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Portland Cement Concrete Pavement Performance as Influenced by Sealed and Unsealed Contraction Joints

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ABSTRACT

In the 1950s and 1960s, the contraction joints in portions of several Wisconsin pavements were purposely left unfilled in an effort to determine the effect joint filling (and routine refilling) had on subsequent pavement performance. After 11 to 19 years of observation it was determined that the initial filling or refilling of contraction joints (40- to 100-ft spacings) had no beneficial effect on overall pavement performance. In 1974 a carefully designed joint and sealant study began with the objectives of evaluating the effect of joint spacing and joint sealing or nonsealing on total pavement performance, and evaluating joint sealants. This study was conducted on a new 9-in. jointed reinforced concrete pavement on a well-drained subgrade, employed five joint sealants, and considered four joint spacings (20, 40, 60, and 80 in.). A total of 22 test sections were evaluated, including eight control sections in which the joints were left unsealed and 14 test sections in which the joints were sealed (the joints in these test sections were resealed to maintain a sealed system for 10 years). Based on 10 years of monitoring total pavement performance (considering summer and winter ride, pavement distress and material integrity), it was found that some sealants served well for 10 years, short joint spacings gave the best pavement performance, and the pavement with unsealed joints had better performance than the pavement with sealed joints. It was concluded that there may be conditions and circumstances that do not justify the cost of sealing PCC pavement joints.

In order to understand the origin of the subject of this paper, it is helpful to review past experience in Wisconsin relating to sealing of joints in portland cement concrete (PCC) pavements. In 1953 a jointed plain concrete pavement (JPCP), with a 40-ft contraction joint spacing of 0.25-in. wide joints, was built on US-151 in two contiguous counties (Lafayette and Iowa) in the southern part of the state. In Wisconsin the counties perform the maintenance work, and, at that time, PCC pavement joint resealing was, or was not, routinely performed in each county based on a number of factors. In both counties the joints and cracks were sealed (actually filled) with an asphalt-based sealant at the time of construction; but in Iowa County they were routinely resealed (refilled) to prevent the intrusion of incompressibles and water, whereas there was no reseal-

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ing in Lafayette County. After 11 years of service and based on pavement performance factors (faulting, cracking, spalling, patching, etc.), S.T. Banaszak, Wisconsin Department of Transportation (WisDOT), concluded: "It is quite apparent that the omission of the joint sealer resulted in better overall pavement performance than that of the sealed joints." (Unpublished data.) Clearly, the sealed joints were not sealed but only filled, yielding a partially sealed condition; however, this study indicated that keeping some of the water and incompressibles out of the joint was of no benefit to overall pavement performance.

Based on the above experience and that of several other pavements on which sealing at the time of construction had inadvertently been omitted, several iconoclastic engineers propounded what at the time was, and to many still is, an outrageous question: Is it actually necessary to seal the contraction joints in PCC pavement? (1). Their curiosity prompted a more systematic investigation.

BACKGROUND

Past Experience in Wisconsin

In 1958 several test sections were placed in the southbound lanes on US-41 in Washington County. This jointed reinforced concrete pavement (JRCP) was 9-in. thick, rested on a 6-in. gravel or crushed stone base course, and had 9 in. of granular subbase material. The subgrade soil had a K value of about 250 pci. The joints, which contain load-transfer dowels, were sawed 0.25-in. wide at 100-ft intervals and filled with hot-poured sealant conforming to ASTM D 1190. One experimental section had sealed joints, one had alternately sealed and unsealed joints, and another section had all unsealed joints.

The performance of the two types of joints (initially sealed and unsealed) was monitored via biannual visual inspections. By 1966 the investigators were reporting that the condition of the unsealed joints was "far superior" to the sealed joints. Specifically, the unsealed joints exhibited less corner cracking and spalling than their sealed counterparts.

