WisDOT Asphaltic Mixture New Specifications Implementation – Field Compaction and Density

Signe Reichelt
Aaron Coenen
Jay Behnke
Behnke Materials Engineering, LLC

WisDOT ID no. 0092-15-09

June 2016

RESEARCH & LIBRARY UNIT

WISCONSIN HIGHWAY RESEARCH PROGRAM

WISCONSIN DOT
PUTTING RESEARCH TO WORK

Technical Report Documentation Page

1. Report No. 0092-15-09	2. Government Accession No	3. Recipient's Catalog No
4. Title and Subtitle WisDOT Asphaltic Mixture New Specifications Implementation – Field Compaction and Density		5. Report Date June 2016 6. Performing Organization Code
7. Authors Signe Reichelt, Aaron Coenen, Jay Behnke		8. Performing Organization Report No.
9. Performing Organization Name and Address Behnke Materials Engineering, LLC 1209 E Elmwood Ave, Unit B Beloit, WI 53511		10. Work Unit No. (TRAIS) 11. Contract or Grant No. WHRP 0092-15-09
12. Sponsoring Agency Name and Address Wisconsin Highway Research Program Wisconsin Department of Transportation Research & Library Unit 4802 Sheboygan Ave. Rm 104 Madison, WI 53707		13. Type of Report and Period Covered November 2014 - June 2016 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

The main research objectives of this study were to evaluate HMA Longitudinal Joint type, method and compaction data to produce specification recommendations that will ensure the highest density longitudinal joint, as well as evaluate and produce a specification for Thin Layer Overlay HMA that will ensure proper and consistent compaction throughout the pavement.

In 2014, longitudinal nuclear density data was collected throughout Wisconsin on 28 projects. In 2015 three projects were visited (for more extensive data collection) with varying longitudinal joint type: vertical, notched wedge, milled and safety edge. Additionally one thin lift overlay project was visited.

Each 2015 project consisted of nuclear density readings, core density, NCAT Asphalt Permeameter and Hamburg Wheel testing. Results showed that a nuclear density gauge, specifically when used in the parallel position (relative to traffic and paving direction), is an acceptable tool to use to determine in place densities. However, a nuclear / core correlation on a test strip is recommended for all projects. The standard nuclear gauge overestimates density, while the thin lift nuclear gauge underestimates density.

The milled longitudinal joint achieved the highest density, followed by notched wedge and safety edge. Vertical longitudinal joints had the lowest average joint densities. Heating joints resulted in higher densities for all joint types where data was available. Rolling pattern included both contractor standard practice and FHWA recommended methods but was not found to have significant influence on longitudinal joint density.

17. Key Words Hot Mix Asphalt; Longitudinal Joints; Overlays (pavements); Nuclear Density Gages; Compaction	18. Distribution Statement No restriction. This document is available to the public through the National Technical Information Service 5285 Port Royal Road Springfield VA 22161

18. Security Classif.(of this report)	19. Security Classif. (of this page)	20. No. of Pages	21. Price
Unclassified	Unclassified	111	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

DISCLAIMER

This research was funded through the Wisconsin Highway Research Program by the Wisconsin Department of Transportation and the Federal Highway Administration under Project 0092-15-09. The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views of the Wisconsin Department of Transportation or the Federal Highway Administration at the time of publication.

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof. This report does not constitute a standard, specification or regulation.

The United States Government does not endorse products or manufacturers. Trade and manufacturers' names appear in this report only because they are considered essential to the object of the document.

EXECUTIVE SUMMARY

This report documents the findings of the Wisconsin Highway Research Program (WHRP) Project 0092-15-90, *Wisconsin Department of Transportation (WisDOT) Asphaltic Mixture New Specification Implementation – Field Compaction and Density Validation* (0092-15-09) study. The two research objectives of this study include: (1) evaluate the HMA longitudinal joint type, method and compaction data to produce specification recommendations to ensure improved density of the longitudinal joint, and (2) evaluate and produce a specification for thin layer overlay HMA to ensure proper and consistent compaction throughout the pavement.

In 2014, longitudinal joint nuclear density data was collected throughout Wisconsin on 28 projects. This data was revisited during this study to aid in deciding which type of field projects to visit and whether the data collected on the field projects was representative of the whole population (i.e., statewide). The 2014 density data indicated significant reduction in density as pavement mix type (i.e., traffic category) Equivalent Single Axel Load (ESAL) increase. This finding influenced a closer look at E-10 and E-30 field projects. This secondary evaluation of 2014 density data also drew attention to the fact that there is a significant difference between confined and unconfined joint density. The results of a density survey, also conducted as part of this research, emphasized the different rolling pattern used on the unconfined and confined longitudinal joints throughout Wisconsin.

In 2015 four projects were visited with various types of longitudinal joint including:

1. STH 26 (1110-10-71) – Vertical Longitudinal Joint
2. USH 41 (1107-00-74) – Notched Wedge Longitudinal Joint, where the unconfined edge was Milled out
3. CTH H (5897-00-70) – Safety Edge Longitudinal Joint
4. USH 8 (1595-09-60) – Thin Lift Overlay

Each project visit consisted of the following testing: nuclear density readings (additionally the use of the thin lift gauge versus conventional on USH 8), core density, NCAT Asphalt Permeameter and Hamburg Wheel testing (American Association of State Highway and Transportation Officials, AASHTO T 324).

The 2015 results indicated the nuclear density gauge has the highest correlation to cores when used in the parallel position (relative to traffic and paving direction). However, a nuclear / core correlation on a test strip is recommended for all projects considering the parallel orientation overestimates density. The standard nuclear gauge overestimates density, while the thin lift nuclear gauge underestimates density.

In reference to the nuclear density data collected in 2014, the milled longitudinal joint achieved the highest percent compaction, followed by the notched wedge. Vertical longitudinal joints had the lowest average joint densities. Heating joints resulted in higher densities for all joint types where data was available. In reference to the field visits in 2015, rolling pattern was found to be significant on only one of the project sections tested. Therefore rolling pattern is not considered a definitive method to increase longitudinal joint density for the Wisconsin mixes studied.

As a result of this study, the research team recommends 90% compaction on the longitudinal joint, tested with a nuclear density gauge in the parallel position within 2 inches of the joint and 92.0% compaction on the mainline. These compaction targets are for the nuclear density gauge, not cores. Regarding the longitudinal joint type, the research team recommends keeping the notched wedge longitudinal joint, but also proposes to mill out the unconfined side of the notched wedge for the higher ESAL projects. Finally, it is recommended to measure density on the thin lift overlay projects as opposed to the current standard of “ordinary compaction.”

TABLE OF CONTENTS

Disclaimer ii
Executive Summary iii
Table of Contents v
List of Figures vii
List of Tables ix
Chapter 1: Introduction 1
- Longitudinal Joint Study 2
- Thin Lift Overlay Study 5

Chapter 2: Literature Review 5
- Longitudinal Joint 5
- Thin Lift Overlay 9

Chapter 3: Initial Analysis of 2014 Nuclear Density Data & Survey 12
- 2014 Nuclear Density Data Collection 12
- Analysis of 2014/2015 Density Data Collection 15
- Longitudinal Joint Best Practices Survey 22

Chapter 4: Research Methodology 25
- Work Plan 25
- Selection of Field Projects 27
- Field Visits 33

Chapter 5: Analysis of Field Visit Density & Core Data 46
- STH 26 – Vertical Longitudinal Joint 49
- USH 41– Notched Wedge Longitudinal Joint / Milled 52
- CTH H– Safety Edge Longitudinal Joint 54
- USH 8– Thin Lift Project 56
- Hamburg and Permeability Data 57
- Cores on the longitudinal joint 61

Chapter 6: Conclusions 64
- Density Validation: 64
- Longitudinal Joint Type 64
- Rolling Pattern 65
- Density Targets 65

Chapter 7: Recommendations 70
- Density Validation: 70
- Longitudinal Joint Type: 70
- Density Targets: 71
- Further Recommendations Based on Observations 72

Chapter 8: WisDOT Specification Recommendations 74
Works Cited 70
Appendix A – WisDOT Longitudinal Joint Density Data Collection Procedure 71
Appendix B – Survey of Current Paving Practices & Opinions 70
Appendix C – Longitudinal Joint Study Work Plan 74
Appendix D – Thin Lift Study Work Plan 76

Appendix E – IDOT District 4 Notch Wedge / Mill Spec 77
Appendix F – IDOT District 4 Centerline joint study 78
Appendix G – IDOT Joint Sealant Specification... 80

