Seal/No Seal GROUP

Tech Brief

Field Evaluation of Joint Sealant Performance

Reasons for Using Joint Sealants in Concrete Pavements

One of the best explanations for the reasons behind sealing joints is stated as follows: "Transverse joint sealing is widely believed to be beneficial to concrete pavement performance in two ways. First, sealed joints are believed to reduce water infiltration into the pavement structure, thereby retarding the occurrence of moisture-related distresses such as pumping, faulting, corner breaking, and freeze-thaw damage (D cracking). Second, sealed joints are believed to reduce or prevent the infiltration of incompressibles (i.e., sand and small stones) into the joints, thereby reducing the likelihood of pressure-related joint distresses such as spalling and blowups and preventing pressure-related damage to nearby fixed structures."[1]

Historical Background on Joint Sealant Evaluations

Perhaps the first observed recommendation for maintaining joint sealing occurred from a study evaluating pavements constructed between 1906 and 1912 in Michigan and Canada.[1] The researchers recommended that cracks be regularly maintained to keep the streets in good condition.[1] However, the method and extent of evaluation is not known.

An excerpt from a 1953 report defines the state-of-the-practice at that time as follows: "the problem of preventing the infiltration of water, silt, sand, and other earthy materials into the joints and cracks in concrete pavements is one that has been exceedingly troublesome to highway engineers ever since the concrete pavements first came into existence more than 40 yr. ago. Despite determined and prolonged efforts on the part of engineers, chemists, technicians, and the producers of filling and sealing materials, the problem remains to a large extent unsolved. Substantial progress has been made, but the final answer is not yet at hand."[2] Unfortunately, sixty-eight years later (2021), this same statement may very well still apply and its now 130 years since the construction of the first concrete pavement (1891).

The 1982 Synthesis of Highway Practice on Resealing Joints and Cracks in Rigid and Flexible Pavements indicated that several agencies had developed joint sealant evaluation procedures[3]. The report recommended a training manual, prepared by Texas A & M

University in 1979, for establishing priorities for street maintenance. This manual was subsequently published and promoted by the FHWA. The manual used three levels of distress severity: low, medium, and high for assessing sealant condition. This no doubt followed the same approach used by the recently developed (1976-77) Pavement Condition Index (PCI)[4]. During this same period, the Moisture Accelerated Damage (MAD) program was also developed and promoted by the FHWA. This program also used the low, medium, and high severity criteria approach. In subsequent sections of this Tech Brief, it will become evident how the PCI three distress level concept was also used to produce sealant evaluation procedures in the 1970s and 80s that are still in use today.

A second form of joint sealant evaluation also emerged at this time that determined the percent of sealant failure that had failed within a joint. One of the earliest reports of this technique was for sealing cracks in flexible pavements in 1985.[5] In this study, sealant failure was defined as any visible crack that would allow water to penetrate into the sealant itself or the interface between the sealant and the flexible pavement. Sealant performance was recorded as the percentage of visible failure in the sealed cracks. Performance ratings were subsequently developed based on the subjective evaluation of an advisory panel for the different failure levels. It appears that this initial approach used only visual distress observation and recommended conducting the surveys in cold weather so that the sealant distress was more evident. This form of rating would later be referenced, adopted, and modified by other researchers for concrete pavements, and is the second most common evaluation technique after the three-level severity criteria developed by the PCI approach.

The 1985 field performance rating scale indicated in Table 1 was subsequently used on a LTPP Pavement Maintenance Materials study published in 1999.[6] The only change was that the data was presented as effectiveness level (i.e., 100 – failure level) instead of failure level.

TABLE 1[5]

FIELD PERFORMANCE RATINGS

RATING	FAILURE LEVEL
VERY GOOD	0 - 10%
GOOD	10 - 20%
FAIR	20 - 35%
POOR	35 - 50%
VERY POOR	50 - 100%

Sealant Evaluation Techniques

Sealant condition evaluation is generally based on determining two things: (1) the presence of incompressibles in the joint, and (2) the ability to prevent water infiltration into the pavement structure. Water infiltration is typically assessed by observing missing sealant and adhesive and cohesive sealant failures.

For research purposes, other properties are often determined such as structural evaluation through deflection testing and ride quality, but these are not discussed in this tech brief. However, structural evaluation and ride quality are necessary to determine the impact of sealant performance on pavement performance. As discussed later, pavement growth is another important attribute which is almost never evaluated and can impact pavement performance.

