Material Specifications for Longitudinal Joint Construction, Remediation and Maintenance

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16. Abstract

Asphalt pavement density at and near longitudinal construction joints is often significantly lower than the density in the mainline areas of the pavement, which can manifest in premature deterioration of the joint area relative to the mainline. The objective of this project is to synthesize the most probable solutions to deliver better longitudinal joints in Wisconsin. Based on detailed review of published literature and State Highway Agencies' current practice, methods and materials for quality management and improvement are divided into three categories: Construction and Design (CD), Materials and Methods During Construction (MDC), and Materials and Methods Post-Construction (MPC). This report includes various options available within each of these categories and the ranking for how much each method is used nationally. Using the collected information and input from various stake holders in Wisconsin and a few other states, the research team recommends that WisDOT continue their current standard practice regarding joint geometry and testing of joint density, but also consider evaluation of other alternatives that are showing significant promise in reducing risk of premature joint failures and minimizing the risk of accepting lower density at the joints relative to mainline of pavements. Implementation and evaluation of Void Reducing Asphalt Membrane during the construction process on a trial basis is recommended based on published data and review of case studies. Use of penetrating asphalt emulsions post construction is recommended as both a preventative and remedial treatment for longitudinal joints. It is recommended WisDOT continue to modify the provisional specifications for these materials based on experience with these materials in this region. Although the research was not able to produce life cycle cost estimates of the joint deterioration in Wisconsin or of the proposed treatments using Pavement Condition Index (PCI) data collected by WisDOT, a framework for utilization of the PCI data to accomplish this goal is presented for future consideration.

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Contents

Figures

Tables

Executive Summary

Pavement density of longitudinal construction joints in asphalt is often significantly lower than the density in the mainline areas of the pavement, which can manifest in premature deterioration near the joint location relative to the mainline. The hypothesized mechanism of joint deterioration is defined as follows: "Premature longitudinal joint distress is caused by damage resulting from intrusion of water and air into the asphalt mixture at and near the joint." The objective of this project is to synthesize the most probable solutions to deliver better longitudinal joints in Wisconsin. Methods and materials for improvement are divided into three categories: Construction and Design (CD), Materials and Methods During Construction (MDC), and Materials and Methods Post-Construction (MPC).

Information and data extracted from a literature review, review of State Agency standard practice, review of WisDOT pavement distress survey data, and interviews with a number of pavement experts is used to define the most probable solutions to improve joint performance based on the understanding of the cause of distress. Findings of this study indicate that reducing mixture permeability at and near the joint is the most promising method to improve joint performance. Reducing permeability can be achieved in various ways using both construction-related factors and supplemental materials.

The research team recommends that WisDOT continue their current standard practice regarding joint geometry and construction practice as well as testing of joint density. Although there is not consensus in the literature regarding a joint geometry or construction process that categorically results in the highest quality joint across all pavement types and design scenarios, review of recent WisDOT joint density data supports continuation of current standard practice. Density measurement (either by nuclear/electronic gage or cores) is the most practical method to measure joint quality available today, although calibration of gage readings to actual joint density is critical; there is an opportunity for a laboratory study to justify the 3.0% air void increase currently allowed in the SPV for the unconfined joint density.

Implementation and evaluation of Void Reducing Asphalt Membrane during the construction process on a trial basis is recommended and is relatively low risk based on published data and review of case studies. Although a specification and construction provision exists (Appendix A) that should allow rapid implementation on a trial basis, the material properties that control performance in Wisconsin are unknown. It is recommended the joint density provision (with associated incentives and disincentives) be waived on projects utilizing VRAM or the Contractor being given the option of either testing joint density as a pay factor or utilizing VRAM. Careful tracking of joint (and mainline) performance of these projects is critical to understanding the cost-benefit of using this treatment.

Use of penetrating asphalt emulsions is recommended as both a preventative and remedial treatment for longitudinal joints post-construction. It is recommended WisDOT continue to modify the provided provisional specification (Appendix B) based on experience with these materials in this region.

Although the Pavement Condition Index (PCI) data supplied by WisDOT could not be reliably used to conduct cost-benefit analyses for the recommended treatments because the data collection method is not designed to capture and isolate longitudinal joint distress, the database is an invaluable tool to understand costs associated with joint performance. Refinement of this database of a project-specific basis and perhaps more accurate longitudinal joint distress collection will help justify the use of more costly processes/materials for improving joint performance.

1. Introduction

1.1 Project Background

A longitudinal joint in asphalt pavement is created when two adjacent paving passes are placed at a time interval that allows the first pass to cool to ambient, or near-ambient, temperature before the second pass is placed and compacted alongside the first pass. Longitudinal joints are most often located between driving lanes and paved shoulders but can also occur at or near the centerline of driving lanes. Pavement density at and near the location of the joint is often significantly lower than the density in the mainline areas of the pavement, which can manifest in premature deterioration near the joint location relative to the mainline. The distress associated with longitudinal joints is not confined to a single mix type or geographical area: according to the Asphalt Institute (AI) and Federal Highway Administration (FHWA) cooperative report "Best Practices for Constructing and Specifying HMA Longitudinal Joints," as many as 50% of FHWA divisional pavement engineers reported being "unhappy with the performance of…longitudinal joints" in 2009 (1).

Many States have enhanced or created specifications specifically relating to joint performance over the last decade. Interestingly, industry experts interviewed during the AI/FHWA effort were not categorically in agreement with the "best-practices" to construct high quality longitudinal joints; the agency specifications review conducted during this study also revealed a wide range of joint construction practices and materials to improve joint performance. These findings suggest that (a) there may be multiple methods that can be similarly effective at producing a quality longitudinal joint, (b) there may be regional factors (mix designs, climate, etc.) that greatly influence the methods required to produce a quality joint, and (c) there may be disagreement as to the means to quantify "quality" as it pertains to longitudinal joints.

Mixture density is often used as a surrogate for quality because it can be measured relatively easily and because density has been correlated to permeability and performance of asphalt pavements (2). In fact, at the time of this report, at least 33 Agencies either routinely or as a special provision utilize longitudinal joint density specifications to control quality of joints; for many of these agencies joint density is a pay item eligible for incentive or penalty. By contrast, in 2011 this number is reported to be as low as 12 Agencies (3). The methods that individual Agencies use to measure density, however, are sometimes drastically different, sometimes even within a certain region.

In Wisconsin, WHRP Project 15-09 investigated the influence of construction practice, mix design type, and joint type on the density achieved at the location of the joint. Some of the findings of that report supported WisDOT practice at that time while other findings, such as recommended joint types, density targets and methodology to measure joint density evolved into later specification and practice – exemplified by the HMA Longitudinal Joint Density Special Provision for certain paving projects (4). Since the time of that report WisDOT has further modified their mixture design and production specification, harmonized joint construction technique among regions, refined the longitudinal joint density specification, as well as built a much more robust data set of paving jobs on which longitudinal joint density was a pay item for contractors.

The increased attention paid to longitudinal joint construction has also provided opportunity for development or refinement of innovative materials and practices designed to aid in achieving higher joint quality. These materials and methods may add varying costs and complexity to the paving project, but in theory reduce the life cycle cost of the pavement by delaying maintenance and potentially extending service life. Other materials and methods have similarly been developed to address longitudinal joint density/quality following construction; these materials are typically sprayed or applied to the constructed joint a short period after construction to minimize traffic disruption. The challenge for agencies wishing to supplement their current practice with these materials and practices is understanding which materials/processes best fit their unique needs and abilities as an Agency, appropriately specifying the material/process, and determining how to best address acceptance in the field in order to minimize risk.

1.2 Project Objectives

The objective of this research is to synthesize the most probable solutions to deliver better longitudinal joints in Wisconsin by:

- Identifying and comparing materials, processes, and experiences available to improve longitudinal joint performance both during and after construction;
- Recommending best-practices for using selected materials and processes relative to Wisconsin standard practice; and
- Summarizing quality assurance requirements for each selected alternative.

Successful completion of the stated objectives gives WisDOT engineers more information and tools to confidently implement new best practices for longitudinal joint design and construction.

1.3 Report Structure and Deliverables

This report is divided into the five sections following summarized below:

- *Section 1: Introduction and Project Objectives*

- *Section 2: Identification of Processes and Materials to Improve Longitudinal Joints* – This section includes a synthesis of published technical literature as well as information extracted from industry experts. Also included is a summary of U.S. and International agency specifications to identify trends and other improvement methods widely used in practice. A listing of joint improvement methods identified during this review phase is given.

- *Section 3: Review of WisDOT Joint Density and Pavement Condition Index Data* – This section presents the findings of a review of WisDOT longitudinal joint density and Pavement Condition Index (PCI) data with the goal of identifying trends that may indicate areas for potential improvement in the context of this project. PCI data is used to estimate the average time for onset of longitudinal joint distress and progression of distress from low severity to higher severity levels.

- *Section 4: Proposed Joint Improvement Methods & Materials* – This section presents the proposed table of joint improvement methods and materials presented by the research team and agreed upon by the project oversight committee. Specific details for each selected method are presented in this section.

- *Section 5: Summary and Recommendations* – This section presents a final summary of findings and recommendations from this study and offers opportunities for continued improvement of practice.

- *Section 6: Appendices* - This section includes the construction guidance/provisions for the two material-based improvement methods described in this study. The State Standard Specification database is also included.

2. Identification of Processes and Materials to Improve Longitudinal Joints

2.1 Common Longitudinal Joint Types and Terminology

Many literature sources and Agency specifications use different terms to describe the various types of longitudinal joints commonly encountered. For the purposes of this report, the following table offers a generalized joint geometry summary. Unless specifically stated, use of these terms for joint type in this report is intended to be interpreted in the general or WisDOT specification context.

Table 1. Description of Joint Types Identified in Literature

Joint Type	Description
Hot Joint (Produced when Paving Full-Width, in Echelon, or in Tandem)	Two or more pavers are staggered or offset longitudinally with the screed adjustment of the trailing paver set to match grade and layer thickness of the unrolled mat from the first paver; both mats are at approximately the same temperature with joined and compacted producing a uniform appearance with no apparent joint. The temporary joint resulting from the first paver is most typically a vertical edge or butt type joint.
"Butt" Joint or "Vertical" Joint	Mat at the edge of the paver width is allowed to form an unconfined, semi-vertical edge under gravity, usually ~60° angle of repose depending on the mixture; angle of repose of the unconfined edge is dependent on mix type/characteristics, thickness, temperature, and paver settings/attachments.
Tapered Joint, incl. Notched-Wedge (A.K.A. "Michigan Joint"), and Full Taper	A taper from the surface of the uncompacted mat to the substrate is created with a paver attachment, with or without the use of vertical notches, to provide a smoother transition from the surface of the paved layer to the substrate. In the case of Notched Wedge Joints, a vertical notch of approximately ½"-3/4" is created from the mat surface to a taper sloped at approximately 3:1 to 12:1 to a second vertical notch of the same proportion as the first down to the substrate. Geometries vary widely among sources.
Milled or Cut-Back Vertical Joint	A pre-defined area of the hot (when cutting back) or finished (when milling) mat is removed prior to paving the second lane, creating a vertical or near vertical edge against which the second pass is placed and compacted against. In at least some sources, particularly internationally, a cut back joint is secondarily milled to create a textured surface to improve surface interlock between passes.

2.2 Cause of Premature Longitudinal Joint Distress

Various causal mechanisms of premature longitudinal joint failure have been identified, ranging from inability to achieve sufficient density at the joint location, infiltration, and subsequent damage from water at the joint, mixture segregation, aggregate bridging, and others (5-13). Assuming good paving practice, the following general hypothesis can be stated: "Premature longitudinal joint distress is caused by damage resulting from intrusion of water and air into the asphalt mixture at and near the joint." Intrusion potential can be quantified by permeability (also called hydraulic conductivity) of the mixture at and near the joint.

Mixture density is the most-often used as a surrogate for mixture permeability, and a well-established relationship between mixture air void content (an indicator of density) and permeability has been shown in the literature. NCHRP Report 531 concluded that in-place air void content is "the most significant factor impacting permeability of HMA mixtures" and an in-place air void content below about 7% is recommended to limit distress caused by higher permeability (2). A study conducted on Wisconsin mixtures similarly found a strong correlation between permeability and air void content, and further determined a significant difference between coarse or fine-graded mixtures exists, with coarse graded mixtures having a greater permeability response to changes in air void content (Figure 1) (14). This finding confirms mix design factors are also contributing to permeability within a given region (similar aggregate types, mix design process, etc.).

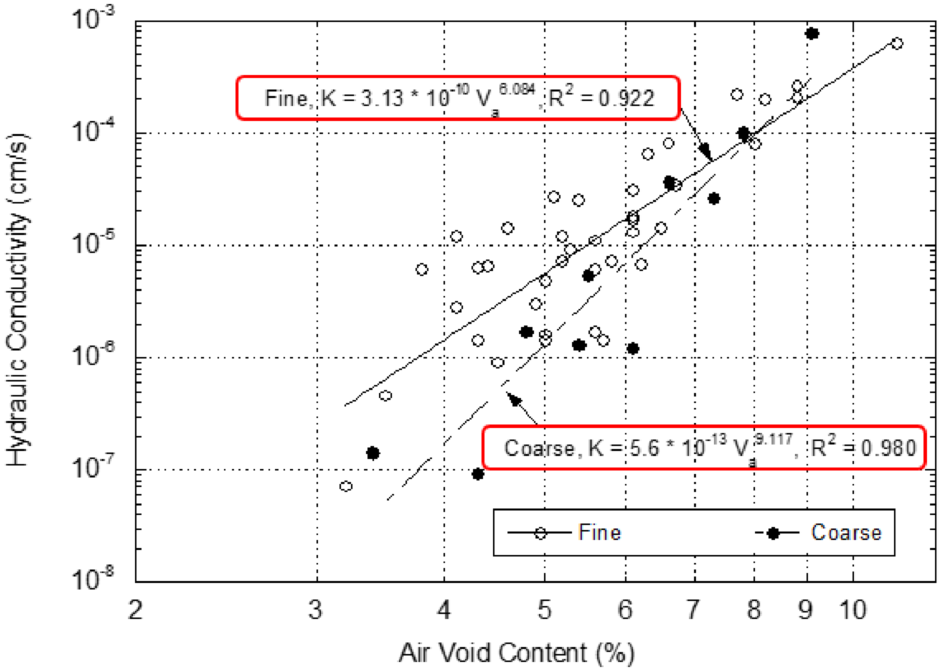


Figure 1. Relationship between air void content and permeability for mix designs from the same region (From (14)).

Generalized limits on permeability to control water infiltration for a uniform sample have been given in the literature, but these limits are intended for mainline consideration or the pavement where there are no joints and there is significantly more traffic loading than at the joint. In addition, since there are various methods to measure field permeability, and translation of lab-based methods to field applications is less extensively studied, the application of these limits to joint areas is questionable due to the discontinuity of adjacent layers paved at the joints and the difference in loading conditions leading to failures. In other words, minimum acceptable density limits or maximum acceptable permeability limits at the joint have not been conclusively determined. As such, many Agencies assign minimum joint density limits as a percentage of mainline minimums (example: Wisconsin DOT and Iowa DOT)

The relationship between mixture density and pavement performance has been reported in several studies. An often-cited relationship is that a 1% increase in air voids above about 7% total air voids can produce an approximate loss of 10% of pavement life (15). It is expected that there is density gradient between the mainline and joint area of a pavement, and one would expect differing (poorer) performance at the joint relative to the mainline by way of density alone. However, the limited traffic at the joint may alter this relationship between density and performance, but a tradeoff with water infiltration may also be present due to the discontinuity of the joint.

Permeability of a compacted mixture is controlled by both mixture density and mix design factors. It must therefore be assumed that there is variability among mix designs and relationship between air voids and permeability for different designs could be different.

2.3 Identification of Materials and Methods to Improve Joint Performance: Literature Synthesis

Published literature from approximately the last 20 years investigating materials and methods intended to improve joint performance was identified and summarized in Table 2. In addition to the literature review, the authors also consulted with industry experts to identify materials and methods. The consultation included interviews with contractors, material suppliers, DOT representatives, and State Paving Association representatives. The following is a synthesis of the findings:

Regarding Joint Quality Testing

- Pavement density is the most commonly cited measure of longitudinal joint quality in the literature. Agencies typically use either nuclear density gages (often correlated with pavement cores) or pavement cores to measure density.
- Higher joint density is correlated with better joint performance, which matches research and experience with mainline pavement performance.
- Permeability testing has been used primarily as a research tool for measuring joint quality; differences and uncertainty in methods to measure permeability, difficulty in measuring permeability at the actual joint, and test method variability are all cited as reasons why permeability is not more widely used by Agencies.
- For Agencies utilizing supplemental materials during construction (such as joint adhesive) method specifications are common. Typically these specifications outline the process by which a certain material or process is to be used and may specify a type of material directly by brand name (example: Crafco).

Regarding Joint Geometry, Rolling Operations, and Construction Practice

- There is not consensus in the literature regarding a joint geometry that categorically results in the highest quality joint:
    - Several studies note that the added safety advantages of tapered and notched wedge type geometries make them preferable.
    - Several studies mention notched-wedge type geometries as producing high quality joints relative to vertical butt joints and various milled or cut-back options;
    - Several studies have determined that the joint geometry producing the highest quality joint depends on design and mixture-related factors;
- There is not consensus in the literature regarding preferred rolling pattern or roller types required to achieve target density:
    - The rolling pattern that produces the highest quality joint does not appear to be the same across regions and mixture types and several rolling patterns may produce a joint similar in quality for a given project;
    - Several agencies directly specify a longitudinal joint rolling pattern and types of rollers to be used in a method specification.
- Several studies have demonstrated the efficacy of ancillary equipment or processes for producing high quality joints. Examples include joint re-heaters, cutting wheels, unique joint-making add-ons to pavers, and others. Notably, however, some studies have reported little to no increase in joint quality using these devices and have noted the added complexity of using such devices effectively (particularly for cutting wheel processes).
- There is general consensus in the literature that joint quality is substantially controlled by workmanship and contractor experience and that these factors are at least as important as joint geometry and rolling pattern.
- There is general consensus in the literature that ensuring good design (such as adequate NMAS/t ratio) and paving practice (such as measures to limit segregation, paver settings, etc.) are required to produce quality longitudinal joints.
    - As an example, one study (16) found joint quality (measured by density) statistically improved as a result of a “best-practices” type memorandum and field training program in Virginia focusing on communicating proper joint construction techniques to Contractor. It should be mentioned that the goal of this study was specifically *not* to introduce new standards, materials, or specifications. The improvement noted was on the same order as

those "obtained by using recommended superior joint construction techniques, such as use of a rubberized joint and use of the cutting wheel".