LIST OF FIGURES

Figure 1 - Notched wedge longitudinal joint ... 3
Figure 2 - Normal vertical longitudinal joint ... 3
Figure 3 - Safety edge longitudinal joint ... 4
Figure 4 - Milled longitudinal joint ... 4
Figure 5 - Nuclear gauge in the parallel orientation ... 5
Figure 6 - Nuclear gauge in the perpendicular orientation ... 5
Figure 7 - NCAT longitudinal joint study methods (ranked from best to worst for the 1994 WI projects) ... 6
Figure 8 - FDM notched wedge detail ... 9
Figure 9 - Location of the longitudinal density tests ... 12
Figure 10 - 2014 density data and 2015 project visits ... 13
Figure 11 - Density data by joint type ... 14
Figure 12 - Density data by ESAL ... 15
Figure 13 – 2014 mainline and joint density (parallel), relative to WisDOT specifications ... 17
Figure 14 – 2014 mainline upper and lower density (parallel), relative to WisDOT specifications ... 18
Figure 15 – 2014 joint density (parallel) separated by joint type, relative to WisDOT specifications ... 19
Figure 16 - Joint parallel density for unconfined and confined edge, separated by joint type ... 21
Figure 17 – Wisconsin survey respondent opinion ... 22
Figure 18 Rolling pattern assumed best practices (according to Wisconsin contractors) ... 23
Figure 19-AI/FHWA rolling pattern best practices for a longitudinal joint ... 23
Figure 20 - Joint types evaluated with field visits ... 25
Figure 21 - Layout of cores and nuclear gauge readings per 1800' section ... 26
Figure 22 - Layout of Thin Lift testing ... 27
Figure 23 - STH 26 cross section ... 28
Figure 24 - STH 26 plan layer thicknesses & mix types ... 29
Figure 25 - Longitudinal rumble strip specification ... 29
Figure 26 - USH 41 cross section ... 30
Figure 27 - USH 41 plan layer thicknesses & mix type ... 30
Figure 28 - CTH H cross section ... 31
Figure 29 - CTH H layer thicknesses & mix types ... 31
Figure 30 - USH 8 cross section ... 32
Figure 31 - USH 8 layer thickness & mix type ... 32
Figure 32 - USH 8 centerline rumble strip detail ... 32
Figure 33 STH 26 unconfined edge ... 34
Figure 34 STH 26 confined edge ... 35
Figure 35 - STH 26 longitudinal joint, photographed 3/31/16 ... 36
Figure 36- USH 41 joint photographed 3/31/16 ... 39
Figure 37 - USH 41 longitudinal joint 3/31/16 ... 39
Figure 38 – CTH H ... 41
Figure 39 - CTH H photographed 03/31/16 ... 42
Figure 40 – USH 8 ... 44
Figure 41 - Parallel correlation to cores ... 47

Figure 42 - Perpendicular correlation cores 47
Figure 43 - Core data vs nuclear density data (parallel orientation) 48
Figure 44 – Nuclear density data (parallel) - STH 26 vs 2014 E-10 vertical joint projects 50
Figure 45 –Nuclear data STH 26 - FHWA recommended vs. contractor practice rolling pattern 51
Figure 46 - Nuclear data - USH 41 vs. 2014 notched wedge & milled projects 53
Figure 47 –Nuclear data USH 41- FHWA recommended vs. contractor practice rolling pattern 54
Figure 48 - Nuclear density (parallel) CTH H vs 2014 E-3 safety edge projects 55
Figure 49 - Parallel nuclear vs. cores for standard and thin lift gauge 56
Figure 50 - Nuclear density (parallel) - USH 8 vs 2014 E-3 density data 57
Figure 51 - Hamburg test (AASHTO T-324) 58
Figure 52 -Hamburg & density vs WisDOT proposed specification requirement 59
Figure 53 - NCAT permeameter photographed on STH 26 60
Figure 54 - Permeability using the NCAT permeameter 61
Figure 55 - Centerline of CTH H 62
Figure 56 - Centerline cores vs. adjacent confined and unconfined cores 63
Figure 57 - Mainline – 2014 nuclear parallel mainline and joint density, with suggested specifications 67
Figure 58 - Mainline and joint density, parallel (all data) - E-10/30 filtered 68

LIST OF TABLES

Table 1 - AI & FHWA recommendations vs typical Wisconsin practice....................................... 8
Table 2 - Thin lift overlay vs standard mix specifications... 10
Table 3 - Analysis of data for Figure 13 box and whisker plot 17
Table 4 - Analysis of data for Figure 14 box and whisker plot 18
Table 5 - Analysis of data for Figure 15 box and whisker plot 20
Table 6 - Analysis of data for Figure 16 box and whisker plot 21
Table 7- STH 26 - vertical unconfined rolling pattern 33
Table 8 - STH 26 - vertical confined vertical rolling pattern 35
Table 9 - USH 41 – notched wedge unconfined rolling pattern 37
Table 10 USH 41 notched wedge confined rolling pattern... 38
Table 11 - CTH E safety edge unconfined rolling pattern.. 40
Table 12 - CTH E safety edge confined rolling pattern.. 40
Table 13 - USH 8 Thin Lift rolling pattern... 43
Table 14 - 2014 and 2015 summary of data collection... 46
Table 15 - Correlation of density to cores 46
Table 16 - Analysis of data for Figure 43 box and whisker plot 49
Table 17 - Data included in Figure 44 box and whisker plot... 50
Table 18 - Data used for Figure 44 box and whisker plot 52
Table 19 - Data used in Figure 46 box and whisker plot.. 53
Table 20 - Data used in Figure 47 box and whisker plot.. 54
Table 21 - Data used in Figure 48 box and whisker plot.. 55
Table 22 - Data used in Figure 50 box and whisker plot.. 57
Table 23 - Analysis of data for Figure 58 box and whisker plot 67
Table 24 - Analysis of data for Figure 59 box and whisker plot 69

Chapter 1: Introduction

This report documents the findings of the Wisconsin Highway Research Program (WHRP) Project 0092-15-90, *Wisconsin Department of Transportation (WisDOT) Asphaltic Mixture New Specification Implementation – Field Compaction and Density Validation* study. It is divided into two sections: the Longitudinal Joint Study and the Thin Lift Overlay Study.

The intent of this research was to use density data to evaluate various HMA longitudinal joint types and methods of construction; and to produce specification recommendations that result in the highest density (ergo increased pavement life) longitudinal joint. The second part of this research was to evaluate and produce a specification for Thin Lift Overlay HMA that ensures proper and consistent compaction to maximize durability. These are two distinct investigations and therefore separated accordingly in this report. The findings were used to validate current WisDOT specifications and suggest modifications where applicable.

Density has been one of the primary acceptance criteria and indicators of Hot Mix Asphalt (HMA) performance. Poor field compaction, which results in low density, significantly increases a pavement's susceptibility to surface cracking due to reduced strength of the pavement surface. Low density also increases pavement permeability, which in turn allows damaging water into the pavement. Both poor field compaction and high permeability expedite pavement damage and increase the rate of fatigue cracking. The National Cooperative Highway Research Program (NCHRP), the National Asphalt Pavement Association (NAPA) and National Center for Asphalt Technology (NCAT) have shown in place air voids of dense graded mixes should not be higher than 8% (i.e., no less than 92% total maximum density) (*1*) (*2*). WisDOT density specifications range from 89.5% to 92.0% depending upon the mix and base type; well below these recommendations. While WisDOT has used percent compaction of Theoretical Maximum

Specific Gravity of the mix (Gmm) as a measure of mainline pavement durability at standard thicknesses, density has not been used to evaluate longitudinal joints specifically.

Longitudinal Joint Study

It should be noted; Minnesota (considered similar to Wisconsin in climate and use of dense graded mixes) has a higher mainline density specification and also has a longitudinal joint specification. Minnesota, according to the Materials Lab Supplemental Specifications for Construction Section 2360.3.D.1, requires 92.0 to 93.0% for mainline density while requiring 89.5 to 90.5% for a confined edge and 88.1 to 89.1% for an unconfined edge. Other recommendations for minimum compaction of the longitudinal joint vary from 89.0 to 91.0% (*3*) for states such as Iowa and Michigan.

Longitudinal joint density is an important factor in pavement longevity. Poor joint performance can prematurely ruin an asphalt pavement by allowing water to access the pavement structure and permeate the underlying layers; thus, increasing the detriment of freeze thaw cycles. To maintain the integrity of mainline pavement, maintenance should begin when longitudinal joints begin showing signs of failure. In other words, to increase the life of an asphalt pavement as a whole, emphasis should be placed on the durability of longitudinal joints.

WisDOT specifies to "place all layers as continuously as possible without joints" (WisDOT, 460.3.2.8.1). The ideal solution to accomplish this would be to use the Echelon paving practice which is the act of using multiple pavers side-by-side to cover the entire width of the roadway. However, while Echelon paving will essentially eliminate the longitudinal joint, it is not practical for most construction projects.

The notched wedge longitudinal joint is the standard joint detail for all WisDOT projects as long as "pavement thickness conforms to the minimums specified, [and] unless the engineer directs or allows an alternate joint" (WisDOT Standard Section 460.3.2.8.3). The notched wedge (Figure 1) is formed by providing a vertical notch and a taper. It is the preferred joint type to use during construction when the adjacent lane is not paved in the same day, and the roadway is open to traffic. This joint type allows for a vehicle to more safely maneuver from the newly paved lane onto a lower existing adjacent lane. Lane 1 is the first lane paved and lane 2 is the second lane paved, as depicted in Figure 1. Lane 1 has an unconfined edge joint and Lane 2 has a confined edge joint.

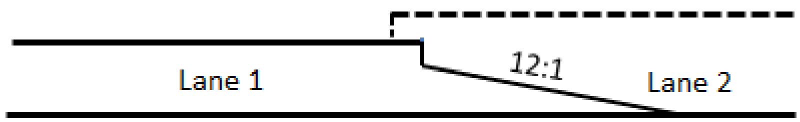


Figure 1 - Notched wedge longitudinal joint

The normal vertical joint (Figure 2) does not require any special equipment. As the paver travels, the unsupported edge of the first lane will repose at about 60 degrees (*4*).

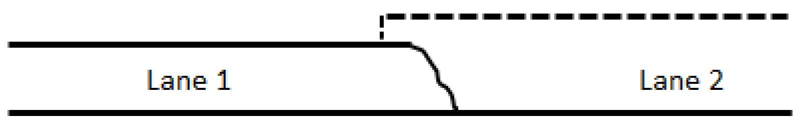


Figure 2 - Normal vertical longitudinal joint

The safety edge (Figure 3) is promoted by the Federal Highway Administration (FHWA) to improve pavement edge drop off on the shoulders of roadways and reduce roadway departures (*5*). The safety edge joint does not have a notch, but rather a 30° angle of repose. While this joint type is designed for the outside edge of pavements with gravel shoulders, it is thought to aid with transitions between adjacent lanes similar to the notched wedge geometry. This is not a WisDOT approved longitudinal joint; however the safety edge has been accepted by some engineers for the centerline longitudinal joint on projects in Wisconsin.

