Impact of Rumble Strips on Longitudinal Joint Pavement Performance

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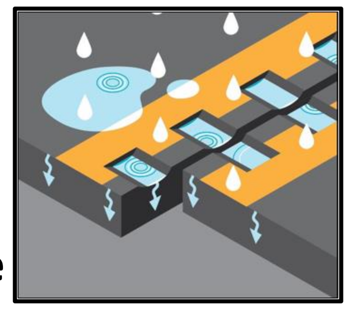
The Heritage Group

INTRODUCTION

- **Rumble strips** are an effective and low-cost solution to reduce severe roadway departure crashes.
- NCHRP Synthesis 490: Adding centerline rumble strips resulted in:
  - 45% reduction in crashes on rural two-lane roads
  - 64% reduction on urban two-lane roads
- **Challenging Questions**:
  - Impact on pavement life?
  - Durability of joint?
- **VRAM = Void Reducing Asphalt Membrane**



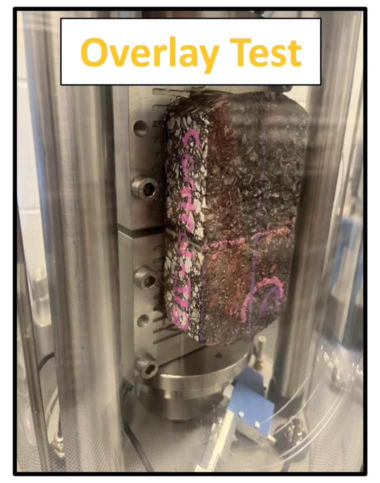
STUDY OBJECTIVES

- **Evaluate permeability** and **cracking** susceptibility of rumble strips milled into a longitudinal centerline joint.
- Determine **impact** of using VRAM on **longitudinal joint performance** with and without the addition of **rumble strips**.

METHODOLOGY

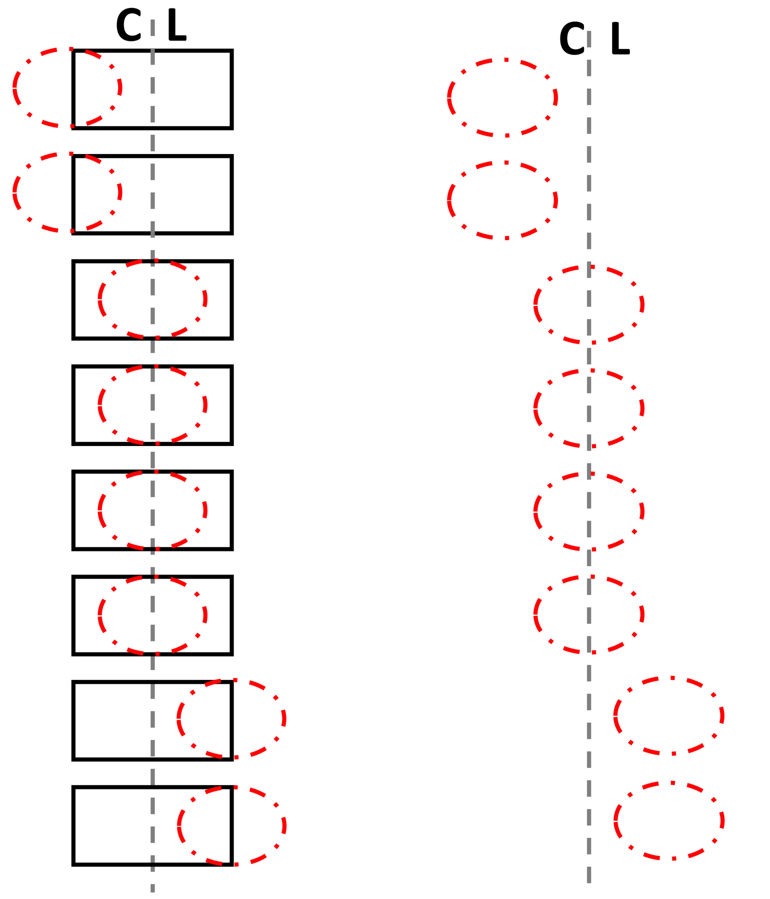
Test Name	Test Method	Type of Specimen	Route-1 Illinois Test Section	Lowell Plant Test Section
Disk-Shaped Compact Tension (DCT)	ASTM D7313	PMLC	-	X
Indirect Tensile Asphalt Cracking Test (IDEAL-CT)	ASTM D8225	PMLC	-	X
		Field Core	X	X
Overlay Tester (OT)	Tex-248-F	Field Core	X	X
Permeability	FM 5-565	Field Core	X	X

Note: ASTM = American Society for Testing Materials; FM= Florida Method; PMLC = Plant Mix Lab Compacted; SR = State Route; Tex = Texas



FIELD TRIALS

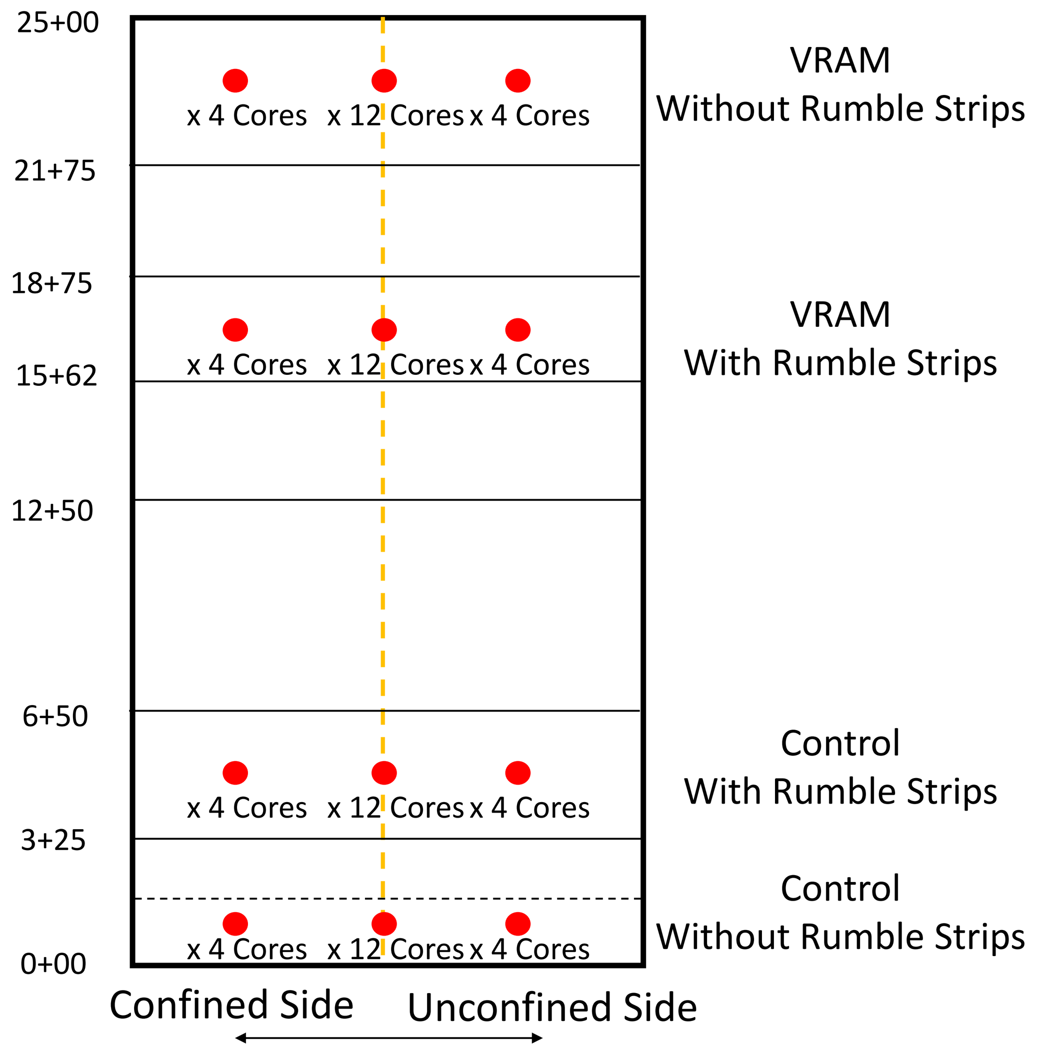
Route-1, IL



Centerline with Rumble Strips and VRAM

Centerline without Rumble Strips and VRAM (Intersection)