Regarding Materials to Improve Joint Performance

Several materials intended to improve joint performance were identified, and it appears materials can be divided into two categories including those to be used during construction, and those to be used following completion of the joint (topical treatments). These materials are summarized in Table 3.

- Several studies have found use of tack coat alone does not appear to categorically improve joint performance, although use of tack coat is unlikely to affect construction practice or joint performance negatively.
- Use of hot-applied joint adhesive is common, although findings from the literature regarding its effectiveness are mixed.
- There are several relatively new materials and application methods that show promise but do not have significant published literature yet, such as:
  - "Void Reducing Asphalt Membrane" (VRAM), also known as "Longitudinal Joint Sealant" (LJS). Often cited under the trade name "Jband".
  - "Rapid Penetrating Emulsion" (RPE)
- Several methods are intended to be routine maintenance or reparative treatments as opposed to preventative measures, such as crack sealing ("crack filling"), mastic treatments, micro-surfacing, and spray-patching. Although these maintenance procedures are important, they are not the focus of this project and are not widely elaborated on in this report.

Table 2. Synthesis of Select Published Studies on Joint Improvement Methods and Materials

Studies Investigating Relationship between Longitudinal Joint Geometry and/or Rolling Operation and Quality (ordered by year published)		
Citation	**Year**	**Summary of Findings**
P. S. Kandhal, T. L. Ramirez, P. M. Ingram. **Evaluation of Eight Longitudinal Joint Construction Techniques for Asphalt Pavements in Pennsylvania**, NCAT Report 02-03. National Center for Asphalt Technology, Auburn University, AL, 2002.	2002	▪ Coarse-graded 9.5 mm NMAS surface mixture used for all sections; hot-applied paving grade tack coat used on joint face on all but one section; ▪ Joint density measured with cores directly over joint and at location 12” from joint; 6-year field performance evaluation also conducted; ▪ Among techniques and materials, density was grouped by statistical significance: - Group A: Edge restraining device (average 7.7% air voids at joint) - Group AB: Cutting wheel (8.7% AV), Joint Maker (9.2% AV), and Rolling from Cold Side (9.3% AV) - Group B: Rolling from Hot Side (10.0% - 10.3% AV) - Group C: Rubberized Tack Coat (12.9% AV) - Group D: Full Taper with Infrared Heating (14.8% AV) ▪ Performance rankings changed over time, but higher joint density generally produced better performance; ▪ Authors recommend use of rubberized joint material or notched wedge joint to achieve consistent performance; ▪ Authors recommend joint density 2% lower than that specified for the mat away from the joint; core method is required for joint density.
L. J. Fleckenstein, D. L. Allen and D. B. Schultz. **Compaction at the Longitudinal Construction Joint in Asphalt Pavements** (KYSPR-00-208). Kentucky Transportation Center at the University of Kentucky, Lexington, KY, 2002.	2002	▪ Four joint construction methods, some with additional joint adhesives, were evaluated. Each trial section had a corresponding Control section; in total 12 projects were constructed; ▪ Coring at the joint location, 6” from joint, 18 inches from joint, and six feet from joint on each side of joint. Field testing was also conducted; normalized permeability and normalized density were primary measures of quality (actual levels of air voids and permeability were not reported) ▪ The highest increase in density relative to the Control was observed for the infrared joint reheater, followed by the edge restraining device, then the notched wedge geometry, which produced only a “marginal” increase relative to the Control. ▪ Notched wedge was found “easiest to construct” and had “one of the highest reductions in permeability at the joint.” ▪ The Joint Maker was not found to increase density significantly; ▪ There is a density gradient from lower density at the joint to higher density away from the joint that is expected; ▪ Contractors are achieving densities at the joint that are 2-3% less than density at the center of the mat without any “special method” or change to compactive effort. ▪ Projects that used joint adhesive “appear to be performing as well or better than those sections…without adhesives.”
Toepel, A. **Evaluation of Techniques for Asphaltic Pavement Longitudinal Joint Construction**. WisDOT ID WI-08-03. June, 2016	2003	▪ Study was follow up to NCAT research in Michigan and Wisconsin and noted wedged joint study in Wisconsin was not as successful as Michigan; ▪ Noted lack of experience and equipment in producing a high performing wedge joint; ▪ This study evaluated eight methods of joint construction; ▪ “The density results and the ten-year performance evaluation both show that the wedge joint constructed by steel side roller wheel and the wedge joint constructed by tag-along roller perform the best. However, based on worker comments, it is much easier to construct the wedge joint with the steel side roller wheel than with the tag-along roller.”
E. R. Brown, C. J. Bognacki, W.F. Troxler and L. Dep, J. S. Benson and J. A. Scherocman. **Factors Affecting Compaction of Asphalt Pavements (Longitudinal Joint Density)**. Transportation Research Circular E-C105,	2006	▪ Article notes several issues arising from use of joint heaters, including unevenness in heating, variability between machines, and localized overheating causing damage to mix; ▪ Edge-restraining devices have been “demonstrated on a number of projects without significant success.”; ▪ Cut-back joints work well for airfields but success is dependent on equipment/operator; can be very costly

Transportation Research Board of the National Academies, Washington, DC, 2006.		▪ "Does not seem to be any significant data which indicates that the cutting back the joint results in a more durable longitudinal joint on a long-term basis."; ▪ Mentioned original intent of wedge is for safety, not necessarily joint quality; ▪ Two problems typically associated with wedge joint: difficulty compacting wedge section and difficulty matching joint height at the upper notch; ▪ Hypothesized that deterioration of wedged joints occurs from bottom upwards due to lack of density within the wedge
Daniel J.S. and William L.R., 2006, **Field Trial of Infrared Joint Heater to Improve Longitudinal Joint Performance in New Hampshire. Transportation Research Record, Vol. 1946, pp. 157-162**	2006	▪ In the base layer, the infrared joint shows an average air void content that is 0.6% lower than the control joint. The binder layer infrared and control joint densities are similar. ▪ The surface infrared joint has an air void content 2.5% below the control joint. ▪ On both the binder and the surface layers, the infrared test section shows significantly better performance than the control section, in terms of cracking along the centerline.
Mallick, R., Kandhal, P., Ahlrich, R., and Parker, S. **Project 04-05: Improved Performance of Longitudinal Joints on Asphalt Airfield**. Airfield Asphalt Pavement Technology Program Final Report, 2007	2007	▪ This is a survey and "Best-Practices" report made to the FAA based on work prior to 2007; ▪ Based on summarized findings, the authors recommend paving in tandem or echelon when possible; ▪ If echelon is not possible, authors recommend notched-wedge over vertical joints; ▪ Use of rubberized tack coat (hot applied adhesive sealer) is encouraged on all joints; ▪ Cutting wheel is lowest priority and requires significant contractor skill.
Sebaaly, P.E., Fernandez, G. and Hoffman, B. **Evaluation of Construction Techniques for Longitudinal Joints in HMA Pavements**. Journal of the Association of Asphalt Paving Technologists, Vol.77.(2008)143-182	2008	▪ Two rolling patterns and five different joint practices (geometry and material) evaluated; ▪ Rolling pattern – hot overlap and hot pinch – not found to statistically change joint density; ▪ Joint geometry was a significant factor, but impact of joint geometry varied between projects; ▪ Of the three selected geometries for further study, all were found the be able to meet minimum density requirements and no significant effect of geometry on wither the hot or cold side of the joint was found.
S. Zinke, J. Mahoney, E. Jackson, G. Shaffer. **Comparison of the Use of Notched Wedge Joints vs. Traditional Butt Joints in Connecticut**, Report No. CT-2249-F-08-4. Connecticut Transportation Institute, University of Connecticut, Storrs, CT, 2008.	2008	▪ Two paving projects using notched wedge vs. butt joint geometry; nuclear density and cut cores were evaluated; also evaluated use of rubberized joint sealant; ▪ Higher density noted on hot side for both joint geometries due to lateral confinement; ▪ Density profile across the joint is more uniform and density at the joint found to be higher for notched wedge joint; ▪ Cut cores are needed to correlate nuclear density at the joint; ▪ Wedge portion of joint should be compacted with vibratory plate or similar device; ▪ Rubberized joint sealant generally had little to no effect on joint density at the joint itself; ▪ Authors recommend considering average joint density (average of cold and hot side density) for acceptance
A. Cross and S. Bhusal. **Longitudinal Joint Density and Permeability in Asphalt Concrete**, FHWA-16 OK-08-07, ODOT SPR Item Number 2197. Oklahoma State University, Stillwater, OK, 2009.	2009	▪ Three paving projects evaluated for permeability (lab and field), non-nuclear density, and cut cores; ▪ Oklahoma notably uses relatively fine-graded mixtures, though not typically as fine as Wisconsin; unknown joint type geometry used in study; ▪ Permeability is dependent on the method used and statistically significant differences between methods may exist; ▪ "Permeability starts to increase when in-place voids exceed 8 percent. A critical void content for field and laboratory permeability was found between 10 and 12 percent voids."; ▪ When the difference in air voids between the joint and cold-side mat are greater than 2.5%, higher joint permeability was usually found; ▪ Similarly, "A difference in unit weight between the mat and adjacent to the mat on either side of the longitudinal joint of greater than 4.5 pcf was related to high joint permeability."
Huang B. and Shu X., 2010, **Evaluation of Longitudinal Joints of HMA Pavements in Tennessee**	2010	▪ The infrared heater, polymer emulsion, and basic emulsion gave the three lowest air void content. ▪ Overall, joint heater performed best among the techniques because it yielded low air void content and permeability. ▪ The longitudinal joint constructed without any special technique exhibited higher air void content, higher permeability, and lower IDT strength than its neighboring area on cold and hot side.

		▪ The air voids distribution obtained from the X-ray CT images shows that the effectiveness of infrared heater in improving joint quality was through increasing the compaction degree of longitudinal joint deep to the overlay bottom and thus making the joint denser.
Appea, A., and Clark, T. **Longitudinal Joint Data Collection Efforts in Virginia Between 2005 and 2009**.Transportation Research Record 2154,Transportation Research Board of the National Academies, Washington DC(2010):108–113.	2010	▪ Joint density statistically improved as a result of a "best-practices" type memorandum and field training program in Virginia focusing on communicating proper joint construction techniques to Contractors; ▪ The improvement noted was on the same order as those "obtained by using recommended superior joint construction techniques, such as use of a rubberized joint and use of the cutting wheel".
S. G. Williams. **HMA Longitudinal Joint Evaluation and Construction**, Report TRC-0801. University of Arkansas, Fayetteville, AR, 2011.	2011	▪ Report contains extensive literature review prior to 2011; ▪ Project divided into two phases: Phase 1 selected field sites of varying age and performance to determine appropriate joint evaluation protocols; Phase 2 involved testing 8 joint construction techniques on two resurfacing jobs each; ▪ Density gradient of varying severity noted, even within 6" from joint varied by as much as approximately 6% air voids (as measured with nuclear density); ▪ Using density, permeability, absorption, and IDT (among other factors) to judge joint quality, "joint heater (JH), joint stabilizer (JB), and notched wedge (NW) methods were the most successful at limiting the potential for deterioration at the longitudinal joint." In this report, Joint Stabilizer" is a spray-applied fog type treatment; ▪ The best technique appears to depend on whether density or water-related responses are weighted more heavily; for example, joint adhesive generally did not significantly increase density, whereas it significantly reduced absorption, permeability, and infiltration. ▪ "Applying tack coat to the joint did not significantly improve joint performance." ▪ Joint adhesive appears to have only a localized impact on performance due to only being applied to the joint face and apparently limited migration throughout the mixture; ▪ "For the relationship of density and permeability / infiltration, natural groupings of infiltration data were segmented at 92 and 89 percent density, suggesting that these minimum density values are appropriate specification limits."
Nener-Pante, D. **Longitudinal Joint Performance: A Field Study of Infrared Heated and Notched Joint Construction.** Maine DOT Report ME 12-07. 2012	2012	▪ Maine DOT noted continued joint failure using milled or cut-back vertical joints with joint adhesive; ▪ Trimmed (cut-back) edge with joint sealer, Notched-wedge, and notched-wedge with infrared joint heaters were compared using density on field trial; ▪ Double-tack application applied to notched wedge when joint heater was not used; ▪ Using core density at the joint relative to the mat density as the indicator of quality, it is concluded the vertical edge with adhesive performed the worst, although actual joint densities were similar between treatments. ▪ No statistical difference was found using joint density normalized to mat density, although pairwise analysis did show the notched-wedge performed significantly better than the trimmed edge. The infrared notched wedge was not significantly different than either of the other two treatments; ▪ "Core density results from a similar project found that the notch-wedge apparatus produced vastly lower density values than those found in this project. It is hypothesized that the notch-wedge can produce highly variable results depending on the set-up and operation of the apparatus in the field."
S. Reichelt, A. Coenen, and J. Behnke. **WisDOT Asphaltic Mixture New Specifications Implementation – Field Compaction and Density**. WisDOT ID 0092-15-09. June, 2016	2016	▪ Nuclear and cut core density were used as primary measures of joint quality although Hamburg Wheel Tracking and NCAT Permeability Testing were included for data subsets; ▪ A standard nuclear gauge overestimates density (1.8% for joints in parallel orientation); a nuclear/core correlation on a test strip is recommended for all projects; ▪ In terms of nuclear density data, the milled longitudinal joint achieved the highest percent compaction, followed by the notched wedge. Vertical longitudinal joints had the lowest average joint densities. ▪ "All joint density averages decreased as ESAL designation of the pavement increased";

		▪ "Rolling pattern was only found to be a statistically significant factor in achieving density on one project"; for this unique project, the authors suggest that the mixture type may have required a specific rolling pattern that the contractor already was aware of. Earlier in the report, survey respondents indicated rolling pattern was the second most cited "best practice" for joint quality behind only the joint method. ▪ Study recommends use of notched wedge joints unless echelon paving is available; study recommends milling out of joint for highest ESAL level mixtures (although WisDOT mixture designations have changed since this report)
Kim, E. **Evaluation of Asphalt Longitudinal Joint Construction and Practices in South Carolina**. Clemson University Thesis, August, 2017	2017	▪ Three mixture types, two joint geometries (safety edge and butt joint), and one rolling pattern over nine field projects was investigated; ▪ Significant density, permeability, and IDT gradients found for eight of nine projects; ▪ Safety edge without wedge compaction did not significantly improve performance relative to the butt joint; ▪ Increasing layer depth statistically improved quality of the joint; ▪ The type of mixture (mix design) is found to significantly affect the ability to construct a quality joint
Montgomery, S. R., & Haddock, J. E. (2017). **Fog seal performance on asphalt mixture longitudinal joints** (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2017/18). West Lafayette, IN: Purdue University.	2017	▪ Permeability and density used to evaluate Longitudinal Joint Seal (LJS / VRAM) and asphalt emulsion fog seal ▪ "Application of fog seals can improve the performance of the longitudinal joints with respect to permeability…benefits were irrespective of the specific fog seal material…fog seal should be reapplied at 5-7 year intervals." ▪ Migration of VRAM into asphalt layer critical to performance ▪ "SS-1h fog seal treatment appears to have better performance than the VRAM, the effectiveness of the treatments over time is not known."
Shanley L., 2019, **Evaluation of Longitudinal Joint Sealant in Illinois**. FHWA/IL/PRR-168 [I2004-01]. Illinois Department of Transportation.	2019	▪ Joint sealant (VRAM / LJS) significantly decreased the field permeability (at least half permeability of control sections) ▪ Nuclear density readings were affected by the joint sealant due to change of Gmm ▪ Formulations of joint sealant is critically important ▪ The ability of various joint sealants to withstand traffic without tracking still remain a concern
Williams, C., Podolski, J., Kamau, J. **Use of J-Band to Improve the Performance of the HMA Longitudinal Joint**. Minnesota Department of Transportation Report MN 2020-33. 2020.	2020	▪ Evaluated full scale sections with and without commercially available LJS / VRAM material: Jband. ▪ "Field cores containing VRAM showed better results [relative to] control section in that they have the highest joint bond energy, fracture energy, and work of fracture and good surface energy." "The use of VRAM also reduces permeability and air void content…" ▪ "…concluded that the use of VRAM improves the performance of the asphalt pavement mat at the longitudinal joints because it reduces permeability and lowers air void content, thereby protecting against deterioration…"
Turgeon, C. **MnDOT Pavement Preservation Manual**. Minesota Department of Transportation, 2020	2020	▪ Micro-surfacing isolated on joint; used on medium to high severity longitudinal joint deterioration. ▪ "Method has a higher production rate than patching; two lane closures are required since…machine must straddle the joint" ▪ Restriping always required ▪ Spray/Blow patching similarly used for more advanced deterioration; quicker than hand patching, specialized equipment
U.S. Department of Transportation Federal Highway Administration. **Improving Longitudinal Joint Performance.** Tech Brief FHWA-HIF-21-023. December 2020	2020	▪ Notched wedge may provide higher density than butt joints due to confinement; NMAS is a major consideration for NW geometry with respect to compaction density ▪ Use of smallest NMAS possible can help with joint density; fine gradations typically less permeable for a given air void content ▪ Overlap and pinching is recommended to eliminate bridging ▪ Use of cores rather than gages is preferred for both mat and joint density ▪ Waive density as a percent of Gmm when VRAM is used
Trepanier, J., Senger, J., Thomas, T., Exline, M. (2021) **A Materials Approach to Improving Asphalt Pavement Longitudinal Joint Performance**. Transportation Research Board, Transportation Research Board 100th Annual Meeting, January, 2021.	2021	▪ Study outlines the experiences Illinois DOT has with void reducing asphalt membrane (see Shanely, 2019) ▪ Material specification properties are elucidated with development history; distresses targeted include rutting, thermal cracking, material flow after application, and tracking resistance ▪ Discussion of rate based on mixture type and layer thickness (appears in special provision) ▪ Illinois approximates a "life extension of the joint area" of 3-5 years, with a calculated benefit of 3-5 times the initial cost of installation.