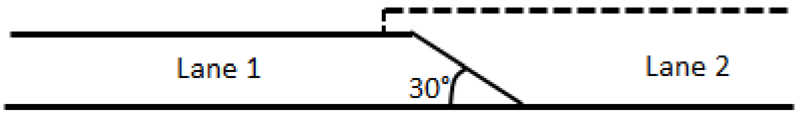


Figure 3 - Safety edge longitudinal joint

The milled longitudinal joint is a method that is described for lane 2 only, as depicted in Figure 4 (i.e., a second or subsequent lane). The first lane that is paved may be constructed using any other joint method: notched wedge, vertical or safety edge. Then, before construction of lane 2, a mill removes the HMA leaving a 90 degree edge on lane 1.

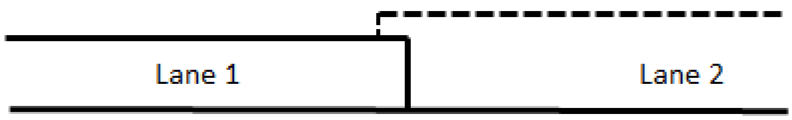


Figure 4 - Milled longitudinal joint

Joint heating is another method used to promote stronger longitudinal joints. This involves reheating the longitudinal joint of lane 1 just before paving lane 2 to promote a better bond between the two lanes. WisDOT special testing provision 460.015 for reheating pavement longitudinal joints requires reheating the joint within 60°F of the mix temperature at the paver auger. Joint temperature measurements are required immediately behind the heater. Other studies have recommended temperature ranges between 212 º to 250º F (*6*).

In 2014, WisDOT collected density data on HMA projects throughout Wisconsin. This nuclear density data was collected and categorized by ESAL (E-1 (60 gyrations), E-3 (75 gyrations), E-10 (100 gyrations) and E-30 (100 gyrations)), upper versus lower layer, mainline average (up to three tests across the lane), joint type (notched wedge, normal vertical, safety edge, milled and heated), joint location (centerline or shoulder), edge of joint (confined or unconfined) and gauge orientation (parallel vs perpendicular). The parallel and perpendicular joint orientations are shown in Figures 5 and 6.

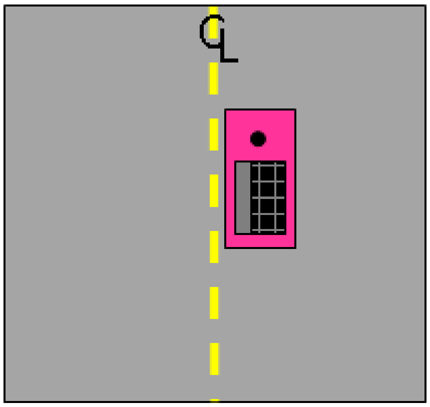


Figure 5 - Nuclear gauge in the parallel orientation

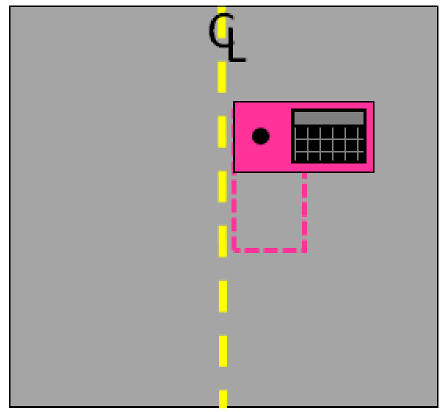


Figure 6 - Nuclear gauge in the perpendicular orientation

For this research, 2014 density data was evaluated and four additional field projects were visited and tested the following year. Data was analyzed to determine (1) which longitudinal joint type and method results in greatest compaction, and (2) what is the best method to validate density on a thin lift overlay pavement.

Thin Lift Overlay Study

According to WisDOT, a thin lift overlay pavement is greater than 1.00 to 1.50-inches. This thin lift overlay study was added onto the longitudinal joint study in an effort to combine some of the nuclear density and core data analysis. WisDOT currently specifies "ordinary compaction" for thin lift overlays, with no requirement for density testing.

This research was separated into six subgroups: (1) Literature Review, (2) Survey and Analysis of Current Practices (3) Research Methodology, (4) Analysis of Field Visit Data, (5) Conclusions and (6) Recommendations.

CHAPTER 2: LITERATURE REVIEW

Longitudinal Joint

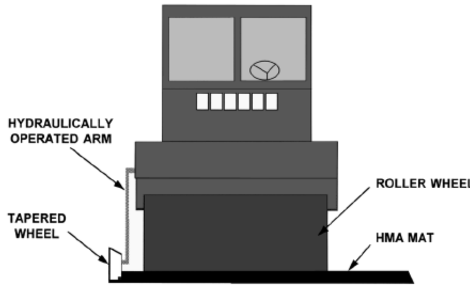
Previous research reveals a variety of opinions regarding HMA longitudinal joints. The primary factors that have been recommended to improve the longitudinal joint include joint type, mix selection criteria, project planning, specifications, best practices and alternative techniques.

In 1994 the National Center for Asphalt Technology (NCAT) Interim Report 94-01 (*7*) evaluated longitudinal joints in four states, including Wisconsin. The initial findings of the Wisconsin data concluded that the cutting wheel (Figure 7(a)) achieved the highest relative densities, followed by the edge restraining device (b), the AW-2R joint maker (c), rolling technique A (d), wedge joint with tack (e), rolling technique C (f), rolling technique B (g) and finally, wedge joint without tack.

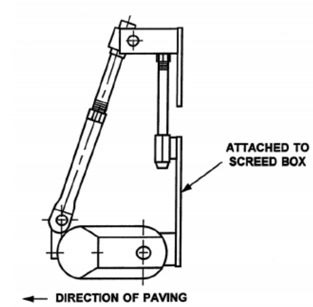
NCAT continues to evaluate the cracking and raveling performance of the Wisconsin test sections at one and five years after construction. The latter findings of years one and five were drastically different from when the interim report was written. The edge restraining device resulted in the highest ranking, followed by the notched wedge with tack, notched wedge without tack, joint maker, cutting wheel, rolling technique A, rolling technique C, and roller technique B. After 5 years, NCAT found that the joint type had a larger impact on pavement performance than varying roller techniques. (*8*)

Colorado was also evaluated as part of the NCAT study. In Colorado, all three rolling techniques (A, C, and B, respectively) performed better than the notched wedge, cutting wheel and joint maker methods for cracking and raveling. The research does not directly compare the two states to determine the cause for this difference, but does mention that the "density at the joint in all [Wisconsin] test sections was relatively lower than normally expected." (*8*)

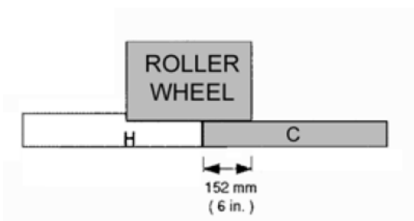
(a) Cutting wheel
(www.highwaymaintenance.com)



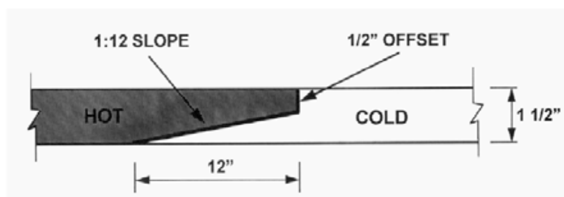
(b) Edge restraining device
(Kandhal, 1994)



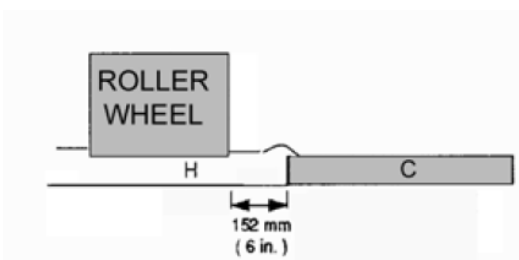
(c) AW-2R joint maker
(Kandhal, 1994)



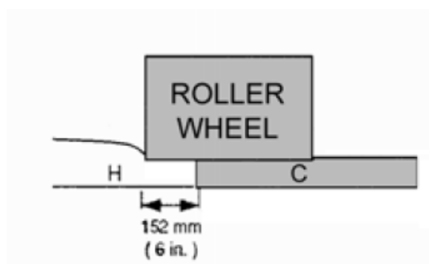
(d) Roller technique A
(Kandhal, 1994)



(e) Notched wedge
(Kandhal, 1994)



(f) Roller technique C
(Kandhal, 1994)



(g) Roller technique B
(Kandhal, 1994)

Figure 7 - NCAT longitudinal joint study methods (ranked from best to worst for the 1994 WI projects)

Currently, WisDOT's mainline density targets range from 89.5% for a lower layer over gravel on a low volume road, to 92.0% for an upper layer on a high volume road. WisDOT specifications require each sublot to consist of three tests randomly located transversely across the mainline and up to three tests across shoulders depending on shoulder width. Each sublot is comprised of 1500-feet. Sublots are averaged on a daily basis to constitute one complete lot. A penalty is applied if the lot density average falls more than 0.4% below target, or if an individual density falls greater than or equal to 3% below target. Incentives are applied if the lot density average is 1.1% above target and the air voids for all representative mix are between 3.5 and 5.0%.

Pennsylvania conducted a study to look at longitudinal joint density data from 2007 to 2011. In 2007 best practices were established, documented, and distributed, which by 2009 improved joint densities statewide by 1.1%. In 2010 Pennsylvania moved to an incentive/disincentive via Percent Within Limits (PWL) specification requiring 89% density on longitudinal joints. The study concluded the most evident factor influencing joint density was the joint type, specifically the notch wedge joint producing 1.5% higher densities than the vertical joint. During that time, contractors purchased special equipment to densify the tapered wedge joint. (*9*)

According to a co-operative effort between the FHWA and the Asphalt Institute (AI), factors to consider in order to best construct a longitudinal joint include: planning techniques, design techniques, pavement lay down operations, rolling and compaction, testing and specifications (*10*). Table 1 is a summary of the recommendations of AI and FHWA in comparison to standard practices used in Wisconsin.