Lowell, IN



VRAM Average Application:
- 18” wide
- Lowell rate 1.25 lb/ft
- Route-1 rate 1.38 lb/ft

Rumble Strips:
- Lowell: 16” wide and spaced 6” apart (front to back)
- Route-1: 8” wide and spaced 6” apart (front to back)

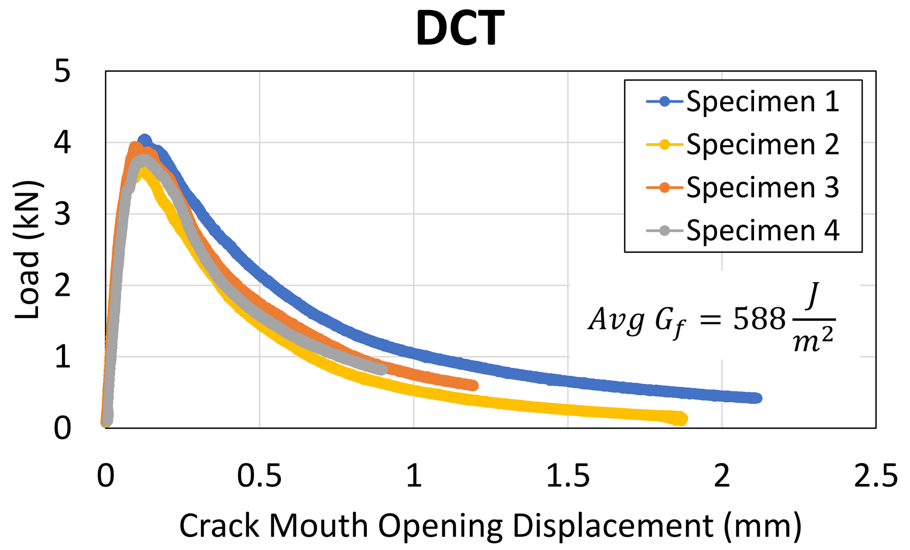
Sampling:
- Mix of cores from directly on top of joint, and adjacent to the joint confined and unconfined sides.
- Cores randomly divided for lab testing.

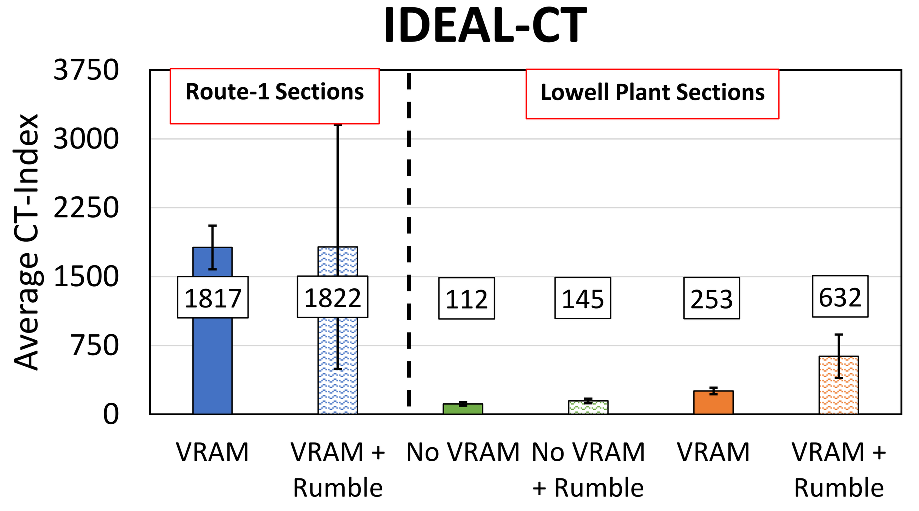
CRACKING RESULTS

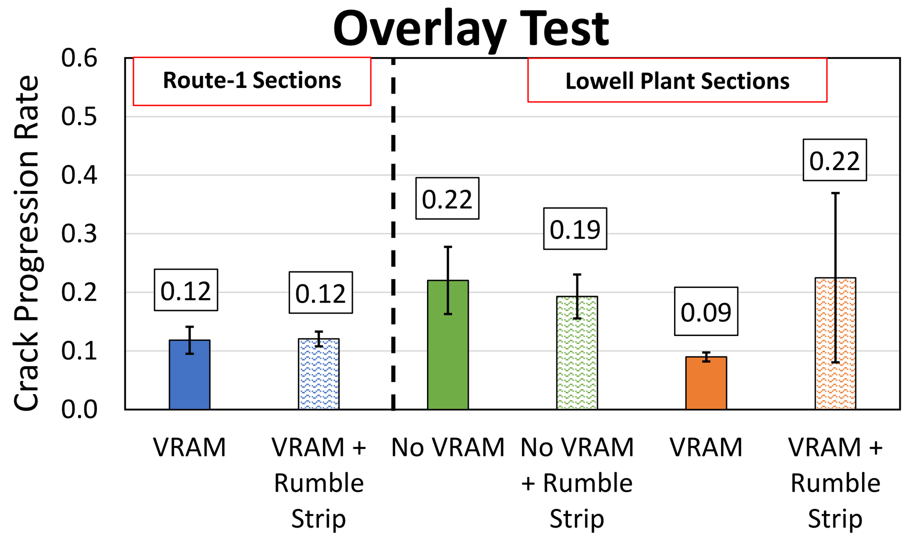
DCT:
- Good low temperature cracking resistance of lab produced samples using Lowell surface mix.

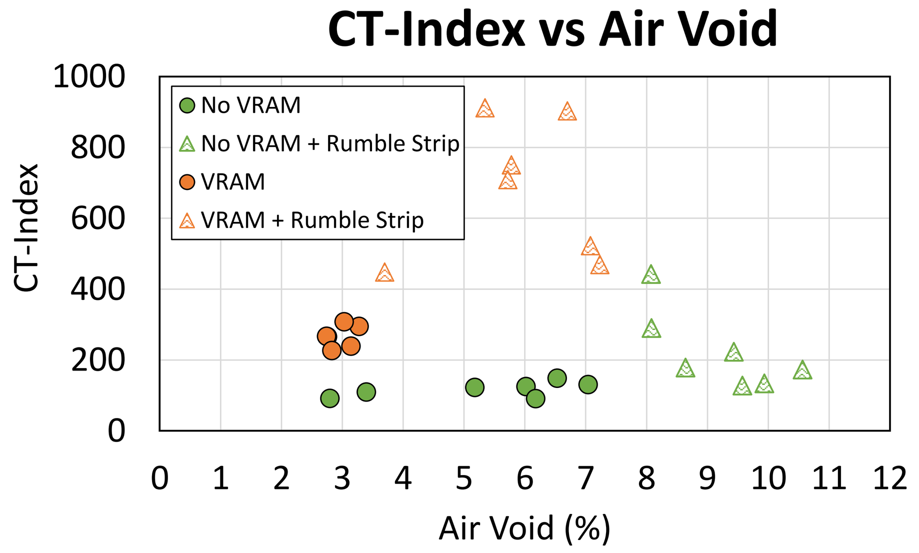
IDEAL-CT:
- No significant difference observed in CT-Index with or without rumble strips for Route-1 that contained VRAM.
- Impact of specimen geometry and air voids on CT-Index for field cores.

Overlay Test:
- No significant difference between average CPR values for cores sampled along Rt-1.
- Lowest CPR value observed for VRAM without rumble strip.