Table 3. Description of Joint Improvement Materials

Material	***Application Timing***		***Description of Process/Material***
	Supplemental Materials used During Construction Process	***Supplemental Materials used Following Construction Process and/or Low Joint Density Remedial/Repair***	
Asphalt Emulsion Tack Coat	✓		Asphalt emulsion or hot-applied paving grade tack coat used for general paving operations is applied to joint face prior to paving second pass; sometimes double or "heavy" application is used.
Hot-Applied Joint Adhesive	✓		Specialized hot-applied joint sealant is applied to joint face typically using a melter kettle/hand wand prior paving second pass.
Void Reducing Asphalt Membrane (VRAM); a.k.a. Longitudinal Joint Seal (LJS)	✓		Specialized hot-applied asphalt membrane is spray-applied to existing substrate at predefined width centered at anticipated joint location using modified asphalt distributor. The first pass covers ~50% of VRAM width. Alternatively, VRAM can be applied to Notched-Wedge face of first pass (i.e. on wedge) prior to paving second pass.
Rapid Penetrating Emulsion ("RPE")	✓	✓	Dilute asphalt emulsion containing surface-tension reduction additives designed to penetrate existing surface. Spray-applied at pre-calculated rate using standard asphalt emulsion distributor.
Rubberized Crack Sealing/Over-Banding Joint	✓	✓	"Traditional" rubberized/polymerized hot-applied crack sealant used for standard crack-filling operations. Applied with standard melter kettle/hand wand/drag box.
Asphalt Emulsion Fog Seal	✓	✓	Undiluted or diluted asphalt emulsion applied at pre-determined width and rate on or over joint using standard asphalt distributor. Limited penetration of asphalt residue is expected.
Specialty Fog Seal Incl. Rejuvenating Fog Seal	✓	✓	Same process as asphalt emulsion fog seal. Materials include undiluted or diluted materials that may or may not be emulsified and may or may not contain residual asphalt binder and/or polymer. Examples include emulsified bio oils or aromatic extract materials.
Mastic Treatment		✓	Specialized hot-applied mastic material is applied using a melter kettle/hand wand/drag box over deteriorated joint. Mastic portion allows for thicker irregularities to be filled relative to traditional rubberized crack sealant.
Micro-surfacing, fixed width		✓	Asphalt emulsion micro-surfacing process using modified rut fill box to be applied at fixed width over joint; joint deterioration can be milled or un-milled at time of micro-surfacing application
Spray or Injection ("Blow") Patching		✓	Specialized process consisting of a single truck mounted unit that sequentially sprays asphalt emulsion, asphalt emulsion/aggregate slurry, and/or virgin aggregate chips using air pressure into joint deterioration areas. Considered an "all-in-one" patching-type process.

2.4 Synthesis of Agency Specification Review

To further define the current “State of Practice” and identify any novel processes and materials being used in practice, a review of DOT Standard Specifications was conducted. For this process the authors downloaded the most recently available electronic version of each U.S. State Standard Specification and isolated the section regarding asphalt pavement construction. Using the general listing of processes and materials above, the authors made note of specific language in each States’ specification. The outcome of this review is a list of processes and material and the minimum percentages of State Agencies that utilize a given process or material as determined from their relative Standard Specification; since not all information is always made public in electronic or accessible format, and some States may list longitudinal joint information in other locations (such as construction and design manuals), the percentage is expressed as a minimum. Nevertheless, this percentage allows the authors to make general conclusions regarding regional biases, items with consensus, etc. The final summary of this review is included in the next subsection. A summary of the U.S. Agency Specification review is included as Appendix C of this report.

Although a thorough review of international literature and specification was not a core focus of this project, a limited review was conducted to determine if the findings for U.S. literature and Agency review were also supported internationally, or if other concepts not used in the U.S. require further study. For this project four Countries were included based on familiarity of the research team or availability of the Standard Specifications: Germany, United Kingdom, Sweden, and China. The following is a summary of the international review:

- Germany
    - Specification is method-based, including joint geometry and roller type/pattern;
    - Overlap and pinching of the joint specified
    - Vertical butt joints are apparently used
- United Kingdom
    - Joints are cut back to expose full layer thickness;
    - Vertical faces are “painted” with hot asphalt binder
- Sweden
    - Core density used near joint; specification is joint density within 2% of mainline
    - Overlap and pinching material at the joint specified
    - Joints are often cut back and milled; milling produces a rough edge for interlock
    - Emulsion is used to coat joint faces
- China
    - Echelon paving for interstate and state highways;
    - Cutting wheel used before mixture cools to expose full layer
    - Cut face is coated with paving asphalt or tack coat
    - Method type specification for placement and compaction

It is apparent from the limited international review that cutting or milling back of joints appears to be more popular internationally than in the U.S., but much of the same methodology is used overseas, such as overlap and pinching of the joint and use of tack or paving asphalt to coat the joint face. Very little information on supplementary materials was found in the international review conducted.

2.5 Proposed Organizational Structure for Practices, Processes, and Materials to Improve Longitudinal Joint Performance

Based on the findings presented in this section, the research team designated three groupings in which to organize the identified joint improvement methods/materials:

- ***Construction & Design (“CD”)***: These are pre-construction design considerations, practices during the construction process, and ancillary test items during construction. Examples include specifying joint geometry, paving methods, and testing of joint density.

- ***Methods and Materials During Construction ("MDC")***: This grouping is intended to include supplementary process/materials to the general paving process during construction. An example is using joint adhesive on the cold face of the joint.
- ***Methods and Materials Post-Construction ("MPC")***: This grouping is intended to include processes/materials used "immediately" (within the same season) following construction and therefore used before joint deterioration requires extensive structural repair or replacement. This grouping does not include routine cold/hot patching processes intended for minor or isolated distress areas. An example is fog sealing the joint following construction.

Using this proposed structure, the authors identified 16 unique items within these groupings reported to impact joint performance. The groupings and associated items are shown in Table 4. The order and coding in Table 4 is arbitrary and used to sort items more quickly. The "Minimum Agency Count" is the number of reviewed or known State DOT Agencies that specify or have shown recent or sustained experience via specification, provision, or change order of (for) a line item; since not all information is public, the count is expressed as a "Minimum" count. The MPC Grouping is intended to include methods and materials used before joint deterioration requires extensive structural repair or replacement (examples of extensive structural repair includes saw cutting and patching, and mill/inlay processes); MPC does not include routine cold/hot patching processes intended for minor or isolated distress areas.

It is evident that the majority of Agencies are focusing efforts on the CD options and the asphalt emulsion tacking option of the MDC, with only a minority addressing the MPC options. While all Agencies have verbiage with respect to paving equipment following established grade or reference lines and minimizing mixture segregation (so-called paving "best-practices"), there is not agreement among the Agencies regarding a joint geometry that categorically results in the highest quality joint. The authors isolated the 22 States in the FHWA "Wet-Freeze" region and found that at least 13 (59%) directly specify a joint geometry, although the type of geometry is not consistent. Interestingly, of the wet-freeze States reviewed, four dictate joint type based on the layer thickness or Nominal Maximum Aggregate Size (NMAS) of the mixture. Vertical butt joints are used with larger NMAS and/or thinner lifts.

The authors feel that the general lack of consensus within the CD options is promoting development and use of materials within the MDC and MPC options. Several State-Agency funded studies focused on these options, with at least one ((17) Illinois) resulting in widespread use of MDC-3:Void Reducing Asphalt Membrane (VRAM) item. These combined findings help provide validation that the initial hypothesis, i.e., joint deterioration is largely controlled by permeability, is correct.

The information shown in Table 4 was presented to this project's Project Oversight Committee (POC), to generate feedback as to which items the POC felt would most likely benefit Wisconsin. From the feedback, Table 4 was further reduced into a selected fewer number of items to focus the remainder of the study on. This is presented in Section 4 of this report.

Table 4. Summary of Identified Joint Improvement Processes and Materials

Construction & Design (CD)			***Supplemental Materials During Construction (MDC)***			***Supplemental Materials Post-Construction and/or Low Joint Density Remedial/Repair (MPC)[5]***		
Item	***Coding***	***Minimum Agency Count[0]***	***Item***	***Coding***	***Minimum Agency Count[0]***	***Item***	***Coding***	***Minimum Agency Count[0]***
Specific Joint Geometry Selection[1] Vertical Butt Joint Tapered Joint (inc. Notched Wedge) Milled and/or Cut-Back Joint	CD-1	23 (46%)	Direct Tacking or Double-Tacking Joint with Asphalt Emulsion	MDC-1	46 (92%)	Penetrating Asphalt Emulsion (Examples include: "RPE")	MPC-1	6 (12%)
Echelon and/or Tandem Paving[2]	CD-2	12 (24%)	Dedicated Joint Adhesive and/or Hot Applied Asphaltic Coating Applied to Cold Joint Face[4]	MDC-2	14 (28%)	Rubberized Crack Sealing/Over-Banding Joint with Asphaltic Coating[4]	MPC-2	7 (14%)
Specialized Joint Pre-Compaction and/or Forming Equipment	CD-3	15 (30%)	Void Reducing Asphalt Membrane or Longitudinal Joint Seal	MDC-3	16 (32%)	Asphalt Emulsion Fog Seal	MPC-3	3 (6%)
Joint Reheaters (Infrared or Other)	CD-4	4 (8%)				Specialty Fog Seal (Incl. Rejuvenating Fog Seal. Bio-Based, etc.; not necessarily asphalt-containing)	MPC-4	2 (4%)
Cold-Side Overlap and/or Hot Pinching	CD-5	13 (26%)				Mastic (hot applied) Treatment	MPC-5	1 (2%)
Specific Rolling Equipment and/or Rolling Pattern[3]	CD-6	23 (46%)				Micro-surfacing, fixed width/specialized	MPC-6	1 (2%)
Joint Density Measurement	CD-7	33 (66%)						

[0] Count is Agencies that specify or have known recent or sustained experience via specification, provision, or change order of (for) line item; since not all information is public, the count is expressed as a "Minimum" count.

[1] Joint type selection includes any specific verbiage to joint type selection by mixture type, traffic pattern, etc.

[2] Included when specification directly identifies echelon or tandem paving as available or preferred option.

[3] Included when specification includes specific types of rollers to be used and/or specific pattern of rolling to be followed for rolling Longitudinal Joint.

[4] "Hot Applied Asphaltic Coating" usually in reference to paving grade asphalt; often specified as same grade as used during paving operations.

[5] Intended to include methods and materials used before joint deterioration requires extensive structural repair or replacement (examples of extensive structural repair include saw cutting and patching, and mill/inlay processes); also does not include routine cold/hot patching processes intended for minor or isolated distress areas

3. Review of WisDOT Standard Practice, Joint Density and Pavement Condition Index Data

A key aspect of recommending a particular joint improvement process in Wisconsin is to better understand the current state of joint performance in the State and estimate joint deterioration timelines. If accurate data on joint performance can be leveraged, estimate of life cycle cost for certain treatment options can be determined. Toward this goal, longitudinal joint density information from 2018 and 2019 was used to understand the effectiveness of current practice.

Beginning in about 2015 the Wisconsin DOT has made a focused effort to increase the effective virgin asphalt in the mixture principally by way of reduced design gyrations in the laboratory, increased Voids in Mineral Aggregate (VMA) limits, and the process of air void regression (design asphalt content is determined at 4% total air voids, whereas production asphalt content targets 3% air voids). Other States have implemented similar practices (Indiana, for example, recently implemented SuperPave5 for dense graded designs). Mainline density data in Wisconsin appears to support these changes with noted increases in average field density following the specification changes. Wisconsin has also recently (ca. 2018) begun implementing a Percent within Limits (PWL) quality control process on an increased number of projects.

For Wisconsin PWL projects, longitudinal joint density measured by means of nuclear density six inches from the joint location is a pay item eligible for incentive. Density is measured on both the "confined" (hot pass against cold joint) and "unconfined" sides of the joint (Figure 2), with pay evaluated separately on each side of the joint (that is the contractor may earn incentive on neither, one, or both sides of the joint per testing lot).

Prior to 2020, Wisconsin used primarily three longitudinal joint types: vertical butt joints, notched wedge type joints, and pave wide, mill back vertical joints at the discretion of the region. Beginning with 2020 bid lettings, WisDOT has implemented statewide notched wedge geometry on most project types in an effort to harmonize practice throughout the State (Figure 2). Current WisDOT specification also has provisions for joint geometry (and method to achieve joint geometry), tacking of the joint face, and overlapping the cold side of the joint (Figure 3). Overlapping of the joint is intended to reduce the likelihood of "bridging" at the joint location; although this method results in some aggregate crushing at the joint, it helps ensure compactive effort is properly applied to the hot pass.

Joint density data averaged from all State project generated between 2018 and 2020 appears to support this change, with notched wedge geometries producing higher average unconfined and confined joint density relative to vertical butt joints and the highest average density for Low Traffic mixtures. This may be a result of the lateral support provided by the notched-wedge during paving (i.e., the mixture cannot push laterally under rollers). In Wisconsin the cold joint face is tacked with the project tack coat (usually a 50% residual solids slow setting asphalt emulsion). Although a standard notched-wedge geometry is specified, rolling patterns are left to the discretion of the contractor. An example of this data for the 2020 construction season is shown in Figure 4.

Figure 2. Wisconsin Notched-Wedge Joint construction practice including unconfined joint density measurement by nuclear method.

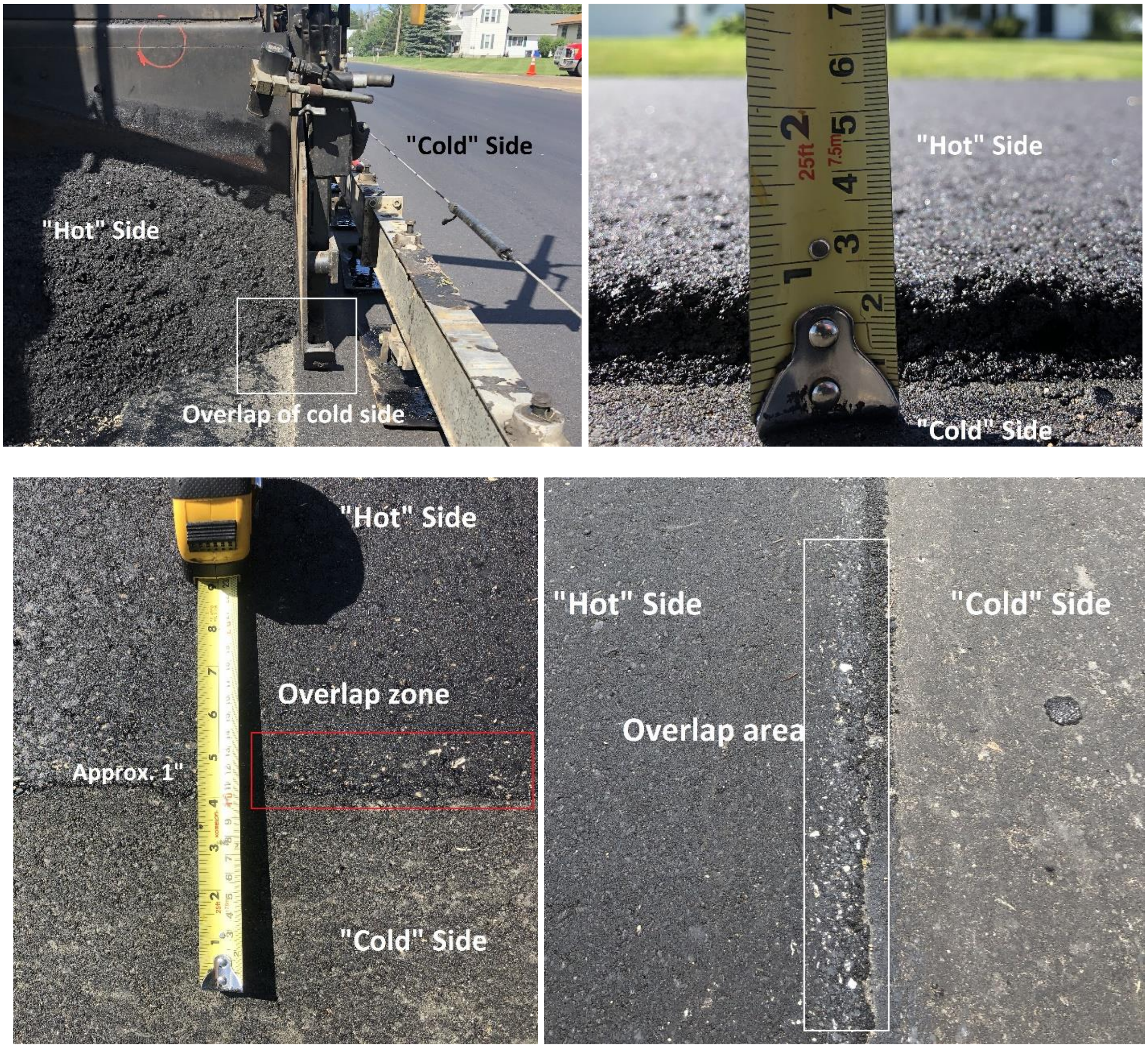


Figure 3. Overlap and pinching of cold side of joint to prevent bridging. Note the broken aggregate in the overlap zone.