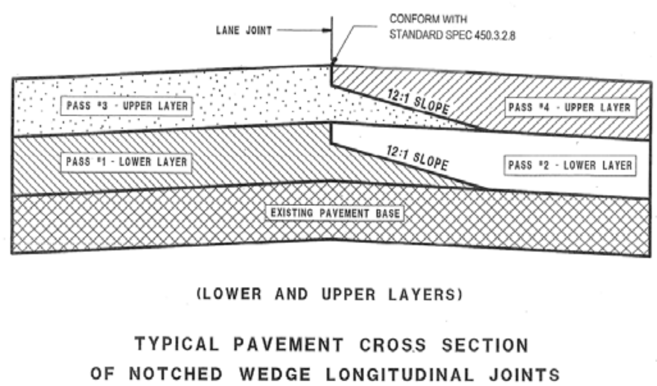
Table 1 - AI & FHWA recommendations vs typical Wisconsin practice

AI & FHWA Recommendations	Wisconsin Practice
Mix Selection and Design Considerations	
Use the smallest NMAS, fine graded (0.45 power curve) mixes	☑*
Lift Thickness at 3 times the NMAS	☑
Consider use of the Notched Wedge Joint	☑
Pay for tack separately	☑
Planning	
Include Longitudinal Joint Construction in the pre-pave meeting	☑
Horizontally offset longitudinal joints by at least 6"	When applicable
Consider infrared joint heaters, especially in cold weather paving	Limited
Use the Rubber Tire roller on the confined joint	Not specified
Alternative Techniques and Materials for Construction	
Consider Echelon paving when possible	When applicable
Mill and fill one lane at a time	☑
Cut back the joint 6-8 inches	Not specified
Evaluate the use of joint adhesives	Not evaluated
Evaluate the use of surface sealers	Not evaluated
Specifications	
Minimum longitudinal joint density	Not specified
Construct test strip that includes a longitudinal joint	Not specified
Determine optimum roller pattern for density at the joint	Not specified
Payment scale for joint density	Not specified
Construction Best Practices	
Follow best practices to reduce segregation	Not specified
Use string line guide for paver operator to make straight pass	Not specified
Tack coat uniformly applied to full width of paving lane	☑
Ensure paver is set up correctly – screed, augers, end gate, speed	Not specified
Use paver automation	Not specified
Compact unsupported edge of mat with the first pass of vibratory roller drum extended out over the edge of the mat approximately 6 inches	Not specified
Tack existing face of the joint	☑
Overlap the existing lane 1 inch	Not specified
Compact the supported edge of the joint with the first pass of the vibratory roller drum on the hot mat staying back from the joint 6 to 8 inches. The second pass should then overlap onto the cold mat 4 to 6 inches.	Not specified

*WisDOT uses 12.5mm and 19.0mm

Comparable to the recommendations by AI and FHWA, WisDOT specifies a dense graded HMA and requires pavement to be placed at least 3 times the Nominal Maximum Aggregate Size (NMAS). A dense graded mix of this thickness is nearly impermeable (*11*). Also, in 2015 specifications, WisDOT increased tack specification requiring 0.05 to 0.07 gallons per square yard, after dilution which helps to ensure uniform tack application. Finally, according to the Facilities Development Manual (FDM) Pavement Section 14-10, WisDOT considers the notched wedge longitudinal joint as the “standard joint to be used at HMA pavement centerlines and lane lines,” as shown in Figure 8.

Figure 8 - FDM notched wedge detail



Although several of the recommendations in Table 1 are followed, the remaining best practices recommended by AI and FHWA, are not currently addressed by WisDOT specification. For this research, contractors’ standard practices were evaluated and the joint type was analyzed to determine which factors ultimately affect density and the longevity of Wisconsin longitudinal joints.

Thin Lift Overlay

Thin lift overlays are used to extend the life of an HMA pavement. However, the intended performance depends on the condition of the existing pavement structure, the HMA mix design and the quality of the construction. WisDOT currently uses Special Provision 0195.01 for Thin Lift HMA mix design, which targets a lower gyration level ($N_{design\,=}$ 40), increases the aggregate requirements and uses a polymer modified asphalt binder. Table 2 shows a comparison of the thin lift overlay specification versus a standard WisDOT HMA.

Table 2 - Thin lift overlay vs standard mix specifications

	Thin Lift E-3 9.5mm design	Standard E-3 9.5mm design
Sieves – Percent Passing		
12.5mm	100	100
9.5mm	90-100	90-100
4.75mm	0-90	90 max
2.36mm	20-65	20-65
1.18mm	30-60	--
0.6mm	20-45	--
0.075mm	3-10	2.0-10.0
Volumetrics		
VMA	--	15.5
Gyrations Nini	6	7
Gyrations Ndes	40	75
Gyrations Nmax	60	115
Aggregate Properties		
Percent Crush (2F)	min 75%	min 60%
FAA (AASHTO 304)	min 45	min 43
LA Abrasion (500 rev)	max 42	max 45
Dust, RAP and AC requirements		
Dust/Pbe ratio	0.6-1.4	0.6-1.2
Percent Binder Replacement	max 10%	max 20%-25%
PG Binder Grade	PG 58-34	Project specific
Tack Coat Application		
Gallons per square yard	0.05 – 0.08	0.05 – 0.07
Layer Thickness		
Minimum Thickness	1.00” To 1.50”	1.5”

The National Cooperative Highway Research Program (NCHRP) Synthesis 464 surveyed 47 agencies throughout the United States and Canada and compiled recommendations for mix design and construction of thin lift overlays. WisDOT follows several of the suggestions for mix design such as: lowering the gyration level to increase asphalt content, reducing the gradation of Recycled Asphalt Pavement (RAP) to the Nominal Maximum Aggregate Size (NMAS) of the thin lift, and increasing the amount of tack coat. While WisDOT increased the *maximum* tack coat application rate, the *minimum* required for a thin lift overlay remains the same as the standard mixture specification. Additionally, the NCHRP Synthesis determined that most states generally do not require a certain density level or target value for thin overlays, including Wisconsin. (*12*).

Standard nuclear density testing on a thin lift overlay may be problematic because the standard gauges use a backscatter mode for testing asphalt. The backscatter mode is where the source is positioned near the surface of the test material and the top four inches of material are penetrated by the gamma ray photons. Density gauges using the backscatter mode, read further than 1.5-inches down into the pavement, causing test results to include material other than the intended 1.5-inches of asphalt placed as a thin lift. The alternative to the standard nuclear density gauge is a thin lift gauge, which claims to differentiate between the thin lift of asphalt and the underlying material. The thin lift gauge uses two sets of photon detectors and mathematic models to determine the density of the top layer of asphalt (*13*).

The most reliable determination of in-place density is to core the pavement; however, this type of testing is destructive, and therefore generally undesirable. The National Asphalt Pavement Association (NAPA) recommends two options for determining density on thin lift projects: to calibrate the gauge daily, or to set up a rolling pattern for the project (*14*). For the purposes of this study, evaluations of in-situ densities were tested using a standard nuclear density gauge and a thin lift nuclear density gauge. Pavement cores were tested to determine the validity of both gauges.

Chapter 3: Initial Analysis of 2014 Nuclear Density Data & Survey

2014 Nuclear Density Data Collection

The current WisDOT specification does not require density along the longitudinal joint. In 2014 WisDOT requested contractors and WisDOT personnel to collect density data near the longitudinal joint for informational purposes. This data was collected in conjunction with the standard WisDOT Quality Management Program (QMP) and Quality Verification (QV) testing that includes only mainline density collection. A handout and worksheet were distributed to contractors, consultants, and WisDOT staff throughout the state (see Appendix A). Joint densities were taken with nuclear density gauges, both in the parallel and perpendicular orientations, located within 0.5 to 2-inches of the longitudinal joint. Each joint density location was transverse to the corresponding mainline density per sublot, see Figure 9.

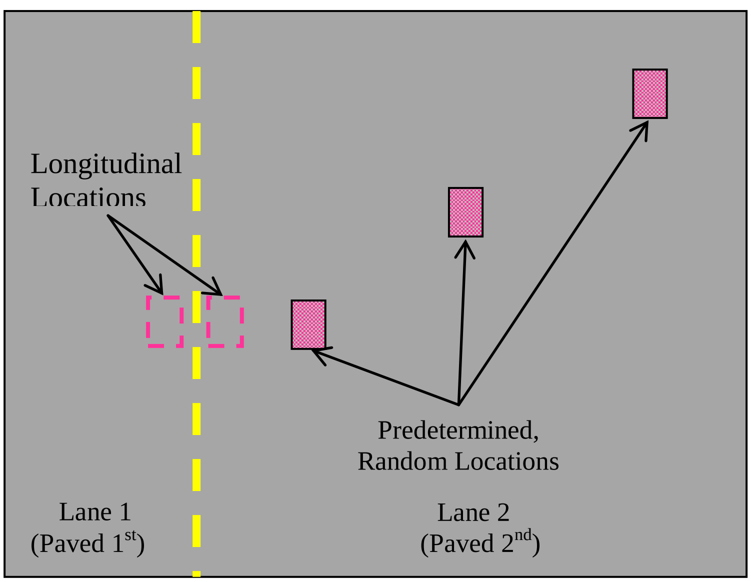


Figure 9 - Location of the longitudinal density tests

Over 1400 density data sets were collected on 28 different WisDOT projects. Many identifiers were included in the 2014 data collection, including the following:

1. Project Information (State ID, County, ESAL, Nominal Maximum Aggregate Size (NMAS) and gauge type)
2. Layer (upper or lower)
3. Joint Type (milled, normal-vertical, notched wedge, safety edge)
4. Heated joint (yes or no)
5. Joint location (centerline or shoulder)
6. Edge of joint (confined or unconfined)
7. Gauge rotation (parallel or perpendicular)

Project data was collected in 24 of 72 Counties, spanning all 5 WisDOT Regions, see Figure 10 below. A majority of data was collected in the Southeast (SE) and Southwest (SW) Regions, which coincide with the major urban areas of Milwaukee and Madison, respectively. Figures 10 – 12 show the distribution of project data that was collected in the 2014 Density Study and 2015 field project visits.