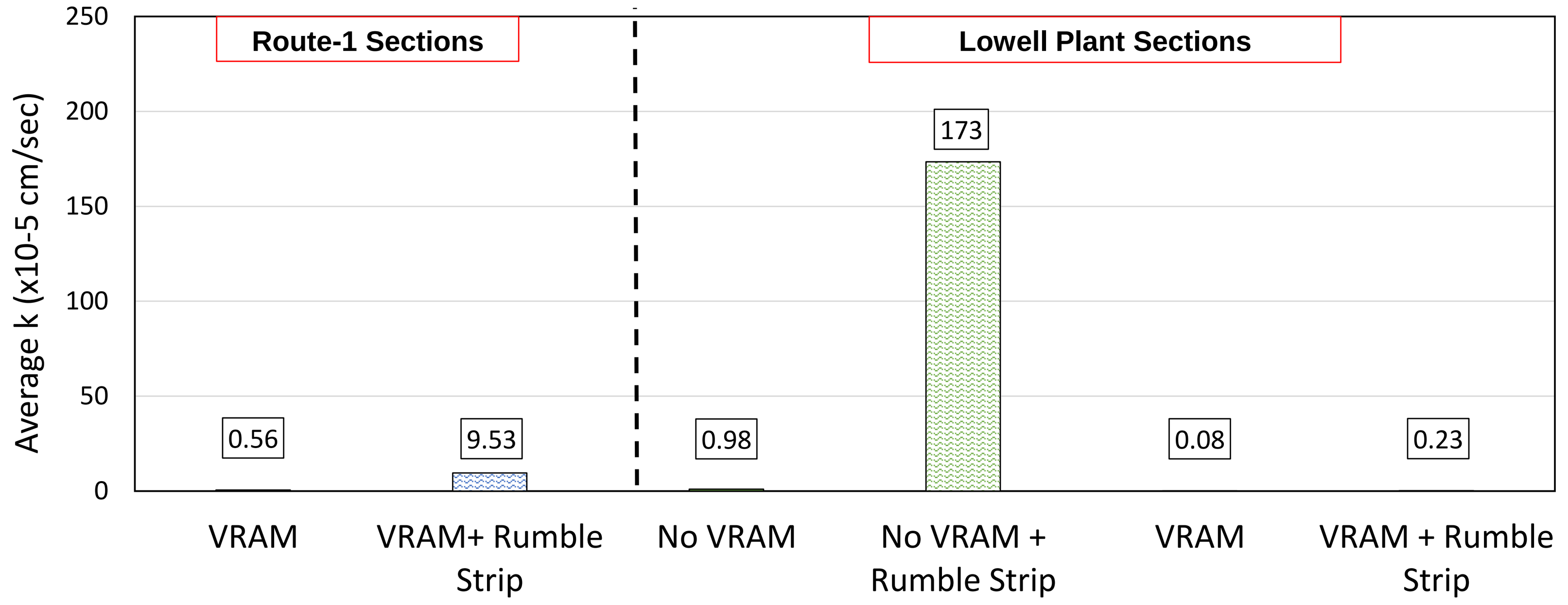








PERMEABILITY RESULTS



- Observed minimal to no permeability of cores that contain VRAM.

CONCLUSIONS

- **IDEAL-CT** cracking results showed **higher values for cores that contained VRAM** compared to the complementary control section.
- **Overlay test** explored as a test method to evaluate cracking resistance of joint cores under cyclic loading.
  - Route-1 cores containing VRAM showed similar crack resistance with and without rumble strips.
  - Lowell CPR results indicate poorer crack resistance for a joint without VRAM, with or without rumble strips.
- VRAM was **effective in reducing permeability** in cores with and without rumble strips.

Future Work:
- Monitoring of field performance at existing sample locations as well as new sample location from new projects.
- Long-term aging of the surface mixtures to simulate the effects of aging over the service life of the pavement.

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ABSTRACT

Milled centerline rumble strips are commonly used to reduce lane departure crashes. Safety benefits of installing rumble strips are viewed as a higher priority than the potential impacts to longitudinal joint performance, often leading to a reduced pavement life. There are several different approaches to minimize the impact that rumble strips may have on joint performance, such as careful selection of pavement candidates for installation of rumble strips, using a sealant on top of the rumble strip (top-down) or using a joint sealer (bottom-up). The objective of this study was to assess the impact of using a void reducing asphalt membrane (VRAM) as a joint sealer on longitudinal joint performance with and without the addition of rumble strips. Laboratory testing was completed on plant mix lab compacted specimens and field cores sampled along the centerline joint of two different roadways. Testing consisted of low and intermediate temperature cracking tests and permeability testing. Results from this study showed that VRAM was effective in mitigating increased permeability concerns with the addition of rumble strips into the pavement surface. In terms of laboratory cracking results, there was no significant difference observed between CT-Index values with and without rumble strips for cores sampled from one project location, while the second project location showed that CT-Index increased with the presence of the VRAM. Continued monitoring of field sections included in this study and future trial sections will be beneficial in understanding the link between laboratory testing, field performance, and variability associated with centerline joint performance.

Keywords: Longitudinal Joint; Rumble Strips, Void Reducing Asphalt Membrane; Permeability; Cracking

INTRODUCTION

Rumble strips are an effective and low-cost solution to reduce severe roadway departure crashes. They can be added to the centerline, edge line or shoulder of a pavement. There has been an increased usage of rumble strips on two-lane highways and major arterials due to the added safety benefits. When vehicle tires come into contact with the grooves in the pavement, it produces noise and vibration to alert drivers they have wandered out of their lane. Rumble strips can also help drivers navigate during poor weather conditions such as rain, fog, or snow. In 2016, NCHRP Synthesis 490 found that "Adding centerline rumble strips resulted in a 45% reduction in crashes on rural two-lane roads and a 64% reduction on urban two-lane roads" [1].

Departments of transportation (DOT's) have varied practices for the design, installation, and maintenance of rumble strips. Decisions on where to include rumble strips (urban versus rural settings), dimensions, whether to seal them, and how to re-apply pavement markings is not standardized across states [2]. However, one constant question among state DOT's that is always raised when cutting into a pavement is the effect that it will have on pavement life. When it comes to rumble strips, this is often a secondary concern as improving safety for the traveling public is the primary concern.

It is well documented that a critical component in construction of a pavement and long-term performance of a roadway is the longitudinal joint. In 2009, the Federal Highway Administration (FHWA) surveyed their Divisional Offices and found that about 50 percent reported dissatisfaction with the performance of their longitudinal joints [3]. Premature joint failures are often the result of permeability, low density, segregation, or lack of adhesion at the interface. As a result, joints may fail by cracking, raveling or potholes that allow for the infiltration of water. Concerns exist on whether adding centerline rumble strips will increase pavement degradation at the longitudinal joint. Ultimately, premature joint failures lead to a reduction in service life of the pavement and higher agency and user costs due to increased frequency of maintenance and construction.

Objective

The focus of this paper was to evaluate the permeability and cracking susceptibility of rumble strips milled into a longitudinal centerline joint. A primary goal was to assess the impact of using a void reducing asphalt membrane (VRAM) on longitudinal joint performance with and without the addition of rumble strips. This was accomplished through a combination of laboratory tests on plant mix lab compacted specimens (PLMC) and field cores sampled directly on top and adjacent to the centerline joint. Laboratory tests evaluated permeability and low and intermediate temperature cracking properties of the surface course mixture with and without rumble strips.

BACKGROUND

Joints, Rumble Strips, and Their Impact on Pavement Performance

Joints created during the construction process of a pavement are inherently weak spots and areas for concern to achieve adequate density. When considering adding rumble strips to a pavement there are generally four types of rumble strips: milled, rolled, formed, and raised. In the United States, milled rumble strips are the most common type and have the greatest potential for negatively affecting the long-term pavement performance [4]. Milled rumble strips can be installed on both new and existing asphalt concrete or Portland cement concrete pavements. A milling machine simply cuts a groove into the pavement surface to a given length, width, depth and spacing. This study focuses specifically on milled rumble strips at the centerline only. The standard rumble strip mill depth for the two roadways included in this study (Indiana and Illinois) is 12.7 mm (0.5-in) [4].

Concerns regarding damage to the surface course mixture by milling directly on top of the longitudinal joint and potentially leading to an increase in permeability or cracking susceptibility have been expressed by contractors and agencies. Poorly constructed joints or cracked joints will allow water to infiltrate the pavement structure and can lead to early pavement degradation. Rumble strips provide another potential reservoir to hold water in the grooves and are generally perceived to accelerate joint deterioration.