Qualitative Visual Evaluation and Assessment: This form of evaluation is similar to that previously discussed for the 1985 Utah study (Table 1). The condition of the sealant is only visually assessed for the three distresses previously mentioned. It is qualitative in nature and could be conducted from the shoulder of the roadway. Ratings are then typically assigned as indicated in Table 1, albeit each agency could have its own rating system based on their own experience.

Quantitative Assessment of the Percent Failure or Sealant Effectiveness: This technique also evaluates the three distresses previously mentioned but evaluates quantitatively the length of each distress and converts it to the percent of the joint that is deficient. This provides a quantitative result for each joint which can then be statistically evaluated over the entire section. A research quality use of this technique will evaluate the joint condition one foot at a time across the entire joint. This technique is typically applied only to transverse joints.

LTPP Joint Sealant Damage Evaluation[7]: According to LTPP, joint seal damage is any condition that enables incompressible materials or a significant amount of water to infiltrate the joint from the surface. LTPP uses the following three severity levels for transverse joints and **no** severity levels for longitudinal joints:

> **Low Severity**: Damage exists in less than 10% of the joint.
>
> **Medium Severity**: Damage exists in 10 to 50% of the joint.
>
> **High Severity**: Damage exists in more than 50% of the joint.
>
> **Measurement**:
> **Transverse Joints**: LTPP indicates to record the number of sealed transverse joints at each severity level. Any joint seal with no apparent damage is low severity.
>
> **Longitudinal joints**: The number of sealed longitudinal joints are recorded. In addition, the length of damaged sealant is also recorded. It should be noted that any damage that is less than 3 ft is not recorded as damaged.

ASTM Pavement Condition Index (PCI)[8]: PCI is a rating system used to assess the overall pavement condition and provides a score between 0 and 100 with 100 being the best condition[8]. Determining PCI involves several steps: (1) a pavement survey is conducted which identifies the type of distresses present and the severity and extent of each distress. The severity of each distress is given a rating of low, medium, or high. The extent of distress is generally the area of the pavement incurring the distress; (2) a deduct chart is then then used to convert the severity and extent of each distress into a "deduct" value which represents the impact on the overall pavement condition. For joint sealants, instead of a deduct graph, ASTM D6433-18 assigns a standard deduct value for each severity level; Low = 2, Medium = 4, High = 8[8]. A deduct value of 0 indicates a distress has no effect on either pavement structural integrity or surface operational condition, whereas a value of 100 indicates an extremely serious effect. The deduct values are summed and the total subtracted from 100 to provide a pavement condition rating (PCI). ASTM defines the three levels of sealant damage with both photo examples and narrative as described below[8]. Unlike other PCI distresses which are based on the condition of individual PCCP slabs, the ASTM procedure for joint seal damage is an assessment of the overall condition of the pavement over its entire area.

> **Low Severity:** "if a few of the joints have sealer, which has debonded from, but is still in contact with, the joint edge. This condition exists if a knife blade can be inserted between sealer and joint face without resistance."[8]
>
> **Medium Severity:** "Joint seal damage is at medium severity if a few of the joints have

any of the following conditions: joint sealer is in place, but water access is possible through visible openings no more than 3 mm (1⁄8 in.) wide. If a knife blade cannot be inserted easily between sealer and joint face, this condition does not exist; pumping debris are evident at the joint; joint sealer is oxidized and “lifeless” but pliable (like a rope), and generally fills the joint opening.”[8]

High Severity: “Joint seal damage is at high severity if 10 % or more of the joint sealer exceeds limiting criteria listed above or if 10 % or more of sealer is missing.”[8]

SHRP Sealant Condition Number (SCN): The first reporting of the SCN number appears to be from the SHRP 349 program under the H106 project on Materials and Procedures for the Repair of Joint Seals in Concrete Pavements[9]. In this study it was reported that common practice at the time (1993) for some agencies was to replace sealants when a specified amount of sealant had failed (25% to 50%). As part of the research, the project developed a recommendation for assessing joint sealant condition and guidelines for determining when to reseal. Appendix 1 contains the Table identifying the process for sealant replacement. This Tech Brief only discusses the sealant evaluation process. An abbreviated description of the sealant evaluation consists of: (1) collecting project related data such as thickness, specifications, joint spacing, etc., (2) exhuming one or more samples to determine shape factor, etc., and (3) conducting a careful evaluation of 10 joints representative of the pavement under consideration. The joint evaluation procedure considers water resistance and stone intrusion as described below:

Water Resistance: “The percentage of overall joint length where water can bypass the sealant and enter the joint”.[9] The percent of joint allowing water to enter the joint is then computed as follows: percent allowing = (total length of joint allowing entrance/total length of joints evaluated) X 100

Stone Intrusion: “The amount of stones, sand, and debris embedded in the sealant”.[9] Stone intrusion is evaluated by three levels of severity as shown below:

Low Severity: “Occasional stones or sand stuck to the top of the sealant (or material embedded on the surface of the sealant/channel interface).”[9]

Medium Severity: “Sand or debris stuck to sealant and some debris deeply embedded in the sealant and some debris stuck to and deeply embedded in the sealant or filling the joint.”[9]

High Severity: “Much sand and debris stuck to and deeply embedded in the sealant or filling the joint.”[9]

Upon completion of the joint evaluation as described above, the Seal Condition Number (SCN) is computed as follows: SCN = 1(L) + 2(M) + 3(H) where[9]:

L = The number of low severity seal conditions recorded on the pavement survey form.
M = The number of medium severity seal conditions.
H = The number of high severity seal conditions.

To better appreciate the basis for the SCN equation, Table 2 indicates the Low, Medium, and High Criteria for the evaluation on the left and the SCN Sealant Number shown on the right. It should be noted that the matrix indicated on the left represents the average for the section so there can only be one rating for the water entering and only one rating for the stone intrusion (i.e., the average of the section for each distress). This limits the range of SCN values to between 2 & 6. Note that this is not consistent with the SCN ratings indicated on the right of Table 2.

TABLE 2 SCN Rating System[9]

	Low	Med	High
Water entering, % length	< 10	10-30	> 30
Stone intrusion	Low	Med	High
Sealant Rating	**Good**	**Fair**	**Poor**

Sealant Condition Rating

Sealant Rating	SCN
Good	0 to 1
Fair	2 to 3
Poor	4 to 6

Sealant Condition Number

Weighted Seal Damage (WSD)[1]: The weighted sealant damage equation is indicated in Figure 1. The coefficients used in the equation were selected based on combining the PCI deduct values with the LTPP low, medium, and high distress level ratings. The joint sealant ratings were developed using the LTPP Distress Manual criteria for low, medium, and high. The PCI deduct values associated with low, medium, and high severity are 2, 4 & 8. Note that the equation below has divided the PCI deduct values by two to simplify the equation (i.e., 1,2,4). As indicated, this results in a WSD ranging between one and four, with one the best and four representing the worst condition.

$$WSD = 1\left(\frac{NLSD}{TJ}\right) + 2\left(\frac{NMSD}{TJ}\right) + 4\left(\frac{NHSD}{TJ}\right)$$

where WSD = Weighted sealant damage (1 to 4)
NLSD = Number of joints rated with low-severity sealant damage
NMSD = Number of joints rated with medium-severity sealant damage
NHSD = Number of joints rated with high-severity sealant damage
TJ = Total number of joints rated

Figure 1 Weighted Sealant Damage (WSD) Equations[1]

National Transportation Product Evaluation Program (NTPEP): The NTPEP joint sealant evaluation process is based on the SHRP SCN described previously[10]. Again, the SCN is based on the evaluation of water infiltration and debris retention. As with the SHRP work, other features are also evaluated such as spalling and joint movement but are not discussed herein. The SCN is the same equation as the SHRP program: SCN = 1(L) + 2(M) + 3(H). However, NTPEP changed the number of distress levels as indicated below (i.e., 3 to 4): Note that %L= the percent length of joint allowing water infiltration.