Because of the previous report, the investigation was expanded, and in 1966 a second, larger experimental project was started on WI-78 in northern Columbia County. This 4-mi segment of pavement was similar to US-41 in design features, except that contraction joints were spaced at 80 instead of 100 ft. Like US-41, WI-78 was a four-lane divided highway. The pavement structure, designed for a subgrade K value of 300 pci, consisted of a 9-in. JRCP, over 6 in. of base course, and 6 in. of select excavation. The joints in the southbound pavement were sealed with a hot-poured sealant (ASTM D 1190), whereas the northbound pavement joints were left unsealed. It was also decided in 1966 to expand the objectives of the studies on US-41 and WI-78, and, what had begun as a study of joint performance became a study of pavement performance.

In 1977, based on evaluation criteria such as pavement distress and ride and materials integrity (one pavement was 19 and the other was 11 years old), it was concluded that the inclusion or omission of a joint sealant at the time of construction did not exert a significant influence on pavement performance (1).

The three aforementioned studies were not well-designed research projects and all had one deficiency, that is, the joints were neither truly sealed nor could they be with the joint spacing, joint shape factor, and sealants used. Thus, although these studies did clearly indicate that keeping some of the water and incompressibles out of the joint was of no benefit, they did not answer the real question concerning the cost-benefit of truly sealed contraction joints.

Experience of Others

Until the midtwentieth century little progress had been made in the art of joint and sealant design since the first apparent use of a sealant in road construction in seventh- or eighth-century B.C. Mesopotamia where asphalt block or asphalt brick pavements were built, the asphalt serving as a sealant and cement (2,3). Until then, most sealants were merely asphaltic-based compounds and little or no attention was paid to allowable sealant extensions, sealant strains, or joint shape factors. However, in the 1950s joint and sealant design began to be subjected to scientific investigation, the preeminent contribution being made by Egon Tons in the late 1950s (4,5). Such investigation, coupled with the development of new and promising sealants, helped usher in an era in which there was at least the potential for designing a joint that would remain sealed.

By the early 1970s there was a tremendous volume of research and information on PCC pavement joint sealing; however, the vast bulk of this research was on joint or sealant performance. There appeared to be a dearth of information available on overall pavement performance as influenced by joint sealing, the emphasis being placed on the secondary issue of sealant and joint performance. The benefit of keeping incompressibles and water out of joints appears to have been accepted in general, with few or no qualifications as to pavement type, subgrade characteristics, environmental conditions, or material properties.

Origin of Pavement Performance Study

Although the findings of the studies in Wisconsin were provocative, they were not conclusive. The searches for information from other agencies on total pavement performance (as influenced by joint sealing, or lack thereof) was even less conclusive because most research was devoted to only sealant or joint performance. This lack of information was enough to justify a carefully controlled study of the subject in the state. However, the great advances in joint sealing theory and sealing materials, coupled with the research by other agencies on the benefits of close contraction joint spacings, compelled the state in 1973 to begin a study of pavement performance as influenced by sealed and unsealed contraction joints at various spacings.

OBJECTIVES

The a priori arguments concerning joints and joint sealing were set aside to take a fresh look at pavement performance. The objectives of the study were to evaluate (for a period of 10 years and possibly longer):

1. The effect of joint sealing, or lack thereof, on total pavement performance;
2. The effect of joint spacing on total pavement performance; and
3. The performance of various joint sealants.

STUDY DESIGN

Highway Factors

The pavement test area is a 9-in., slip-formed, mesh-reinforced, dowelled PCC pavement. The test area is on US-51 from Wausau to Merrill in Marathon County (north-central portion of the state). US-51 is a four-lane divided highway with an average daily traffic (ADT) of 7,000 (11 percent heavy vehicles). The subgrade is a sandy glacial outwash material. The 8-in. base course, concrete coarse aggregate and shoulders are a crushed gravel (primarily igneous material). No shoulder pavement was placed on the crushed gravel shoulders. Wisconsin's crushed gravel for base and shoulders is well graded and is not considered to be free draining (maximum size is 0.75-in. with a P200 of 3 to 10 percent for base material and 8 to 15 percent for shoulders).

Winter maintenance for snow and ice control consists primarily of plowing and chemical application; few, if any, abrasives have been used on this section of highway. This portion of the state receives 30 in. of rainfall annually and temperatures commonly range from 100°F to -40°F.