Figure 1 provides an example of a deteriorated centerline joint with rumble strips along US-36 between Raccoon Lake and US-231, a highway in Indiana.

Figure 1: Example of deteriorated centerline joint with rumble strips taken on July 7th, 2021.

Some practitioners have found that "longitudinal joints in good to fair condition can have rumble strips milled into them without accelerating deterioration" [5]. However, other practitioners and reports have identified a need to conduct research and monitor long-term pavement performance of roadways with centerline rumble strips [6]. For example, there is an active project sponsored by the Federal Highway Administration on Centerline Rumble Strip Effects on Pavement Performance. This research effort is focused on three major areas: (1) quantify the impacts of centerline rumble strips installation on the performance and maintenance of all the pavement types currently used in Oregon, including in mountainous areas or snow zones; (2) identify the best construction practices for centerline rumble strip installation to avoid any negative impacts on pavement performance; and (3) identify, evaluate, and compare the effectiveness of potential surface treatment options to mitigate any pavement performance issues pre- and post-installation of centerline rumble strips by considering performance, cost, and safety [7].

Mitigating the Impact of Rumble Strips

There are several methods to try and combat concerns for early degradation of the longitudinal joint. Examples include altering the installation process of rumble strips, setting limits on the application of rumble strips, or using a sealant on top or below of the rumble strip. During the installation process to avoid cutting rumble strips directly into the joint, two smaller rumble strips can be added to either side of the centerline joint, or the rumble strips could be offset from the joint when possible (typically more commonly done for edge line or shoulder rumble strips). Another option during the pavement construction process would be to offset the joint or overlay so the center line rumble strip can be placed in the center of the roadway and not directly on top of the joint. This option can be challenging when adding rumble strips to an existing pavement surface. Furthermore, the maintenance of rumble strips is not commonly considered independent of the rest of the roadway. In fact, NCHRP Synthesis 490 reported that only five agencies stated that they purposefully reseal rumble strips [1, 8].

Some agencies have set a maximum age or minimum thickness to avoid negative ramifications of installing rumble strips on existing pavements [8]. The ideal time to install rumble strips is shortly following the construction of a fresh asphalt surface as opposed to an existing or old pavement surface. Another example to mitigate the potential impact of rumble strips is to adopt a top-down approach to preserve joint performance by sealing centerline rumble strips with a fog seal or a penetrating asphalt emulsion immediately following installation or throughout the service life of the roadway. In the 2016 NCHRP Synthesis 490 report it was stated that only 44 percent of responding agencies use a sealant as part of rumble strip construction, but one-third of those reported that this is not a standard practice [1].

The Illinois Department of Transportation developed a concept to seal the longitudinal joint region from the bottom up using a longitudinal joint sealant (LJS) comprised of highly-polymer modified asphalt cement with fillers. The LJS is also commonly referred to as VRAM. VRAM is placed prior to paving and once the asphalt mixture is placed on top, it melts and migrates up into voids helping to reduce permeability, improve density and crack resistance of the mix near the joint location [9]. In the current study, VRAM is explored as a potential material solution to mitigate concerns of adding rumble strips to the centerline joint. This bottom-up approach of using VRAM can be used in combination with the traditional top-down approach of applying a fog seal to the top surface of the joint after installing rumble strips.

METHODOLOGY

Field Sections

Two roadway locations were constructed, sampled, and are continuing to be monitored to evaluate how VRAM influences the properties of hot-mix asphalt (HMA) such as cracking resistance and permeability, particularly at the centerline joint with and without the addition of rumble strips. Due to the presence of VRAM and agency requirements, there was no longitudinal joint density specification required on either project.

Lowell Plant Test Section

The first field section near Lowell, Indiana was on the entrance of a contractor's hot mix plant. This location was selected as it provided an experimental site to construct and sample numerous cores along the centerline joint of a roadway with high truck traffic volume, while avoiding the concerns of sampling on a major interstate or state-owned roadway. The test sections were constructed in August 2021 and sampled after approximately three months of service. Paving consisted of adding 1.5-inch surface course (Nominal maximum aggregate size 9.5 mm) with PG 64-22 and 25% Reclaimed Asphalt Pavement (RAP) over an existing surface. VRAM was applied at a width of 18-inch and application rate of 1.25 lb./ft to the centerline joint between the existing and surface pavement layers. Conventional Asphalt Emulsion Non-Tracking (AENT) tack was applied prior to the placement of the surface mix. Rumble strips were installed at a width of 16-inches, and approximate spacing of 6-inches apart (front to back). It should also be mentioned that the control section with rumble strips had a surface spray-applied rejuvenator placed on top of the pavement surface after the installation of rumble strips.

To complete the desired testing plan described in the laboratory testing methods section below, twenty 6-inch diameter samples were collected from the roadway in each test section for a total of eighty cores. Twelve samples were taken directly over the centerline joint, and eight samples adjacent to the centerline joint (four on the unconfined and four on the confined side). The only difference between cores taken at the centerline within each test section and those cores offset (confined and unconfined sides) is the presence of the joint. Since the focus of this paper is on centerline joint performance, results of cores sampled directly on top of the centerline joint only are presented and discussed. The overall layout of test sections is shown in Figure 2, while a detailed schematic of the sampling locations with respect to the joint is shown in Figure 3.

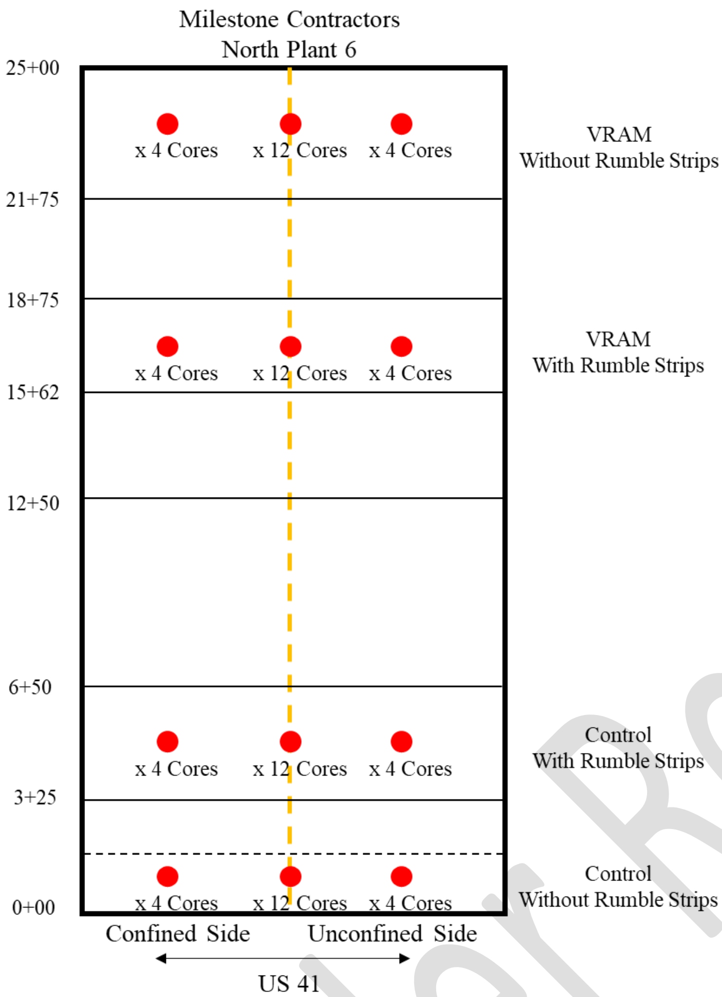

Figure 2: Lowell test section layout.

