TechBrief

The Concrete Pavement Technology Program (CPTP) is an integrated, national effort to improve the long-term performance and cost-effectiveness of concrete pavements. Managed by the Federal Highway Administration through partnerships with State highway agencies, industry, and academia, CPTP's primary goals are to reduce congestion, improve safety, lower costs, improve performance, and foster innovation. The program was designed to produce user-friendly software, procedures, methods, guidelines, and other tools for use in materials selection, mixture proportioning, and the design, construction, and rehabilitation of concrete pavements.

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U.S. Department of Transportation
Federal Highway Administration

Performance of Sealed and Unsealed Concrete Pavement Joints

This TechBrief presents the results of a nationwide study of the effects of transverse joint sealing on performance of jointed plain concrete pavement (JPCP). This study was conducted to assess whether JPCP designs with unsealed transverse joints performed differently from JPCP designs with sealed transverse joints. Distress and deflection data were collected from 117 test sections at 26 experimental joint sealing projects located in 11 states. Performance of the pavement test sections with unsealed joints was compared with the performance of pavement test sections with one or more types of sealed joints. It should be noted that most of the test sections studied were 10 years or less in age at the time of data collection.

BACKGROUND

The sealing of transverse contraction joints in JPCP has been standard practice throughout much of the United States for many years. Its widespread use is due to the common belief that sealing joints improves concrete pavement performance in two ways: by reducing water infiltration into the pavement structure, thereby reducing the occurrence of moisture-related distresses such as pumping and faulting; and, by preventing the infiltration of incompressibles (i.e., sand and small stones) into the joints, thereby reducing the likelihood of pressure-related joint distresses such as joint spalling and blowups.

Transverse joints in jointed concrete pavement (JCP) are typically created by making an initial sawcut to force controlled cracking, followed by a second, wider sawcut to produce a reservoir for the joint sealant material. This traditional approach of sawing and sealing transverse contraction joints is estimated to account for between 2 and 7 percent of the initial construction cost of a JCP. Moreover, these sealed transverse joints require resealing one or more times over the service life of the pavement, leading to additional costs in terms of labor, materials, operations, and lane closures.

Recently, several State departments of transportation (DOTs) have been questioning conventional transverse joint sawing and sealing practices. These agencies contend that the benefits derived from sealing do not offset the costs associated with the placement and continued upkeep of the sealant over the life of the pavement. As a result, they have been experimenting with different sawing and sealing alternatives, for example:

- Narrow unsealed joints, consisting of single sawcuts that are left unsealed.
- Narrow filled joints, consisting of single sawcuts that are filled with sealant that adheres to the sides and bottom of the sawcut.

- Narrow sealed joints, consisting of single sawcuts that contain a narrow backer rod and sealant material.

To address the question of the effect of joint sealing on JCP performance, the FHWA sponsored a study to collect and examine field performance data from a wide variety of in-service concrete pavement joint sealing experiments across the United States. This TechBrief presents the results of this nationwide study. It should be noted that most of the test sections studied were 10 years or less in age at the time of data collection.

FIELD SURVEYS

As part of the field testing program, distress and deflection data were collected on 117 different test sections at 26 pavement projects located in 11 States (Arizona, Colorado, Florida, Georgia, Illinois, Indiana, Iowa, Minnesota, New York, Ohio, and Wisconsin). The locations of these projects are shown in figure 1. These projects represent a range of concrete pavement designs, sealant material types, and transverse joint configurations.

A standard, systematic, and comprehensive field data collection effort was employed in the study to obtain consistent and meaningful data. At each selected site, a visual distress survey was performed in general accordance with the procedures and distress definitions found in the *Distress Identification Manual for the Long-Term Pavement Performance Program* (Miller and Bellinger 2003), developed under the Strategic Highway Research Program. For each observed distress, the location, size, and severity were identified and drawn approximately to scale on distress survey maps. Because the focus of this study was on the effects of sealed or unsealed joints on performance, particular attention was paid to the following distresses:

- *Blowups and other pressure damage:* The infiltration of incompressibles into poorly sealed joints could conceivably lead to blowups at joints or cracks or damage to bridges and other fixed structures.
- *Joint faulting:* Infiltration of water into transverse joints is believed to contribute to pumping of fines beneath slab corners, which results

