DETERIORATION OF JOINTED PORTLAND CEMENT CONCRETE PAVEMENTS

by

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Research Engineers

(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies.)

Virginia Highway & Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the Virginia Department of Highways & Transportation and the University of Virginia)

Charlottesville, Virginia

November 1975
VHTRC 76-R19

1240

SUMMARY

Information has been gathered regarding the performance of more than 400 lane-miles of jointed PCC interstate pavements located in five construction districts in Virginia. The factors causing pavement deterioration have been identified, the processes associated with deterioration have been described, and typical examples of distress, or failure types, have been recorded.

Recommendations are made with respect to (a) criteria for determining the latest time at which the initiation of permanent pavement repairs should be considered, (b) a rapid technique for visual surveys to ascertain pavement conditions, (c) the communication of the study findings to field forces, (d) the practice of installing temporary bituminous patches, and, (e) the continuation and expansion of preventive maintenance activities.

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INTRODUCTION

Maintenance operations on pavements are difficult to conduct because of the restrictions on lane closures that must be imposed in order to accommodate traffic flow. The restoration of jointed portland cement concrete (PCC) pavements typically requires that a detailed sequence of repair activities be performed at a series of locations. The required number of repairs within a specified time period for particular traffic situations can be achieved only be detailed prior planning.

Pavement repairs are planned after considering the type and amount of pavement distress, the traffic flow requirements, and the repair procedures and materials that are available. Various combinations of procedures and materials have been tried in Virginia on an experimental basis and as a part of contract and maintenance force operations. The overall purpose of this project has been to study methods and procedures for effecting permanent repairs of PCC pavements with minimum interruptions to traffic.[1]

PURPOSE AND SCOPE

This report presents the factors involved in and the processes of PCC pavement deterioration on interstate pavements in Virginia. Recognizable types of pavement distress are described and the subject of pavement repairs is discussed.

FACTORS CAUSING PAVEMENT DETERIORATION

Most of the deterioration in jointed PCC pavements has occurred at the transverse joints. Various causes of deterioration have been identified nationally,[2] but four major factors have contributed to the deterioration of joints in Virginia. These have been the metal inserts used for forming the joints, difficulties experienced with joint sealants, densely graded subbase and shoulder materials, and the construction of long slabs.

Most pavements in this study incorporated the metal inserts. It should be emphasized, however, that other pavements with the metal inserts and of the same age as those requiring extensive repairs have performed reasonably well, and that the poorer performance can be readily related to the greater influence of the other three factors leading to deterioration. The relative performance of the several jointed PCC pavements will be discussed after the factors related to joint deterioration are described in the following paragraphs.

Metal Inserts

The tubular metal joint insert shown in Figure 1 was used to form transverse contraction joints in many of the concrete pavements constructed in Virginia in the early 1960's. Placed in the fresh concrete, this device provided a weakened vertical plane at which contraction joints would occur. After the concrete hardened, the insert was crimped downward and a poured sealant was introduced.

A survey of these metal joint inserts in 1968 found their condition to be "fair to rusted" and badly rusted after four to six years of service.(3) Because the inserts were anchored by small flanges extending into opposing faces of concrete at the contraction joints, weakened planes existed and were aggravated by corrosion products. Remnants of a corroded metal insert lifted easily from a joint are shown in Figure 2.

The insidious nature of the concrete deterioration resulting from insert corrosion is indicated in Figures 3 and 4. Figure 3 shows a pavement area adjacent to a transverse joint containing the metal insert. The location of delaminated concrete was outlined on the pavement surface by sounding the pavement with a ball peen hammer. This technique for locating unsound concrete is documented in a report dealing with the detection of deteriorated concrete in bridge decks.(4) Figure 4 shows a core taken vertically through the joint. The metal insert and well-formed contraction joint are in the central portion of the core. The embedded flange of the insert had corroded sufficiently to rupture the concrete approximately two inches below the roadway surface. Weakened planes of this type, initially not evident from the surface, propagate under repeated wheel loadings and eventually intercept the pavement surface at 6 to 12 inches from the joint face.

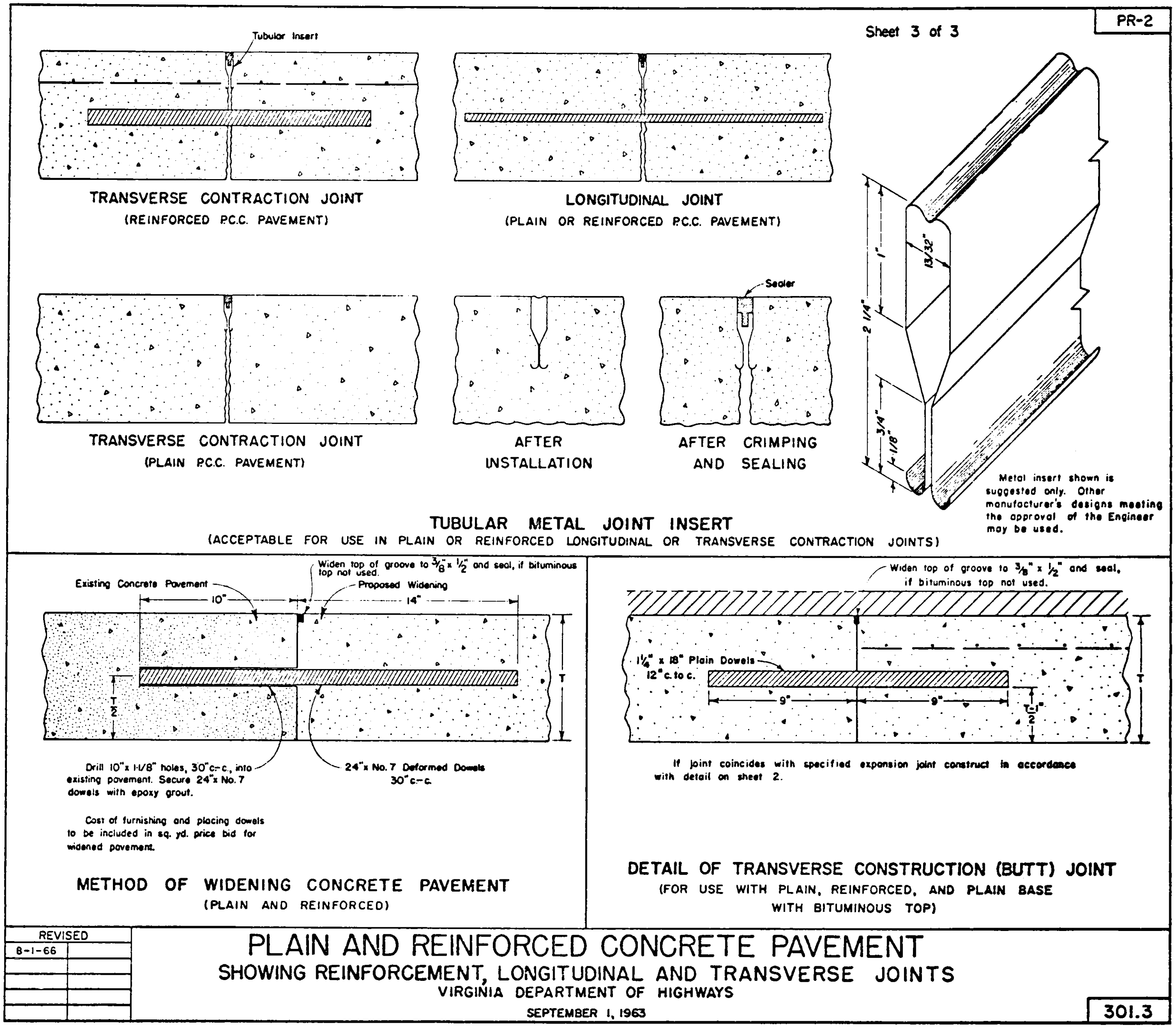


Figure 1. Tubular metal joint insert as it was accepted for use in PCC pavements in Virginia.

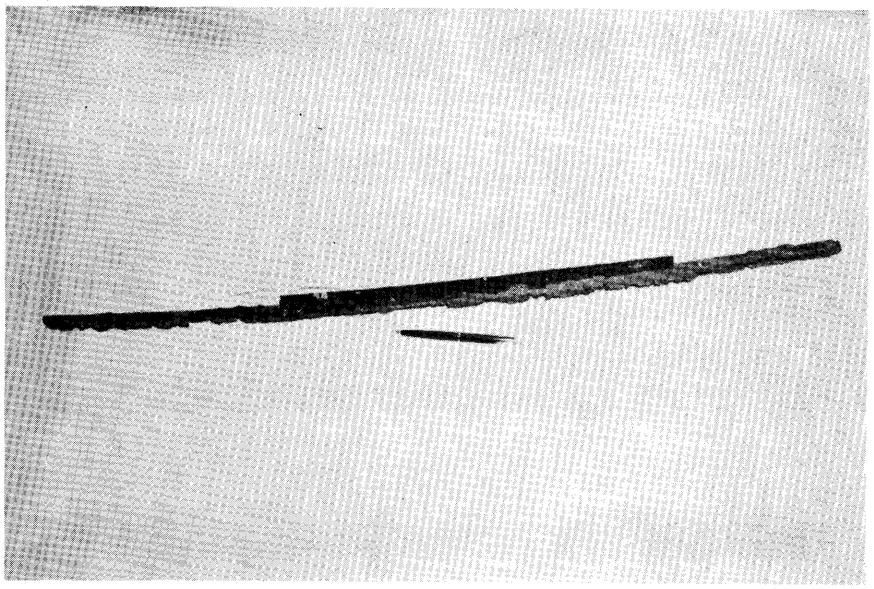


Figure 2. Remnants of corroded metal insert.