Research Features

Four contraction joint spacings of 20, 40, 60, and 80 ft were used for this study. At the time, a 20-ft contraction joint spacing was considered a practical minimum; however, within 3 years the state routinely used a shorter joint spacing. All joints were cut transversely with respect to the centerline.

The intent of the study was to use one or two of the most promising sealants from three sealant groups (thermoplastic, chemical setting, and preformed sealants). Based on contact with other states and information from a literature search by the Transportation Research Information Service, four sealants, together with the standard sealant, were selected for inclusion in the study.

1. Rubberized asphalt (Federal Specification SS-S-1401),
2. Coal tar-based polyvinyl chloride (ASTM D 3406),
3. Two-component cold-pour polysulfide (Federal Specification SS-S-00195A),
4. Preformed neoprene compression seal (ASTM D2628), and
5. Standard sealant (ASTM D1190).

Two test sections were used for each combination of joint spacing and sealant (including no sealant in the joints). Therefore, a total of 22 test sections (each a nominal 1,000 ft in length) were used (Figure 1 and Table 1). In 14 test sections all the joints were sealed and in 8 test sections all the joints were left unsealed. Test sections were randomly placed; no attempt was made to place all sealed test sections next to one another and all unsealed test sections next to one another. It was recognized that the performance of one test section may influence the performance of a contiguous test section. Therefore, the use of two test sections for each combination of joint spacing and sealant provided a replica test section to help determine if one test section influenced another.

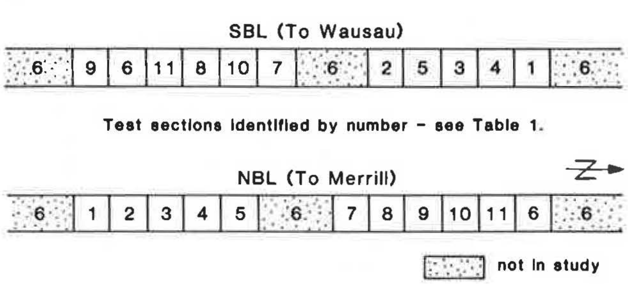

FIGURE 1 Schematic drawing of test section layout.

TABLE 1 Characteristics of the Various Test Sections

Test Section	Sealant	Joint Spacing (ft)	Sealant Depth to Width Ratio	Original Joint Width (in.)
1	Polyvinyl chloride	20	2.7	3/8
2	Preformed compression	40	NA[a]	3/8
3	None	40	10	1/4
4	Polysulfide	20	1.2	5/8
5	None	80	10	1/4
6	Standard	80	10	1/4
7	Polysulfide	40	0.6	1-1/4
8	None	20	10	1/4
9	None	60	10	1/4
10	Preformed compression	60	NA[a]	1/2
11	Rubberized asphalt	20	1.0	7/8

Note: See Figure 1 for schematic drawing of test sections.
[a]NA = not applicable.

The design of the joint width for the joints in each test section (except the unsealed and standard joints that were 0.25-in. wide) was based on data from Wisconsin (6), the American Concrete Institute (7), sealant manufacturers (8), and other states' agencies (9). The sealant shape factor (depth to width ratio) was based on manufacturer recommendations and design aids (10) (Table 1).

The centerline joint was sealed with either a rubberized asphalt or polyvinyl chloride sealant, and the centerline joint was only sealed in the test sections that contained a sealant in the transverse joints. More detailed information on the study design and layout is available elsewhere (11,12).

Pavement Performance Indicators

The pavement performance indicators for this study are as follows:

1. Three pavement performance indicators were documented annually for 10 years.
   a. Ride was measured summer and winter on a scale from 0 to 5 according to the Wisconsin Roadmeter, a response-type road roughness measuring system.
   b. Pavement distress (faulting, blowups, cracking, joint spalling, etc.) was measured each fall.
   c. Sealant performance was determined each winter.
2. Thousands of joint movement readings were taken at various temperatures throughout the year for several years to determine joint movement as a function of joint spacing and temperature.
3. Cores were taken when the pavement was 10-years old to observe subsurface distress at joints.