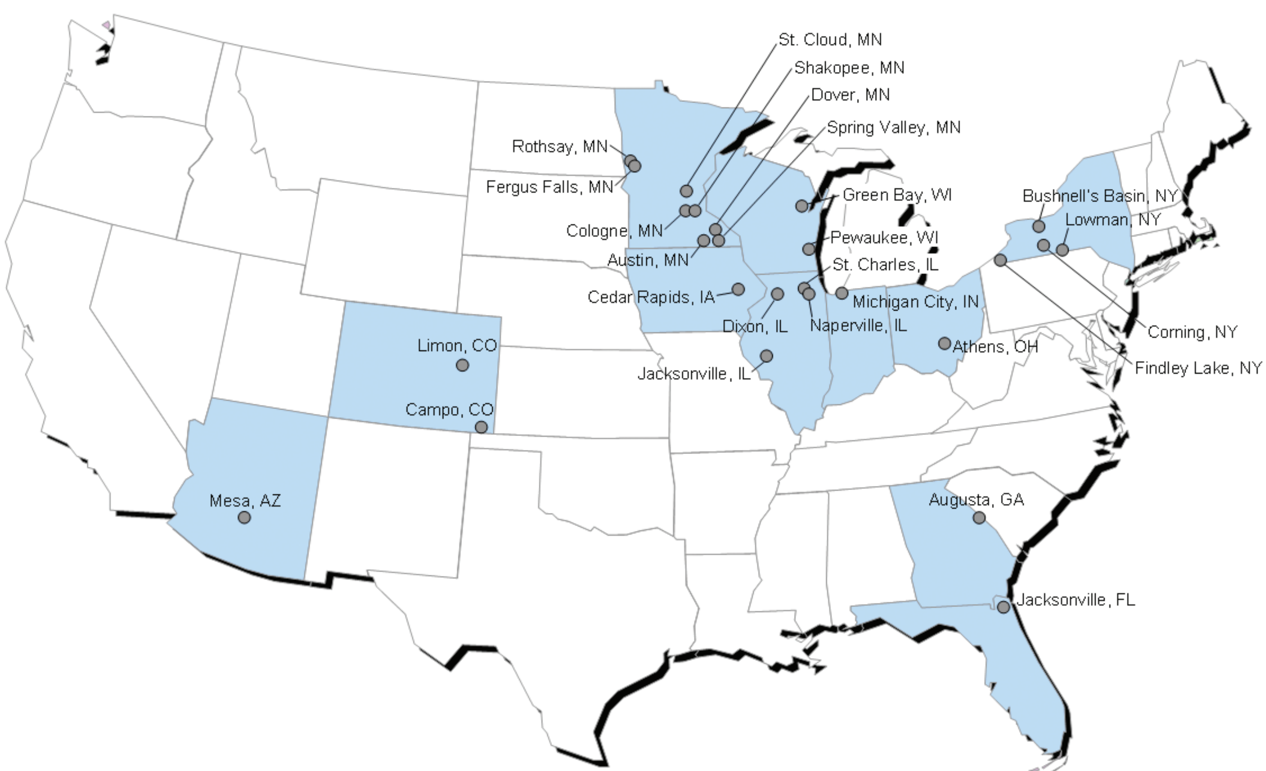

Figure 1. Location of joint sealing experimental sites. (Note: Most of the test sites studied were 10 years or less in age at the time of data collection.)

in faulting. Joint faulting is a major contributor to roughness in both doweled and undoweled JPCP.

- *Joint spalling:* Infiltration of incompressibles into joints has long been considered to be a contributing factor to the development of spalling at transverse joints. Spalling may have two adverse consequences: increased pavement roughness and increased repair costs.
- *Joint sealant damage:* Joint sealant damage is defined as any sealant-related condition that allows incompressible material or a significant amount of water to infiltrate the joint. Types of joint sealant damage noted under this project include adhesive failures (debonding), cohesive failures (splitting), and the absence (loss) of sealant.

For sections with sealed transverse joints, a primary goal of the field survey activities was to assess how well sealed the joints were and how well the sealant was performing. To determine how well the sealant was performing, the entire length of each joint was assessed to estimate the joint length that was performing well and the joint length that exhibited joint sealant failures. The lengths of the following three types of joint failures were estimated separately:

- *Adhesive failures:* An adhesive failure is an area where the sealant has become debonded from the joint reservoir side. For this study, adhesive failures in hot-poured sealants were generally located visually or by attempting to slide a small straightedge between the sealant and the reservoir sides.
- *Cohesive failures:* A cohesive failure is a sealant material failure that can be described as an internal splitting of the material, typically near the center of the joint reservoir. Applicable to only hot-poured and silicone sealant materials in this study, cohesive failures are typically observed in joints where the sealant has been placed too thin in the joint reservoir or where the sealant has lost its elastic properties.
- *Absence of sealant:* The third type of sealant failure noted was when an area of sealant was found to be missing from the joint.