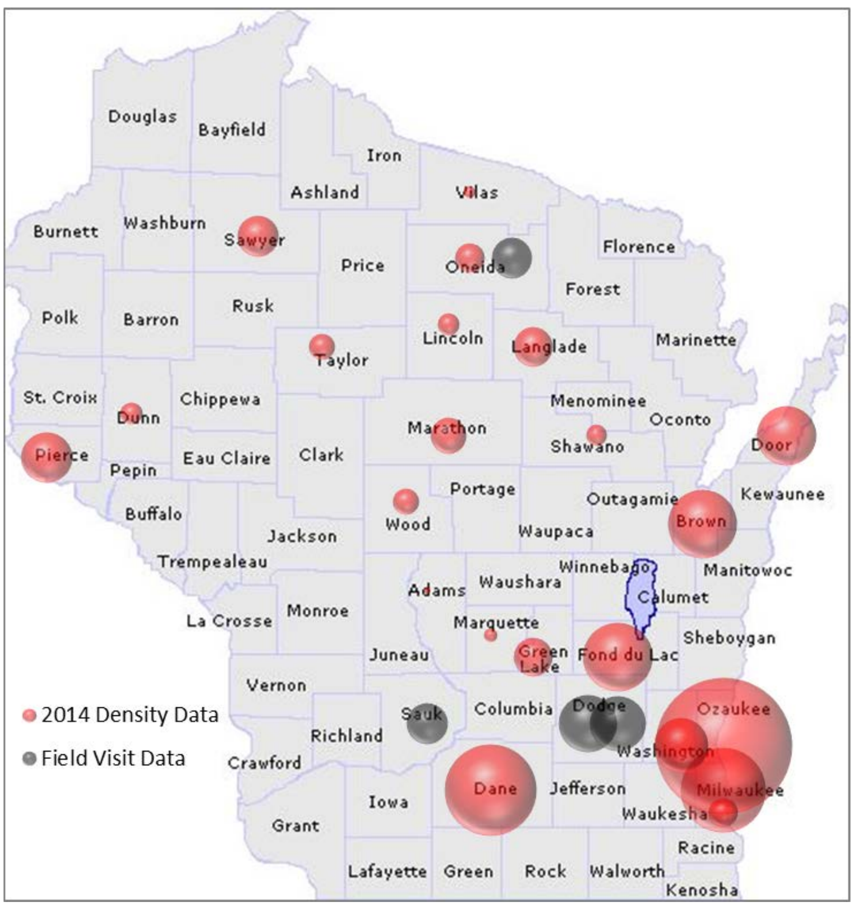


Figure 10 - 2014 density data and 2015 project visits

Figure 11 shows the data separated into each type of longitudinal joint; milled, normal vertical, notched wedge, and safety edge. Nearly half of the data points collected were on projects using the notched wedge longitudinal joint. The remaining projects were comprised of 37% vertical joint, 10% milled joint and 2% safety edge joint.

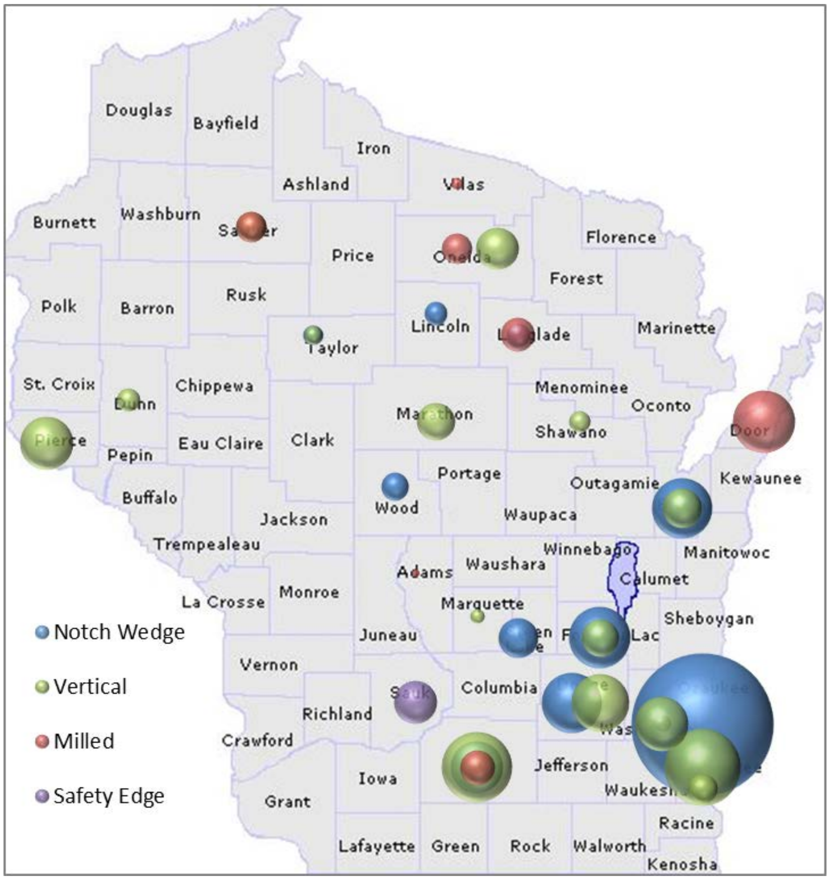


Figure 11 - Density data by joint type

Figure 12 shows the data separated into Equivalent Single Axle Load (ESAL) designation for the HMA mix design used. The E-10 and E-30 ESAL designations were grouped together based on their similarity. E-10 and E-30 designs use 100 gyrations for N_{design} and are the same in all other design properties except crush count, where the E-30 requires 98/90 (one face/two face) and the E-10 requires 85/80. More than half, 55%, of the data points collected were on projects that used either an E-10 or E-30 design. E-3 designs made up 28% of the data, while E-1 designs accounted for 17%. There was no data collected for E-0.3 designs.

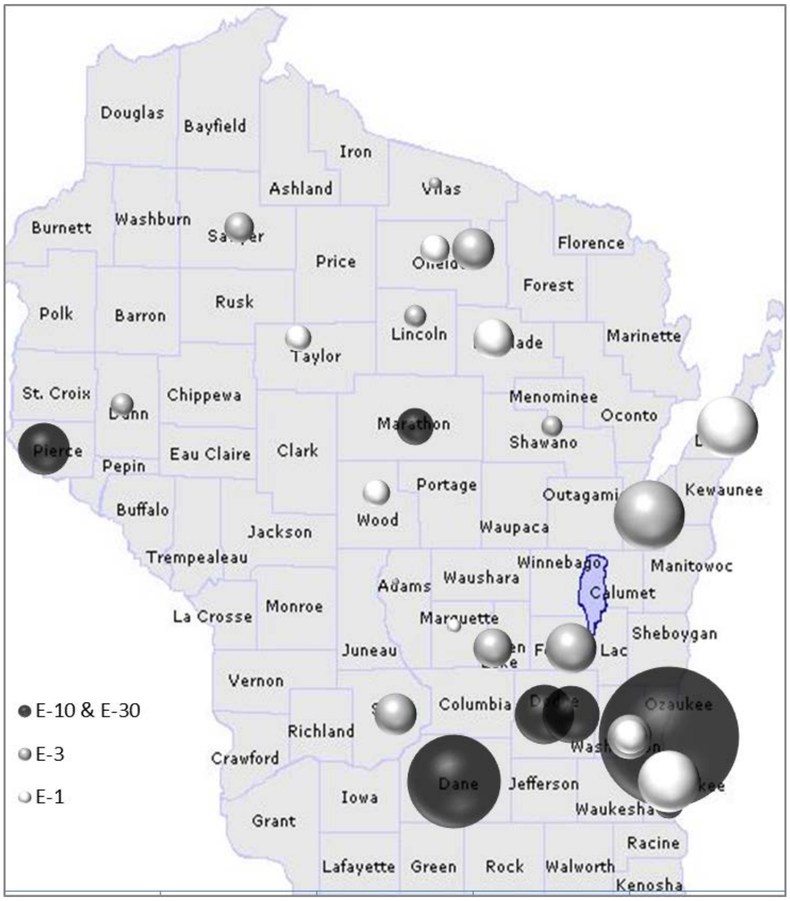


Figure 12 - Density data by ESAL

Upper layer mixes (all 12.5mm) accounted for 87% of the data collected in 2014 and lower layer mixes (all 19.0mm) made up 13% (see Table 14 for summary of dataset).

Analysis of 2014/2015 Density Data Collection

The F- and t-test statistical method was used to analyze the data to determine if the datasets in question are statistically similar to each other at 95% reliability. Furthermore, box and whisker plots were used to identify outliers and data variability.

The figures and tables throughout this section represent the 2014 nuclear density readings in parallel position for mainline and longitudinal joint. The 2015 field visit data is presented in its entirety in Chapter 5 and appears in summary where otherwise noted. Mainline densities are the average of predetermined random locations (Figure 9) across the lane. Joint densities are tested within 0.5 to 2-inches of the longitudinal joint. All nuclear density readings collected in this study are calculated using the lab tested Gmm. The referenced WisDOT density target is that for an upper layer E-10/E-30 design, which is the highest WisDOT density specification requirement.