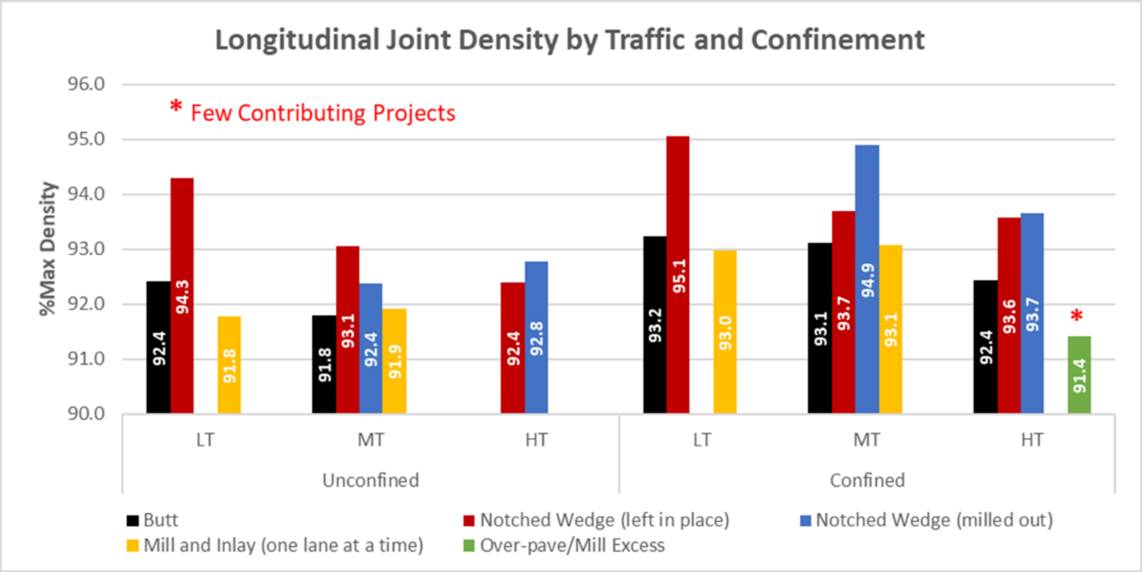


Figure 4. Wisconsin nuclear density data averaged for the 2020 construction season for several joint types. LT, MT, and HT are design traffic level designations as defined by WisDOT Standard Specification. Figure provided by WisDOT BTS personnel.

The concept of density gradient was discussed above; if the joint density is significantly different than the mainline density, it can be reasonably concluded that it will exhibit different performance from the mainline. Figure 5 summarizes density data from 2018 examining this concept. In Figure 5, "LT" is the standard WisDOT "Low Traffic" designation. Approximately 25% of WisDOT surfaces are paved with a 12.5 mm NMAS LT mixture. MT is defined in Figure 5. Since 2018 predates the switch to notched wedge geometry, both vertical butt and notched wedge geometries are shown.

It is important to note that because joint density was only measured on a select number of projects in 2018, the data must be assumed to be representative of the State as a whole. Nevertheless, Figure 5 shows that confined joint density is always higher than unconfined for both joint geometries, often by more than 1%. Interestingly, confined density is almost equivalent to mainline average density for both LT and MT mixtures. This data shows that a density gradient exists at the joint, and that the gradient may be large enough to support the notion of differing performance at the location of the joint and therefore may support the concept of utilizing materials or methods supplemental to the construction process for at least certain project circumstances. It is recommended that similar analyses be continued when more data becomes available since as indicated the data presented here is limited.

Overall, this data supports the changes that WisDOT has made in terms of mixture design requirements and joint construction techniques. Opportunity does exist to improve on homogeneity across the joint, and joint performance as a result of these changes may not manifest for several more seasons.

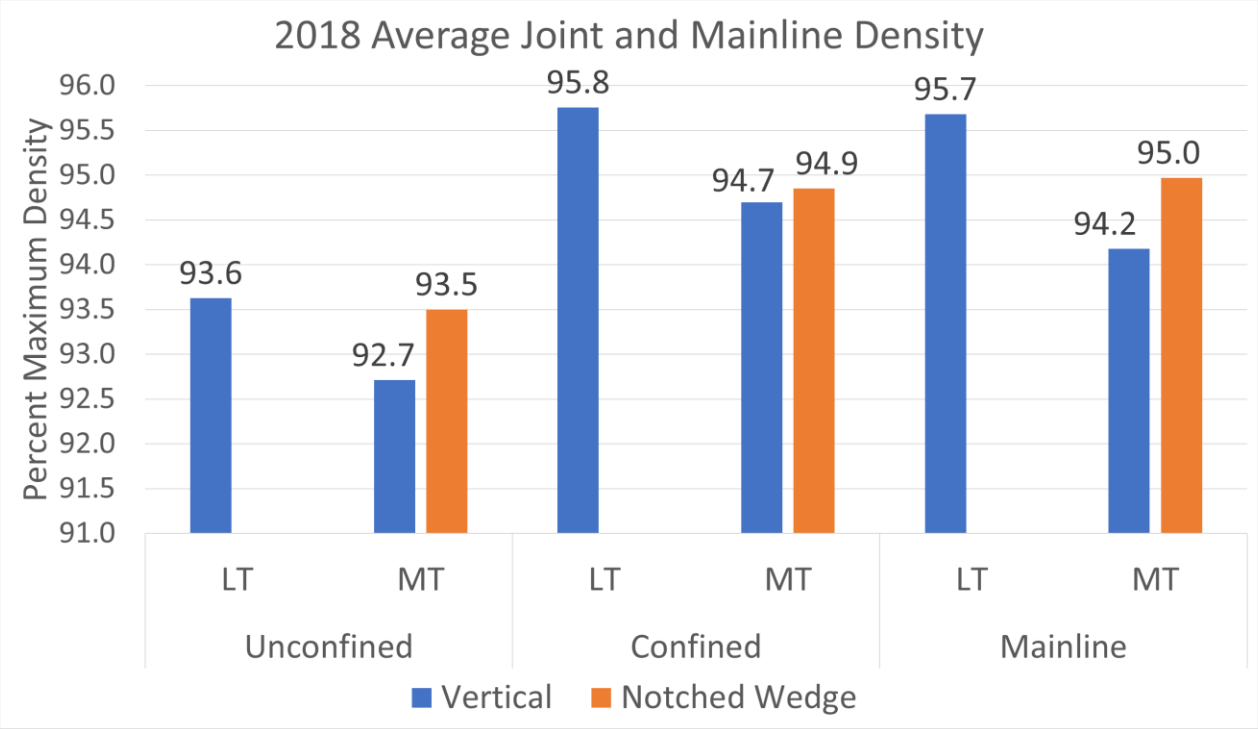


Figure 5. Wisconsin nuclear density data averaged for the 2018 construction season for joint locations against mainline. Figure generated from data supplied by WisDOT BTS personnel.

Using Network Survey Data to Estimate Joint Deterioration Timelines

Since the use of supplementary materials and processes inherently add cost to the paving process, understanding the rate of deterioration for longitudinal joints in Wisconsin becomes important. It is hypothesized that Pavement Condition Index Data can be used to determine joint deterioration timelines and understand timeline to certain maintenance triggers. The Wisconsin DOT contracts statewide distress survey covering the entire State Highway network every two years (interstates surveyed annually); distresses are tracked using images taken by a survey vehicle and this data is used to determine Pavement Condition Index (ASTM D6433) for the various State Highways. In consulting with Wisconsin DOT pavement management unit staff, it was discovered that this process does not include a focused longitudinal joint quality monitoring effort; however, the research team believes left-side longitudinal cracking density data can substantially be attributed to longitudinal joint distress. Therefore, for the purposes of this work, all distress data was sorted to show the difference between the overall PCI with and without the left-side longitudinal cracking distress. To provide a time boundary on the analysis, the research team further sorted the data for project surfacing-years (the construction year the upper layer of the mixture was placed) between 2009 and 2019, which is the last year of complete data available to the research team. Excluding unknown project IDs, this resulted in 898 evaluation sections (individual projects are divided into analysis sections of a fixed length).

For the WisDOT survey, distress density is calculated for a standard survey area of 0.1 mile long and 12 feet wide lane. Lineal distresses like longitudinal cracking assume a one-foot width. An example calculation is given below for clarity. Distress density is interpreted as the percentage of total survey area exhibiting the distress level indicated.

$$\text{Distress Density} = \frac{\text{LongJnt}_{\text{M}}(\text{ft}) * \text{Lineal Distress width (ft)}}{\text{Survey Area (sqft)}} * 100$$

Example Calculation:

$LongJnt_M(ft) = 100ft$

$Lineal\ Distress\ width = assumed\ 1\ ft\ for\ Lineal\ Distesses$

$Section\ Length = 528\ ft$

$Lane\ Width = 12\ ft$

$Survey\ Area = Section\ Length\ (ft) * Lane\ Width\ (ft)$

$$Density\ of\ LongJoint_M = \frac{100\ ft * 1\ ft}{528\ ft * 12ft} * 100 = 1.6$$

ASTM D6433standard uses the language of “Low”, “Medium” and “High” to designate distress severity. Since Deduct Values (DV) for “Low”, “Medium”, and “High” severity cracking density given in ASTM D6433 are based upon a best fit logarithmic plot (Figure 6), the research team further sorted the data by assigning arbitrary deduct value bin ranges for given crack densities. For example, using the Low Density DV fit line, density values less than 0.5% were assumed to have a DV of zero. This was done because (1) the best fit line equations are not public knowledge, and (2) it allows the research team the ability to manipulate the data to gain greater clarity.

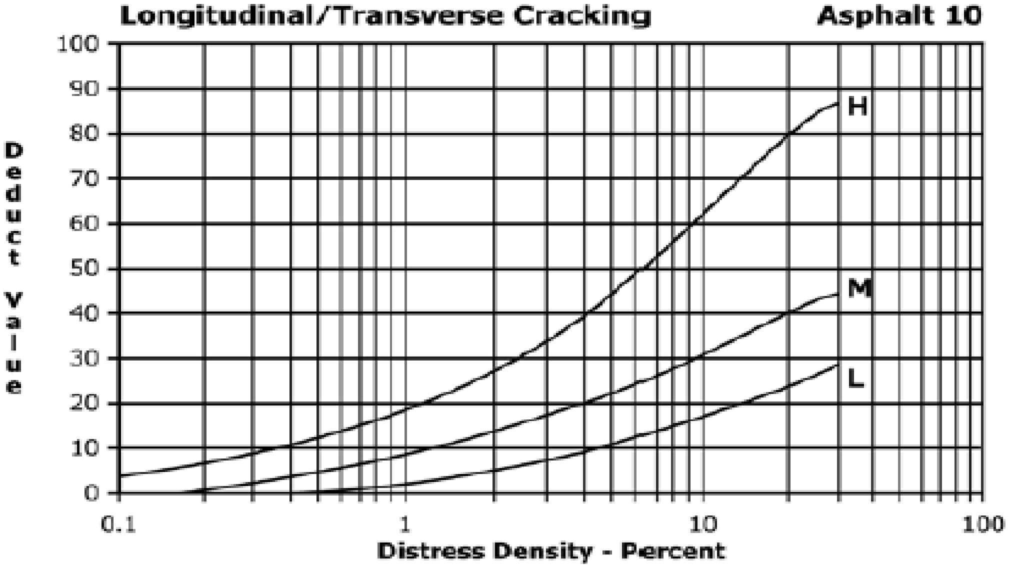


FIG. X3.14 Longitudinal/Transverse Cracking

Figure 6. Longitudinal cracking Deduct Value determination from ASTM D6433.

Analysis of the distress data sought to answer two questions; (1) after what time of construction do longitudinal joints begin to show signs of distress, and (2) how soon after distress appears does the given distress transition to higher severity levels? Figure 7 shows low severity distress density compared to surface year. Surface year is the year the pavement surface was constructed (the survey year is 2019). For example, there are 114 total projects assessed in 2019 that were paved in 2010. It is observed in Figure 7 and Figure 8 that a marked jump in low severity cracking occurs between 2015 and 2016 projects, and that the average value grows only slightly thereafter. A high standard deviation is noted, meaning a wide range in performance is observed for a given year, which is to be expected given the natural variability of the paving process, traffic patterns, and weather across an entire State. When the data is further sorted to quantify only those projects that have low severity deduct values equal to zero, the same trend is observed: less than approximately 20% of projects four or more years old are in this category. Interestingly, 30% of projects less than one year old show some form of low severity distress.

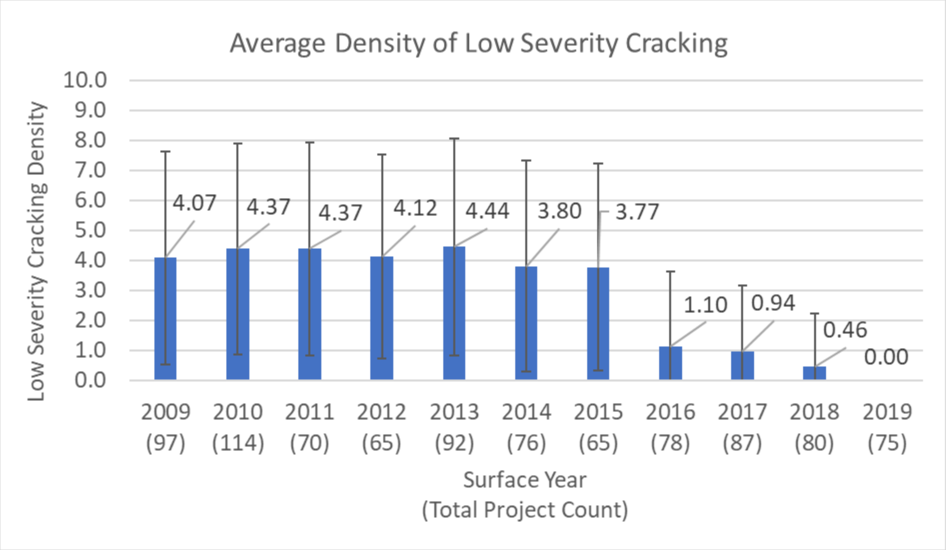


Figure 7. Average low severity cracking density. Error bars show one standard deviation from the mean.

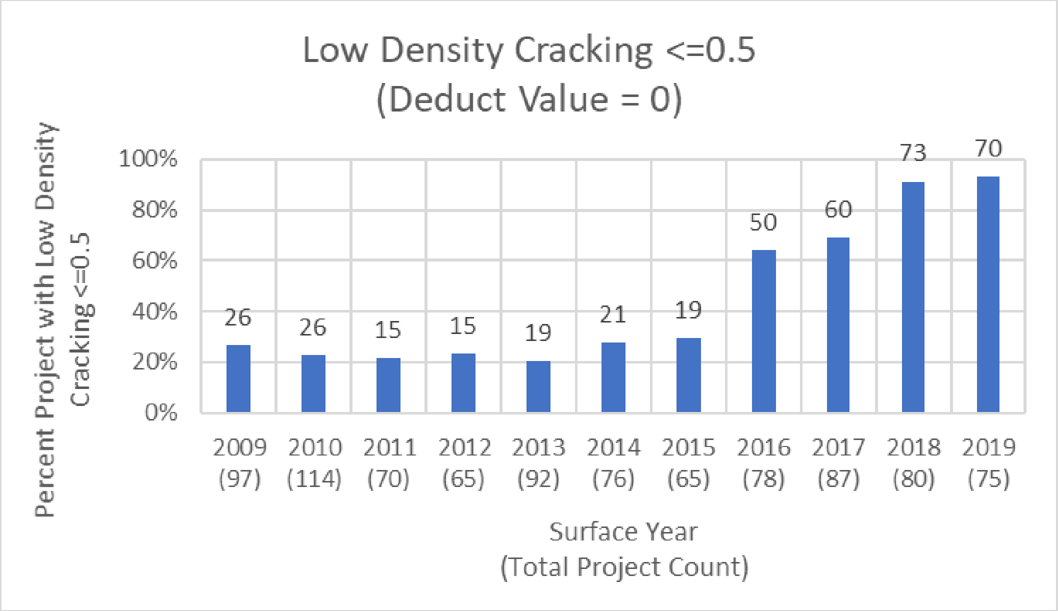


Figure 8. Low density cracking sections sorted for deduct values equal to zero.

In order to confirm that this apparent trend shows average onset of distress, average sum of total deduct value is plotted versus surface year. Sum of total deduct includes all low, medium, and high severity distress. The results are shown in Figure 9. Aside from surface year 2013, it is apparent that total deduct value increases with time, with the data suggesting non-linear growth, which is consistent with the concept of pavement deterioration given in the pavement maintenance and preservation industries (a backward "S" shaped curve is usually cited). One primary reason for the "leveling out" is hypothesized: high deduct value pavements begin to receive maintenance and rehabilitation treatments after a certain distress level is reached, which might keep the total deduct value from climbing higher.