The total joint length with sealant failure was calculated as the sum of the measured lengths of adhesive, cohesive, and absence failures. To normalize the total failure length computed for each joint, this total length of sealant failures was converted into a percentage of total joint length.

As part of the joint sealant field evaluation process, an estimate also was made of the total joint lengths containing "coarse-grained" and "fine-grained" incompressible material. Coarse-grained particles were defined as stones with a diameter of 50 to 100 percent of the observed joint width, while fine-grained particles were defined as those with a diameter less than 50 percent of the observed joint width. The total recorded length of each incompressible type within a joint was converted into a percentage of total joint length.

Deflection testing was conducted with a falling weight deflectometer (FWD) to assess the support conditions and load transfer efficiencies of the various pavement structures included in the study. For this study, a standard sensor spacing and a multiple-drop load sequence were employed. The FWD testing was performed by the participating State DOTs (i.e., each participating DOT conducted the testing using its own equipment and operator) following a prescribed testing protocol to provide consistency in the way the deflection data were collected.

To allow for joint, edge, and midslab testing without repositioning during testing, the positions for five sensors along the longitudinal sensor bar were -305, 0, 305, 610, and 914 mm (-12, 0, 12, 24, and 36 in.) from the center of the load plate. Optional placements for two additional sensors, if available, were 1,219 and 1,524 mm (48 and 60 in.) from the center of the load plate. The FWD drop loads were approximately 40, 53, and 80 kN (9,000, 12,000 and 18,000 lbf), recorded as load levels 1, 2, and 3, respectively. A testing pattern consisting of a sequence of drop load levels 3, 1, 2, and 3 was used at each test position.

Within each test section, a group of four consecutive slabs was tested. To complete this testing efficiently, the FWD made two passes over the four-slab group. For the first pass, down the center of the outer traffic lane, the FWD was positioned so that the load plate was placed equidistant between the lane–shoulder and lane–lane longitudinal joints. Along the first pass, five transverse joint-leave tests and four center-slab tests were taken. For the transverse joint approach tests, the load plate was placed as close as possible to the joint. For the center-slab tests, the FWD was maneuvered so that the load plate was as close to the geometric center of the slab as possible. The second pass consisted of an edge pass in which the FWD load plate was positioned as close as possible to the outer lane–shoulder joint. Along the second pass, 10 corner tests and 5 outer edge tests were taken. A summary of the deflection testing locations in each four-slab group is outlined in figure 2.

To aid in the analysis of the FWD data, temperatures were collected at various depths within the pavement by way of a multidepth temperature probe placed in a hole 13 mm (0.5 in.) in diameter drilled into the slab.

FAULTING ANALYSIS

An analysis of the collected faulting data found that the only sites where significant faulting occurred were the three sites with undowelled joints: St. Cloud, Minnesota (MN 7), Pewaukee, Wisconsin (WI 1), and Green Bay, Wisconsin (WI 2). At the MN 7 site, the average joint faulting in the hot-pour–sealed section was 4.73 mm (0.19 in.), and the average joint faulting in the unsealed section was 3.77 mm (0.15 in.). Constructed in 1954, this section is by far the oldest experimental site surveyed for this study. Also, although the available project data do not provide a record of past restoration work, the appearance of the pavement surface (i.e., the visibility of large aggregates) suggests that the pavement was diamond ground at some time in the past. There is also some question as to whether or not the unsealed section was truly unsealed over its entire 50 years or more of service.

At the Pewaukee (WI 1) site, average joint faulting for the three silicone-sealed sections was 6.16 mm (0.24 in.), and the average joint faulting for the one unsealed section was 4.79 mm (0.19 in.). This is the second oldest site in the study, constructed in 1983.

At the Green Bay (WI 2) site, the average joint faulting in the undowelled section with preformed sealant was 4.19 mm (0.16 in.), and the average joint faulting in the undowelled, unsealed section was 4.81 mm (0.19 in.). At the same site, the average joint faulting in the dowelled section with preformed sealant was 0.77 mm (0.03 in.), and the average joint faulting in the dowelled, unsealed section was 0.96 (0.04 in.). This is the third oldest site in the study, constructed in 1988.