When analyzing all 2014 density data, the F- and t-tests showed there is a statistically significant difference between average mainline density and longitudinal joint density. Joint density is on average 2% lower than mainline density. Data analysis also showed a roughly 60% correlation between ESAL-designation and joint density, with joint density decreasing as ESAL level increases, as seen in Figure 13.

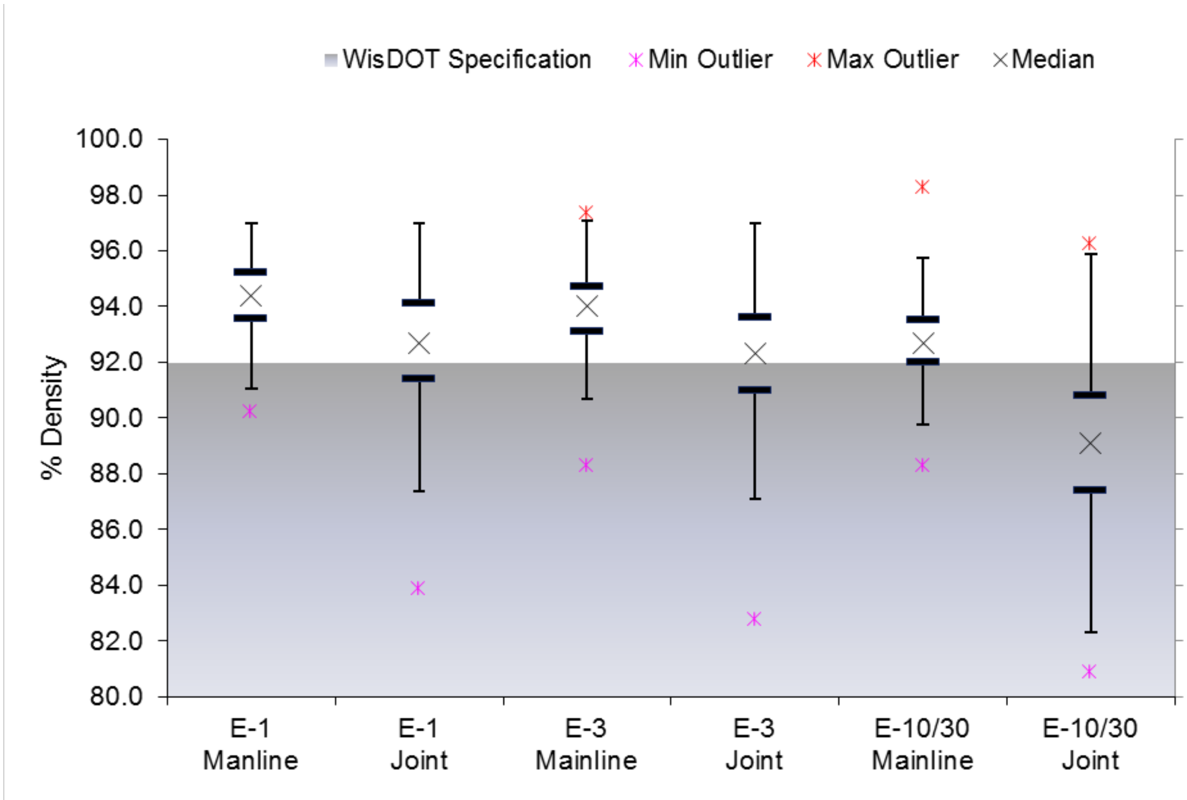


Figure 13 – 2014 mainline and joint density (parallel), relative to WisDOT specifications

Table 3 - Analysis of data for Figure 13 box and whisker plot

Labels	E-1 Manline	E-1 Joint	E-3 Mainline	E-3 Joint	E-10/30 Mainline	E-10/30 Joint
Min	90.3	83.9	88.3	82.8	88.3	80.9
Q_1	93.6	91.4	93.1	91	92	87.4
Median	94.4	92.7	94	92.3	92.7	89.1
Q_3	95.2	94.1	94.7	93.6	93.5	90.8
Max	97.0	97	97.4	97	98.3	96.3
IQR	1.7	2.7	1.6	2.6	1.5	3.4
ST DEV	1.3	2.1	1.4	2.3	1.2	2.5
Upper Outliers	0.0	0	1	0	9	2
Lower Outliers	9.0	9	9	10	17	3

Table 3 shows that all average mainline and joint densities, with the exception of the E-10/E-30 joint density, exceed 92.0%. The highest occurrence of outliers, both upper and lower, is found in the same dataset, the E-10/30 mainline density. The IQR data, which is the difference between the 75th (Q3) and 25th (Q1) percentile, shows the highest variability in the E-10/30 joint density, and the lowest variability in the E-10/30 mainline.

The data in Figure 13 *does* include heated joints. Heated joints resulted in higher densities for all joint types where data was available. Heated joints increased densities by an average of 0.7, 1.2, and 1.5% for milled, vertical, and notched wedge, respectively. All data analysis beyond Figure 13 does not include heated joint data.

Figure 14 emphasizes that upper and lower layer densities are similar for the mainline even though WisDOT currently has differing minimum density targets for each. However, the lower layer data in Figure 14 represents 13% of the total 2014 dataset.

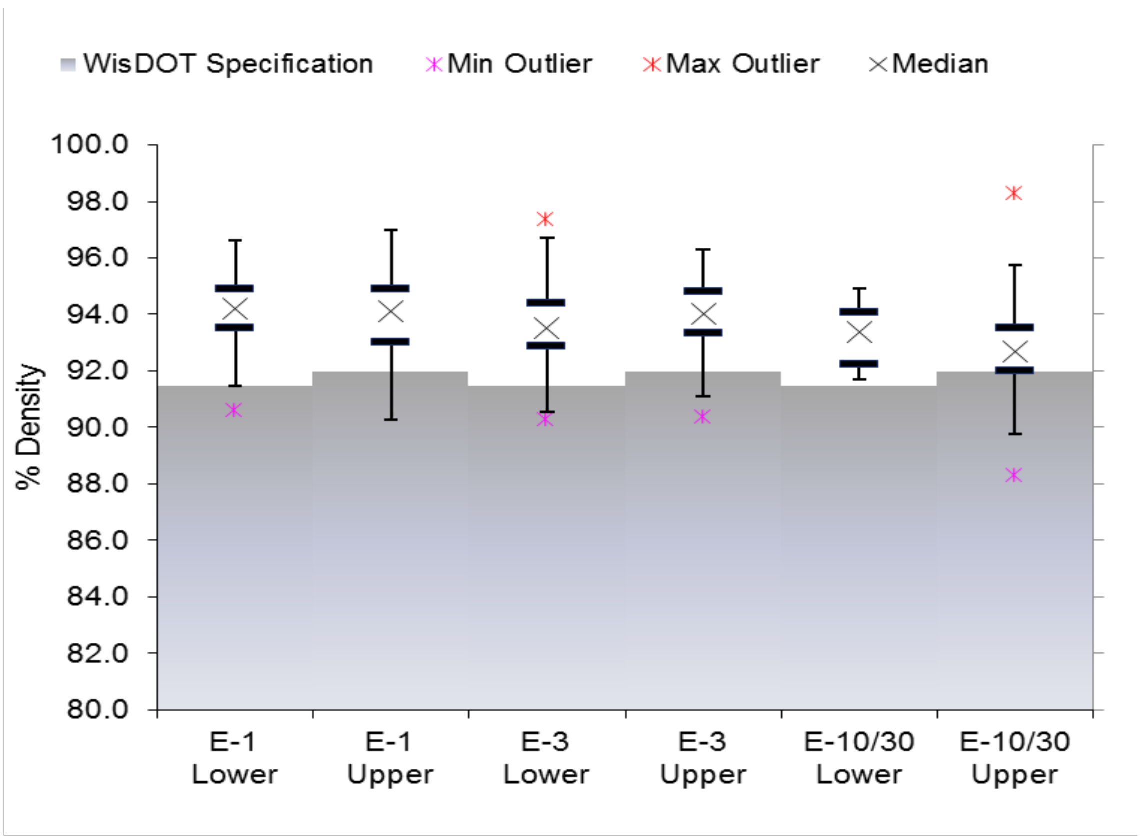


Figure 14 – 2014 mainline upper and lower density (parallel), relative to WisDOT specifications

Table 4 - Analysis of data for Figure 14 box and whisker plot

Labels	E-1 Lower	E-1 Upper	E-3 Lower	E-3 Upper	E-10/30 Lower	E-10/30 Upper
Min	90.6	90.3	90.3	90.4	91.7	88.3
Q_1	93.5	93.0	92.9	93.3	92.3	92.0
Median	94.2	94.1	93.5	94.0	93.4	92.7
Q_3	94.9	94.9	94.4	94.8	94.1	93.5
Max	96.6	97.0	97.4	96.3	94.9	98.3
IQR	1.4	1.9	1.6	1.5	1.8	1.5
ST DEV	1.2	1.4	1.4	1.2	1.0	1.3
Upper Outliers	0	0	1	0	0	9
Lower Outliers	4	0	1	4	0	17

Figure 15 below, identifies differences in density based on longitudinal joint type. It should be noted, safety edge data in Figure 15 only represents one project, and the project was an E-3 mix.