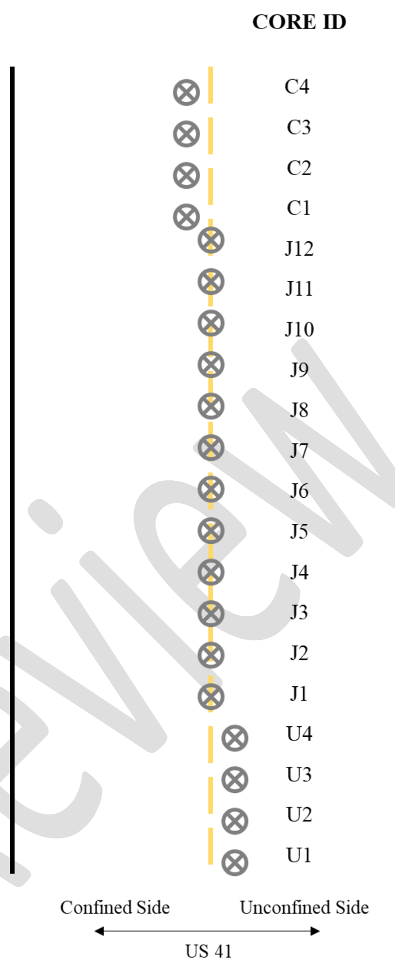

Figure 3: Example of typical sampling layout in each test section.

Indirect tensile asphalt cracking test (IDEAL-CT), overlay tester (OT), and permeability tests were performed on field cores. Additionally, plant produced-lab compacted specimens were prepared and tested to evaluate a baseline cracking resistance of the asphalt mixture using Disk-shaped compact tension (DCT), and IDEAL-CT tests. This allowed researchers to make comparisons of results from lab prepared specimens to those obtained from field cores. Figure 4 shows an example of the coring layout in the field, while further information on each test method is provided in the following subsection.

Illinois SR-1 Test Section

The second location included in this study was a 7.2-mile project going north from the Clark County/Edgar county line in Illinois along SR-1. Construction consisted of 2.25-inch removal of HMA, 84 lb./sq-yd fine graded level binder with 1.5-inch 9.5 mm surface course. VRAM was applied on top of the new level binder mix at the centerline joint at a width of 18-inches and an average yield of 1.38 lb/ft application rate, followed by a conventional non-tracking tack coat material (Figure 5). Rumble strips were installed 8-inches wide and about 6-inches apart (front to back). This field section provided researchers with a second trial location to evaluate the bottom-up approach of mitigating potential impacts of rumble strips on joint performance on state route with approximate average daily traffic of 4,600 vehicles per day and truck percentage of 17%.

Figure 4: Example of coring along Lowell test section.

Figure 5: Application of tack coat material following VRAM along Illinois SR-1.

Eight cores were taken from four different locations along Illinois SR-1 for a total of thirty-two cores. A mix of cores were sampled along the centerline joint and along the edge line to obtain cores with and without the longitudinal joint sealer. However, for comparisons purposes in this paper a constraint of the SR-1 data set should be noted that those cores sampled on the edge line of the pavement with and without rumble strips do not contain a joint. Therefore, the influence of VRAM on centerline joint performance (with and without rumble strips) can only be examined without a true control section not containing VRAM and a joint. Figure 6 summarizes the coring layout and orientation at the four different sample locations; however, results and discussion will be focused on cores from the centerline only to be consistent.

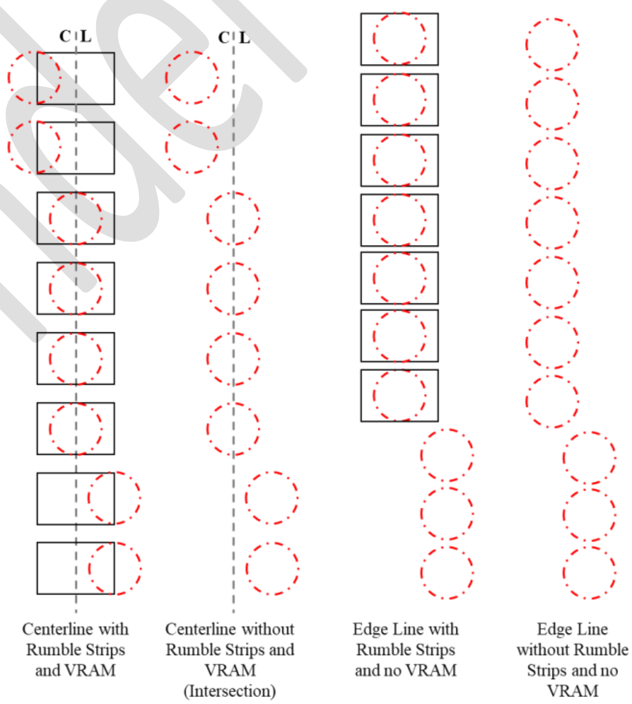

Figure 6: Schematic of Illinois SR-1 coring layout.

Laboratory Testing Methods

The following section describes laboratory tests that were carried out on extracted field core specimens sampled along the centerline longitudinal joint as well as sampled loose asphalt mixture from the Lowell Test section. A range of laboratory tests were conducted in this study to provide an estimate of cracking resistance at low and intermediate temperatures as well as permeability using a laboratory experimental set up. Table 1 summarizes the laboratory testing plan, while a brief description of each laboratory test included in this study and the anticipated outcome is provided below.

Table 1: Summary of laboratory testing plan.

Test Name	Test Method	Type of Specimen	Lowell Plant Test Section	Illinois SR-1 Test Section
Disk-Shaped Compact Tension (DCT)	ASTM D7313	PMLC	X	-
Indirect Tensile Asphalt Cracking Test (IDEAL-CT)	ASTM D8225	PMLC	X	-
		Field Core	X	X
Overlay Tester (OT)	Tex-248-F	Field Core	X	X
Permeability	FM 5-565	Field Core	X	X
Note: ASTM = American Society for Testing Materials; FM= Florida Method; PMLC = Plant Mix Lab Compacted; SR = State Route; Tex = Texas				

Disk-Shaped Compact Tension (DCT): DCT testing is commonly used to determine the fracture energy of asphalt mixtures. Testing is typically conducted at 10°C warmer than the PG low temperature grade and run in crack mouth opening displacement (CMOD) control mode at a rate of 1 mm/min. In this study, the test temperature was -12°C after conditioning specimens for a minimum of 2 hours. Dimensions of the DCT specimen are 150 mm (6-in) diameter, 50 mm (2-in) thick, notch length of 62.5 mm (2.5-in), and two 25 mm (1-in) pin loading holes. Loading rate was controlled using a constant CMOD rate of 0.017 mm/s (0.00067 in/s) inside the testing device (Figure 7). A baseline of the low temperature thermal cracking properties of the overlay asphalt mixture were assessed using plant produced lab compacted specimens only for the Lowell surface course mixture. Outcomes analyzed in this study from this test included peak load and fracture energy.

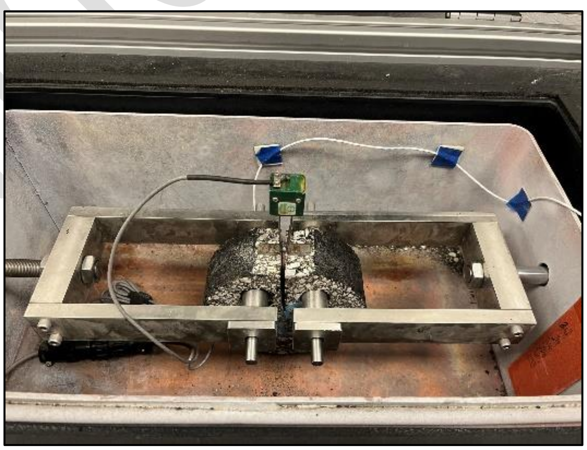

Figure 7: DCT test set up.

Indirect Tensile Asphalt Cracking Test (IDEAL-CT): The IDEAL-CT is a test used to determine the cracking susceptibility of an asphalt mixture. IDEAL-CT uses 150 mm (6-in) diameter cores or compacted lab specimen. The test was designed for 62 mm (2.4-in) specimen height but may be used for other heights, such as, 1 ½-in or 2-in. Field cores were cut at the interface of the surface and intermediate lifts taking care to preserve the VRAM with the surface mix prior to testing. For plant produced lab compacted samples, there was no VRAM included and pills were compacted to the standard height of 62 mm. The test is run in an indirect tensile fixture at 25°C (77°F) at 50 mm per minute (2-in/min) loading rate. Figure 8 shows the IDEAL-CT testing device and fixture with a sample loaded such that the joint is inline and centered with the loading head. Outcomes analyzed from this test included, peak load, fracture energy, tensile strength, and the CT-Index.