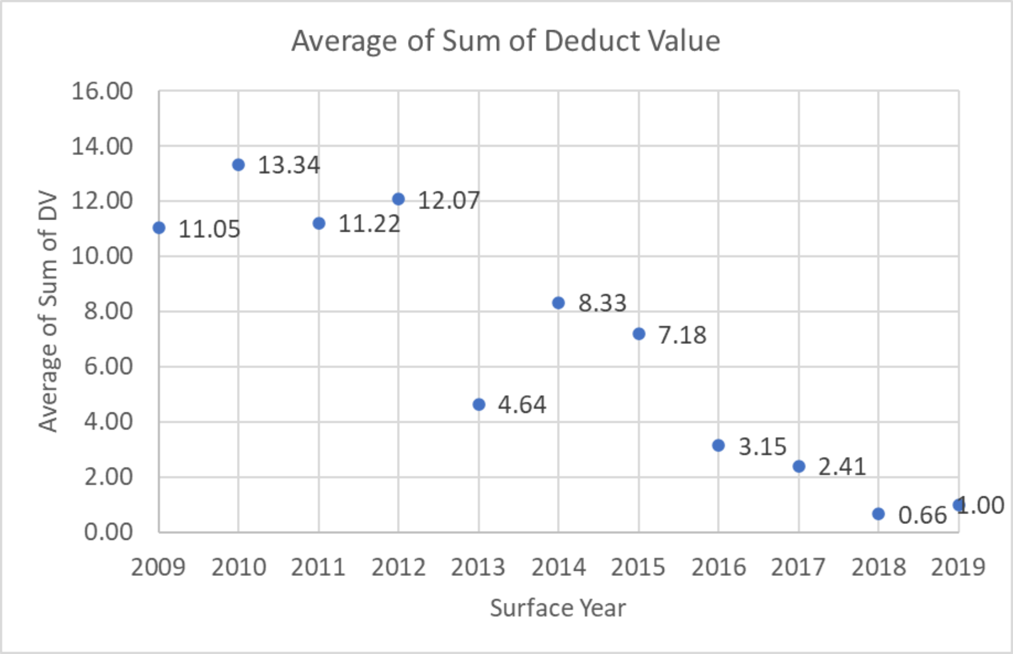
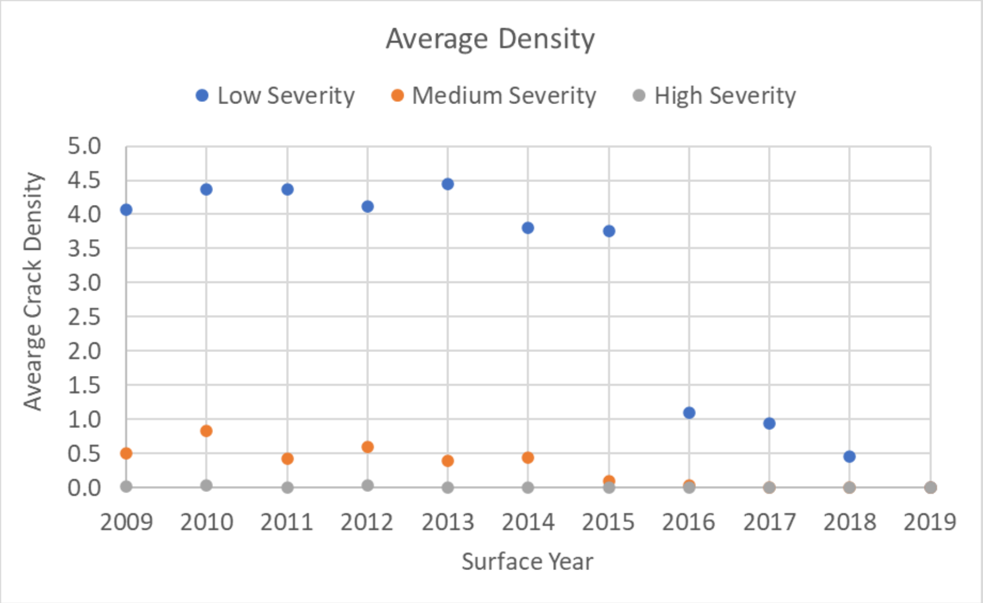


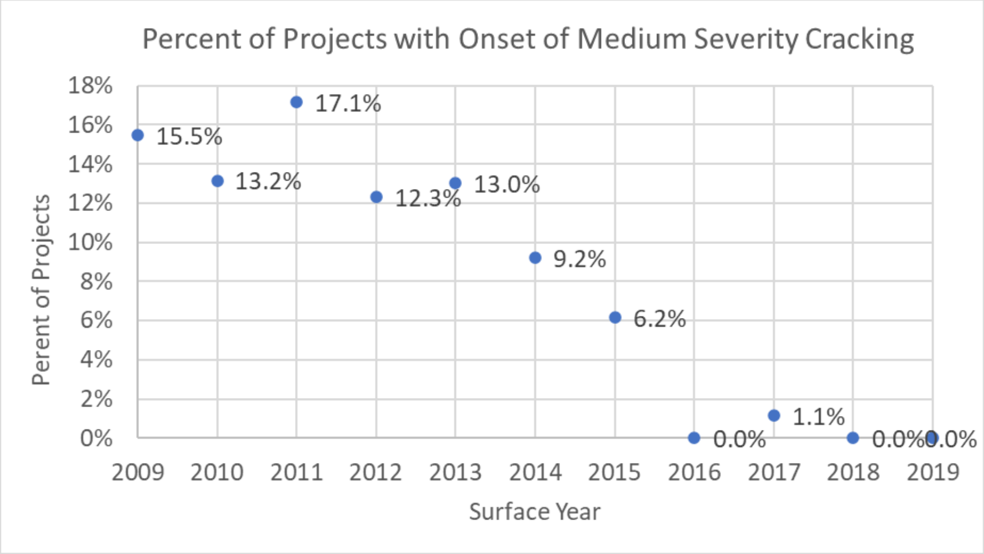
Figure 9. Sum of total deduct value, including Low, Medium, and High Severity.

To understand average onset of transition from low to medium (or higher) distress, Figure 10 shows the three severity levels plotted on one chart. Medium severity crack density begins to appear for the 2014 and earlier surface years, but doesn't appear to grow beyond the 0.5-1.0% density level. High severity cracking appears only on a fraction of a percent of all segments surveyed. Figure 10b shows the data only for projects with high values of low severity cracking and a low value of medium severity cracking. Only the projects with deduct values of low severity cracking greater than deduct values of medium severity cracking and with a medium severity not equal to zero were considered. This process helps capture the transition of from low to medium severity cracking as the medium severity cracking is just beginning to register on the survey. From this figure, 6% of the pavements would start to exhibit medium severity cracking when pavements were in service for four years and about one-fifth of the project would have also transitioned to medium severity cracking after eight years (as observed in surface year 2011).

This analysis confirms that average onset of longitudinal joint distress is approximately four years after paving, and that progression of distress from low to medium appears to occur within three years of onset of distress. These findings are supported by a webinar hosted by the Transportation Research Board (TRB) in early 2021 which posed the following question to attendees, the majority of which were DOT representatives, "How many years do you expect your longitudinal joints to last before a repair is needed?" Responses were split with 44% "4-6 Years", 26% reported "7-9 Years", while a combined 21% indicated more than 10 years.



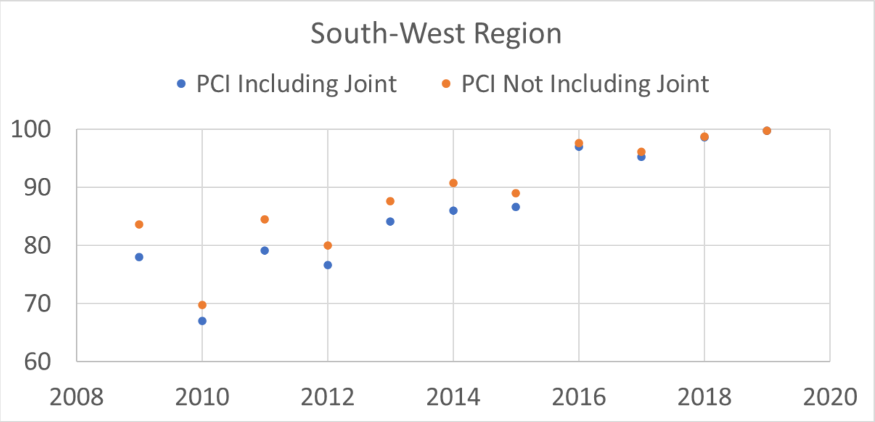
(a)

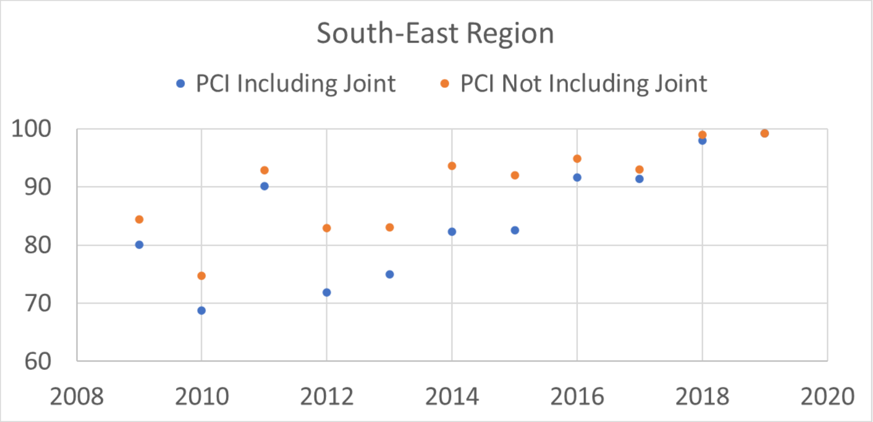


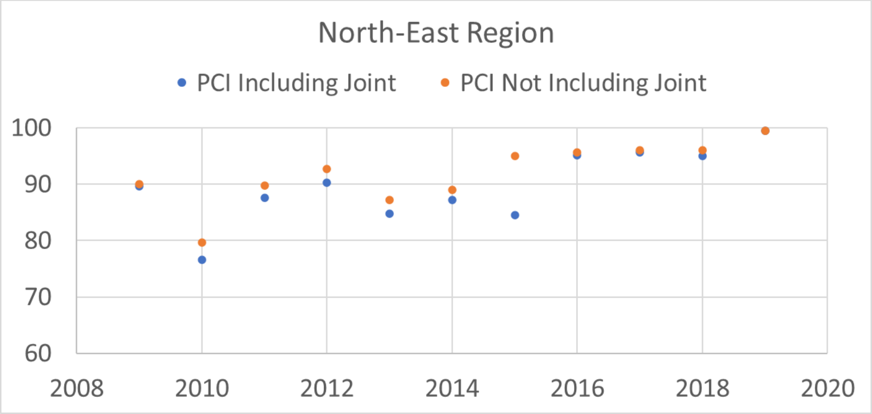
(b)

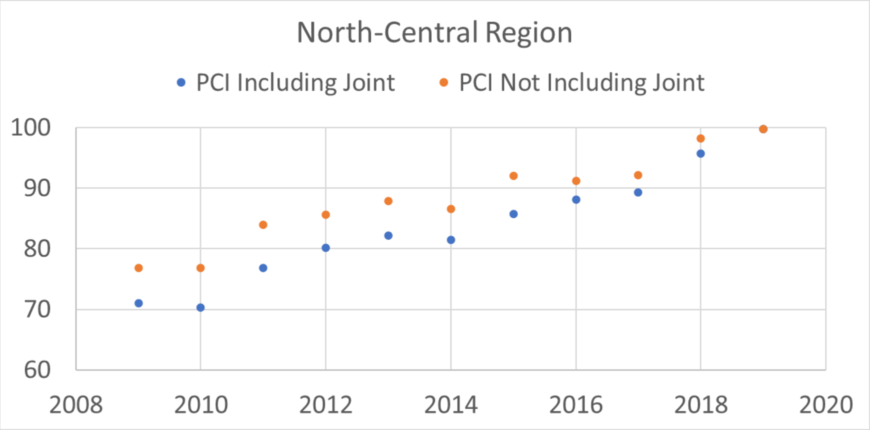
Figure 10. Crack density separated by distress level (a) and data sorted to show onset of Medium Severity cracking (b).

Since distress type and density alone are not used to trigger maintenance or rehabilitation, the full PCI analysis for the survey years indicated was modified to include PCI calculation with the inclusion of longitudinal joint distress, and the PCI calculation without longitudinal joint distress. The authors hypothesize that such an analysis procedure can be used to extract life cycle costs of various treatments, since individual DOTs can use their maintenance costs to determine a net present value. This can then be compared against the costs of supplemental treatments during the year of construction following a similar approach as Trepanier, et al. (2021). Furthermore, projects with exceptional performance can be analyzed to determine if a common denominator (mix design or other) exists to replicate in future projects. The results of this analysis are shown in Figure 11 for each of the five DOT management regions.


South-West Region
● PCI Including Joint
● PCI Not Including Joint
100
90
80
70
60
2008
2010
2012
2014
2016
2018
2020


South-East Region
● PCI Including Joint
● PCI Not Including Joint
100
90
80
70
60
2008
2010
2012
2014
2016
2018
2020


North-East Region
● PCI Including Joint
● PCI Not Including Joint
100
90
80
70
60
2008
2010
2012
2014
2016
2018
2020



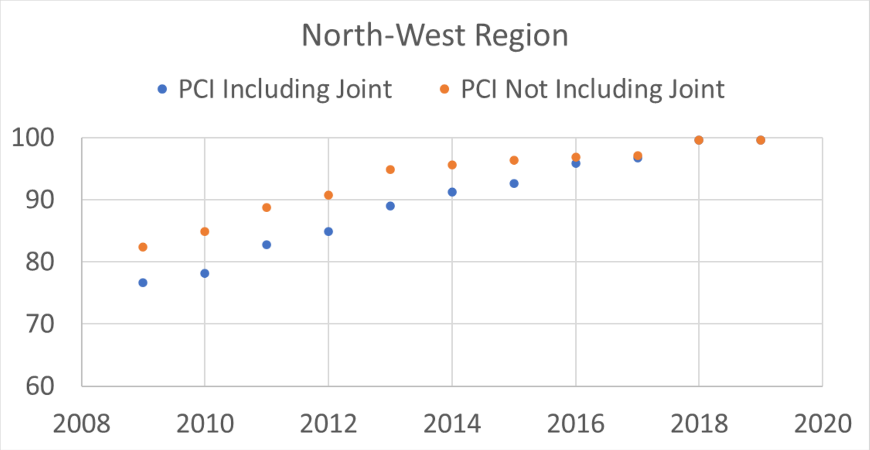


Figure 11. PCI with and without inclusion of left side longitudinal cracking for WisDOT regions.

For a network at a given surface year that receives routine maintenance and experiences a somewhat fixed rate of growth in traffic with time, the expected trend in PCI with surface year for a given survey year is a consistent decrease in PCI with subsequently older surface years, such as what is observed in Regions 4 and 5. The difference between the PCI with and without the longitudinal joint included is also reasonable in these regions: the longitudinal joint contributes to a larger reduction in total PCI with subsequently older surface years to a point of near steady state where the difference remains consistent, This could be a result of maintenance activities preventing further joint deterioration or other distresses becoming more significant with age, or a combination of both.

Interestingly, Regions 1, 2, and 3 exhibit much more inconsistent trends. On average, it appears Region 2 shows the greatest difference between PCI values, although the PCI is shown to both decrease and increase with time. Differences as high as about 12 points is noted in Region 2. Region 3, by contrast, exhibited only one surface year with a PCI below 80, and the PCI difference remained at three or below for all years except 2015. Overall, each of the five regions appears to confirm that longitudinal joint distress begins to contribute to PCI reduction around 3-5 years following construction.

Consulting with WisDOT pavement management staff it was noted that WisDOT does not have a uniform maintenance or rehabilitation PCI trigger, and the inherent subjectivity in collecting and analyzing PCI data makes it very difficult to make network decisions on a region-wide, much less State-wide, level. To better understand effects of mix design, construction requirements, etc., individual projects from each region would need to be isolated and analyzed individually. Although such analyses is beyond the scope of this project, it presents an opportunity for WisDOT to better leverage their database of survey data to make decisions on policy.

4. Proposed Joint Improvement Methods & Materials

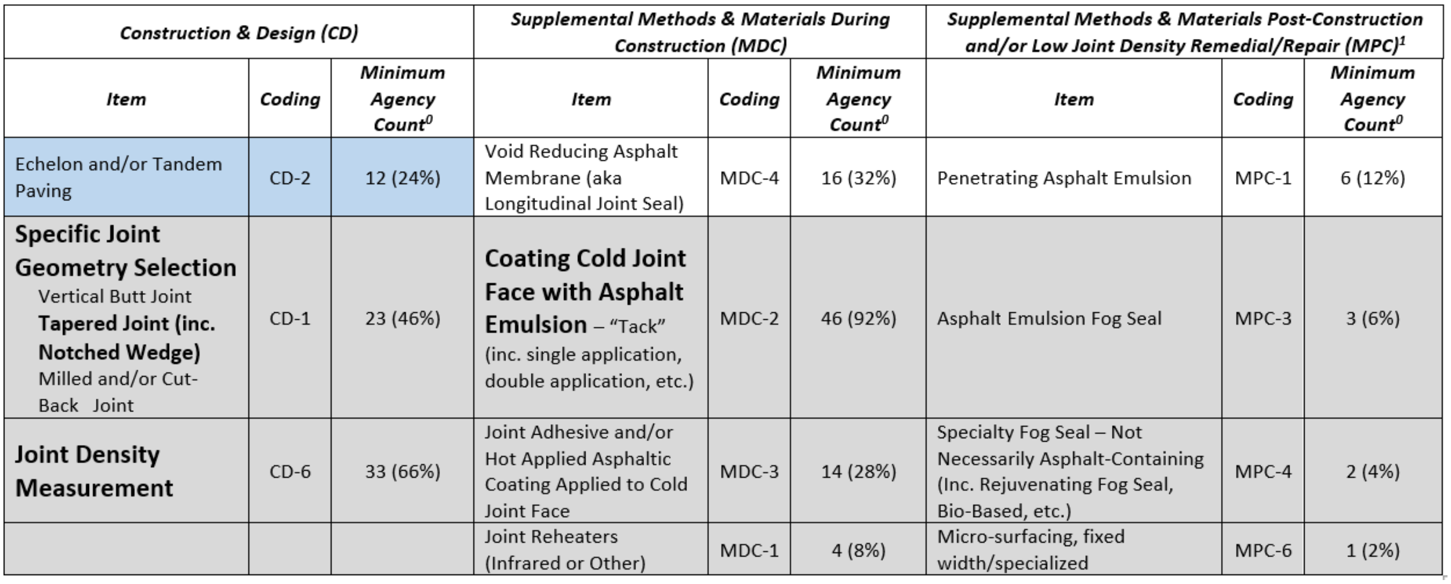
The table of proposed joint improvement processes and materials (Table 4) was presented to the Project Oversight Committee during a virtual meeting in January 2021. One of the objectives of that call was to reach consensus on which items were most practical and feasible for WisDOT to implement on a provisional or trial basis based on the information gained from the literature and specification reviews, and industry expert interviews. Topic prioritization forms were completed by all POC members and a follow up virtual meeting was held in early March 2021 to discuss the results. Three items were identified as high priority that the POC reached general consensus on, including two from the MDC grouping and one from the MPC grouping:

- Materials During Construction (MDC) Grouping:
    - Asphalt Emulsion Tack Coating the Cold Face
    - Void Reducing Asphalt Membrane (VRAM) / Longitudinal Joint Seal (LJS)
- Materials Post Construction (MPC) Grouping:
    - Penetrating Asphalt Emulsion / “Rapid Penetrating Emulsion”

Based on the POC feedback and the findings from the review phase of this project, Table 4 was modified to prioritize those items determined to offer the highest probability of improving joint performance, shown in Table 5.