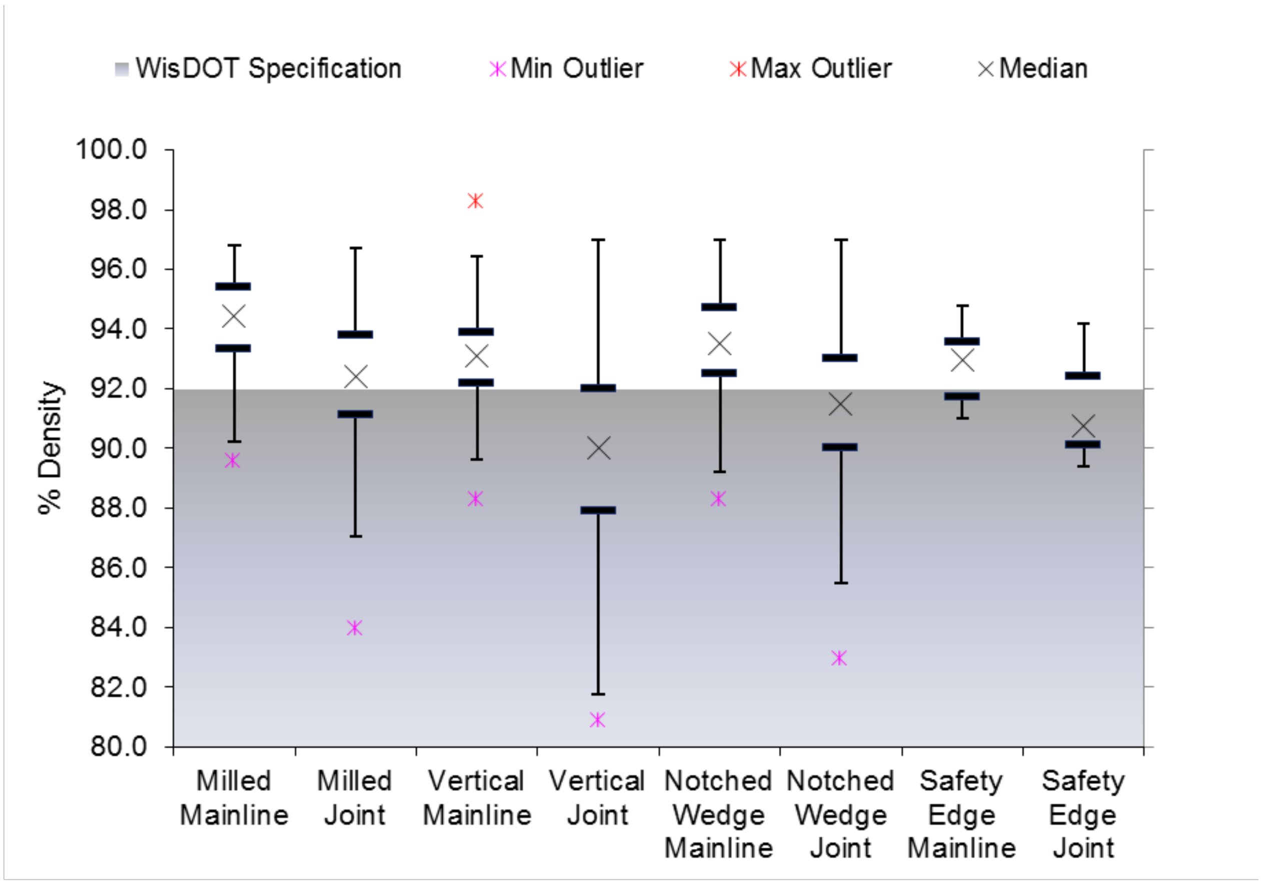


Figure 15 – 2014 joint density (parallel) separated by joint type, relative to WisDOT specifications

Table 5 - Analysis of data for Figure 15 box and whisker plot

Labels	Milled Mainline	Milled Joint	Vertical Mainline	Vertical Joint	Notched Wedge Mainline	Notched Wedge Joint	Safety Edge Mainline	Safety Edge Joint
Min	89.6	84.0	88.3	80.9	88.3	83.0	91.0	89.4
Q_1	93.3	91.1	92.2	87.9	92.5	90.0	91.7	90.1
Median	94.5	92.4	93.1	90.0	93.5	91.5	93.0	90.8
Q_3	95.4	93.8	93.9	92.0	94.7	93.0	93.6	92.4
Max	96.8	96.7	98.3	97.0	97.0	97.0	94.8	94.2
IQR	2.1	2.7	1.7	4.1	2.2	3.0	1.9	2.3
ST DEV	1.4	2.0	1.4	2.9	1.5	2.4	1.1	1.5
Upper Outliers	0	0	7	0	0	0	0	0
Lower Outliers	2	4	11	2	1	3	0	0

When looking at the complete dataset, statistically there is minimal correlation between joint type and joint density. Nonetheless, the milled joint produced the highest recorded densities, and the vertical yielded the lowest. In Figure 15 and Table 5, the normal vertical longitudinal joint produced the lowest average density with the highest variability when compared to other joint types. Additionally, the normal vertical longitudinal joint produced greatest number of lower and upper outliers. Combining Tables 3 and 5 data, the pavement type with the highest variability is the E-10/30 Normal Vertical.

Lastly, the 2014 density data analysis showed that density readings on the confined edge are statistically different than the densities on the unconfined edge. The confined edge has a roughly 1.5% higher density than the unconfined edge. Table 6 shows that the milled confined longitudinal joint exhibits the highest average longitudinal joint density, followed by the notched wedge. The lowest average longitudinal joint density was the vertical unconfined, which also had the highest variability.

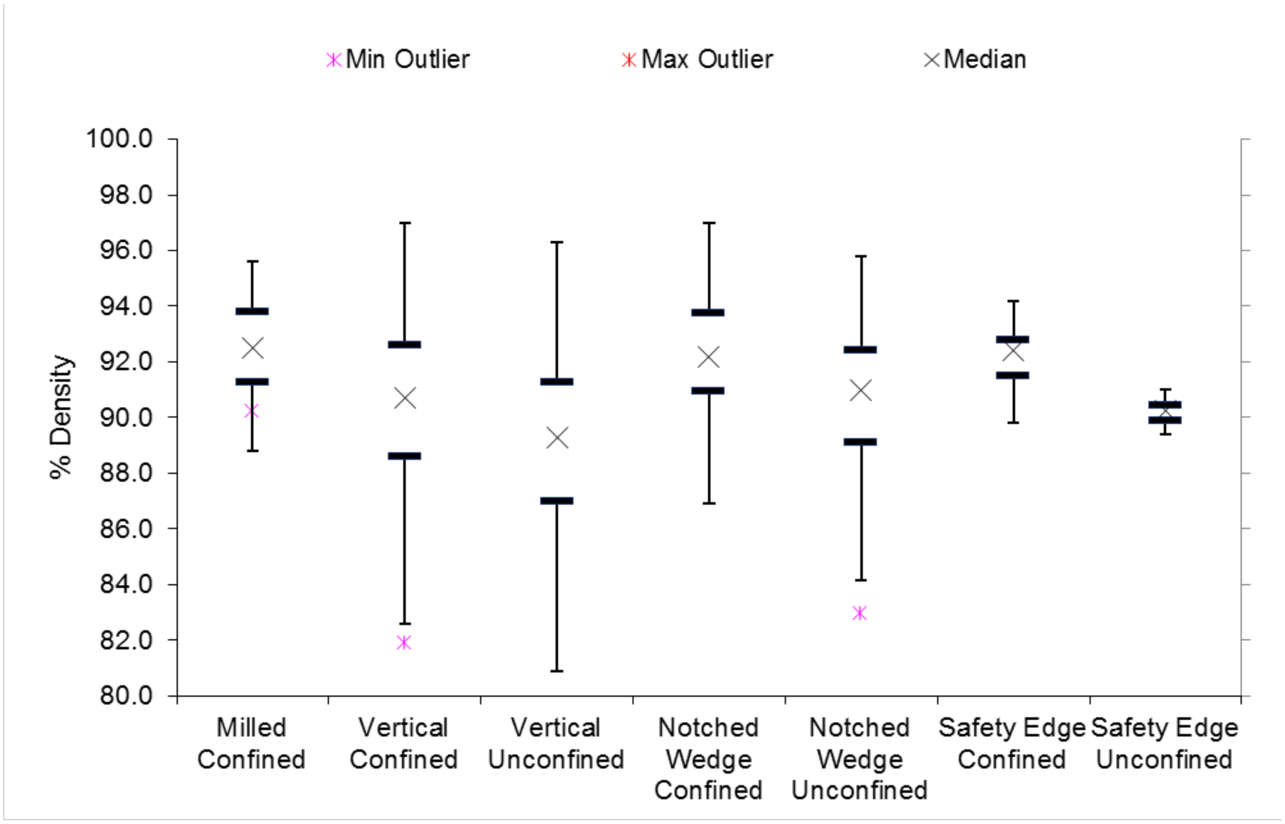


Figure 16 - Joint parallel density for unconfined and confined edge, separated by joint type

Table 6 - Analysis of data for Figure 16 box and whisker plot

Labels	Milled Confined	Vertical Confined	Vertical Unconfined	Notched Wedge Confined	Notched Wedge Unconfined	Safety Edge Confined	Safety Edge Unconfined
Min	84.0	81.9	80.9	86.9	83.0	89.8	89.4
Q_1	91.3	88.6	87.0	91.0	89.1	91.5	89.9
Median	92.5	90.7	89.3	92.2	91.0	92.4	90.3
Q_3	93.8	92.6	91.3	93.8	92.4	92.8	90.5
Max	96.7	97.0	96.3	97.0	95.8	94.2	91.0
IQR	2.5	4.0	4.3	2.8	3.3	1.3	0.5
ST DEV	2.0	2.8	3.0	2.2	2.2	1.5	0.6
Upper Outliers	0	0	0	0	0	0	0
Lower Outliers	37	1	0	0	2	0	0

Longitudinal Joint Best Practices Survey

After a review of previous studies and preliminary analysis of 2014 joint density data, the research team conducted a survey of current construction practices in Wisconsin. A questionnaire was created to capture paving practices used by contractors and was distributed via WisDOT staff and the Wisconsin Asphalt Pavement Association (WAPA). Several questions sought the opinions of respondents, while others focused on knowledge of best practices for longitudinal joint construction of the respondent.

Eight responses were received, four were from WisDOT and/or consultant personnel and four were from contractors. The four contractor respondents represented asphalt paving companies that geographically covered the western half, the northeastern quarter, the southeastern quarter and south central region of Wisconsin. Figure 17 shows the ranking of longitudinal joint quality practices from most important to least important. (A copy of the survey and a summary of the responses can be found in Appendix B.)