The rate at which these spalls develop is no doubt related to localized variations in concrete strength as well as to the magnitude and frequency of wheel loadings. Thus, the spalls form earliest in the most heavily traveled lanes but at different rates from location to location. For this reason, a given section of roadway will have some spalls which are readily apparent but many others which are incipient and can be located only by sounding the joint edges with a hammer or similar instrument. The Department prohibited the use of metal inserts in mid-1968 at the recommendation of the Research Council.[5]

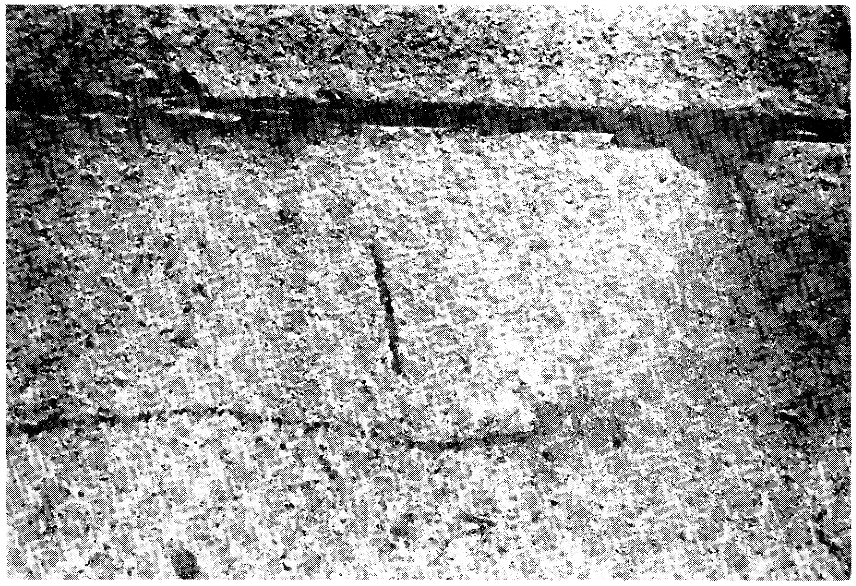


Figure 3. Pavement area adjacent to transverse contraction joint formed with metal insert.

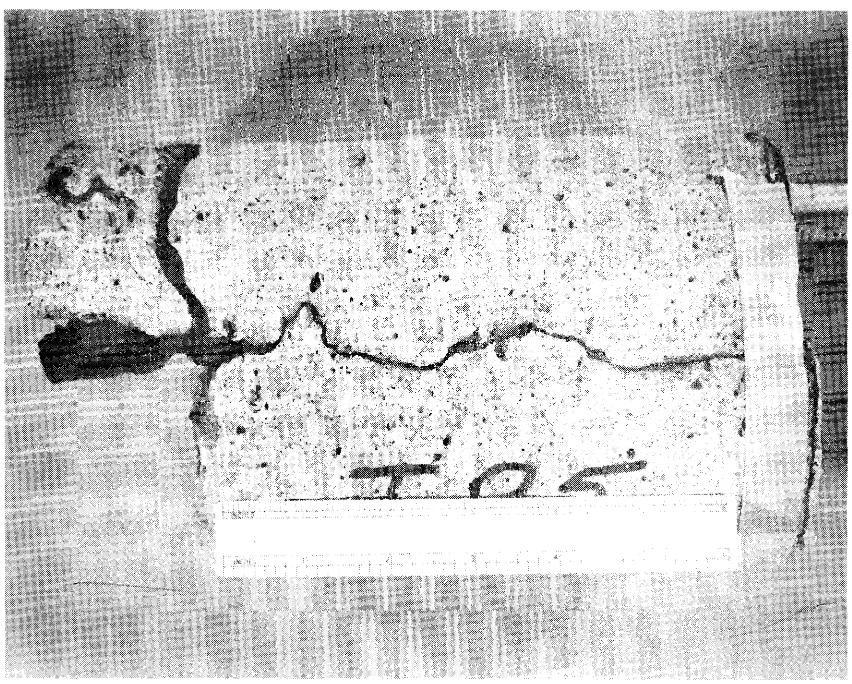


Figure 4. Core from area shown in Figure 3 showing vertical contraction joint and horizontal plane of weakness.

Subbase and Shoulder Materials

Most surface water can be expected to find its way to the underside of pavement slabs through the edge joint, which is difficult to seal and is observed in a poorly sealed condition. Recent studies[6] have shown that 70 percent of the surface water flowing over a crack only 1/32 inch wide will enter the crack and proceed to the lower pavement layers. According to presently accepted design procedures,[7] such surface water would be quickly carried away from the pavement through a pervious shoulder material. During the early 1960's, however, this factor was not given broad consideration and it has been observed that many of the problem pavements were constructed of very densely graded subbase and shoulder materials. These materials, used for their good strength characteristics and to facilitate construction, resulted in an impervious barrier at the pavement edge. As a consequence, during a steady downpour, a reservoir of water is probably maintained along the outer pavement edge and is therefore available to pump subbase and shoulder materials under the action of traffic-induced slab deflections. Depending on the permeability of the subbase and shoulder materials, this water may remain for significant periods of time after rainfall has ceased.

As wheel loads cross the joint, pressures on trapped water are reduced under the approach slab and increased under the leave slab. A net deposition of soil particles is caused under the approach slab by this pumping action. The accompanying faulting produces a less satisfactory pavement from the standpoint of rideability, but more important is the increased stress at the joint, which may be predicted by its occurrence. Pumping may result in a migration of fine, incompressible material into the contraction joints from their outer edge and bottom portions. Unchecked, the reservoir can extend itself towards the pavement centerline while progressively undermining the structure and infiltrating the remaining bottom portion of the transverse joint. Early indications of pumping are soil staining of the shoulders and, later, faulting of transverse joints.

Several projects constructed during the early 1960's on Interstate 95 in Spotsylvania and Stafford Counties contained subbase materials which have contributed significantly to differences in performance.[8] Pavements constructed on subbase materials having an average of 12 percent passing the number 200 sieve (U. S. Standard Sieve Series) quickly developed pumping problems with accompanying faulted joints. After four to six years under traffic, these pavements were also highly subject to blowups due in part to incompressibles pumped into the joints from below. A sharp contrast in performance is seen on projects in the same area built on subbases with an average of 7 percent passing the number 200 sieve. After eight years under traffic these projects had 75 percent less pumping than did those constructed with the more densely graded subbases, even though extensive efforts had been made to eliminate pumping problems from the densely graded sections through the use of edge drains installed by maintenance forces.(8) In addition, joint faulting and blowups were very significantly reduced on the coarser graded subbases.

In recognition of the superior performance of pavements constructed with open graded subbases and shoulder materials, the Department, in 1973, adopted a shoulder material specification allowing no more than 6 percent of such material to pass the number 200 sieve, and requiring the use of nonplastic materials.

Joint Sealants

The infiltration of incompressible materials, water, and deleterious chemical agents such as deicers into the longitudinal and transverse joints of a concrete pavement promotes conditions which hasten the need for repair, reduce the riding quality, and generally shorten the useful life of the pavement.

Incompressible materials restrict the free joint movement (expansion and contraction) resulting from temperature and moisture variations and give rise to localized high compressive stresses that may cause failure of the concrete.

Water infiltration (and the inevitable cyclic freezing and thawing accompanying it) leads to concrete deterioration through frost action and to loss of the support capabilities of the subgrade. Such a loss, usually accompanied by slab pumping at the joints, accelerates the structural failure of the slab. Deicing agents may infiltrate a joint and cause damage through deterioration of the concrete and corrosion of the reinforcing steel.

In an attempt to prolong the useful life of a pavement through the prevention of infiltration, it is common practice to seal the slab joints with one of two sealants: (1) a hot or cold, field-molded (poured-in-place) sealant; or; (2) an extruded, preformed compression seal (neoprene, etc.).

Important factors influencing the effectiveness of these sealants are joint design, joint spacing, sealing material, installation procedures, and climatic conditions. These factors were considered in the summer of 1969 through an extensive survey of the literature relating to the experiences of other highway agencies.(9)

Temperature and moisture changes and the accompanying volume changes of concrete are the primary cause for the opening and closing of joints in PCC pavement slabs. The largest temperature variations occur at the slab-atmosphere interface and are due primarily to the daily (and seasonal) heating and cooling of the atmosphere so that joints are generally open in the cool winter months and closed in the warm summer months.[10]

Figure 5 is a graphical record of the behavior of three contraction joints (3/8 inch wide) in 9-inch reinforced concrete pavements where joints are spaced 61.5 feet apart. Joint A is in a pavement which has been well maintained, apparently with frequent efforts to reseal joints and to remove excess water through the provision of edge drains. Note that the seasonal joint movements (measured over a 10-inch gauge length spanning the joint) are clearly evident. In this case, a base line was chosen corresponding to the smallest joint opening measured during the summer of 1970. Subsequent measurements show that the joint opens a maximum of approximately 0.10 inch during each winter while always returning to very near the base line during the summer. Clearly, this joint is functioning as joints in concrete pavements are intended, i.e., to accommodate the expected seasonal changes in slab length without detrimental effects to the pavements.

Joints B and C are in a pavement having design characteristics identical to those above. This pavement was constructed of a different type aggregate, but, more importantly, it did not receive the maintenance attention given to the pavement in which joint A is located. Note that beginning at the previously mentioned base line in mid-1970, joints B and C opened considerably more than did joint A during the winter of 1970-71. During this period, joints B and C (123 feet apart) were observed to be open to infiltration by the deicing chemicals and sands used heavily on the pavement. The pavement was also subject to pumping. Subsequently, when these joints attempted to close in the summer of 1971, it can be seen in Figure 5 that approximately 0.055 inch of residual opening remained. If this measurement is assumed to be average for the pavement and is projected over one mile (86 joints) of roadway, a "locked-in" compressive strain of around 4.7 inches per mile results.

In the summer of 1972 these stresses overcame the compressive strength of the concrete so that joint B sustained a crushing failure. Note in Figure 5 that in mid-1972 the "locked-in" movements amounted to 0.065 inch and 0.085 inch for joints B and C, respectively. When the failure occurred at joint B, the gauge points moved dramatically closer together as shown by the graph plunging below the base line in Figure 5. At the same time, a reduction of stresses took place at joint C so that its graph shows a dramatic increase in joint opening even during warm weather. Joint C then returned to cyclical type movements, but from a different datum.