Of the remaining projects (all of which contain dowelled joints), average joint faulting levels exceeded 1 mm (0.04 in.) at only one site: Spring Valley, Minnesota (MN 3). At the MN 3 site, the average joint faulting in the silicone-sealed section was 1.31 mm (0.05 in.), the average joint faulting in the section with preformed sealant was 0.99 mm (0.04 in.), and the average joint faulting in the section with unsealed joints was 1.16 mm (0.05 in.). At all of the remaining sites, the average joint faulting levels were less than 1 mm (0.04 in.).

A statistical analysis of the collected faulting data also was completed to determine if there was any statistical difference between faulting on sealed joints (i.e., hot-poured, preformed, and silicone) and faulting on unsealed joints. Using a 95 percent confidence interval, no significant difference in average joint faulting was detected between sealed joints of any kind and unsealed joints. It should be noted that with few exceptions the magnitudes of average joint faulting were very low, most less than 1 mm (0.04 in.). The notable exceptions were the few sites with undowelled joints.

JOINT SEALANT FAILURES

There are two sites at which all three categories of sealant (silicone, preformed, and hot pour) were used: Mesa, Arizona (AZ 1) and Athens, Ohio (OH 1).

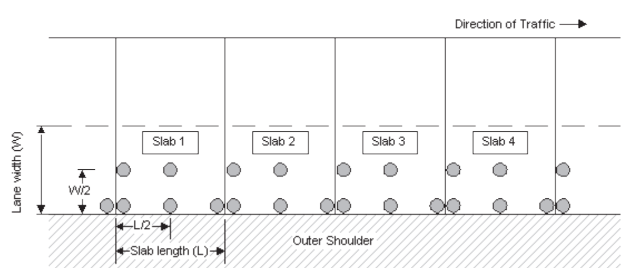

Figure 2. Illustration of falling-weight deflectometer test locations within each four-slab group.

At both of these sites, a considerable degree of joint sealant failure had occurred in the test sections with at least one of these types of sealant. At the AZ 1 site, the average percentages of joint length with one or more types of sealant distress (adhesive failure, cohesive failure, or absence) were 8 percent, 41 percent, and 50 percent for the silicone, preformed, and hot-pour sections, respectively. At the OH 1 site, the average percentages of joint length with one or more types of sealant distress (adhesive failure, cohesive failure, or absence) were 38 percent, 18 percent, and 57 percent for the silicone, preformed, and hot-pour sections, respectively. Thus, the hot-pour sections had the greatest amount of sealant failure at both sites, while at one site, silicone failed by a smaller percentage than preformed, and at the other, preformed failed by a smaller percentage than silicone. At some of the other sites, the sealed-joint section or sections experienced little or no sealant failure of any kind, while at others, the sealed-joint section or sections experienced significant to substantial sealant failure.

SPALLING ANALYSIS

Low-severity joint spalling was analyzed by site and by joint sealant type. A detailed statistical analysis of the spalling results indicates that the low-severity spalling at unsealed-joint test sections was significantly greater than the low-severity spalling at each of the three types of sealed-joint test sections at the same sites. An overall confidence level of 95 percent was used for this statistical analysis.

Medium- and high-severity joint spalling was analyzed by site and by joint sealing type. The mean differences between medium- and high-severity joint spalling in the unsealed-joint test sections and that in each of the three kinds of sealed-joint test sections were negative, indicating that medium- and high-severity joint spalling in the three types of sealed-joint test sections was greater than that in the unsealed-joint test sections. However, this difference was statistically significant only in the case of preformed sealant.

DEFLECTION ANALYSIS

For this study, deflection testing was conducted on 89 different pavement sections. Deflection testing could not be conducted on all 117 sections due to site constraints. All data from deflection tests taken at the transverse joints (mid-slab and corners), slab interior, and along the longitudinal edge were used in the analyses, as described below.

1. *Analysis of transverse joint deflections at the mid-slab location:* The transverse joint deflections at the mid-slab location (approach or leave side of joint) were first used to determine the joint load transfer efficiency. The transverse joint deflection load transfer efficiency is computed as the simple ratio of unloaded and loaded slab deflections, and provides a measure of the competence of dowel bar and/or aggregate interlock interactions to effectively transfer edge loadings between adjacent slabs.