Water Resistance:

- **No Water Infiltration:** 0 < %L < 1%
- **Low Severity**: 1 < %L < 10
- **Medium Severity**: 10 < %L < 30
- **High Severity**: %L > 30

Stone Retention:

- **No Retention**: "No stones or debris stuck on top of the sealant or embedded on the surface of the sealant/PCC interface."[10]
- **Low Severity**: "Occasional stones and/or debris are stuck to the top of the sealant, or debris embedded on the surface of the sealant/PCC interface."[10]
- **Medium Severity**: "Stones are stuck to the sealant and some debris is deeply embedded in the sealant or material embedded between the sealant and joint fact but not entering the joint below the joint."[10]
- **High Severity**: "A large amount of stones and debris are stuck to and deeply embedded in the sealant or filling the joint, or a considerable amount of debris is embedded between the sealant and the joint face and entering the joint below the sealant."[10] With the four distress levels instead of three as in the SHRP SCN, it is now possible for the SCN to range from 0 to 6. NTPEP does not categorize the SCN numbers beyond acknowledging that 0 is the worst and 6 is the best condition.

Performance Index (Virginia method): Although this research only applied to asphalt crack sealing, the authors developed another evaluation system[11]. The Performance Index (PI) is shown below:

PI = 100 – (AC + PAC X 0.5) where AC = is the percentage of joint with full adhesive and cohesive failures and PAC = is the percentage of joint with partial adhesive and cohesive failures.

Direct Measurement of Sealed Condition (IA-VAC): The Iowa DOT developed a direct means for measuring the efficacy of a joint sealant[12]. The device, called the Iowa Vac Test, allowed for the first time, the ability to directly measure the "seal" of a joint. A foaming shampoo-water solution was sprayed onto the joint and surrounding pavement. Then the test device (a box 6 inches wide by 4 ft long) was placed over the section of joint to be tested and a vacuum applied to the box (max of 2.5 psi). The top of the box was clear so that as the vacuum was applied, any "leaks" in the sealant would produce bubbles in the foam and could be seen through the top. The larger the leak, the larger the bubbles. This allowed both the location of the damage and a qualitative measure of its severity. The device could non-destructively test the joint seal effectiveness in a consistent manner any time of the year up until failure rates became moderate or greater. It could also evaluate newly installed sealants. The use of this device does not appear to have gone beyond the use on a few test projects. The reasons for its use not gaining more popularity are not known to the author.

Direct Measurement of Water Infiltration Volume (Falling Head Permeameter)[13]: Dr. Zollinger has developed a technique for assessing sealant effectiveness through direct measurement of water infiltration using falling head permeators. This technique allows development of actual flow rates through the sealant that can then be used to directly estimate the impact of sealant condition on pavement performance. This aspect will be discussed in a subsequent section. To conduct the testing, three falling head permeators are used to test three locations along a joint. The infiltration results are then computed based on these three devices. As with the Iowa-VAC test, this test can be used at the time of construction, and periodically tested to determine sealant effectiveness over time in terms of water infiltration. This is a direct measurement test for water infiltration and does not rely on subjective evaluations or other surrogate measures for water infiltration.

Sealant Condition Linked to Pavement Performance:

Sealant Condition Number: The origin of the SHRP SCN number is not known to the author, so it may have connections to pavement performance like the WSD number (i.e., PCI). But for both the SCN and WSD, any true relationship to pavement performance would seem tenuous at best. Both use composite statistics with seemingly subjective scales with no fundamental measure of the infiltration attribute or direct linkage to pavement performance such as ride quality or structural capacity.

Zollinger Model: "Subbase erosion is key to understanding the process of joint faulting which can involve several factors one being the effectiveness of the joint seal. Traffic, existence of water along the subbase/slab interface, and erodibility of the base material are major factors."[13] An important parameter considered when describing the number of days per year that water exists underneath a slab/subbase interface is the number of wet days. There are currently several definitions for wet days[13]: (1) LTPP data base considers wet days as the number of days for which precipitation was greater than 0.25mm within a year; (2) PMED defines the number of wet days as the number of days with rainfall greater than 2.5mm.

Although the number of wet days should be proportionate to the amount of rainfall, this number should not necessarily be just a fraction of the annual precipitation. The Zollinger model considers the number of wet days as a function of four factors: (1) Amount of annual precipitation, existence of proper sealants, base material permeability, and existence of other types of subsurface drainage.[13] If this model proves successful, it may for the first time, relate sealant effectiveness to pavement performance.

PMED Model: As described in the Zollinger model discussion, the number of wet days is also considered in the PMED. Although the PMED models are well document, the only impact of sealant on pavement performance is assigned to compression seals.[14] Unsealed, hot pour sealant, and silicone sealants, are all considered to not provide the benefit in pavement performance attributed to compression seals. The data supporting this aspect of the model is not known to the author.