Although the POC noted the importance of the items within the CD column, the literature review indicates WisDOT was taking a commonly acceptable approach to the items in the CD grouping, and no major change is recommended. It was agreed that beyond summarizing the findings from the literature and specification reviews, and industry expert interviews, no further action would be needed. The findings and recommendations for the CD grouping are summarized in Section 5. For the MDC and MPC groupings, more in-depth review of the items prioritized by the POC were required and the in-depth review are detailed in this section.

Table 5. Final Table of Recommended Joint Improvement Practices and Materials.



Construction & Design (CD)			*Supplemental Methods & Materials During Construction (MDC)*			*Supplemental Methods & Materials Post-Construction and/or Low Joint Density Remedial/Repair (MPC)*[1]		
Item	*Coding*	*Minimum Agency Count*[0]	*Item*	*Coding*	*Minimum Agency Count*[0]	*Item*	*Coding*	*Minimum Agency Count*[0]
Echelon and/or Tandem Paving	CD-2	12 (24%)	Void Reducing Asphalt Membrane (aka Longitudinal Joint Seal)	MDC-4	16 (32%)	Penetrating Asphalt Emulsion	MPC-1	6 (12%)
Specific Joint Geometry Selection Vertical Butt Joint **Tapered Joint (inc. Notched Wedge)** Milled and/or Cut-Back Joint	CD-1	23 (46%)	**Coating Cold Joint Face with Asphalt Emulsion** – "Tack" (inc. single application, double application, etc.)	MDC-2	46 (92%)	Asphalt Emulsion Fog Seal	MPC-3	3 (6%)
Joint Density Measurement	CD-6	33 (66%)	Joint Adhesive and/or Hot Applied Asphaltic Coating Applied to Cold Joint Face	MDC-3	14 (28%)	Specialty Fog Seal – Not Necessarily Asphalt-Containing (Inc. Rejuvenating Fog Seal, Bio-Based, etc.)	MPC-4	2 (4%)
			Joint Reheaters (Infrared or Other)	MDC-1	4 (8%)	Micro-surfacing, fixed width/specialized	MPC-6	1 (2%)

[0] Count is Agencies that specify or have known recent or sustained experience via specification, provision, or change order of (for) line item; since not all information is public, the count is expressed as a "Minimum" count.

Good Probability of Improving Joint Performance

May Improve Joint Performance

Not Widely Practical for WisDOT

Bold Items = Current WisDOT Spec.

4.1 Supplemental Methods and Materials During Construction (MDC)

Two items from the MDC column were identified by the POC as high priority for this study. For each item, a detailed description of the material and process is given. If applicable, draft construction guidance is available in the Appendix. Finally, Table 6 presents a summary comparing the MDC items for relevant considerations; since information for joint adhesive was available from the literature search and it is widely used among agencies, it is also included in the summary table for reference. The following sections include the details for each option selected.

Void Reducing Asphalt Membrane / Longitudinal Joint Seal

Common Trade Names/Manufacturers: Trade name **"**Jband"; supplier: Heritage Group/Asphalt Materials Inc.

Specification: Available as special provision for material and process available (Appendix A, MnDOT draft example SPV).

Cost: Approximately \$2.25-2.50 / lineal foot in established regions (18); estimated at approximately \$3.00 / linear foot in newer markets as approximated by MnDOT staff. This includes all costs associated with placing material.

Treatment Description: A hot applied asphaltic membrane is sprayed onto existing paving substrate at the approximate location of the planned joint for a width of approximately 18 inches. The first paved lane pass will cover approximately ½ of the membrane width, and the second paving pass covers the second ½ of the membrane width. Alternatively, in scenarios with notched-wedge geometry, the membrane can be applied to the face of the completed notches and wedge before the second paving pass is placed as normal (Figure 12). The membrane material is a highly modified asphalt (such as PG 82-28) designed to resist flow and tracking after placement.

The membrane is intended to "migrate" into the air voids of the mixture being placed by way of heat and capillary action, thereby reducing permeability at and near the location of the joint. Literature suggests migration heights of up to 50-75% of the surface layer (18). The result is an asphalt-rich mixture near the finished joint that limits moisture and air intrusion.

Figure 12. VRAM applied to existing surface before paving (left); VRAM after placing first pass (center); final pass before rolling (right). Author photos.

Equipment: A specialized distributor is required to handle the highly modified membrane. Early iterations of the product were apparently available in rolls to be applied by hand. The distributor applies the currently available material at approximately 300-350 °F. Specifications for distributor requirements are included in the manufacturer provision. For smaller projects, use of an oil-jacketed kettle has been noted.

Construction Considerations: The manufacturer of Jband reports use for both dense (coarse and fine graded) and open graded mixtures for a variety of project scenarios, including new construction, mill and fill, and overlay over PCC. The material used does not change based on the project scenario, but the application rate is adjusted for both the mix design (coarse vs. fine, for example) and overlay thickness. Less material is used for fine graded mixtures and for low lift thicknesses. This information is included in the manufacturers provision.

Material tracking is a concern for hot weather and sometimes on milled surfaces (dust inhibits bonding), although the material is substantially trackless below approximately 130 °F (See Figure 13). Traffic can also contaminate the membrane with dust and debris, which in turn could affect migration height; it is therefore recommended to limit the amount of traffic crossing the membrane before paving. A pre-paving "checklist" is recommended and supplied by the manufacturer.

Typically, mixture density testing near the location of the joint is waived since the membrane increases the effective binder content of the mixture, thereby affecting both Gmb and Gmm to an unknown degree since migration could be to a variable height. Density testing of the mainline follows standard protocol.

Figure 13. VRAM tracking resistance showing some dust contamination from truck tires. Author photo.

Assurance of Quality : Material specification supplied in special provision generally follows PG+ testing requirements; work is needed to understand if all testing requirements are needed in Wisconsin and to accommodate the current testing capabilities of WisDOT. Generally, samples are taken from supply or distributor trucks during project to ensure conformance to specification. Material rates and geometry (width) are measured in the field in a similar manner as tack coat rate validation. Tracking of material is corrected by applicator and is based on visual inspection.

Asphalt Emulsion Tack Coat

Common Trade Names/Manufacturers: Commodity product: SS-1h, CSS-1h, etc.

Specification: DOT modified AASHTO material specification common. Process given by DOT specification.

Cost: Usually included in paving process but estimated at $0.10-0.25/SY depending on application rate, material specified, and job logistics.

Treatment Description: Asphalt emulsion tack coat (same as that used during paving process) is applied to the cold joint faces as part of the standard tack coat operations. Some agencies specify the use of a “heavier” layer of tack while others may specify a double application. The tack is allowed to break and dry before paving the second lane. An example of this process is shown in Figure 14; note that WisDOT have provisions in the Construction and Materials Manual specifying “full and even coverage” of tack coat, including on the cold joint face. The tack coat coverage in Figure 14 is considered non-uniform.

The residual tack is intended to help prevent movement of the mixture during placement of the second paving pass, thereby allowing for greater/more consistent density to be achieved. Given the low rate of application, the tack residue does not likely migrate into the mixture to a significant level. The tack residue may provide some moisture sealing benefits, although there is not consensus in the literature on this benefit (12).

Figure 14. Placing hot-side pass on tack coat against a milled out vertical joint (left) and on a notched wedge joint (right); State Highway 22, August and September, 2020. Author photos.

Equipment: No specialized equipment is required as the standard tack distributor is already onsite.

Construction Considerations: Tack can be used on any mixture type/project scenario, although the rate should be controlled based on project requirements. Tack should be allowed to dry before opening to traffic, although this appears to be more related to tracking than performance. Coverage and tracking of the material are cited as the two biggest considerations using commodity tack (Figure 15).

Figure 15. Pickup of tack coat residue on paving tires and removal from substrate. Author photo.

Assurance of Quality : Material supplied from approved supplier; DOT usually samples tack in field operations to ensure compliance. Rate calibration typically maintained by contractor and should be checked/verified in field operations by direct measurement of volume measurements. Coverage and tracking are inspected visually and corrected as required by engineer.

Table 6. Summary of MDC Items Prioritized by POC

Item	Description of Process	Equipment Required	Modification to Standard Plans/Processes	Design Considerations	Specification Availability	Quantifying Results/Quality Assurance	Environmental/Safety	Cost with description of units
Void Reducing Asphalt Membrane (VRAM) / Longitudinal Joint Seal (LJS)	Hot-applied asphalt material is sprayed on the existing substrate at a fixed width at the location of the proposed joint; paving commences over the membrane with each pass covering approximately ½” the width of the membrane (other options are possible)	Custom asphalt distributor or oil jacketed kettle (small projects/demo)	Process is separate from standard paving practice; material is placed before paving	Adjust rate for mixture gradation (fine vs. coarse) and layer thickness; monitor tracking of material before paving	Material, equipment, and process specification exists	Material specification for compliance; field rate verification	Exposure to hot applied materials (~300-350 °F)	Average awarded price in Illinois = $2.39/lineal foot (18” spray width typical = approx.. $14.50/SY); up to approximately $3.00/lineal foot for newer markets
Asphalt Emulsion Tack Coating Cold Face	Dilute asphalt emulsion (tack) is applied to cold joint face before paving adjacent lane	Tack distributor	None, tack already being used on project	Tack should be dry before paving adjacent lane; tracking of tack off of cold face	Already included in WisDOT standard specification	Material compliance; coverage verification (visual)	None	Usually included in paving bid price; estimated $0.10-0.25/SY.
Joint Adhesive	Hot applied polymer modified asphaltic material applied to the cold face of the joint before paving second pass	Usually placed by hand wand; Oil-jacket kettle is typical, other mobile units are available	Process is separate from standard paving practice; material placed between adjacent passes	Usually applied immediately before paving to ensure no tracking; rate is manufacturer recommended or experience	Manufacturer supplied material specification; widely available DOT specifications	Certification by the manufacturer; field sampling; coverage verification (visual)	Exposure to hot applied materials	Paid by linear foot; 2019 MnDOT published price $0.30/Linear Foot for approx. 1.75M feet. No conversion to SY.

4.2 Supplemental Methods and Materials Post-Construction (MPC)

One item from the MPC column was identified by the POC as high priority for this study: Penetrating Asphalt Emulsion. Feedback from the POC indicated that "a post construction treatment is critical to the success of this research project. The post construction treatment should be considered for both normal situations and for remedial treatment of a potential failing joint." As such, the inclusion of a remediation factor is added for the MPPC materials. Table 7 presents a summary of the selected MPC item for relevant considerations.

Penetrating Asphalt Emulsion

Common Trade Names/Manufacturers: Rapid Penetrating Emulsion (RPE) by Asphalt Materials Inc.

Specification: Special provision for longitudinal joint treatment is included as Appendix B. Modified AASHTO material specification to include "identification" tests for penetration and water resistance (also included in Appendix B).

Cost: Approximately $0.50/SY depending on application rate, material specified, job logistics, and market maturity.

Treatment Description: The currently available RPE is a dilute SS-1h asphalt emulsion containing a specialty chemical package that promotes penetration of the asphalt emulsion into the substrate before breaking (Figure 16). The product is handled and applied like a standard asphalt emulsion tack. The product is applied at a fixed width over the finished longitudinal joint at a width and rate determined based on project requirements, but is typically applied at 0.10 gal/SY over an 18" width centered at the joint (19). The product can be applied at any time following construction, but restriping is commonly required if applied over paint markings. The manufacturer claims the cured surface does not substantially impact marking adhesion of marking to surface of pavements after penetration. Curing time is dependent on ambient conditions, but because the product penetrates the surface, it is usually non-tracking within one half hour, and water resistance is achieved within one hour according to the manufacturer.

The cured treatment is expected to fill the voids and reduces air void content at and near the joint, thereby reducing mixture permeability (Figure 17). Because the treatment changes the Gmm of the mixture to a variable degree, nuclear density testing following treatment can be misleading. For remediation areas, multiple applications at varying rates are possible.

Figure 16. Rapid Penetrating Emulsion used as a longituinal joint preventative treatment immediately following application (left), after penetrating joint (center), and dried (right). (19).

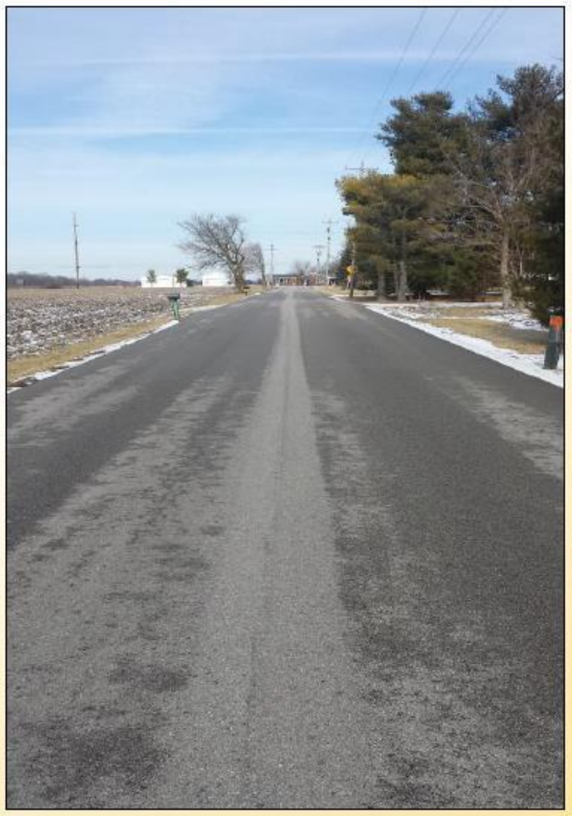


Figure 17. Treated joint during Spring melt event showing water resistance (19)

Equipment: Standard tack distributor is typically sufficient, although a separate distributor is needed to prevent mixing of materials. Care should be taken to avoid contamination. Distributor must be able to apply at a uniform rate and coverage.

Construction Considerations: RPE can be used on any mixture type/design scenario, although penetration is affected by mix design variables. Typically, new (same construction season) pavement surfaces allow more complete penetration because they exhibit the lowest density and have minimal surface contamination from dust and debris. Timing after construction is not critical, although pavement markings may inhibit penetration at that area and re-striping might be required. Application rate should be adjusted to ensure complete product penetration, which may require lowering the target application rate; lack of penetration will cause excess residue to cure on surface, which may negatively affect texture until the residue is worn away (similar to standard fog seal). Weather conditions should match those typically cited for standard emulsion tack coat, although rapid water resistance is part of the material qualification testing protocol. Tracking of fresh, uncured material may be a concern if applying under live traffic.

RPE can be used as a remedial treatment at joint locations that do not conform to WisDOT density specifications although the impact on air void level (density) at those locations would likely require coring since as mentioned nuclear density readings will be impacted by the residue. For remediation type treatment, RPE can be applied as a "spot treatment" or as a uniform fog. Examples of such a treatment method are shown below for U.S. Highway 53 in Chippewa County, Wisconsin, 2020 (Figure 18).

Figure 18. RPE remedial application to low joint density area (left); after penetration and drying (right). Author photos.

Assurance of Quality : Material supplied from approved supplier; DOT usually samples product in field operations to ensure compliance. Material "identification" tests are non-standard test methods that may require additional laboratory equipment to conduct the test (Figure 19). Rate calibration typically maintained by contractor and should be checked/verified in field operations by direct measurement of volume measurements. Coverage and penetration are inspected visually and corrected as required by engineer and material supplier. Coverage should be uniform (indicating no bare spots or heavy areas). Penetration often manifests in an uneven look to the surface texture of the underlying pavement as the emulsion penetrates higher permeability areas at a higher rate than low permeability areas (Figure 16). The dried emulsion should allow the underlying macro-texture to be clearly visible (Figure 18, right) as an indicator the material was not over applied. The rate is ultimately selected based on the goals of the project (preventative vs. remedial, for example).

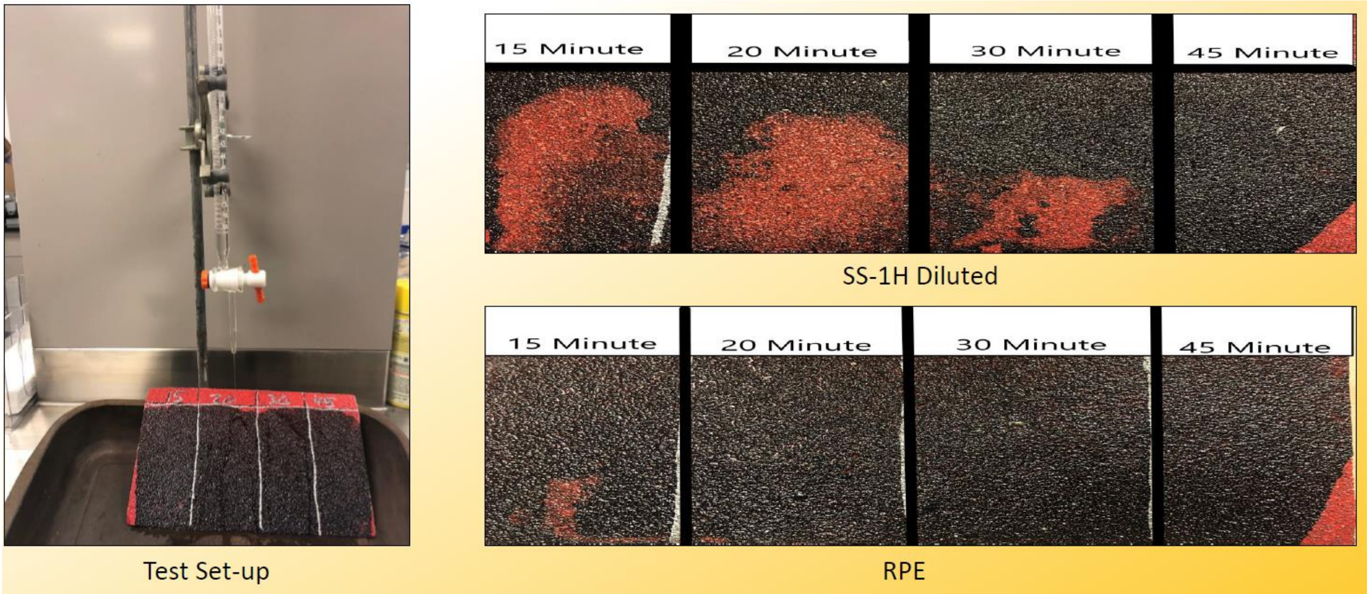


Figure 19. Photo of water resistance test set up and typical result for SS-1h and RPE (19)

It is important to mention that all supplemental materials and processes will add cost and logistical considerations to the construction phase of a given project and therefore should be justified in terms of performance. Trepanier et al. (2021), for example, estimate that the life extension at the joint when using VRAM compared to a control with no treatment is 3-5 years. Using the Illinois model for costs and replacement value the authors estimate a lifetime savings of 3-5 times the cost of installing the VRAM. Although no direct cost analysis was possible for this project, a similar approach could be followed utilizing the PCI database referenced in Section 3 of this report and documenting maintenance and rehabilitation costs in Wisconsin.