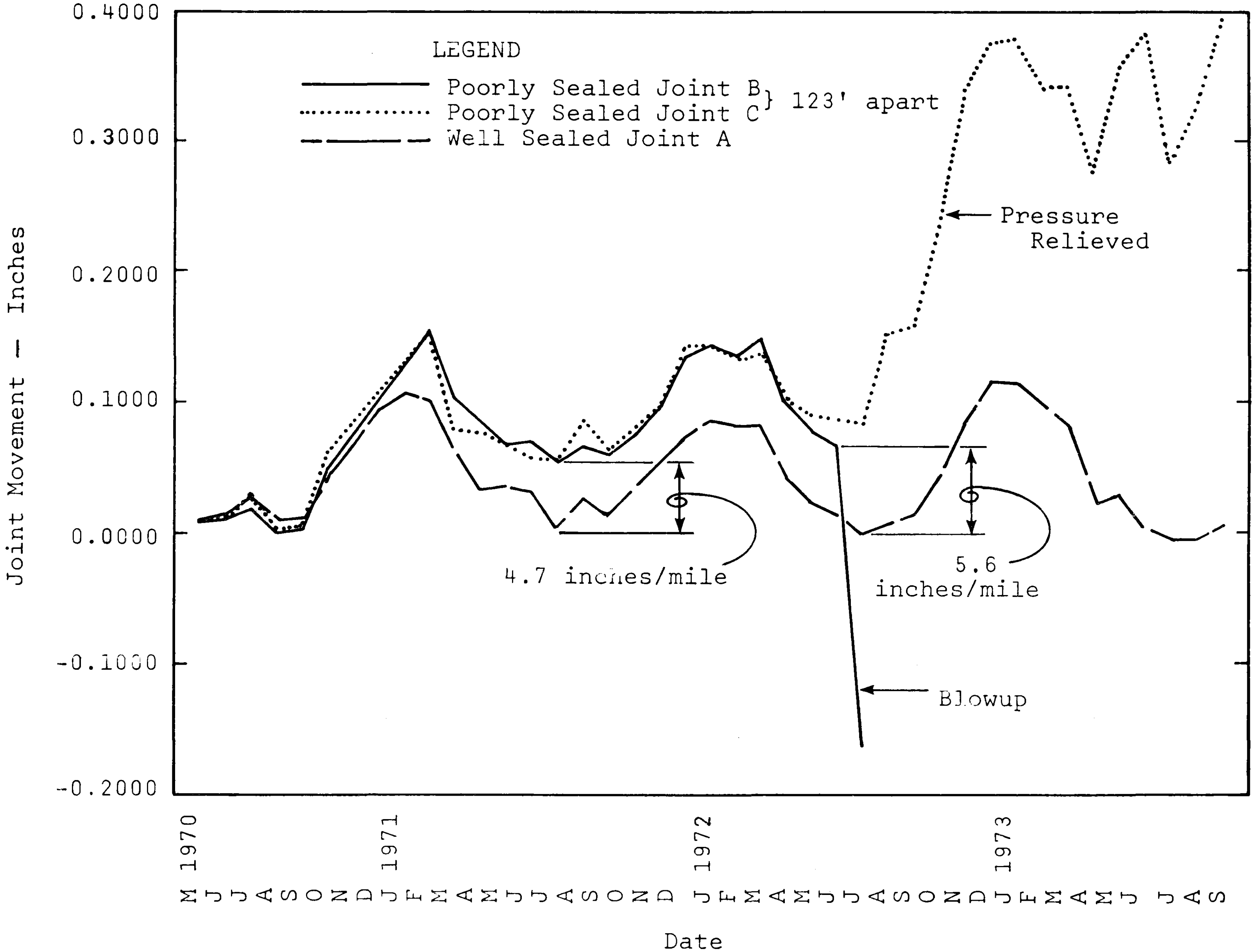


Figure 5. Seasonal movement of 3/8-inch contraction joints (slabs 61.5 feet long).

A widely accepted theory of blowup development consistent with the above measurements and observations was given by Griffin in 1943.[11] The first stage of failure occurs sometime prior to the actual blowup when compressive stresses become high enough to fracture the concrete below the surface, but no distress is evident on the pavement surface. This condition is shown schematically in Figure 6 where it may be seen that disintegrating concrete at the lower joint corner forms an inclined plane with the undamaged concrete above. As the compressive stresses increase, the situation changes to that indicated in Figure 7 where one slab has moved up the inclined plane with sufficient force to shear the corner of the adjacent slab. In this manner, the observed blowup characteristics of one slab overriding the other is generally explained.

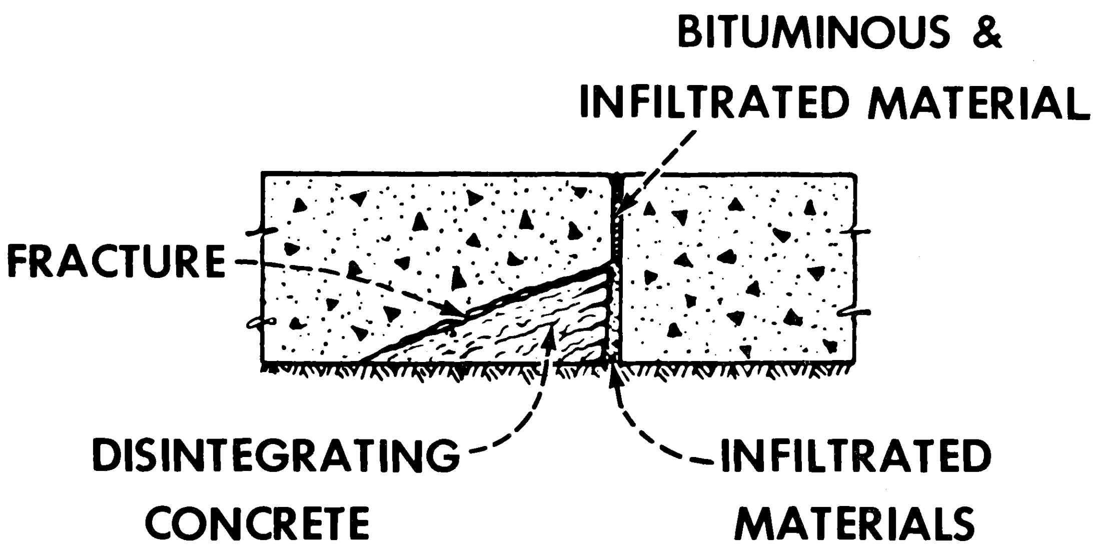


Figure 6. Conditions prior to blowup. (After Griffin[11]).

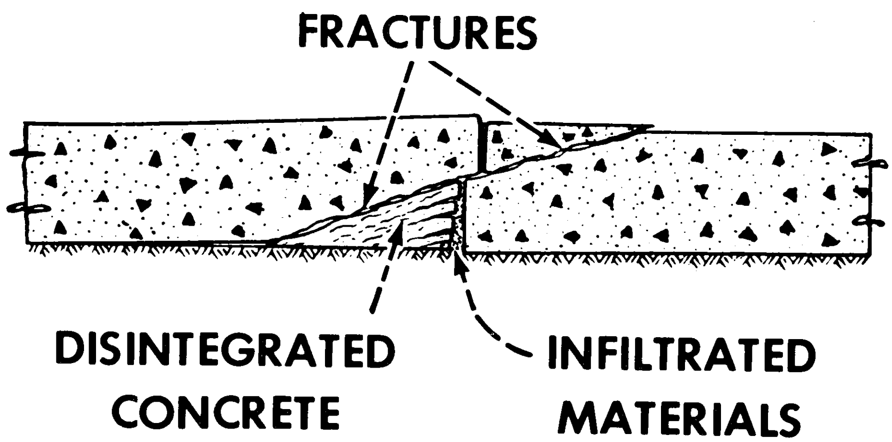


Figure 7. Blowup with characteristic fractures and pavement uplift. (After Griffin[11].)

Slab Length

A majority of the jointed PCC interstate pavements constructed in Virginia in the 1960's incorporated reinforced slabs 61.5 feet in length. This length was modified following the study concerning sealing practices[9] so that Virginia specifications currently allow a maximum joint spacing of 40 feet for reinforced PCC pavement slabs.

The effect of length changes of long slabs on the performance of joint sealants has been discussed in this report along with supporting field data (Figure 5). Long slabs now in service will continue to demand attention since large joint movements can be a prime contributor to joint deterioration.

DETERIORATION PROCESSES

The major factors associated with pavement distress in Virginia have been discussed. These were the use of metal joint forming inserts, poured joint sealants, densely graded subbase and shoulder materials, and the use of long slabs. In order for this information to be useful in planning repair operations, the engineer must be able to recognize the type or combinations of types of distress in a given field situation that is to be dealt with. Because all distress is not apparent at the pavement surface, an understanding of the stress mechanisms is required. Additionally, the field engineer should have some knowledge of the general time frame in which the different modes of distress may be expected to occur.

The following paragraphs deal with the deterioration processes as they have been observed to develop through the service life of Virginia's jointed PCC interstate pavements. It should be borne in mind that different pavements have been subjected to different combinations of the factors leading to deterioration. These differences exist not only from one construction district to another, but also from project to project within the same district. Therefore, the general case is discussed in which stress mechanisms have developed and have led to identifiable pavement deterioration.

Stress Mechanisms

As described earlier, joints with poured sealants were observed to be distressed soon after construction. The extent to which these joints required maintenance by resealing was readily shown to be related to the corrosion of the metal insert. On one project where the joints were sealed well, the insert was found to be in fair condition after more than four years in service.(3)

Corrosion of the bulk of the metal insert does not directly lead to damaging stresses in the adjacent concrete. The stress mechanism develops only as corrosion takes place in the embedded flanges of the insert. Because the corrosion product, iron oxide or rust, occupies a greater volume than did the original insert, tensile stresses are introduced within the concrete. A crack or weakened plane tends to form along the flanges and propagates from there to the pavement surface.