Transverse joint deflections also were used to determine the normalized total joint deflection, dynamic edge foundation support, and transverse edge slab support ratios. The normalized total edge deflection is computed as the simple addition of unloaded and loaded slab deflections, normalized to a common load level of 40 kN (9,000 lbf). The normalized total edge deflection should remain relatively constant regardless of available deflection load transfer, provided that slab thickness, elastic modulus, and foundation support remain constant. The total edge deflection can be used as a relative indicator of the overall edge structural capacity of a test section as well as an input for the backcalculation of edge foundation support.

Incremental analysis of transverse edge deflection response was conducted to provide a means of differentiating slab curling from poor foundation support. In those cases where temperature curling alone was responsible for poor support, incremental slab support should increase over that computed based on individual load levels, provided at least two load levels produced sufficient total edge deflection to close any curl-induced voids.

The uniformity of support under the transverse edge, termed the transverse edge slab support ratio, is computed as the ratio of the backcalculated incremental edge and interior dynamic foundation k-values (Crovetti 1994). In general, incremental transverse edge slab support ratios less than approximately 0.75 are indicative of slabs with poor edge support due to foundation densification/pumping and/or temperature curling (Crovetti 1994).

2. *Analysis of interior slab deflections:* The interior deflections collected at the center-slab test location were used to determine the dynamic foundation support k-value. Interior deflections were first used to compute the deflection basin area, which was then used to backcalculate an initial estimate of the radius of relative stiffness of the pavement system. A slab size correction factor for the estimated radius of relative stiffness was computed, and the effective slab length was computed based on the actual slab dimensions and the transverse joint load transfer efficiency. After computation of slab size correction factors, the adjusted radius of relative stiffness and the dynamic interior foundation k-value were computed.

As with the edge deflections, an incremental analysis was also conducted to provide a means of differentiating slab curling from poor foundation support. For those cases where the slab temperature gradient (top temperature – bottom temperature) is excessively positive and foundation support stiffness is high, the center of the slab may be lifted off the foundation. In these cases, the maximum deflection and the deflection basin area term increase, resulting in a reduced backcalculated foundation k-value. If, however, at least two of the load levels used during testing were sufficient to create maximum surface deflections exceeding the depth of curling-induced voids, incremental analysis should indicate an increased dynamic foundation k-value and a decreased effective slab thickness as compared to values backcalculated from individual load/deflection pairs.

3. *Analysis of longitudinal joint deflections:* The longitudinal joint deflections were used to determine the normalized total edge deflection, dynamic edge foundation support, and longitudinal edge slab support ratios. For slabs with asphalt concrete or gravel shoulders, the total edge deflection is equal to the maximum deflection recorded at the longitudinal edge. For slabs with portland cement concrete (PCC) shoulders (tied or untied), the normalized total longitudinal edge deflection is computed as the simple addition of unloaded and loaded slab deflections, normalized to a 40-kN (9,000-lbf) load level.

Incremental analysis of longitudinal edge deflection response was conducted to provide a means of differentiating slab curling from poor foundation support. The incremental normalized total longitudinal edge deflections were used to compute incremental longitudinal edge slab support. In those cases where temperature curling alone was responsible for poor support, incremental slab support should increase over that computed based on individual load levels, provided at least two load levels produced sufficient total longitudinal edge deflection to close any curl-induced voids. The uniformity of support under the longitudinal edge, termed the longitudinal edge slab support ratio, is computed as the ratio of backcalculated incremental longitudinal edge and interior dynamic foundation k-values. In general, incremental longitudinal edge slab support ratios less than approximately 0.75 are indicative of slabs with poor longitudinal edge support due to foundation densification/pumping and/or temperature curling.

4. *Analysis of corner deflections:* The corner deflections were used to determine the normalized total corner deflection, dynamic corner foundation support, and corner slab support ratios. For slabs with asphalt concrete or gravel shoulders, the total corner deflection is equal to the maximum deflection recorded on the loaded slab corner plus the deflection recorded on the unloaded slab corner. For slabs with PCC shoulders (tied or untied), the normalized total corner deflection is computed as the addition of unloaded and loaded corner slab deflections, normalized to a 40-kN (9,000-lbf) load level, modified by the longitudinal joint load transfer.

Incremental analysis of corner deflection response was conducted to provide a means of differentiating slab curling from poor foundation support. In those cases where temperature curling alone was responsible for poor support, incremental slab support should increase over that computed based on individual load levels, provided at least two load levels produced sufficient total longitudinal edge deflection to close any curl-induced voids. The uniformity of support under the slab corner, termed the corner slab support ratio, is computed as the ratio of backcalculated incremental corner and interior dynamic foundation k-values (Crovetti 1994). In general, incremental corner slab support ratios less than approximately 0.75 indicate slabs with poor corner support due to foundation densification/pumping and/or temperature curling

(Crovetti 1994).