Table 7. Summary of MPC Item Prioritized by POC

Item	Description of Process	Equipment Required	Modification to Standard Plans/Processes	Design Considerations	Specification Availability	Quantifying Results/Quality Assurance	Environmental/Safety	Cost with description of units
Penetrating Asphalt Emulsion	Asphalt emulsion is applied at a fixed width centered on finished joint. Rate is selected to ensure complete penetration. Can be used as preventative and remedial type treatment.	Standard asphalt emulsion distributor	Process is separate from standard paving practice; material is placed after paving is complete or later in season/subsequent seasons	Adjust rate for mixture variables/age. May not penetrate markings; re-striping may be required	Material, equipment, and process specification exists	Material specification for compliance; field rate verification	None.	Approximately $0.50/SY for established markets

5. Summary and Recommendations

5.1 Summary of Findings

The principal objective of this project is to synthesize information about best practices for longitudinal joint construction utilizing the most promising materials/methods to deliver better joints. The information is used to recommend the best promising materials and methods so that WisDOT engineers can implement in the pavement design and construction guidelines or specifications.

Based on the information gathered, a causal mechanism of joint deterioration is defined as follows: "Premature longitudinal joint distress is caused by damage resulting from intrusion of water and air into the asphalt mixture at and near the joint." Information and data extracted from a literature review, review of State Agency standard practice, review of WisDOT pavement distress survey data, and interviews with a number of pavement experts is used to define the most probable solutions to improve joint performance based on this understanding of distress cause.

Findings of this study indicate that reducing mixture permeability at and near the joint is the most promising method to improve joint performance. Reducing permeability can be achieved in various ways using both construction-related factors and supplemental materials. The research team defined a framework to summarize improvement processes and materials currently used into three groupings. The following points summarize the major findings from in-depth analysis of best promising improvements identified for each grouping:

- ***Construction & Design (CD) Group:***
  - There is not consensus in the literature regarding a joint geometry that categorically results in the highest quality joint across all pavement types and design scenarios.
  - The added safety advantages of tapered and notched wedge type geometries make them preferable when the joint will be exposed to live traffic. There are concerns about the ability to effectively densifying the thinner portion of the wedges of such joints as they have lower thickness to NMAS ratios. Contractor familiarity with producing the notched wedge joint should continue to increase delivered quality, and hence, performance.
  - In general, there is consensus in the literature that joint quality is substantially controlled by workmanship and contractor experience. Several rolling patterns may produce a joint similar in quality for a given project, but no single pattern could be identified as the best;
  - Density measurement (either by nuclear/electronic gage or cores) is the most practical method to measure joint quality available today, although calibration of gage readings to actual joint density is required and is critical. Achieving density, however, does not always translate in lower permeability as void interconnectivity is affected by other mix design factors. No reliable or practical methods to measure field permeability as part of standard quality control practices were found during this study.
- ***Materials During Construction (MDC) Group:***
  - There is limited information in published literature confirming the use of standard tack coat on the joint face can effectively improve joint performance, although use of tack coat is unlikely to negatively affect construction practice or joint performance.
  - Use of hot-applied joint adhesive is relatively common across the U.S., although findings from the literature show mixed efficacy. Joint adhesive addresses the joint itself (discontinuity between the paved lane) but does not significantly affect permeability of mixture near the joint.
  - Use of Void Reducing Asphalt Membrane (VRAM) / Longitudinal Joint Seal (LJS) is claimed to be a promising material means to reduce permeability at and near the joint location.

        - Although a specification and construction provision exists (Appendix A) that should allow rapid implementation on a trial basis, more work is required to understand the material properties that control performance in Wisconsin and whether other simpler materials may serve a similar purpose. In some instances alternative testing methods may be necessary accommodate the current testing capabilities of WisDOT.
        - One Illinois DOT published study (18) estimated the life extension at the joint of 3-5 years with the use of VRAM, from which the study calculated a potential life cycle savings of 3-5 times the treatment cost. Pavement Condition Index data analyzed during this project indicated that average onset of joint distress when untreated in Wisconsin is approximately four years after placement; no cost analysis was possible for this project.
- ***Materials Post-Construction (MPC) Group:***
    - The most promising material discovered in this grouping is penetrating asphalt emulsion, which can be used as both a preventive treatment and remediation treatment in the case of non-conforming joint density.
        - A manufacturer-derived specification and construction provision exists (Appendix B) for “Rapid Penetrating Emulsion” that should allow rapid implementation of a trial basis; similar to VRAM/LJS more work is required to understand the material properties that control performance in Wisconsin,

5.2 Recommendations with Respect to Current WisDOT Practice and Specification

Based on the findings of this project, the following recommendations are made for consideration by WisDOT for implementation or modification to standard practice and specification:

- No change is recommended to the recent WisDOT effort to harmonize joint geometry among regions to the default of a notched-wedge geometry for dense graded mixtures; although NMAS relative to the standard notched wedge geometry should be evaluated to ensure reasonable compaction for all NMAS.
- There is literature support for cut back/milled out joints; a focused study of core density at the location of the joint and an analysis of the costs associated with the production of these joints is therefore recommended in the context of allowing the contractor to choose this type of geometry among other options.
- The measurement of joint density as a surrogate for quality is justified but attention to the following details is recommended;
    - Further work is required to correlate pavement cores to nuclear gauge readings to better understand how the current measurement practice correlates to actual joint density;
    - Review of available joint density data indicates that contractors are substantially able to meet the currently specified minimum density requirements at the joint (1.5% reduction in density allowed for confined side of joint, 3.0% reduction for unconfined side); it is recommended WisDOT review these limits in context of their effect on mixture permeability. This is an opportunity for a laboratory study to justify the 3.0% air void increase currently allowed in the SPV for the unconfined joint.
- Use of tack coat on the cold joint face is not likely to negatively impact join performance, and no change to this provision is recommended.
- The Pavement Condition Index database kept by WisDOT is an invaluable tool to understand costs associated with joint performance, but data should be analyzed on individual project basis. This process could help justify the use of more costly processes/materials for improving joint performance.
- Controlled trial projects utilizing Void Reducing Asphalt Membrane (VRAM) / Longitudinal Joint Seal (LJS) is recommended with the following considerations:

    - Early projects should utilize a version of the material and process provision included in Appendix A, but it is noted that other simpler materials may also perform well, and it is recommended WisDOT continue to evaluate material properties needed for this usage;
    - It is recommended the joint density provision (with associated incentives and disincentives) be waived on projects utilizing VRAM or the Contractor being given the option of testing joint density as a pay factor or utilizing VRAM.
    - Consideration should be given to projects that require higher levels of reliability or that present safety risks for testing joint density (interstate work, night work, etc.); careful tracking of joint (and mainline) performance of these projects is critical to understanding the cost-benefit of using this treatment.
- Controlled trial projects utilizing penetrating asphalt emulsion ("RPE") are recommended with the following considerations:
    - Early projects should utilize the material and process provision included in Appendix B, but it is noted that other materials may also perform well, and it is recommended WisDOT continue to evaluate best material properties for this usage.
    - Use of penetrating emulsion as a remedial treatment option is justified, although the extent to which the product corrects the nonconformity (low density) is unknown and may be difficult to measure.

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Appendix A: Minnesota DOT Special Provision for Void Reducing Asphalt Membrane

(2331) VOID REDUCING ASPHALT MEMBRANE (VRAM)

SP20XX-XXX

DESCRIPTION

This Work consists of applying a void reducing asphalt membrane (VRAM).

The VRAM is applied underneath the longitudinal construction joint(s) as shown on the typical sections, prior to paving the final lift of a hot-mix asphalt (HMA) pavement.

MATERIAL

Provide void reducing asphalt membrane meeting the criteria in Table 1.

Add Elastomers to the base asphalt. Use either a styrene-butadiene diblock or triblock copolymer.

TABLE 1 – VOID REDUCING ASPHALT MEMBRANE CRITERIA

TEST	CRITERIA	TEST METHOD
Dynamic shear @ 88°C (unaged), G*/sin δ	1.00 kPa minimum	AASHTO T 315
Creep stiffness @ -18°C (unaged) Stiffness (S) m-value	 300 MPa maximum 0.300 MPa minimum	AASHTO T 313
Ash, %	1.0% - 4.0%	AASHTO T 111
Elastic Recovery, 100 mm elongation, cut immediately, 25°C	70% minimum	ASTM D6084 method A
Separation of Polymer, difference in ring and ball+	3°C maximum	ASTM D7173

CONSTRUCTION REQUIREMENTS

A. Equipment Requirements

Pressure distributor

to apply the VRAM at the desired application rate. Prevent localized overheating by using a distributor with a heating and recirculating system, and an agitating system or vertical shaft mixer.

Melter kettle

for transporting and/or application of the material, capable of applying the VRAM at the desired application rate. Use an oil jacketed double-boiler type with agitating and recirculating systems. Material from the kettle may be dispensed through a pressure feed wand with an applicator shoe or with a spray bar.

B. Material Handling

Provide the Engineer with one copy of the manufacturer's recommendations for heating, re-heating, and applying the void reducing asphalt membrane at the pre-construction meeting.

C. Void Reducing Asphalt Membrane Application

Clean the pavement surface by sweeper/vacuum truck, power broom, or air compressor before VRAM is applied. VRAM can only be applied to a clean and dry surface.

Apply the VRAM within 2 inches of the project established centerline or established lane edge. Use a stringline or paint mark as a guide for the application to maintain a uniform edge alignment. When only one-half of the joint is exposed, such as a mill and inlay project, apply one-half the prescribed width and rate, adjacent to the center of the joint, and coat the vertical face of the cold joint left in place.

Apply the VRAM to the existing surface prior to the tack coat applications. VRAM may be applied over fully cured tack.

Determine the application rate of VRAM based on the maximum aggregate size of the mixture

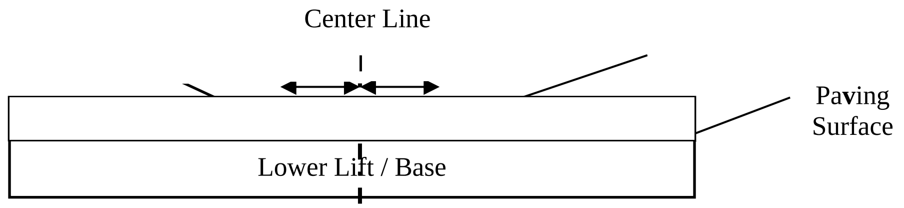
Apply the VRAM, to the existing surface at the width and target application rates in Table 2

TABLE 2 – VRAM APPLICATION

Aggregate Size B (-3/4”)		
HMA Thickness, inch	**VRAM Width, inch**	**Application Rate, pounds per foot**
1 ½	18	1.47
1 ¾	18	1.63
≥ 2	18	1.80
Aggregate Size A (-1/2”)		
HMA Thickness, inch	**VRAM Width, inch**	**Application Rate, pounds per foot**
≥ 1 ½	18	0.95
SMA Mixtures/SuperPave 5 Mixtures*		
HMA Thickness, inch	**VRAM Width, inch**	**Application Rate, pounds per foot**
1 ½	18	1.26
1 ¾	18	1.38
≥ 2	18	1.51

Notes.

*In the event of a joint between an SMA and an HMA mixture, the SMA application rate will be used.



Apply the VRAM in a single pass placed by any application method listed in the Equipment section. VRAM application temperature shall not exceed 330°F.

Apply the VRAM at a width of not less or greater than 1.5 inches of the width specified in the plans. If the width is outside that tolerance, stop placement of the VRAM and take remedial action.

Construction traffic should be able to drive on the VRAM without pick up or tracking, within 30 minutes of placement. Placement of the VRAM will stop and take remedial action if pick up or tracking occurs.

Ensure the paver end plate and grade control device are not in contact with the VRAM.

Exclude the area 1.0 ft on either side of the longitudinal joint from density measurement and pay adjustment.

Check the application rate of VRAM within the first 1,000 linear feet of the day’s application length and every 12,000 linear feet the remainder of the day. Check the rate twice for projects less than 12,000 feet in length. Check the rate by weight per foot. Place a paper or pan at a random location in the path of the VRAM application. Pick up and weigh the paper or pan after application of the VRAM. Calculate the weight per foot. Replace the VRAM in the area where the application rate was checked. The tolerance for the Plan target weight per foot from the VRAM Application Rate Table is ± 10%. Re-apply VRAM in any areas that are deficient by more than 10% of the required application rate. Remove and replace, as directed by the Engineer, VRAM in any areas that show an excess of more than 10% of the required application rate.

QUALITY CONTROL/QUALITY ASSURANCE

Acceptance of the VRAM is based on the certification by the manufacturer that the material meets the requirements listed in T**able 1 – void reducing asphalt membrane**

Field sampling will be used to verify that the delivered VRAM meets the requirements of the specification. The Contractor shall take a sample from the spray bar or applicator shoe during the first 20 minutes of placing VRAM on the Project. After the first sample is taken sample for every 25,000 gallons of material used on the project. Sample in the presence of the Engineer.

Each sample shall consist of a one quart aluminum or steel sample containers. Labeled the sample container with SP number, date, time, location, manufacturer, and BOL number of the sealant.

METHOD OF MEASUREMENT

The Engineer will measure the VRAM by the linear foot, for both full width and half width applications.

BASIS OF PAYMENT

The contract unit price for VRAM shall be compensation in full for equipment, material and labor required to complete the work.

The Engineer will address failures related to material requirements in Table 1 or deficiencies related to workmanship or application in accordance with 1512, “Unacceptable and Unauthorized Work the Engineer may deduct up to 25% of the VRAM Unit Price for material requirement failures.

The Department will pay for VRAM on the basis of the following schedule:

Item No.	Item	Unit
2331.603	Void Reducing Asphalt Membrane, full width	linear foot
2331.603	Void Reducing Asphalt Membrane, half width	linear foot

Appendix B: Example Generic Special Provision for Rapid Penetrating Emulsion Centerline Application

Description.
This specification covers the requirements and practices for applying a rapid penetrating asphalt emulsion (RPE) at the surface of an asphalt pavement at and near the location of a longitudinal joint. Application shall be a minimum width of 18 in., centered on the joint line, and shall be extended, when necessary, to provide coverage as need at the discretion of the Engineer.

Materials.
The type and grade of asphalt material shall be in accordance with the following table. The table includes test methods developed to measure surface penetration performance and its ability to resist water and/or re-emulsification.

Tests on Emulsion	**Test Method**	**Test Requirement**
Viscosity, 25C, SFS	AASHTO T72	50 max
Sieve test, %	AASHTO T59	0.1 max
Identification test, %	Test Method A**	60 min
Water resistance test, %	Test Method B**	60 min
Residue by distillation*, %	AASHTO T59	30 min
Oil in distillate by volume of emulsion	AASHTO T59	1.0 max
Tests on Residue		
Penetration, 25C, 100g, 5s, dmm	AASHTO T49	150 max
Solubility in trichlorethylene, %	AASHTO T44	97.5 max

*300g of emulsion may be used to obtain enough residue for residue testing
**See Below

Construction Requirements.
A pressure distributor shall be provided that is capable of applying RPE within a certain range of applicationrates. The distributor shall be capable of recirculating material for mixing and agitation purposes. The distributor shall be capable of heating the RPE to a temperature of at least 180°F. The distributor shall be equipped with appropriate spray nozzles for the specified application rates and provide uniform coverage. Material may be dispensed through a pressure feed hand wand attached to a portable storage unit or pressuredistributor provided temperature is maintained and application rate can be accurately measured.

The contractor may use a portable storage unit or transfer trailer with mixing and heating capabilities to transport larger quantities of material to the job site.

Preparation of Surface.

Prior to the application of the RPE, the Engineer shall ensure the application area is free of debris and moisture. The area may be cleaned by sweeper/vacuum truck, power broom, air compressor or hand to thesatisfaction of the Engineer.

Application of RPE.

RPE shall be uniformly sprayed at a rate between 0.08 to 0.13 gallon per square yard at a width of 18 inches, centered at the joint location or as specified by Engineer. The rate shall be within +/- 0.02 gallon per square yard of the selected rate. No traffic shall be permitted on the newly appliedRPE until it is non-tracking. The emulsion shall be cured a minimum of two days prior to applying the permanent pavement traffic markings.

Acceptance.

Provide a Bill of Lading to the Engineer for every tanker or distributor supplying material to the project.
For the centerline application, the rate will be checked in 3 different locations randomly within the first 1,000 feet of the day’s application and every 6,000 linear feet. If the initial rate check is off, the rate shall be adjusted and checked within the next 1,000 feet. This process shall be repeated until the desired rate is met. The rate will be checked by gallons per square yard. The rate shall fall within the tolerances specifiedin the construction section.

Method of Measurement.

Centerline application with RPE will be measured in square yards.