Fine aggregate, soil particles, and other incompressibles enter the joints during periods when they are not properly sealed. These particles are visible upon inspection and frequently fill the joint spaces that sealants are to occupy. Joint movements take place and the trapped infiltrate becomes compressed. Some residual joint movements resulting from infiltration were presented in Figure 5. Restricting the movement of concrete at the joint by infiltration from the pavement surface results in compression loading of the concrete adjacent to the transverse joint.

Infiltration and the buildup of compression loads can also take place at the bottom of transverse joints due to the pumping of fines. One survey of pavements in service for periods of two to four years found pumping on more than half of the projects.(12)

Stress Distribution

The infiltration of transverse contraction joints by incompressibles from several sources has been described. Measurable residual openings have been recorded through instrumentation at these joints. An approximate, yet conservative, analysis would indicate that for a compressive strain of 4.7 inches per mile, and ignoring all other factors such as subgrade friction, reinforcing steel, nonhomogeneity of concrete, and the axis of loading, a compressive stress somewhat greater than 200 psi would exist at any transverse section in a slab. The average stress at transverse joints would be higher because of the reduced pavement cross section but would still not exceed 300 psi, just 10 percent of the pavement design strength.

Even though the actual stress distribution at a joint is unknown, it is not difficult to illustrate schematically how a relatively low average stress in the region of the transverse joint can result in failure of the concrete. In Figure 8 a transverse contraction joint is depicted in an open state. The widest opening occurs in the winter months when fine aggregate, associated with snow and ice control, is present on the pavement surface. If the joint sealant has pulled away or is missing, and the metal insert has corroded, this incompressible material can readily be intruded into the narrow, irregular portion of the joint. The lower portion of the joint may also be infiltrated with fines from the subbase material transported by traffic induced pumping.

It is unlikely that either the upper or lower portion of the joint could be filled completely, and certainly not uniformly, with fines. The amount of infiltrated material will vary not only from top to bottom in the joint, but also in the transverse direction from shoulder to centerline. Therefore, when the joint tends to close, some areas of the joint face will be highly loaded while other areas will carry little or no load.

The weakened planes in Figure 8 resulting from the corroded or partially corroded metal insert make the upper region of the joint face particularly susceptible to becoming overstressed.

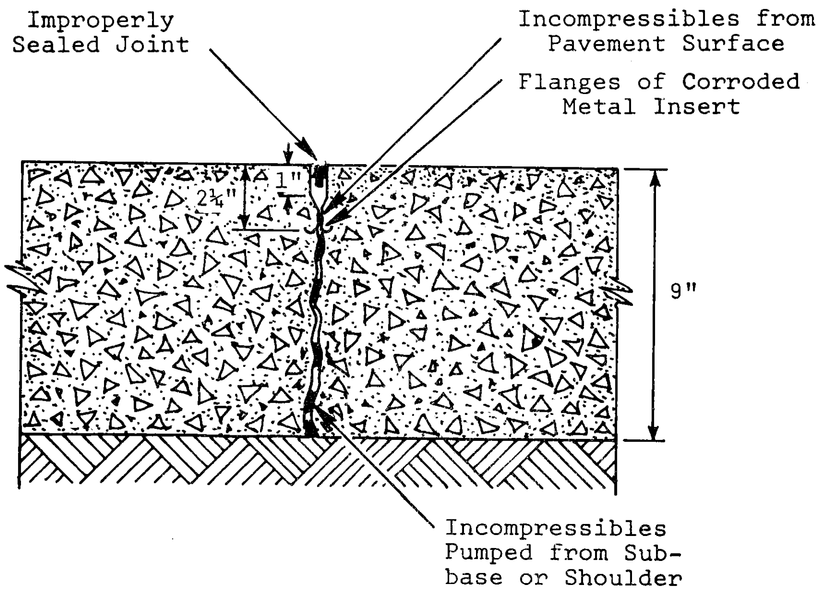


Figure 8. Transverse contraction joint with infiltration from pavement surface, shoulder and subbase.

Failure Types

Localized overstressing causes failure of the affected portions of concrete adjacent to the transverse joint. The resultant redistribution of stresses can then lead to partial or extensive failure of the remaining concrete.

The progressive nature of distress in jointed PCC pavements has been observed. The development of distress in a particular case may result from one or more of the factors discussed in this report. The types of distress fall into two general categories. Based on the pavement depths at which deterioration has occurred, or to which it has progressed, the two types of distress are generally referred to as partial-depth and full-depth. These two categories commonly serve as the descriptive terms to indicate the extent of pavement replacement required in repair contracts. Partial- and full-depth deterioration occur at varying rates depending on the stress mechanism and the stress distribution. Other terms for the distress observed on pavements are spalls, corner breaks, blowups, faulting, fracture and splitting.

Spalls

Stress concentrations have been shown to be produced by infiltrated particles as the joints tend to close. In the upper portion of the joint face, those highly stressed zones, in the presence of weakened planes due to the corroded insert flanges, produce an easily recognizable half-moon spall shown in Figure 9. With poured sealants, incompressibles are able to enter the joint at the earliest time where tire contact has helped to disrupt the sealants.

To demonstrate the fact that areas recognizable as half-moon spalls are partial-depth types of distress, a typical area has been exposed in Figure 10. The unsound concrete in this case can be removed entirely by chipping away less than one inch of additional material.

Corner Breaks

A predominance of distress at slab corners adjacent to the shoulders is indicative of a particular factor leading to deterioration. In this case, the subbase material may be stabilized sufficiently to prevent pumping, however, the shoulder material is too densely graded to allow free drainage. The water accumulated during heavy rainfall does not disrupt the subbase but does result in a migration of fines from the shoulder into the corner zone. With no infiltration from other sources, the corner zone can become overstressed very quickly.

The visible signs of distress in this case are joint spalls at the corners and general corner deterioration. This deterioration usually extends about 12 inches from the corner at the pavement surface and is even more limited with increasing depth. Because corner breaks do not extend more than a few inches into the lower portion of the joints, they are appropriately classified as partial-depth failures.

It is instructive to note that failure types can, and often do, occur in combination from related and unrelated causes. Also, it is important to realize that as deterioration takes place it will extend itself and accelerate the deterioration of adjacent concrete. Figure 11 shows a joint having a corner break in combination with extensive minor spalling and severe localized spalling indicating joint stresses that have probably increased to a level sufficient to disrupt the concrete throughout the lower portions of the transverse joint.

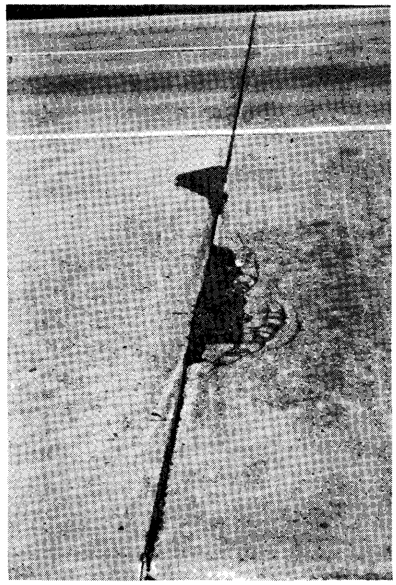


Figure 9. Semicircular (half-moon) spall caused by insert corrosion.

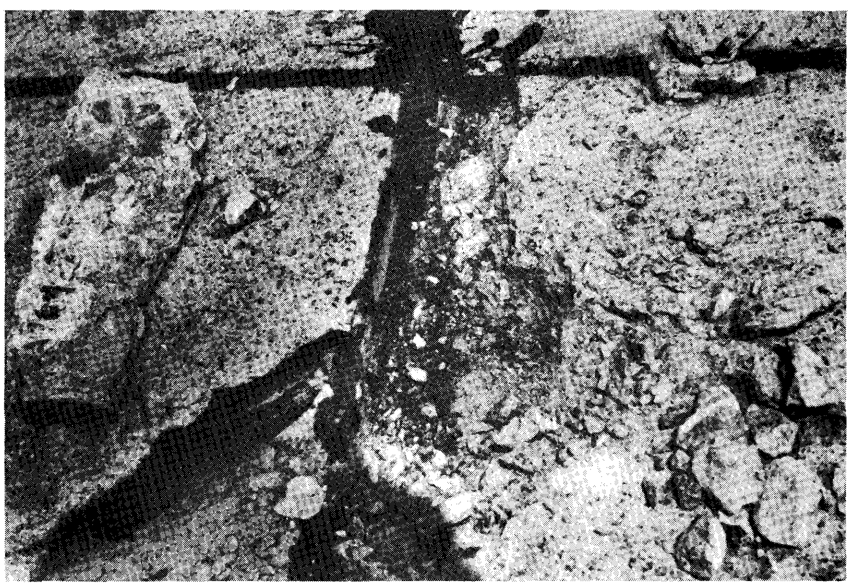


Figure 10. Partial-depth deterioration from spall chipped lightly to show limited depth of defect.

Figure 11. Corner break in left foreground with extensive spall and probable full-depth deterioration extending from corner break.

Blowups

The relief of increased joint stresses by failure of the concrete may result in nearly complete destruction of the joint. This failure, or blowup, may be sudden, with obvious distress at the joint as in Figure 12. The joint movements associated with this type of failure were depicted in Figure 5.

The pavement distress that results from a blowup is not restricted to the upper or partial-depth zone of the joint. Damage occurs throughout the complete slab depth. The need for full-depth removal of concrete surrounding the joint is indicated by its occurrence.

Extensive deterioration from a blowup type of failure may not be readily apparent at the pavement surface. In Figure 13 it can be observed that the joint closing has resulted in spalling of the underside of the joint area while the pavement surface is apparently intact. This actual case is very similar to the case depicted earlier in Figure 6.