COSTS

To estimate cost-effectiveness, the cost for a pavement with unsealed joints must be compared to a similar pavement with sealed joints, that is, the costs to maintain the joints in a sealed condition must also be included. Thus, the costs to create and maintain a sealed joint system must be offset by an equivalent increase in pavement performance and life in order for joint sealing to be cost-effective.

The costs (including the pavement, initial saw cut, reinforcement, and dowel bars) for the pavement with unsealed joints averaged $7.28/yd². The additional costs to create a sealed joint system (including the second saw cut to create an appropriate joint shape factor, backing material, cleaning and sealing) ranged from 8.2 to 22.5 percent of the costs for the pavement with unsealed joints. When the costs for maintaining the joints in a sealed condition for 10 years are added, the pavement with sealed joint systems costs up to 45 percent more than a similar unsealed pavement.

As a point of interest, the cost for sealing joints was not so much related to the sealant cost as it was to the extension range of the sealant. For example, the relatively inexpensive rubberized asphalt had a low extension range and accordingly required sawing a wide sealant reservoir; therefore, considering all costs, the use of this sealant resulted in higher costs than the expensive sealants that had a larger extension range and required less saw cutting.

RESULTS

The following results are based on 10 years of data collection.

Joint Movement

The average joint opening in inches expected from the warmest to coldest temperature was found to be 0.0448 + 0.0044 x joint spacing in feet. Therefore, for a 40-ft joint spacing the average joint will move 0.22 in. from maximum closure to maximum opening.

Further information on joint movement studies and resulting joint design aids is available elsewhere (11).

Maintenance of Seals

Criteria for distinguishing a sealed from an unsealed joint system was derived from a percentage of sealant failure (20 percent). If less than 20 percent of the linear feet of sealant in a test section had failed, the test section was considered sealed. Whenever 20 percent or more of the linear feet of sealant in a test section revealed a sealant failure that allowed water or incompressibles into the joint, the entire test section was considered unsealed, and was resealed in kind as soon as possible.

The preformed neoprene compression seals, in the test sections with a 60-ft joint spacing, failed very early in the study and no attempt was made to reseal these joints. In all other test sections, if resealing was required more than three times in 10 years attempts to maintain a sealed joint were abandoned. Accordingly, the test sections with the 60- and 80-ft joint spacings were not, or could not, be kept sealed and attempts to reseal the joints were abandoned. Therefore, the test sections with 60- and 80-ft joint spacings were not kept sealed but existed in a partially sealed condition for most of the 10 years. The test sections with the 20- and 40-ft joint spacings could be, and were, kept sealed for the entire 10 years.

Resealing joints with poured sealants was accomplished by removing the old sealant, cleaning the concrete sidewall, and placing the new sealant. The preformed neoprene compression seals failed in 4 years in the test sections with a 40-ft joint spacing. The joints with the preformed neoprene compression seals were resealed by removing the old seal, resawing the joint to a greater width, and then installing a new preformed neoprene compression seal.

The unsealed joints were not blown or flushed; incompressibles were allowed to remain in place. The centerline joints that were sealed remained sealed throughout the study.

Sealant Performance

From this study, it was found that sealants can exhibit the lives given in Table 2 (based on the 20 percent failure criteria), if properly placed in an adequately designed joint. For some sealants the life has been extrapolated from present conditions. There is a range in life for the preformed neoprene compression and polysulfide sealants. The shorter life for the polysulfide sealant is for the 40-ft joint spacing and the longer life is for the 20-ft joint spacing. Better joint design and material specification (data derived from this study) has lengthened the anticipated life for preformed neoprene compression seals in a 40-ft joint spacing from 4 to 10 or more years.

TABLE 2 Life of Properly Placed Sealants

Sealant	Life (yr)
Rubberized asphalt	5
Polyvinyl chloride	10
Preformed compression[a]	4-10+
Polysulfide	8-12+

[a]For the 40-ft joint spacing.

