JOINT

VIRGINIA
DEPARTMENT OF HIGHWAYS
SEPTEMBER 1, 1963

302.1

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