Basis of Payment

RPE will be paid for at the contract unit price per square yard for full-width applications complete in place.

Pay Items	**Pay Unit Symbol**
RPE	SY

The cost of materials associated with field rate checks, sweeping, cleaning, and other incidentals shall be included in the cost of the pay item.

Mandatory Information:

TEST METHOD A:

Standard Test Method for Identification of Penetrating Emulsified Asphalts

1. Scope

1.1 This test method, applicable to both anionic and cationic emulsified asphalts, can be used as an identification test of the emulsions ability to penetrate a compacted asphalt mixture or a granular aggregate material.

2. Referenced Documents

2.1 ASTM Standards:

E 11 Specification for Wire Cloth and Sieves for Testing Purposes

D 6934 Test Method for Residue by Evaporation of Emulsified Asphalt

D 6997 Test Method for Distillation of Emulsified Asphalt

3. Significance and Use

3.1 This test method is used to identify or classify an emulsified asphalt as having a penetrating capability as measured by the amount of emulsified asphalt that can pass through a 500 wire sieve in a period of 5 minutes.

4. Sample Conditioning for Testing

4.1 All emulsified asphalts shall be properly stirred to achieve homogeneity before testing.

4.2 Warm the emulsified asphalt to 50 ± 3°C in an oven or water bath. After the sample reaches 50°C, stir the sample to achieve homogeneity.

5. Apparatus

5.1 *Wire Cloth Sieve* – 3” round sieve, number 500 mesh (25 um).

5.2 *Receiver/pan/can* – metal container of size to collect emulsified asphalt passing the wire cloth sieve.

5.3 *Balance* – capable of weighing 500 ± 0.1 g.

5.4 *Water bath* – constant temperature, maintained at 50 ±0.5C

5.5 *Oven* – capable of maintaining a temperature of 50 ± 3C.

5.6 *Thermometric Device* – thermometer 15C or 15F as prescribed in Specification E 1, or equivalent thermometric device.

5.7 *Timer* – capable of measuring time to ± 5 seconds.

6. Procedure

6.1 Dilute the emulsified asphalt with distilled water to a residue of 38%, as determined by distillation (Test Method D 6997) or by evaporation for 3 h at 163 ± 3°C. (Test Method D 6934).

6.2 Warm the diluted emulsified asphalt to 50 ± 3°C in a water bath or oven.

6.3 Tare the receiver/pan. Assemble the 3” sieve and receiver/pan on the balance. Pour 20 ± 0.1 g diluted emulsified asphalt onto the sieve. Immediately after the emulsified asphalt is poured on the sieve, start the timer. After 5 minute ± 15 seconds, remove the sieve from the assembly. Record the mass in grams of emulsified asphalt retained in the receiver/pan.

6.4 Clean the sieve by rinsing with soft water to remove emulsion. Then wash with Acetone, followed by TCE to remove asphalt solids, and another washing with Acetone to remove any excess TCE and RPE chemicals. Air dry the sieve using a pressurized air hose until moisture is gone, and allow the sieve to return to room temperature before conducting another test.

7. Calculation

7.1 Calculate the percent of emulsion passing the #500 sieve in 5 minutes as follows:

Mass retained in pan/20 x 100 = % of emulsified asphalt passing #500 sieve

8. Report

8.1 The average of three tests for % of emulsified asphalt passing the #500 sieve.

TEST METHOD B:

Standard Test Method for Mass Retention of Emulsified Asphalts Subjected to Water Droplets

1. **Scope**
   - **1.1.** The method gives a measure of water resistivity and how quickly an applied asphalt emulsion can become water resistant. This test method is used to measure material runoff caused by a rain effect at different time intervals, allowing the method to measure differences in drying times between products of different formulations.
2. **Referenced Documents**
   - **2.1.** *ASTM Standards:*
     - **2.1.1.** D 6934 Test Method for Residue by Evaporation of Emulsified Asphalt
     - **2.1.2.** D 6997 Test Method for Distillation of Emulsified Asphalt
3. **Significance and Use**
   - **3.1.** This test method is used to measure the effects of secondary additives in Void Filling Emulsions or modified asphalt emulsions on the ability to dry quickly and become resistant to water droplets simulating rainfall.
4. **Sample Conditioning for Testing**
   - **4.1.** All emulsified asphalts shall be properly stirred to achieve homogeneity before testing.
   - **4.2.** Warm the emulsified asphalt to 50 ± 3°C in an oven or water bath. After the sample reaches 50°C, stir the sample to achieve homogeneity.
   - **4.3.** All sandpaper strips should be measured and cut from 8.5”x11” sheets of red P50 grit sandpaper at room temperature.
   - **4.4.** For each trial, 4 strips should be cut to 5.5±0.1” tall by 2±0.1” wide with scissors. Label the top of these strips “A”, “B”, “C”, and “D”.
5. **Apparatus and Materials**
   - **5.1.** *Receiver/pan* – Two large pans for collection of excess emulsion during application and water runoff during test.
   - **5.2.** *Water Release Device* – 100mL titration burette with stopcock, able to measure to tolerance of ±1mL.
   - **5.3.** *Balance* – capable of weighing 10±0.01g.
   - **5.4.** *Oven* – capable of maintaining a temperature of 50±3C
   - **5.5.** *Thermometric Device* – thermometer 15C or 15F as prescribed in Specification E 1, or equivalent thermometric device
   - **5.6.** *Timer* – Capable of measuring time to ±5 seconds
   - **5.7.** *Drying Apparatus* – wire rack or flat metal pan for drying at room temperature and in conditioning oven
6. **Procedure**
   - **6.1.** Determine residue of the emulsified asphalt sample by distillation (Test Method D 6997) or evaporation for 3 h at 163 ± 3°C. (Test Method D 6934).
   - **6.2.** Fill titration burette full of RO water
   - **6.3.** Prepare your data collection table as shown in *Table 1.*
   - **6.4.** Record the dry weight of each sandpaper strips individually into the data table under *Measurement A* to the nearest 0.01g.
   - **6.5.** Lay the strips so they lean against the edge of the pan at an approximate 45-degree angle. Pour your sample across each of the strips, getting full coverage below the top half-inch.

6.6. Allow excess material to drip off the strips and immediately weigh each strip individually, recording under *Measurement B.*

6.7. Allow the strips to dry for 15 minutes. Position the strips in another collection pan below the titration burette. Be sure the burette tip is 1.5 ± 0.1 inches above the sandpaper strip.

6.8. Fully open the burette and drip 10 ± 0.5 mL of water onto the strip at full flow rate. Place the strip into the oven to cure for 2 hours. Repeat for the remaining strips.

6.9. Remove the strips from the oven and cool to room temperature. Weigh the final mass of the strip with dried residue and record under *Measurement C.*

7. Data Collection

Emulsion Name				**Start Time:**	*Enter Start Time Here*	**Tested Asphalt Residue Content**	*Enter % Tested Residue Here (X%)*		
Measurement	Trial 1	Trial 2	Trial 3	Trial 4		T1	T2	T3	T4
A =					R_a				
B =					R_c				
C =					$\%R_{Ret}$				

Table 1: Data Collection Table

Where

A = Mass of dry sandpaper strip

B = Mass of sandpaper strip and applied material immediately after application

C = Mass of sandpaper strip and residue after 2 hours curing in 50°C oven

R_a *= Residue applied before curing and water resistance test*

R_c *= Residue leftover after oven curing*

$\%R_{Ret}$ = Percent Residue Retained

X = Tested Emulsion Residue percentage by distillation or evaporation

8. Calculations

$$Residue\ Applied = R_a = (B - A) * X$$

$$Residue\ After\ Oven\ Curing = R_c = (C - A)$$

$$\%\ \boldsymbol{Residue\ Retention} = \%\boldsymbol{R_{Ret}} = \frac{\boldsymbol{R_c}}{\boldsymbol{R_a}} * \mathbf{100}\%$$

Appendix C: U.S. Agency Standard Specification Database

Numeric Coding Key*	
Construction Design & Methods (CD)	
1	Joint Offset
2	Paver Reference Lines/Automatic Adjustment
3	Guidance to Minimize Segregation during Placement and Spreading
4	Specific Geometry Selection
5	Echelon or Tandem Paving
6	Specialized Joint-PreCompactor or Forming Equipment
7	Joint Reheaters
8	Cold Side Overlap/Pinching
9	Rolling Pattern/Roller Type
10	Joint Density
Materials & Methods During Construction (MDC)	
1	Direct Tacking or Double Tacking Joint Face
2	Joint Adhesive
3	VRAM/LJS
4	Penetrating Emulsion
Materials & Methods Post-Construction/Low Density Remedial (MPC)	
1	Penetrating Emulsion
2	Rubberized Crack Sealing/Over Banding
3	Asphalt Emulsion Fog Seal (Commodity)
4	Non-Asphalt Fog Seal
5	Mastic Treatment
6	Micro-Surfacing
7	Spray/Injection (Blow) Patching

***May not match WHRP 21-05 Final Report Coding; this database was used to refine selections for 21-05final reporting**

Agencies that Specify or have Known Recent or Sustained Experience via Specification, Provision, ChangeOrder, or Research Trial

Agency	Publication Year of Specification Reviewed	Relevant Section(s)	Construction Design &Methods (CD)	Materials & Methods During Construction (MDC)	Materials & Methods Post-Construction/Low Density Remedial (MPC)
Alabama	2018	407; 410.03h	1,2,3,9	1,2	
Alaska	2020	401-4	1,2,3,5,7,10	1,2	2
Arizona	2008	404 -417	1,2,3,4,6,10	1	
Arkansas	2014	401	1,2,3,4,6,8,9,10	1	2
California	2018, Rev.2020	39	1,2,3,4,6,10	1	
Colorado	2019	401-408	1,2,3,4,6,10	1	
Connecticut	2016	406	1,2,3,4,6,10	1,2	
Delaware	2016, Rev.2019	401	1,2,3	1,3	2
Florida	2020	300	1,2,3	1	
Georgia	2013	400	1,2,3,9	1	
Hawaii	2005	401	1,2,3,4,9	1	
Idaho	2018	405	1,2,3,9,10	1,3	
Illinois	2016; LJS Provision 2019	406	1,2,3,4,6,9,10	1,3,4	1
Indiana	2020	401	1,2,3,9,10	2,3,4	1,2,3,4
Iowa	2020	2303/2540	2,3,8,9,10	1,3	
Kansas	2007	600	1,2,3,10	1	
Kentucky	2019	403	1,2,3,5,10	1,4	
Louisiana	2016 /2018	501	1,2,3,4,9	1	
Maine	2020	400	2,3,4,5,6,10	1	
Maryland	2020	500	1,2,3,4,8,9	1,3	
Massachusetts	2020	450	1,2,3,4,5,6,10	1,2,3	
Michigan	2020	500	1,2,3,4,8,9,10	1,3,4	
Minnesota	2018	2365	1,2,3,8,10	1,2,3	3,5,6,7
Mississippi	2017	400	1,2,3,9	1,2	
Missouri	2020	400	1,2,3,6,10	1,3,4	

RED are "wet-freeze" region States

*May not match WHRP 21-05 Final Report Coding; this database was used to refine selections for 21-05 final reporting

**Count is Agencies that specify or have known recent or sustained experience via specification, provision, or change order of (for) line item; since not all information is public, the count is expressed as a minimum

Agencies that Specify or have Known Recent or Sustained Experience via Specification, Provision, Change Order, or Research Trial

Agency	Publication Year of Specification Reviewed	Relevant Section(s)	Construction Design &Methods (CD)	Materials & Methods During Construction (MDC)	Materials & Methods Post-Construction/Low Density Remedial (MPC)
Montana	2020	401	1,2,3,4,8,10	1,3	
Nebraska	2017	500	2,3,4,6,7,9	1	
Nevada	2014	400	1,2,3,10	1	
New Hampshire	2016	400	1,2,3,4,5,8,9	1,2	
New Jersey	2019	401	1,2,3,4,5,6,8	2,3	
New Mexico	2019	423	1,2,3,4	1	
New York	2020	401	1,2,3,8,9,10	2	
North Carolina	2018	600	1,2,3,8	1	
North Dakota	2014	430	1,2,3	1	
Ohio	2019	400 / SS806	2,3,5,8,9,10	2,3,4	
Oklahoma	2019	411 / OHD-14	1,2,3,9,10	1	
Oregon	2021	735	1,2,3,4,9	1	
Pennsylvania	2020	405	1,2,3,6,8,9,10	2,3	2
Rhode Island	2004/ Amended2018	400	1,2,3,4,10	1	
South Carolina	2007	401	1,2,3,8,9	1,3	
South Dakota	2015	320	1,2,3,9	1	
Tennessee	2015	407	1,2,3,5,9,10	1,2	3,4
Texas	2014	300	1,2,3,10	1	
Utah	2020	2741-2744	1,2,3,4,5,10	1	2
Vermont	2018	406	1,2,3,4,5,6,7,10	1	
Virginia	2020	315	1,2,3,5,9,10	1	
Washington	2020	5-04.3(12)	1,2,3,4,6,10	1,2	
West Virginia	2017; 2020 Supplement	401	1,2,3,10	1	2
Wisconsin	21; PWL Density Spec.	--	2,3,4,5,6,7,10	1,3	1
Wyoming	2010	400	1,2,3,4,10	1,3	

RED are "wet-freeze" region States

*May not match WHRP 21-05 Final Report Coding; this database was used to refine selections for 21-05 final reporting

**Count is Agencies that specify or have known recent or sustained experience via specification, provision, or change order of (for) line item; since not all information is public, the count is expressed as a minimum

CD			MDC			MPC		
Coding	**Count ****	**Frequency**	**Coding**	**Count ****	**Frequency**	**Coding**	**Count ****	**Frequency**
1	45	90%	1	46	92%	1	3	6%
2	50	100%	2	14	28%	2	7	14%
3	50	100%	3	16	32%	3	3	6%
4	23	46%	4	6	12%	4	2	4%
5	12	24%				5	1	2%
6	15	30%				6	1	2%
7	4	8%				7	1	2%
8	13	26%						
9	23	46%						
10	33	66%						

****Count is Agencies that specify or have known recent or sustained experience via specification, provision, or change order of (for) line item; since not all information is public, the count is expressed as a minimum**

State, W/F Region (a-z)	Standard Specification Directly Specifies Joint Geometry	Commentary on Joint Geometry	Other Commentary
Connecticut	Y	• NW when lift thickness between 1.5-3 in for most mix classes;	Joint density state
		• VB joints to be used outside of this range or **S1 mix** types;	Joint adhesive used
		• Standardized NW geometry	
Deleware	N	NA	Delaware specifies 6" joint offset; specifies immediately sealing all newly laid joints that will not be overlaid with ASTM D6690, Type II sealant; specifies tack on all surfaces
Illinois	Y	• VB and NW allowed;	LJS used on most I DOT major projects
		• NW to be used when lane open to traffic and > 2 in between lanes;	
		• Standard geometry with variability	
Indiana	N	NA	Indiana specifies an offset of approximately 6"; hot-pour joint adhesive on the joint face and a fog-seal over the finished joint is specified
Iowa	N	NA	Joint density state
Kentucky	N	NA	Joint density state
Maine	Y	• NW and VB allowed with provisions for placing each depending on lift thickness	
		• Standardized NW geometry	

State, W/F Region (a-z)	Standard Specification Directly Specifies Joint Geometry	Commentary on Joint Geometry	Other Commentary
Maryland	Y	• VB Joint with overlap of 1-1.5”	Maryland SS 504.03.08 has an eight point list for joint construction, including offsetting joints; tacking joints, the "Maryland Joint": Overlap the existing pavement 1 in. to 1.5 in. when constructing longitudinal joints
			adjacent to existing asphalt pavements; and "initial longitudinal roller pass shall be on the uncompacted hot mat and 6 in. to 1 ft from the joint. The successive roller pass shall compact the overlapped material and the 6 in. to 1 ft material simultaneously"
Massachusetts	Y	• NW may be used with thicknesses 1.25-3.75” when subjected to traffic;	Joint density state
		• NW geometry based on NMAS	Joint adhesive used
		• VB are allowed with provisions on placement/compaction	
Michigan	Y	• NW and VB allowed;	
		• Standard guidance on geometry with wider range	
Minnesota	N	NA	Known to use NW among regions; joint adhesive widely used
Missouri	N	NA	Joint density state

State, W/F Region (a-z)	Standard Specification Directly Specifies Joint Geometry	Commentary on Joint Geometry	Other Commentary
New Hampshire	Y	• VB and “Tapered-Overlapping” joint allowed;	NJ specifies 6" joint offset; Echelon paving with "butt" or wedge joint allowed; joint adhesive required for cold joints; "butt" or wedge joints allowed; paver overlap of 1/2 to 1" specified
		• Tapered joint used when left open to traffic and greater than 1.5” in height	
		• General guidance on taper geometry	
New Jersey	Y	• VB and NW allowed;	Joint adhesive used
		• When under traffic or greater than 2”, use NW	
		• Standardized geometry with variability	
New York	Y	• VB or NW allowed as “Options”	Joint density state
		• NW for “top courses” only	Joint adhesive used
		• Standardized geometry (but only allowed on top course)	
Ohio	N	NA	Joint density state
			Joint adhesive used
Pennsylvania	Y	• VB or NW allowed;	Example of method type specification
		• NW allowed with NMAS 19 mm and smaller	Joint density state
		• Standard geometry via drawing;	Joint adhesive used
Rhode Island	Y	• NW specified unless approved by Engineer;	Joint density state
		• Geometry based on NMAS	

State, W/F Region (a-z)	Standard Specification Directly Specifies Joint Geometry	Commentary on Joint Geometry	Other Commentary
Vermont	Y	• NW specified for 1.25-4 in thickness	Joint density state
		• Standard taper slope only	Joint reheaters used
Virginia	N	NA	Joint density state
			Permeability measured in mix design
West Virginia	N	NA	Joint density state
Wisconsin	Y	• NW directly specified for 1.75 in orgreater lift thickness; VB otherwise	Joint density state
		• Standard drawing for geometry	Trials with adhesive; LJS