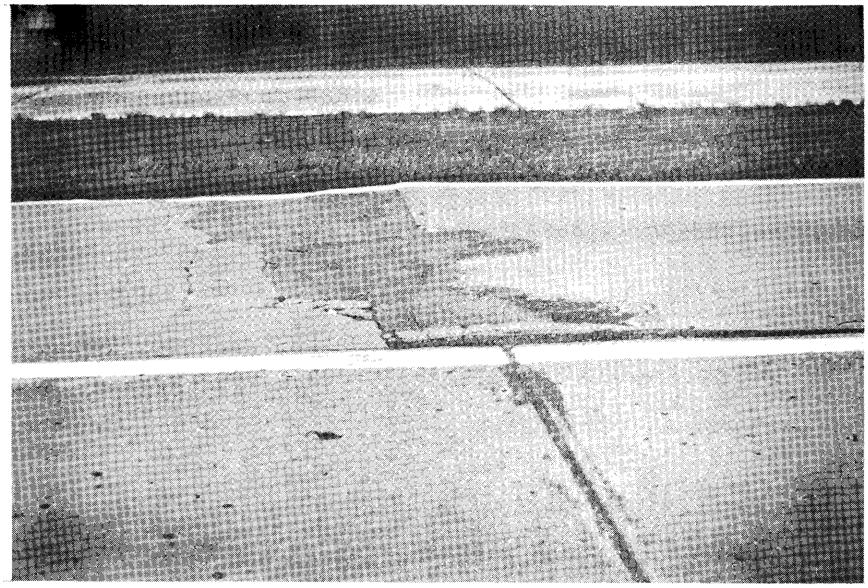


Figure 12. Blowup with bituminous patch.

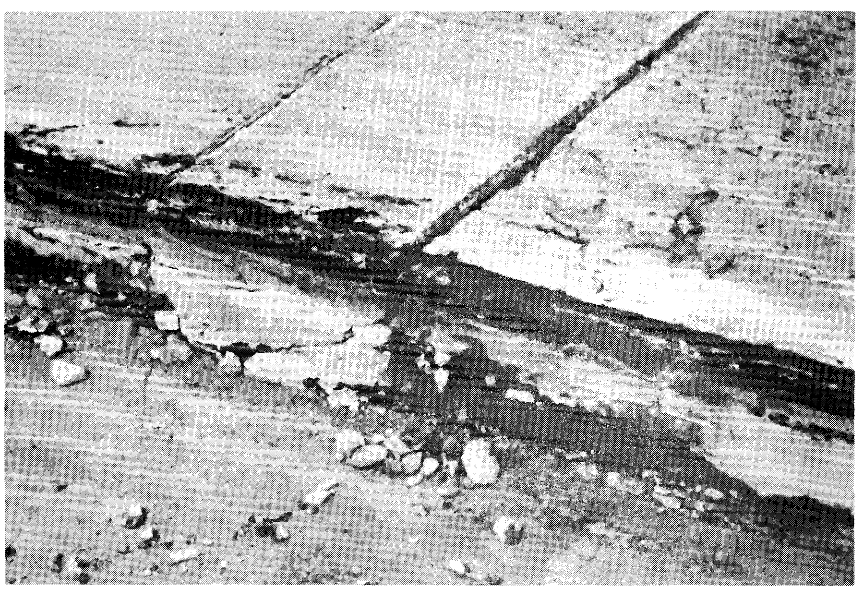


Figure 13. Underside of slab spalled due to infiltrated fines.

The deterioration depicted in Figure 13 cannot be visually detected from the pavement surface, but it can be located by the manual sounding technique cited earlier,(4) and it can be inferred from instrumented joint records.

Other

Several signs of full-depth distress have been described. There are other indicators of distress that may be observed early and that may even afford the opportunity to prevent more extensive deterioration.

Faulting has been described with respect to the pumping phenomenon. The relative vertical displacement of slabs at a joint must disrupt the concrete because of their rigid doweled connection.

Another sign of impending full-depth failure is the appearance of splitting or tensile cracks. These cracks occur perpendicular to the transverse joint and may extend several feet away from the joint. They indicate a buildup of localized compressive stresses from infiltration. A controlled laboratory procedure uses this kind of concrete failure to determine the splitting tensile strength of concrete.(13)

Blowups and other failures which affect the full slab thickness can be repaired only by full-depth patches. Such patches can be either cast-in-place or precast. Where there is evidence that excessive pavement pressures have contributed to failure, it has recently become customary in Virginia to provide pressure relief joints at intermittent locations either as other repairs are undertaken or as a preventive maintenance measure. The details of full-depth repairs and the use of pressure relief joints are to be discussed in a later report.

Severity of Distress

Specific types of distress can be identified at individual joints; however, all joints will not be affected to the same extent. In order to describe the general condition of a particular pavement that may extend for several miles, it is useful to express the incidence of distress in terms of the joints affected. For partial-depth distress, it is convenient to compute the percentage of the total number of joints that are affected. Surveys of jointed pavements can then be used with Table 1 to express the severity of the distress along the entire section as being minor, moderate, or extensive. These terms describe the relative structural condition of the pavement as opposed to its aesthetic quality or safety. Due to the nature of full-depth deterioration, the relative severity of its occurrence can best be inferred from the number of affected joints per mile.

The data for Table 1 came from pavement condition surveys and reflect the judgment of the authors. It can be effectively used to ascertain the relative performance of different pavements, and in the following section the severity terms (abbreviations) will be used to aid in describing the time periods in which deterioration takes place.

Table 1

Severity of Pavement Deterioration as a Measure of the Relative Structural Condition of Pavements

Type Deterioration	Transverse Joints Affected	Severity	(Abbreviation)
Partial-Depth	<20% of total number	Minor	(P.D.-a)
	20-40% of total number	Moderate	(P.D.-b)
	>40% of total number	Extensive	(P.D.-c)
Full-Depth	<1 joint per mile	Minor	(F.D.-a)
	1-5 joints per mile	Moderate	(F.D.-b)
	>5 joints per mile	Extensive	(F.D.-c)

Time Period for Deterioration

The factors contributing to PCC pavement deterioration have been discussed and related, through stress mechanisms, to the resultant partial- and full-depth types of pavement distress. The time periods in which the various severities of distress have appeared have been dependent on the combinations of factors that contributed to distress.

Because long slabs (61.5 feet) were used on most of the projects discussed, and because poured sealants were used on all of the projects initially, there are six possible combinations of the factors that have contributed to pavement deterioration.

Table 2 offers a compilation of these factor combinations, the stress mechanisms involved, and the time periods in which the various severities of distress have occurred.

Table 2

Time Periods for Pavement Deterioration

Causal Factors*	Stress Mechanisms	Time Periods 1-6 Yrs.	5-9 Yrs.	8-12 Yrs.
2	Infiltration (top)	P.D.-a	P.D.-b	P.D.-c
2,4	Infiltration (top and bottom)	P.D.-a	P.D.-b F.D.-a	P.D.-c F.D.-b
1,2	Corrosion of metal insert Infiltration (top)	P.D.-b	P.D.-c	P.D.-c
1,2,4	Corrosion of metal insert Infiltration (top and bottom)	P.D.-b	P.D.-c F.D.-a	P.D.-c F.D.-b
2,3,4	Infiltration (top, bottom and shoulder)	P.D.-a	P.D.-b F.D.-b	P.D.-c F.D.-c
1,2,3,4	Corrosion of metal insert Infiltration (top, bottom and shoulder)	P.D.-b	P.D.-c F.D.-b	P.D.-c F.D.-c

*Causal Factors: 1 - metal inserts
2 - poured sealants
3 - subbase and shoulder materials
4 - 61.5 foot slabs

The data in Table 2 resulted from a great deal of averaging and should be related to specific projects in a general way only. The table is informative, however, for two specific reasons. First, it indicates the progressive nature of pavement deterioration and the accelerating effect of combinations of factors, which explains the variable performance of pavements from district to district and even from project to project within the same district.

Second, the table suggests the importance of pavement surveys for gauging performance. The significance of these specific time periods for the occurrence of deterioration is diminished because, in all cases, some or all of the causal factors have been corrected or modified. However with any structure, the engineer should expect that some deteriorative process or processes will act to shorten the service life of the pavements. Periodic surveys of these PCC pavements would identify pavement distress from any factors. Such factors could then be more readily dealt with, and ultimately, corrected or modified.

PAVEMENT REPAIRS

Deterioration of jointed PCC pavements has been found to occur almost exclusively in the vicinity of the transverse joints. From an engineering point of view, this pavement distress does reduce the structural quality of pavements. This reduction of quality is indicated by the severity classifications in Table 1. The decision to initiate permanent repairs on a roadway should be made after considering the interim activities associated with maintaining the distressed pavement, the ability of the pavement to provide adequate service, and the structural degradation of the joints that advances with time.

Temporary Repairs

The temporary repair of various types of PCC pavement distress is accomplished as a routine maintenance procedure with bituminous patches. Bituminous materials are placed in areas affected by spalls, corner breaks, and blowups with minimal pavement preparation. This procedure serves to restore pavement surfaces to an approximate grade for traffic while causing the shortest possible lane interruptions. Interim joint sealing activities using hot-poured sealants are effective for temporarily halting surface infiltration until preformed neoprene sealants can be properly installed.

Temporary repairs of this type may serve for months or even years. The true meaning of their temporary nature stems from the fact that the causes of deterioration are not remedied when such patches and sealants are installed. Deteriorative processes will normally continue in the area surrounding the bituminous patch and poured sealants.

Bituminous patches do reduce impact loadings from traffic by restoring the pavement grade, and in some cases reduce the infiltration of water and incompressibles that promote joint deterioration. To the extent that these functions are performed by temporary bituminous patches, the deterioration proceeds less rapidly than it would with no attention to repairs.

Pavement Serviceability

Pavements are constructed to provide a safe and efficient route for travel. If this function is impaired by pavement distress, then repairs are needed. In practice, temporary patches are installed as the distress becomes apparent. Therefore, drivers are routinely exposed to pavements having temporary repairs and minor irregularities as contrasted with the larger irregularities that would exist without the temporary repairs.