What Often is not Evaluated in Sealant Condition Assessments

Diurnal and Seasonal Joint Opening Movement: Diurnal joint opening movement is rarely evaluated at either a research level or a network level. Even though DOW developed a simple scratch test device which could easily be installed and left in place to record joint opening movement, it seems to rarely be used. Some research projects install PKs (as does NTPEP) but most measurements are only taken at the periodic measurement intervals and may or may not give a good picture of the movement activity.

Noise Assessment: Since pavement noise did not become a major quality of life issue until the 21st century, almost no historical joint sealant research assessed the impact of joints on overall pavement noise generation. The ACPA has a simple web app which can provide estimates of this impact in just a few minutes and future evaluations should consider this.

Linkage Between Sealant Condition and Pavement Performance: After 130 years of constructing concrete pavements, this question is still highly debated. The statements made in the 1953 report discussed in the beginning of this document are still true today. All future sealant research efforts should be designed to answer this question. It should be remembered however, that using the same or similar joint evaluation techniques that were used over the last 30 to 50 years has not allowed resolution of the argument and probably never will. More scientific approaches need to be used.

Pavement Growth: One of the more difficult items to measure, and rarely attempted, is pavement growth. There are at least two reasons for this. First a reasonably long length of pavement is necessary to be able to reliably measure the pavement growth, and second is the fact it may take 15 to 30 years to become a problem. Most sealant studies are short term in nature typically 3 to 5 years and only use a limited number of joints. 500 ft is a long joint sealant test section and detection of pavement growth in these distances is not simple. The development of blowups and abutment stresses needs to investigate in the modern era as they still occur, and short jointed pavements alone did not solve the problem.

Water Infiltration Rates and or Quantities: Almost all historical joint sealant evaluations used surrogate measures for water infiltration and visible debris ratings for incompressibles. Neither directly measure the attribute properly. That is, the amount of water that will impact the pavement structure needs to be known and predictable so that more reliable measures can be made to determine when the sealant has been defeated.

Sealant Deterioration Rates: With proper measurement systems in place, it may someday be possible to track sealant deterioration rates to determine when replacement is necessary or if sealant is even needed. Even with the current measurement techniques, the composite statistics (i.e., SCN, etc.), should be abandoned and the percent efficient results tracked over time to provide more meaningful comparisons of sealant performance and survival.

Impact of Shoulder Joint [15,16]: Two previous studies described the importance of the longitudinal shoulder joint with findings indicating that 80 to 90% of the surface water enters through this one location. Yet pavement evaluation efforts expend most of the effort evaluating transverse joints. There is a need to include the longitudinal shoulder joints in all evaluations and to treat the pavement structure as a system and not individual components.

The Next Generation of Sealant Evaluation Procedures

Since the cost of installing sealed joints in concrete pavements represents five to ten percent of its initial cost, it's imperative that the effectiveness of joint sealing be established beyond a reasonable doubt. After 130 years of concrete pavement construction, this question has not been resolved. Similarly, the evaluation techniques used today evolved in the 1970s or before and have not resolved the question.

The population of the US has increased approximately 50% since 1980 making in-service field evaluations more and more difficult and impractical from a safety standpoint. During this same period, non-destructive test technology has made significant advances and needs to be considered for resolving the sealant performance question.

Instead of assessing adhesive and cohesive failure lengths as surrogates for water infiltration, could it be possible to detect the moisture in the joint (and hopefully beneath the pavement at the joint) at highway or lower speeds? If possible, this could be tracked over time to develop indications of joint seal effectiveness. Could the presence of incompressibles beneath the joint in the reservoir or between the two pavement slabs below the joint be detected indestructibly instead of visually assessing stone intrusion on the top of the sealant. Do incompressibles enter from the bottom as well, or are most of them installed during the construction process and sealed over?

Is it possible to monitor and record joint opening widths and pavement growth over time reliably and at speed? Can the "slit" technology[17] used in bridge monitoring, or some other technology, be used to evaluate compressive stress build up in pavement slabs and monitored over time?

Should joint activation at the time of construction be recorded to detect early joint activation and their subsequent movement.

Historically, it is typically assumed all joint movement is similar, yet on some projects every third to fifth joint may opening significantly more.

Should curl and warp be monitored from early life to see if this impacts sealant performance?

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