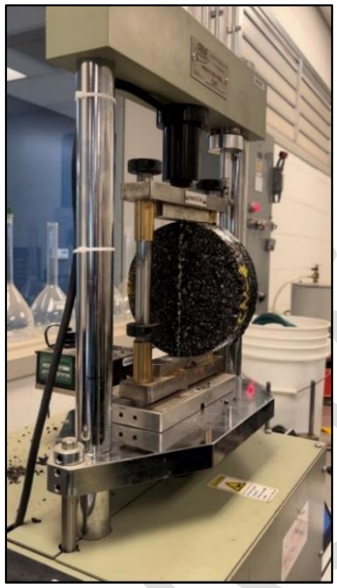

Figure 8: IDEAL-CT test set up.

Overlay Tester (OT): The OT is used to assess the susceptibility of an asphalt mixture to fatigue or reflective cracking. Specimen geometry can be fabricated from a 150 mm (6-in) diameter core, where the specimen length is 150 mm (6-in) with rounded edges, width is 76 mm (3-in) and height equal to 38 mm (1.5-in). The test is typically run at a test temperature of 25°C (77°F). The specimen is glued to two blocks: one is fixed while the other is allowed to slide horizontally. Careful attention was made to cut the sample directly below the VRAM system to ensure it is fully intact. OT samples were glued to the platens in such a way that the bottom cut surface of the pavement is touching the testing platen and the joint was centered between platens (Figure 9). The sliding block applies tension in a cyclic triangular waveform to a constant maximum displacement of 0.6 mm (0.025-in). The sliding block reaches the maximum displacement and then returns to its initial position in ten seconds (one cycle). Examples of outcomes that may be analyzed from this test include peak load, critical fracture energy (CFE) at the maximum peak load on first cycle, crack propagation rate (CPR), and number of cycles to failure. In this study, CPR results are used to compare cracking resistance through the propagation phase of cores with a joint and with the introduction of rumble strips.

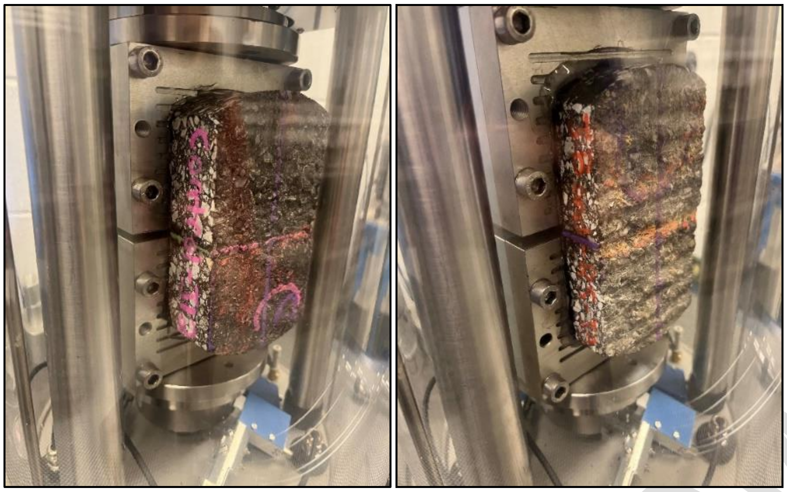

Figure 9: OT set up showing sample orientation without rumble strips (left) and with rumble strips (right).

Permeability: The laboratory permeability test setup is shown in Figure 10 and uses 150 mm (6-in) diameter field cores cut at the interface of the existing pavement surface, taking care to include the VRAM system with the new HMA overlay. The falling head permeameter as developed by Florida DOT was used to determine the average permeability constant (k) for each treatment section. One field core from each of the cracking test groups (i.e., IDEAL-CT and OT) was randomly selected and tested for permeability for the Lowell data set. Meanwhile, the Illinois SR-1 data set had permeability testing on four cores selected from each section that did not contain yellow or white paint marking on the surface of the core.

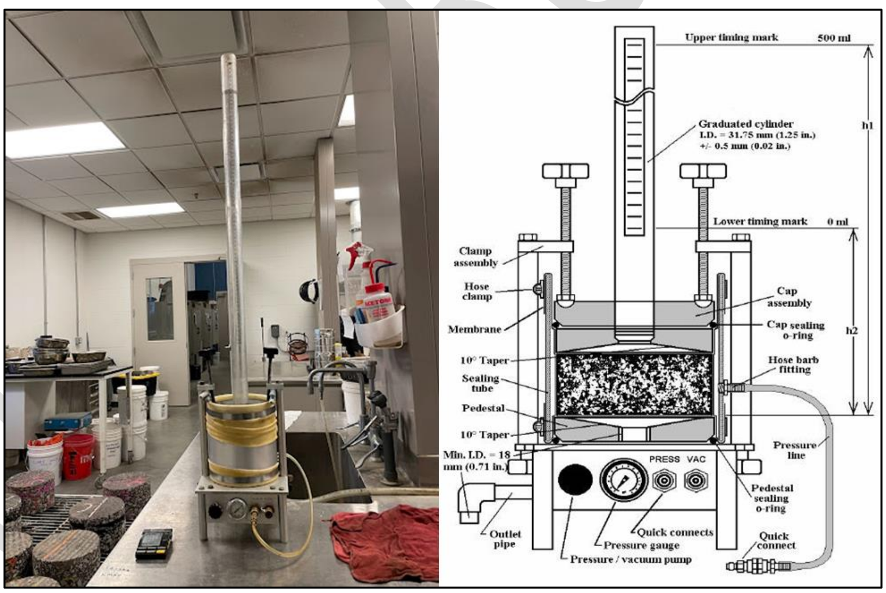

Figure 10: Lab permeability test set up.

It is important to note that the determination of specimen air voids followed a modified procedure in this study. The HMA overlay mixture maximum specific gravity cannot be used in the calculation of air voids because of the additional asphalt supplied by the VRAM. Since the cores are cut at the interface of the existing pavement surface with care taken to keep the polymer modified asphalt layer with the new overlay, to maximize efficient use of cores, all cores had bulk specific gravity run first. After destructive testing, the cores were broken down to run maximum specific gravity. The air void content for that specific core was then calculated. This modified air void procedure is applicable to IDEAL-CT specimens only. It should also be mentioned that the localized air voids may vary within the core depending upon saturation of the VRAM material.

RESULTS AND DISCUSSIONS

In the following section, cracking and permeability results are presented and discussion provided on the impact of rumble strips with and without VRAM. First, crack testing results are summarized for plant produced lab compacted specimens to establish a baseline of the low and intermediate temperature cracking performance of the Lowell Plant surface course mixture. Next, results on field cores are presented for both Lowell and Illinois SR-1 cores.

Table 2 summarizes the results from DCT testing on four plant produced lab compacted specimens. Since the sampled surface asphalt mixture was a Superpave5 design where compaction targets 95% Gmm, the target air void on prepared test specimens was 5.0% ± 0.5%. An average fracture energy of 588 J/m^2 and average peak load of 3.84 kN was calculated. While Indiana Department of Transportation (INDOT) does not require a minimum fracture energy specification, it can be noted that the average fracture energy is above the recommended threshold value of 460 J/m^2 for a moderate traffic level roadway (10-30 million ESAL's) and colder climatic region such as Minnesota [10]. This provides researchers with a preliminary check and baseline of low temperature cracking properties of the surface course mixture. However, further research is needed to establish a local threshold of low temperature cracking properties within Indiana.

Table 2: Summary of DCT results on plant produced lab compacted specimens.

Replicate	Air Void (%)	Peak Load (kN)	Fracture Energy (J/m^2)
1	4.8	4.05	808
2	4.9	3.61	436
3	4.8	3.95	566
4	4.9	3.76	542
Average	4.9	3.84	588
Standard Deviation	0.1	0.19	157
COV (%)	1.2	5.02	27
Note: COV = Coefficient of Variation			

Likewise, to establish a baseline of the intermediate cracking susceptibility of the surface course mixture, the IDEAL-CT test was conducted on four plant produced lab compacted specimens. The average CT-Index was 149 as summarized in Table 3. There are no established benchmark values for CT-Index set forth by INDOT, however from researchers' experience with similar mix design and category of mix, there was little concern of cracking susceptibility of the surface course mixture on the basis of PMLC results.