Pavement Distress

Pavement distress was determined from all observed forms of distress. No faulting was observed; the joints had positive load transfer devices. In Wisconsin, pavement blowups often begin before 10 years of age; however, no blowups were observed in any of the 22 test sections. Because the pavement in this study has had a history free of blowups, the results and conclusions of this study are to be understood in the context of these observed conditions. The two significant pavement distress types observed were joint spalling and panel cracking (transverse, longitudinal, and diagonal).

Joint Spalling

Any joint distress that developed within the first year of the pavement's life was considered to result from factors other than those relating to joint spacing and sealing. To compensate for such factors, the change in joint distress from 1 to 10 years will be considered (Figure 2). Recall that the joints were only partially sealed in the sections with a 60- and 80-ft joint spacing. The spalls did not predominate in any one area along a joint (such as in the corner areas), but were fairly well distributed. In most cases the joint spalling was slight to moderate in severity (partial depth and less than 4-in. wide). Therefore, the extent of spalling is the primary concern. It is immediately clear that (a) for

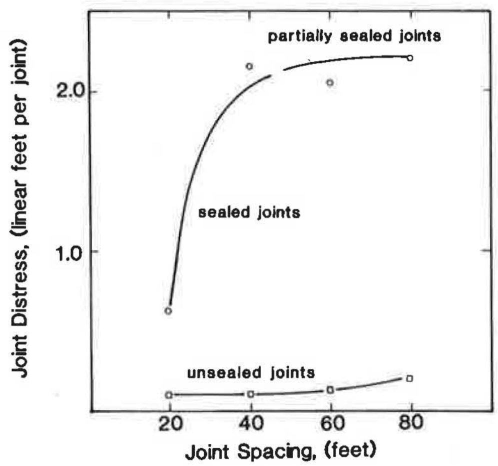

FIGURE 2 Joint distress versus joint spacing.

the sections with sealed joints, there was a large increase in joint distress with joint spacings above 20 ft and (b) the unsealed joints had much less spalling, regardless of joint spacing, than the sealed or partially sealed joints.

An increase in joint distress with joint spacing is understandable, but the small amount of joint distress for the unsealed sections (0.25-in. wide joints), regardless of joint spacing, is unexpected. Some of the joint distress in the sealed sections is due to the resealing operations that occasionally caused small spalls; however, the superior performance of the unsealed sections appears inexplicable.

Panel Cracking

Panel cracking refers to all forms of full-depth cracking within a panel (area bounded by transverse joints and pavement edges). The panel cracks were not corner breaks typical of those due to lack of support or pumping. The panel cracks were primarily transverse cracks with a small amount of longitudinal and diagonal cracking. All forms of panel cracking per test section were summed (Figure 3) and the results indicate that (a) there was a dramatic increase in cracking for panel lengths over 40 ft, and (b) there was more cracking in the sealed and partially sealed sections than in the unsealed sections.

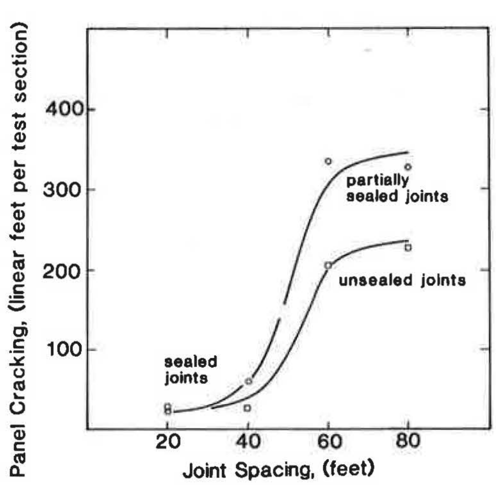

FIGURE 3 Panel cracking versus joint spacing.

Although the difference between the amount of panel cracking in sealed and unsealed sections is not considered significant, the difference in cracking between the partially sealed and the unsealed sections of the same joint spacing is significant. The large increase in panel cracking for the larger joint spacings, regardless of whether joints are sealed or not, is of real concern (Figure 3). Because most of the panel cracking occurred within the first year of the pavement's life, it is believed to result from factors other than loading. Such panel cracking apparently results from the base's frictional restraint to concrete movement, for example, from thermal contraction and concrete shrinkage. The base's frictional restraint increases with increasing panel lengths, causing more cracking in the longer panels. The large amount of panel cracking in the longer panels is common and is one of the reasons for the use of shorter joint spacings.