Various types of distress were observed from a passenger car at a speed of 55 mph. The recorded distress is listed in Table 3 and is grouped according to the severity classifications presented in Table 1. The researchers were aware of the actual pavement condition whereas the average driver would not be.

Table 3

Comments Related to Observed Pavement Distress

Type Deterioration	Severity of Distress	Observed Distress	Comments
Partial-Depth	Minor	Spall	None
	Moderate	Spall Corner break	Poor appearance
	Extensive	Spall Corner break Joint growth	Poor appearance Tire noise
Full-Depth	Minor	Faulting Splitting Joint growth	Poor appearance Tire noise
	Moderate	General deterioration Faulting	Poor appearance Tire noise Driving impaired
	Extensive	General deterioration Blowup	Poor appearance Tire noise Driving impaired

Comments in Table 3 about the condition of the pavement are therefore probably more critical than would be those from regular commuters on a particular roadway.

For partial-depth distress, the comments range from none for minor distress to comments regarding a poor appearance of the roadway and an awareness of tire noise with more severe distress.

Full-depth pavement distress should be expected to result in tire noise, and the more severe types would reduce riding comfort. In Table 3 the observation "driving impaired" is used to express the opinion that certain distress would tend to cause driving maneuvers that otherwise would not have been suggested. Such maneuvers could include lateral movements within the traveled lane, braking, and lane changing to avoid the observed area of distress.

During numerous surveys of interstate pavements, large volumes of traffic were observed. Drivers did not respond to the distressed areas with driving maneuvers or in any other noticeable way. Road users seem to have great confidence in the roadways provided for their driving needs. The appearance of highly visible bituminous patches on the pavement does not erode this confidence. Furthermore, the temporary patches carry traffic safely due to the quality that is achieved through routine maintenance.

There appears to be no basis in observed vehicle maneuvers to suggest that pavement repairs should be initiated at any particular stage of deterioration. This, of course, assumes a continuation of the present policy of routinely installing temporary bituminous repairs to restore the approximate grade of the pavement in areas where the concrete has spalled or cracked. Since temporary repairs do not halt the deteriorative process, permanent repairs will eventually be required.

Effect of Delay in Repairs

The progressive nature of pavement deterioration was demonstrated in Table 2. Because of the combinations of factors that lead to deterioration, any deteriorated area may include both partial-depth and full-depth deterioration. Also, the severity of the distress will increase with time.

Even though extensive distress may be handled by routine maintenance, as the number of temporary patches increases, a point must be reached where it is more desirable to replace them with permanent repairs and attempt to halt or severely retard the process of deterioration.

Evaluation Techniques

A great deal of effort at the national level has been directed toward developing quantitative criteria for aiding in the decision as to when to initiate permanent rehabilitative procedures on pavements. The present serviceability concept was developed in connection with the AASHO Road Tests.[14] Quantitative values may be derived from a subjective rating method called the Present Serviceability Rating (PSR) or from a statistical computation, based on mechanical measurements, yielding a Present Serviceability Index (PSI).

The PSR must be determined by a group of individual raters whose subjective assessments of the pavement can be quantified and averaged. This technique has merit but might require an inordinate amount of educational effort to remove local biases in ratings from various pavement locations. Otherwise a single group of individuals would have to devote a major portion of their total effort to rating all of the pavements to be considered by the technique.

The PSI requires the use of specialized equipment along with manual recording of data. This technique appears to have greater potential for application to bituminous concrete pavements than to jointed PCC pavements where the major problems are concentrated in a relatively small portion of the pavement surface at the transverse joints.

For the reasons stated above the authors feel that a simpler evaluation technique would be of greater practical value for jointed PCC pavements.

Survey Technique

Visual surveys have been made of jointed PCC pavements in which deterioration has occurred. Distress at the transverse joints has been recorded as in Figure 14. The total amount of unsound concrete at the joints as in Figure 14 could be determined by sounding with a ball peen hammer as described earlier in this report; however traffic control is not required for the visual survey and this information, along with knowledge of the factors causing distress, provides a rational basis for assessing the probable situation at each joint.

Information as in Figure 14 can be recorded during field surveys in the manner shown on the data form in Figure 15. This form can be useful in consolidating data by recording, in sequence, only those transverse joints where distress is visible. The remaining joints, with no visible distress, need not be recorded on the form.

Further consolidation of pavement survey data is needed to assist in the assessment of overall conditions within the limits of a project, county, district, or within other limits that might be identified as appropriate or convenient. This need can be met through the use of the form in Figure 16, on which the data from the survey sheet in Figure 15 and additional sheets not presented in this report are summarized. Using this form, large pavement sections may be reviewed quickly to compute the severity of deterioration with respect to guidelines as those in Table 1. Different pavement locations may also be compared to each other as a means of setting priorities for implementing repairs which may be competing for limited maintenance funds. Finally, if the records remain current through the performance of annual or semi-annual surveys, an accurate analysis of the deterioration process and the resulting need for and quantities of repairs can be made, as well as a determination of the performance of repairs that may subsequently be installed.

Blank data forms for the pavement condition survey and summary are in the Appendix.

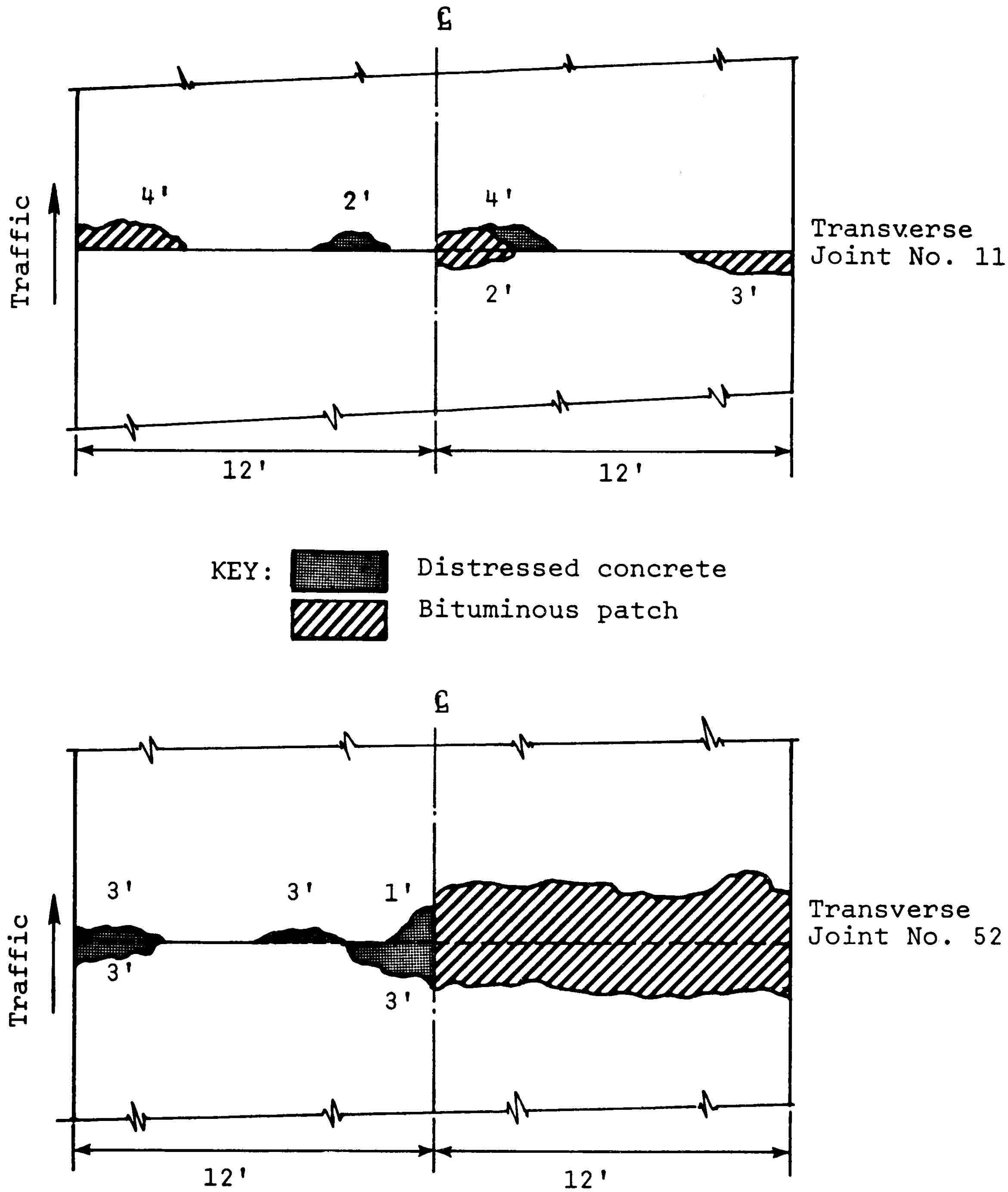
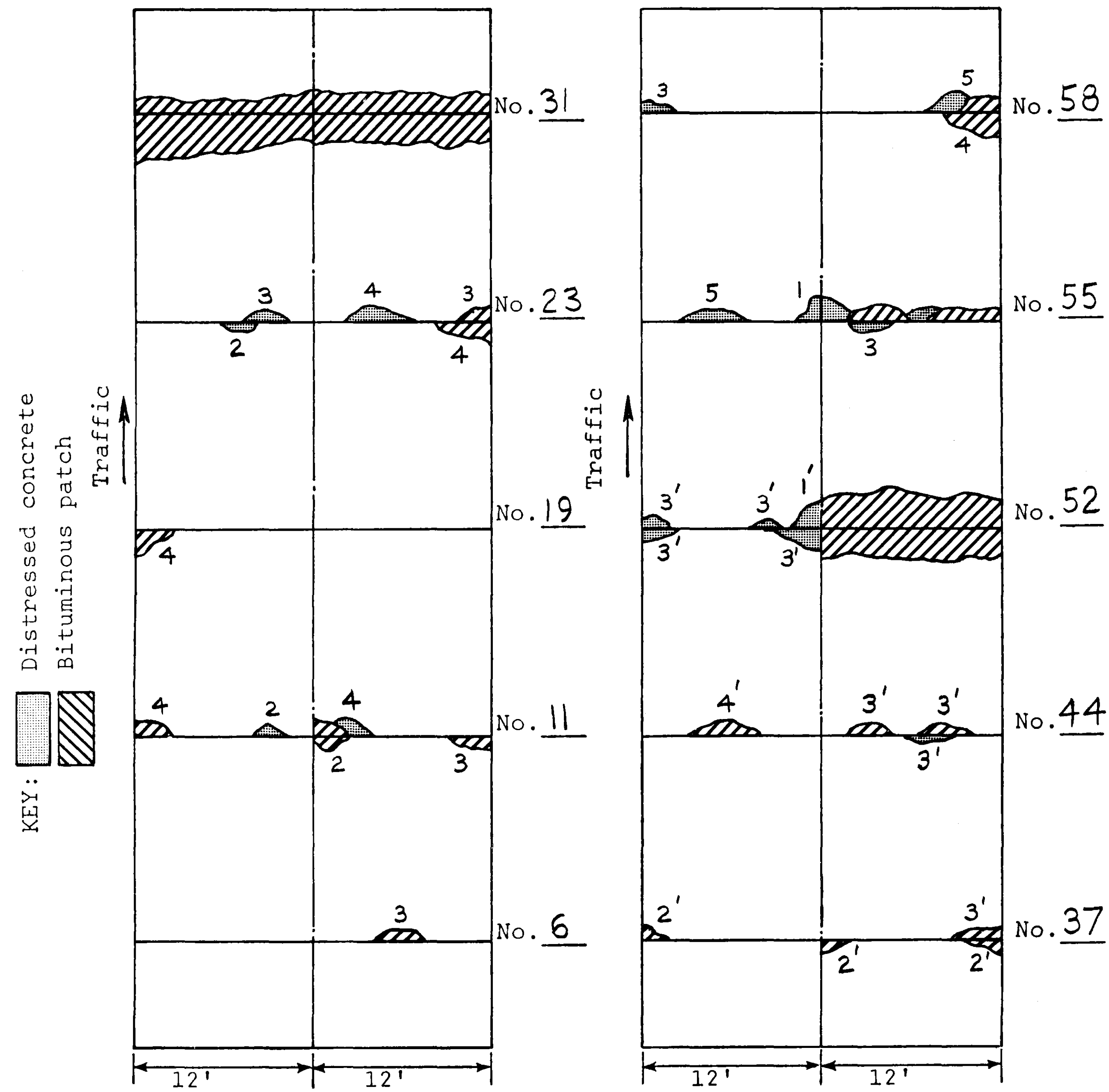