Table 3: Summary of IDEAL-CT results on plant produced lab compacted specimens.

Replicate	Air Void (%)	Peak Load (kN)	Fracture Energy (J/m^2)	Tensile Strength (kPa)	CT-Index
1	5.4	16.2	10486	1107	115.9
2	5.1	14.6	11016	995	162.8
3	5.5	14.2	11053	975	183.6
4	4.9	16.9	10957	1158	133.6
Average	5.2	15.4	10878	1059	149.0
Standard Deviation	0.3	1.3	265	88	30.1
COV (%)	5.3	8.5	2.4	8.3	20.2
Note: COV = Coefficient of Variation					

IDEAL-CT testing was also conducted on field cores from both project locations. For comparison purposes of the impact of VRAM and rumble strips on centerline joint performance, only cores sampled from the centerline of Illinois SR-1 are included in Figure 11. However, researchers noted in general lower CT-Index values for edge line cores (did not contain VRAM) regardless of whether or not rumble strips were present. In the case of Illinois SR-1, CT-Index values were significantly higher for the given surface course mixture compared to those results obtained from Lowell Plant sections. There was no significant difference observed in CT-Index with or without rumble strips for Illinois SR-1 that contained VRAM. In the case of the Lowell Plant sections, when adding VRAM, the CT-Index increases (No VRAM vs VRAM bars). However, with the addition of rumble strips, the CT-Index also increased. Researchers hypothesize that there are two confounding effects taking place. First, field cores that contained rumble strips were approximately 20% thinner than those without rumble strips. Furthermore, after trimming the field cores to remove the binder layer mixture, test specimens were less than 62 mm thick, and the thickness correction factor was used. Second, since these are field cores and not lab prepared specimens, there is less control over air voids. Using the back-calculated method described above for air voids, while accounting for the added asphalt content from VRAM, it was observed in general that air voids on cut specimens were higher in Lowell Plant sections without VRAM, and higher for cores that contained rumble strips (Figure 12). Many researchers have shown that CT-Index is sensitive to air voids and as they increase, CT-Index also increases [11]. Therefore, the combination of having thinner samples and higher air voids for test specimens that contain rumble strips beyond the limits of specimens used to develop the cracking index may contribute to the results observed between rumble strips and no rumble strips. Furthermore, the higher asphalt content from VRAM may be contributing to the relatively high CT-Index values for Illinois SR-1 sections.

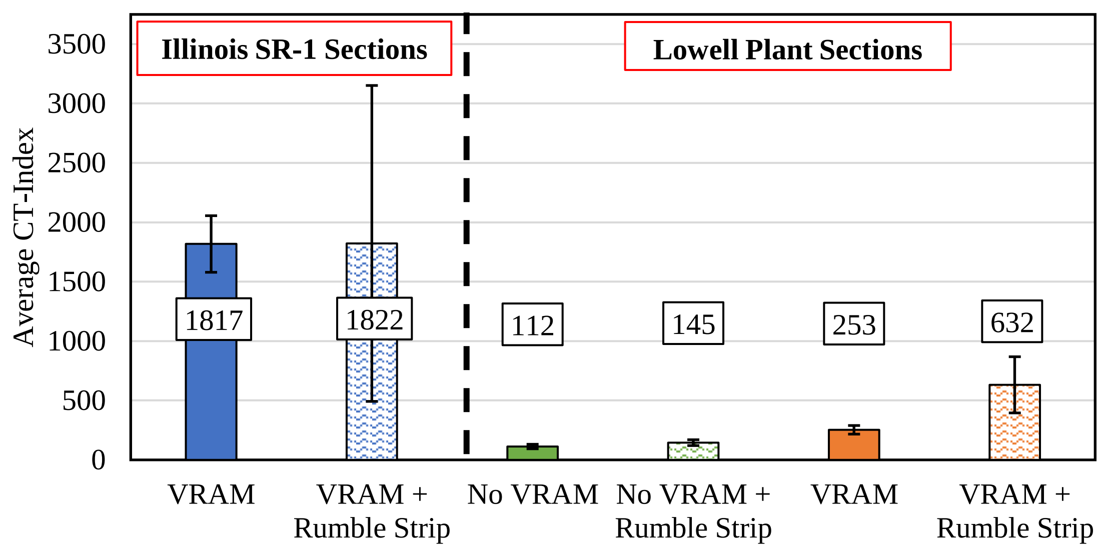

Figure 11: CT-Index results on field cores from centerline joint cores only along Illinois SR-1 and Lowell Plant sections. Error bars denote one standard.

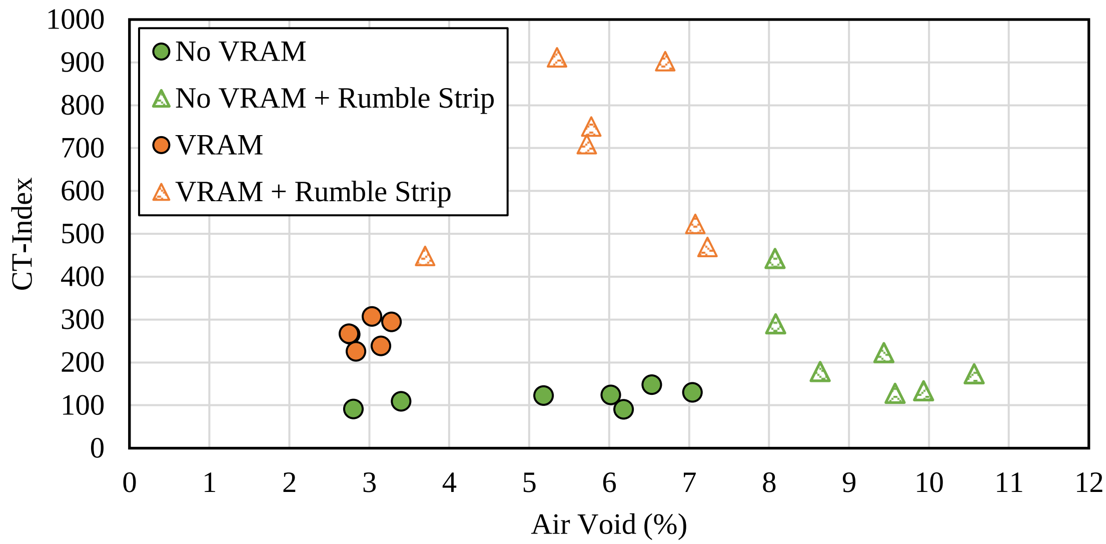

Figure 12: CT-Index results versus measured air void on cut specimens from Lowell Plant sections.

Overlay testing was explored as another method to evaluate intermediate temperature cracking properties of the field cores with and without rumble strips. In particular, researchers were interested in looking at the crack propagation phase using the overlay tester under cyclic loading. Traditionally, the overlay test has been used to evaluate both lab fabricated and field cores for an asphalt mixture without the presence of a joint or rumble strip. In the current study, field cores were used to fabricate and glue test specimens such that the joint was centered directly above the gap between platens and preserving the VRAM layer at the bottom of the specimen. This experimental test orientation was adopted to isolate the joint and evaluate the impact of VRAM on the asphalt mix.

Figure 13 summarizes Crack Progression Rate (CPR) results for both Illinois SR-1 and Lowell Plant field cores sampled along the centerline joint only. Error bars denote one standard deviation calculated for the three test specimens. A lower CPR value is desired, indicating better cracking resistance of the test specimen. There was not a significant difference between average CPR values for cores sampled along Illinois SR-1 with and without rumble strips. For the Lowell Plant sections, the lowest average CPR result was observed for test specimens containing VRAM without rumble strips. Comparable average CPR values were found for the VRAM with rumble strips (0.22), the control section with no VRAM and without rumble strips (0.22), and the No VRAM with rumble strips (0.19). In general, it can be concluded that VRAM was effective in lowering the CPR values of tested specimens without rumble strips, hence improving the fatigue cracking resistance. While test results did not show significant difference between rumble strip specimens, further research is required to evaluate the high testing variability observed for the VRAM + Rumble Strip results possibly caused by areas of low density or from specimen fabrication. Monitoring of current field test sections, as well as the construction of additional field trials may help to refine laboratory test methods to evaluate longitudinal joint cores and correlate lab results to field performance.