The results shown in Figures 2 and 3 indicate a clear preference for the use of short joint spacings and unsealed joints. Even if there were indications that sealed and unsealed sections behave more similarly than data suggest, they would not explain the lack of superior performance of the sealed sections, which is necessary to justify sealing costs.

Change in Ride

Considering all test sections, the change in ride from the 1-year old pavement to the 10-year old pavement was approximately 0.5 psi (pavement serviceability index), indicating that (a) sealed, partially sealed, and the unsealed sections decreased in ride a similar amount; (b) summer and winter rides were similar; and (c) joint spacing had little or no effect on the change in ride.

It was believed, before this study, that the infiltration of water in the unsealed joints would cause a much rougher winter ride in the unsealed test sections than in the sealed sections. This did not prove to be true.

Coring

PCC joint repair projects on other highways have revealed a cone of disintegrated concrete beneath most joints. It is believed this cone is partly due to compressive forces that tend to concentrate in the lower portion of the joint--such concentration being the result of incompressibles in the joint, especially the lower portion. In the pavement project described in this paper, the unsealed joints have been filled with incompressibles (except the upper one to 3 in. in the wheel paths) from shortly after the time of construction. Cores taken at joints at 10-years old indicate no distress beneath any joints regardless of joint spacing or sealing. Although this distress may become significant in the future, at this point there is no difference in material integrity as a result of joint sealing or joint spacing.

CONCLUSION

After 10 years of observation, the following conclusions are justified for this study. Recall that the pavement under consideration had positive load transfer at the joints, was on a well-drained subgrade, had a blowup-free history, was in a northern climatic zone and had gravel shoulders.

1. The pavement with unsealed joints performed better than the pavement with sealed joints,

2. The pavement with shorter joint spacings performed better than the pavement with the longer joint spacings,

3. There are sealants that can keep joints effectively sealed for 10 years when placed in a properly designed joint, and

4. Contraction joint sealing costs cannot be justified.

SUMMARY

When total pavement performance is considered, the results from 10 years of experience on US-51 indicate that shorter joint spacings (e.g., 20 ft) lead to better pavement performance than longer joint spacings, which was an expected result supported by other agencies. However, the conclusion that pavements with unsealed joints performed better than those with sealed joints, is provocative.

Arguments may be made to show that sealed and unsealed test sections behave more similarly than the data suggest. However, such efforts could only prove, at best, equality of performance, which does not sufficiently justify the cost of sealing over nonsealing. The entire costs for maintaining a sealed pavement for 10 years, from sawing a joint reservoir and sealing it to resealing the joint when needed, amounted to as much as 45 percent more than the cost for a similar unsealed pavement. Therefore, to justify this cost, there would have to be (a) a much greater serviceability (ride) during the pavement's life, (b) much less maintenance, or (c) a significant increase in pavement life. At this time, there is no basis for such justifications.

The results of this study correspond to the precursory studies made in the 1950s and 1960s. Today, WisDOT routinely uses a joint spacing of 20 ft or less and is conducting other sealed versus unsealed joint studies because the efficacy of joint sealing is in question. These other studies were necessitated because the present study had limitations and the following questions still remain unanswered:

1. Although joint sealing appears not to be beneficial for dowelled contraction joints, is the same true for nondowelled joints for which there is greater opportunity for pumping and faulting?

2. Although joint sealing appears nonbeneficial on a well-drained subgrade, would it be beneficial on a heavy, poorly-drained soil?

3. Is joint sealing justified where blowups are more prevalent?

A true assessment of joint sealing must be based on total pavement performance, not just sealant and joint performance. This study clearly indicates there are situations for which joint sealing may not be justified. Even if pavement performance can be enhanced and pavement life prolonged by joint sealing and resealing, the cost-benefit of such operations has to be evaluated. Considering the costs for all sealing operations, a pavement would have to ride better, require less maintenance, or its life would have to be extended many years to make sealing a sound investment.

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