A review of the computed slab support ratios provides the following observations:

- 26 of 89 sections have poor longitudinal edge slab support. Of these 26 sections, 9 are unsealed, 4 contain hot-poured sealant, 9 contain silicone sealant, and 4 contain preformed sealant.
- 36 of 89 sections have poor corner approach slab support. Of these 36 sections, 10 are unsealed, 6 contain hot-poured sealant, 16 contain silicone sealant, and 4 contain preformed sealant.
- 33 of 89 sections have poor corner leave slab support. Of these 33 sections, 9 are unsealed, 6 contain hot-poured sealant, 14 contain silicone sealant, and 4 contain preformed sealant.
- 15 of 89 sections have poor transverse edge slab support. Of these 15 sections, 4 are unsealed, 1 contains hot-poured sealant, 6 contain silicone sealant, and 4 contain preformed sealant.

The slab support ratios along the transverse joints are believed to be useful in identifying conditions of the slab support that might be attributable to differences in joint features such as presence or absence of sealant or type of sealant. In general, poor slab support is no more or less common in the unsealed sections than in the sealed sections.

SUMMARY OF FINDINGS

A summary of the most significant findings from this study is included below. When evaluating the findings, the age of the test sections studied should be considered. As indicated previously, most of the test sections studied were 10 years or less in age at the time of data collection.

- In general, for the field test sites examined in this study, the presence or absence of dowels in the transverse joints was far more important a factor in joint faulting than whether the joints were sealed or unsealed. Similarly, if the joints were sealed, the type of sealant was a controlling factor.
- Among the few paired test sections in the study with sealed and unsealed undowelled joints, the faulting in the sealed-joint section was slightly higher than the faulting in the unsealed section at one site and slightly lower than in the unsealed section at another site.
- Among the dowelled pavements that made up most of the sections in this study, joint faulting tended to remain very low (less than 1 mm [0.04 in.]) at nearly all sites, for 10 to 20 years or more.
- Statistical analysis of the data detected no significant difference between average joint faulting in the sections sealed with any of the three types of sealants studied (silicone, hot pour, and preformed) and the average joint faulting in the corresponding unsealed test sections.
- Joints with hot-pour sealant tended to have the highest incidence of joint sealant distress (adhesive failure, cohesive failure, and/or sealant absence), followed by joints with silicone sealant, and followed by joints with preformed sealant. These differences in sealant performance did not, however, correspond directly to differences in faulting, infiltration of incompressibles, or joint spalling.
- Unsealed joints were infiltrated by fine aggregate to a considerably greater degree than any of the sealed joints with any of the three types of sealants studied (silicone, hot pour, and preformed).
- The narrow width of unsealed joints (usually single sawcut) limited the infiltration of coarse incompressibles to a degree comparable to that of any of the three types of sealed joints.
- Statistical analysis of low-severity spalling showed it to be significantly greater in the unsealed-joint sections than in the sealed-joint test sections for all three sealant types studied. Medium- and high-severity spalling, on the other hand, was higher at a statistically significant level) in the sealed-joint sections with preformed sealants than in the unsealed-joint sections.
- Among the parameters calculated from the analysis of deflections measured on the JCPs for this study, the transverse edge slab support

ratio (backcalculated incremental edge k-value in proportion to the backcalculated incremental interior foundation k-value of the same test slab) emerged as the deflection parameter most useful in identifying differences in joint deflection response that might be attributable to differences in joint features such as presence or absence of sealant or type of sealant. In general, incremental transverse edge slab support ratios less than approximately 0.75 (i.e., incremental edge k-value less than 75 percent of incremental interior k-value) is considered indicative of slabs with poor edge support due to foundation densification, pumping, and/or temperature curling.

- Unsatisfactory transverse edge slab support was, in general, no more or less common in the unsealed-joint pavement sections tested than in the silicone-sealed, preformed-sealed, or hot-pour–sealed sections tested.
- Slab curling due to a temperature gradient is likely to produce low slab support, regardless of sealing treatment, as evidenced by reductions in slab support for sections with all of treatments when the same slabs were tested at a lower temperature.
- Even at sites where slab curling did not appear to be an issue, slab edge support tended to be either adequate or inadequate regardless of joint sealing treatment, which suggests that the joint sealing treatment has a fairly minor influence, if any, on the quality of slab support.

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