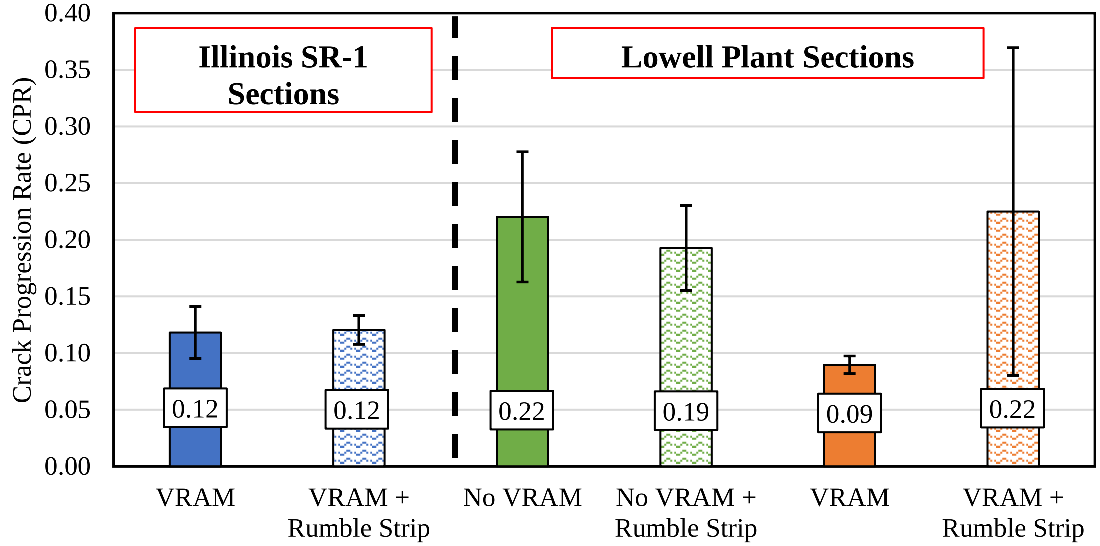

Figure 13: Summary of crack progression rate results from overlay testing for Illinois SR-1 and Lowell Plant test sections with error bars denoting one standard deviation.

Lastly, Figure 14 summarizes the lab permeability test results for Illinois SR-1 and Lowell Plant test sections. Results show minimal to no permeability in field cores that contained VRAM with or without rumble strips. The impact of adding rumble strips to the centerline joint on permeability was more severe for sections that did not contain VRAM along the centerline joint. Therefore, it can be concluded that VRAM was effective in reducing the permeability at the centerline joint with and without rumble strips.

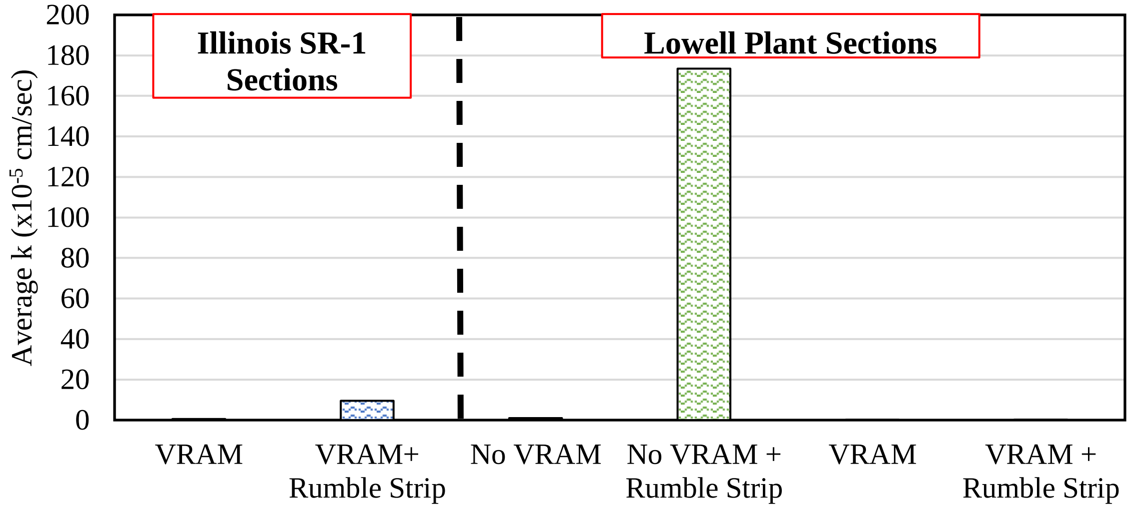

Figure 14: Summary of lab permeability results for Illinois SR-1 and Lowell Plant test sections.

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Safety of the traveling public is of the utmost concern and the use of centerline rumble strips is among one of the most cost-effective countermeasures used by agencies to reduce head-on and opposite direction sideswipe collisions. With the addition of milled rumble strips along the centerline of a pavement, concerns arise that the joint will deteriorate faster from increased permeability and/or premature cracking. Several different methods have been proposed to mitigate the impact of rumble strips on joint performance. The current study explored a bottom-up approach of sealing the pavement by applying a VRAM to the joint prior to the paving of the surface lift and installation of rumble strips. Lab testing on PMLC and field cores was conducted at low and intermediate test temperatures to evaluate the cracking resistance of the surface course mixture as well as permeability testing. The following conclusions and recommendations are made on the basis of results and observations included in this study:

- Testing on PMLC specimens provided a baseline of cracking properties of the surface course mixture used in the Lowell Plant test sections. Results indicated little concern for low or intermediate temperature cracking susceptibility prior to the installation of rumble strips. However, an extension of this study can be to perform long-term aging of the surface mixture to simulate the effects of aging over the service life of the pavement.
- There was no significant difference observed in CT-Index with or without rumble strips for Illinois SR-1 that contained VRAM. In the case of the Lowell Plant test sections that included VRAM (with or without rumble strips), the CT-Index was higher for sections that contained VRAM demonstrating an increase in cracking resistance of the asphalt mixture. A limitation of the current data set is the lack of control on air voids from field cores, challenges associated with measuring air voids with the additional asphalt content from VRAM, and the change in specimen thickness with the installation of rumble strips, as the CT-Index appears to be sensitive to these specimen parameters even with the use of correction factors.
- The overlay test was explored to evaluate cracking resistance of joints. The test applies cyclic tensile loads and low crack progression indicates increased resistance to cracking. The Illinois test sections showed that crack resistance was the same for joints with and without rumble strips suggesting that VRAM was able to maintain cracking resistance. The Lowell test sections showed poorer crack resistance for a joint without VRAM, with or without a rumble strip. The VRAM joint without a rumble strip showed better cracking resistance, similar to the level of the Illinois test section. The Lowell section with VRAM and a rumble strip had approximately the same CPR as the joints without VRAM; however, the test result variability is very high. Further research is needed to evaluate the high testing variability of cracking tests (OT and IDEAL-CT) when using longitudinal joint cores.
- The bottom-up approach of using a VRAM to seal the centerline joint prior to the installation of rumble strips was effective in mitigating permeability concerns. Test sections that contained VRAM showed minimal to no permeability and therefore durability of the longitudinal joint would be expected to improve.
- It is planned to monitor the field performance of both test section locations for signs of premature joint deterioration and to better understand the link between laboratory results and field performance. Researchers also intend to explore other opportunities for additional field trials to study the impact of rumble strips on longitudinal joint pavement performance.

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AUTHOR CONTRIBUTION STATEMENT

The authors confirm contribution to the paper as follows: study conceptualization and design, Thomas, Wielinski, DeCarlo; data collection: DeCarlo; analysis and interpretation of results: DeCarlo, Thomas, Wielinski; draft manuscript preparation: DeCarlo, Thomas. All authors reviewed the results and approved the final version of the manuscript.

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