Figure 14. Typical plan of distress at transverse joints in PCC pavements.

1370

PAVEMENT CONDITION SURVEY (2-LANE)

Record only those transverse joints where distress is observed.



DATE ØØ-ØØ-ØØ SHEET NO. 1 of 4.

ROUTE I-ØØ DISTRICT Abc COUNTY Xyz

LANE: NBL___ SBL ___ EBL ✓ WBL ___

Location of Joint No. 1 on this survey: First joint from expansion joint at east end of bridge over Def River.

Figure 15. Pavement condition survey form with typical data recorded.

PAVEMENT CONDITION SUMMARY (2-LANE)

Transverse PCC Pavement Joints (numbered in sequence) and Linear Feet of Visible Distress at Each Joint Face.
(Circle joint numbers to indicate a blowup.)

1			21			41			61			81		
2			22			42			62			82		
3			23	3 / 2	7 / 4	43			63			83		
4			24			44	4	6 / 3	64			84		
5			25			45			65			85		
6		3	26			46			66			86		
7			27			47			67			87		
8			28			48			68			88		
9			29			49			69			89		
10			30			50			70			90		
11	6	4 / 5	(31)	12 / 12	12 / 12	51			71			91		
12			32			(52)	7 / 6	12 / 12	72			92		
13			33			53			73			93		
14			34			54			74			94		
15			35			55	6	12 / 3	75			95		
16			36			56			76			96		
17			37	2	3 / 4	57			77			97		
18			38			58	3	5 / 4	78			98		
19	4		39			59			79			99		
20			40			60			80			100		

DATE ØØ-ØØ-ØØ SHEET NO. 1 of 10.

ROUTE I-ØØ DISTRICT Abc COUNTY Xyz

LANE: NBL___ SBL___ EBL ✓ WBL___

Location of Joint No. 1 on this Sheet: First joint from expansion joint at east end of bridge over Def River.

Note: Location information not required if this is a continuation sheet, however it will be helpful for future reference to remark below the location of joints near structures as bridges culverts and ramps.

REMARKS:

Figure 16. Summary sheet with typical condition survey information from Figure 15.

Permanent Repairs

Permanent repairs of transverse joints are accomplished by restoring or rebuilding portions of the pavement slab adjacent to the joint. The purpose for installing permanent repairs goes beyond the important function of temporary repairs, which is to restore the safe traffic carrying ability of the roadway, and includes the overall objectives of rehabilitating the pavement structure and halting the deterioration processes.

The decision to initiate permanent repairs in lieu of temporary patching must be made after considering constraints such as traffic demand, the work load on state force maintenance personnel, and the ability at specific times to obtain qualified contractors and to allocate the necessary funding. Therefore it may be impractical, even undesirable, to initiate permanent repairs of all distress during the earliest stages of deterioration. The information available in this report describing the causes for and identification of pavement distress, along with data that can be gathered periodically through pavement condition surveys, can serve to ensure that when permanent repairs are specified, the type and extent of the pavement distress can be clearly stated.

A description of permanent repairs is beyond the scope of this report, however, many such repairs have been made on jointed PCC pavements in Virginia. Cast-in-place and precast materials have been employed in both full-depth and partial-depth repairs. Two subsequent reports on full-depth and partial-depth repairs, respectively, will describe the repair procedures in which these materials were used and will discuss the performance of these installations.

OBSERVATIONS AND CONCLUSIONS

On the basis of information gathered in this study of jointed PCC interstate pavements, along with existing published information on similar pavements, observations and conclusions are made as follows:

1. The deterioration of jointed PCC pavements has occurred almost exclusively at the transverse joints, and the primary factors leading to the pavement distress observed in Virginia have been —

    a. the use of metal inserts for forming the transverse joints,

b. difficulties experienced with poured joint sealants,

c. the construction of densely graded subbase and shoulder materials, and

d. the use of 61.5 foot long slabs.

2. The factors noted above have been eliminated from current design standards and construction specifications, but will continue to affect the maintenance requirements of the pavements in which they were incorporated.

3. Pavement distress resulting from these factors may be visually noted and classified generally as partial-depth or full-depth deterioration. Joint spalls and corner breaks comprise the majority of partial-depth distress. Blowups and failures stemming from ruptures of the lower joint faces comprise the majority of full-depth distress.

4. The severity of pavement distress may conveniently and effectively be expressed in terms of the percentages of joints affected for partial-depth distress and in terms of the number of joints per mile affected by full-depth distress. (See Table 1.)

5. Areas of distressed pavement may be located in part by visual inspection and the remaining portions by the hammer sounding technique.

6. Identification of the combination of factors contributing to distress at a particular pavement location, and the time period during which they have existed, can aid in the proper identification of the distress types that need to be repaired. (See Table 2.)

7. Deterioration of jointed PCC pavements is a progressive phenomenon and distress at a particular location will tend to become more severe until the factors contributing to the stress mechanisms are identified and corrected.

8. Bituminous concrete patches produce safe, temporary repairs for jointed PCC pavements, but do not inhibit the processes of deterioration. Hot-poured sealants provide interim relief from surface infiltration until preformed neoprene sealants can be scheduled for installation.

9. The decision to initiate permanent repairs of jointed PCC pavements is dependent upon factors such as funding and the ability of state forces to maintain the roadway with temporary bituminous patches. However, general guides, based on the overall structural condition of a pavement, suggest the initiation of repairs before more than 20 per-cent of the transverse joints in a particular location are affected by partial-depth distress, or, when one joint per mile exhibits full-depth distress.

10. Preventive maintenance activities such as the cleaning and sealing of transverse joints and the installation of edge drains through the shoulders should improve pavement performance.

RECOMMENDATIONS

1. Permanent repairs should be considered for a pavement location not later than the times when visual survey results indicate that 20% of the joints are affected by partial-depth distress, or when one joint per mile is affected by full-depth distress.

2. Information should be made available to field forces describing the factors involved in, and the processes of, pavement deterioration, the types of pavement distress, and the currently recognized stages of deterioration for jointed PCC pavements in the affected districts.

3. Visual surveys of jointed PCC pavements should be conducted at least on an annual basis to determine the percentage of joints in a pavement location that exhibit partial-depth distress, and the number of joints per mile that exhibit full-depth distress.

4. The use of bituminous patches for the temporary repair of jointed PCC pavements is an effective means for maintaining these roadways in a safe condition for traffic, and the practice should be continued as needed.

5. Preventive maintenance activities such as the cleaning and sealing of transverse joints and the installation of edge drains should be continued and expanded.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the interest and efforts of R. W. Gunn, materials technician supervisor, in the conduct of the field work associated with this study.

The study is under the general direction of J. H. Dillard, state highway research engineer, and is financed from state research funds.

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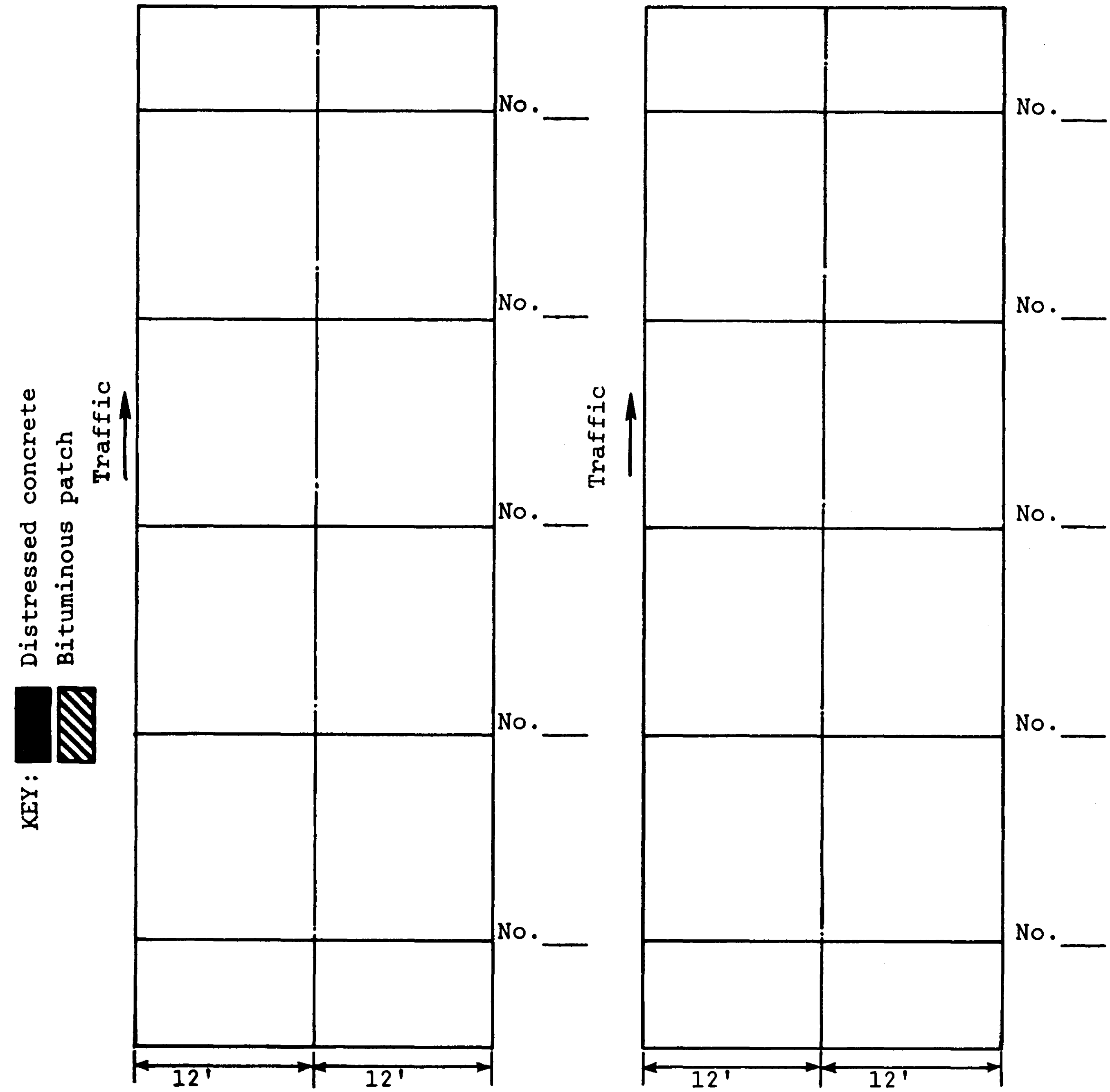
APPENDIX

PAVEMENT CONDITION SURVEY (2-LANE)

Record only those transverse joints where distress is observed.



DATE__________ SHEET NO.___of___.

ROUTE____________ DISTRICT ____________ COUNTY ______________

LANE: NBL____ SBL ____ EBL ____ WBL ____

Location of Joint No. 1 on this survey:___________________________

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1282

PAVEMENT CONDITION SUMMARY (2-LANE)

Transverse PCC Pavement Joints (numbered in sequence) and
Linear Feet of Visible Distress at Each Joint Face.
(Circle joint numbers to indicate a blowup.)

1			21			41			61			81		
2			22			42			62			82		
3			23			43			63			83		
4			24			44			64			84		
5			25			45			65			85		
6			26			46			66			86		
7			27			47			67			87		
8			28			48			68			88		
9			29			49			69			89		
10			30			50			70			90		
11			31			51			71			91		
12			32			52			72			92		
13			33			53			73			93		
14			34			54			74			94		
15			35			55			75			95		
16			36			56			76			96		
17			37			57			77			97		
18			38			58			78			98		
19			39			59			79			99		
20			40			60			80			100		

DATE________________ SHEET NO.___of___.

ROUTE_______________ DISTRICT__________________ COUNTY__________________

LANE: NBL____ SBL____ EBL____ WBL____

Location of Joint No. 1 on this Sheet:_______________________________

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Note: Location information not required if this is a continuation sheet, however it will be helpful for future reference to remark below the location of joints near structures as bridges culverts and ramps.

REMARKS;____

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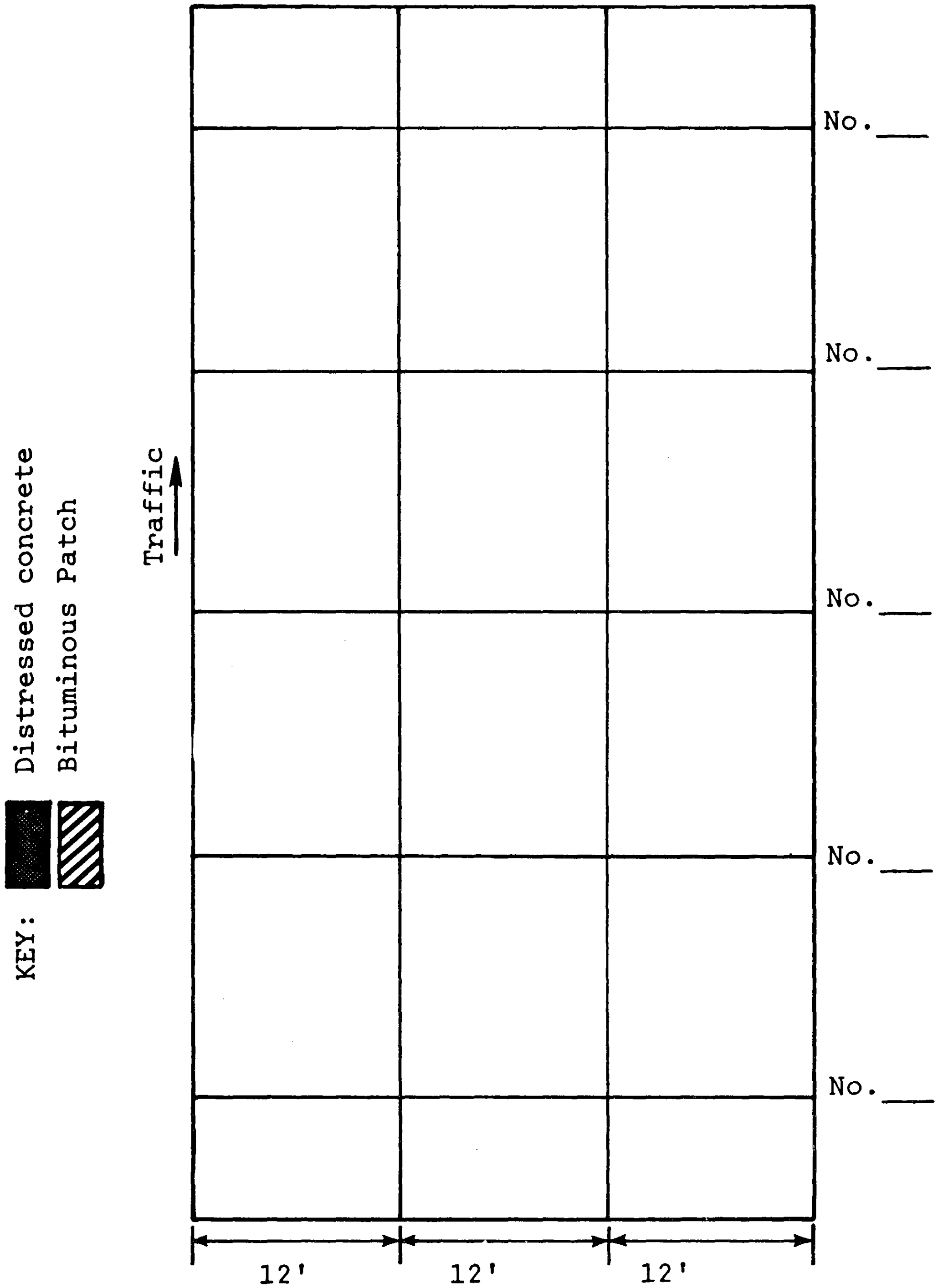
PAVEMENT CONDITION SURVEY (3-LANE)

Record only those transverse joints where distress is observed.



DATE________________________ SHEET NO.____of____.

ROUTE__________________ DISTRICT__________________ COUNTY__________________

LANE: NBL ____ SBL ____ EBL ____ WBL ____

Location of Joint No. 1 on this Survey:______________________________

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1384

PAVEMENT CONDITION SUMMARY (3-LANE)

Transverse PCC Pavement Joints (numbered in sequence) and
Linear Feet of Visible Distress at Each Joint Face.
(Circle joint numbers to indicate a blowup.)

1				21				41				61				81			
2				22				42				62				82			
3				23				43				63				83			
4				24				44				64				84			
5				25				45				65				85			
6				26				46				66				86			
7				27				47				67				87			
8				28				48				68				88			
9				29				49				69				89			
10				30				50				70				90			
11				31				51				71				91			
12				32				52				72				92			
13				33				53				73				93			
14				34				54				74				94			
15				35				55				75				95			
16				36				56				76				96			
17				37				57				77				97			
18				38				58				78				98			
19				39				59				79				99			
20				40				60				80				100			

DATE________________ SHEET NO.____of____.

ROUTE_______________ DISTRICT_________________ COUNTY___________________

LANE: NBL ____ SBL ____ EBL ____ WBL ____

Location of Joint No. 1 on this Sheet:_________________________________

____

Note: Location information not required if this is a continuation sheet, however it will be helpful for future reference to remark below the location of joints near structures as bridges culverts and ramps.

REMARKS:____

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