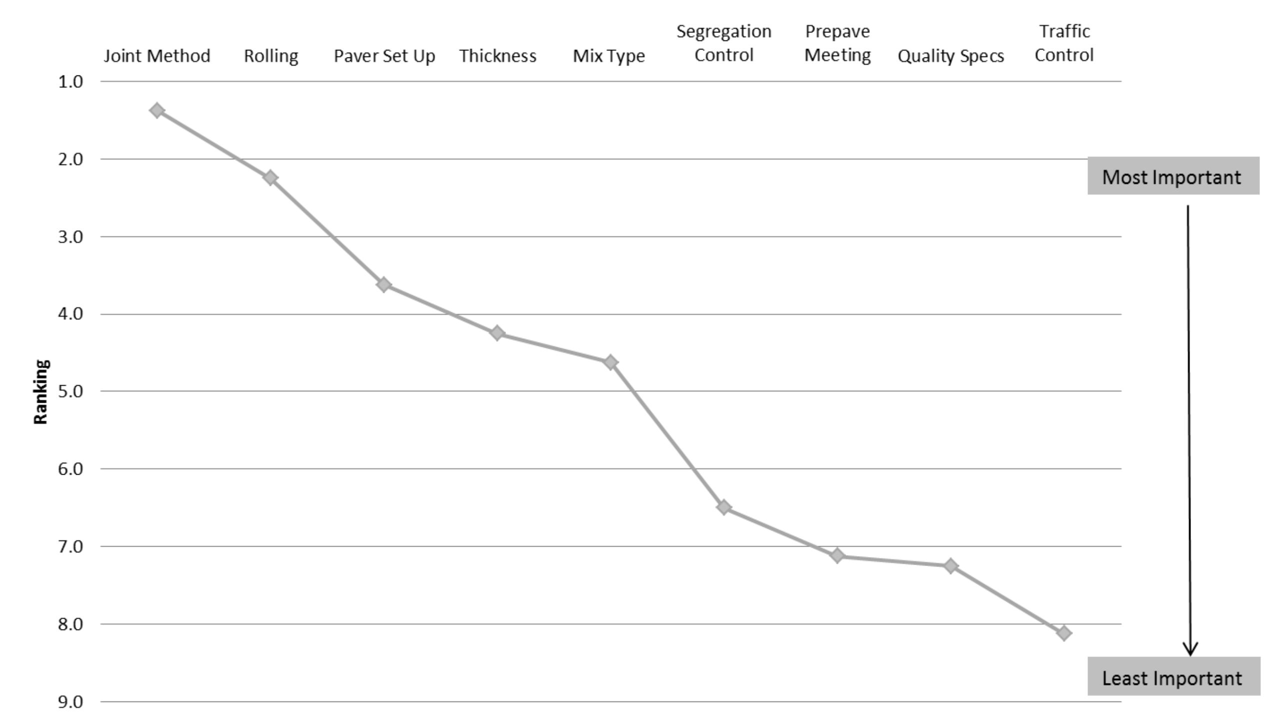


Figure 17 – Wisconsin survey respondent opinion

Joint Type and Rolling Pattern are ranked No. 1 and No. 2 for importance in achieving a quality longitudinal joint. While the *importance* of rolling pattern was nearly unanimous, the responses for *assumed* best practices for rolling pattern employed by the respondents were not (see Figure 18).

UNCONFINED JOINT

Responses	FIRST PASS
43%	Roll 10"-12" away from the edge (on the mat)
43%	Overhang 6" off the edge
14%	Overhang 2" off the edge
Responses	**SECOND PASS**
14%	Roll 12" away from the edge (on the mat)
57%	Overhang 3"-6" off the edge
29%	Overhang 0" off the edge

CONFINED JOINT

Responses	FIRST PASS
29%	Roll 12" - 18" away from the joint (on the mat)
14%	Roll 10" away from the joint (on the mat)
57%	Overhang 6" off the joint
Responses	**SECOND PASS**
14%	Roll 12" away from the joint (on the mat)
57%	Overhang 6" off the joint
29%	Overhang 0"-1" off the joint

Figure 18 Rolling pattern assumed best practices (according to Wisconsin contractors)

Since joint densities had not been recorded in Wisconsin until the 2014 Density Validation data collection, it is difficult to determine which of the various preferences in rolling pattern result in increased density, historically. The FHWA and Asphalt Institute recommend the following (10) (Figure 19):

UNCONFINED JOINT

FIRST PASS

First pass of the gyratory roller drum extended out over the edge of the mat approximately 6-inches

CONFINED JOINT

FIRST PASS

First pass of the vibratory roller drum on the hot mat staying back from the joint 6 to 8-inches

SECOND PASS

Second pass should then overlap onto the cold mat 4 to 6-inches off the joint

Figure 19-AI/FHWA rolling pattern best practices for a longitudinal joint

AI/FHWA research gives an alternative recommendation for rolling an unconfined longitudinal joint if the mat breaks down or pushes underneath the weight of the roller. When this phenomenon occurs, it is suggested that the first pass of the roller remain 6-inches away from the unconfined edge, but warns that this may cause stress cracks parallel to the joint.

Furthermore, AI/FHWA stated that a similar stress crack is possible when the roller maintains 6 to 8-inches away from the joint on the first pass of the confined joint. However, the alternative of overlapping 4 to 6-inches onto the cold mat may starve the joint of material and cause more harm to the longevity of the joint. Therefore, the recommendation stands for the confined joint. That is, to stay back 6 to 8-inches on the hot mat during the first pass.

From the data gathered in survey responses and the FHWA/AI research, 2015 field visits were structured to research current rolling practices employed by the contractor compared to FHWA/AI best practices, identified as "contractor rolling pattern" and "FHWA/AI rolling pattern," respectively.

CHAPTER 4: RESEARCH METHODOLOGY

Work Plan

Longitudinal Joint Study

The 2014 joint density data showed that E-10 and E-30 pavements have the lowest joint density, below 90% (Table 3), and that unconfined joint densities are 1.5% lower than confined joint densities, on average. Analysis also revealed no significant difference between lower lift and upper lift joint densities. Furthermore, data showed that E10/30 mixes have the highest variability (Table 3 and Table 5). Such findings demonstrated a need to focus additional efforts on E-10 and E-30 12.5mm mixes for subsequent field visits. Projects included testing on confined and unconfined edges of longitudinal joints as well as the following joint types:

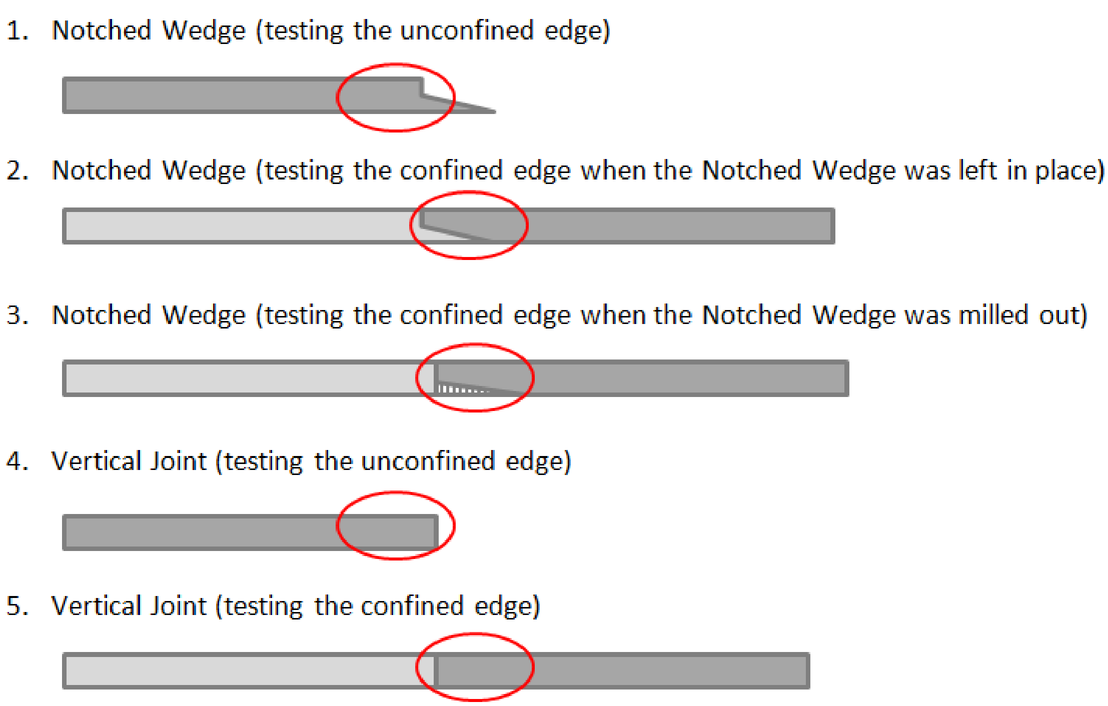


Figure 20 - Joint types evaluated with field visits

To determine if rolling pattern has a significant effect on density, the work plan specified two 1800-foot test sections to evaluate contractor typical rolling pattern and the AI/FHWA suggested Best Practices Rolling pattern. Hamburg performance tests and NCAT Permeability tests were included to further distinguish any mix variability, in other words, to compare the 1800-foot test sections within each project as well as to compare between projects.

In each 1800-foot test section, the work plan required six lots of nuclear density gauge readings in perpendicular and parallel positions. Each lot included three tests across the mat, with the 3rd test located within 2-inches of the longitudinal joint (Figure 9). The plan called for ten cores taken at the same locations as nuclear density readings. Figure 21 below is a schematic of the Longitudinal Joint Work Plan testing layout. The complete work plan can be found in Appendix C.

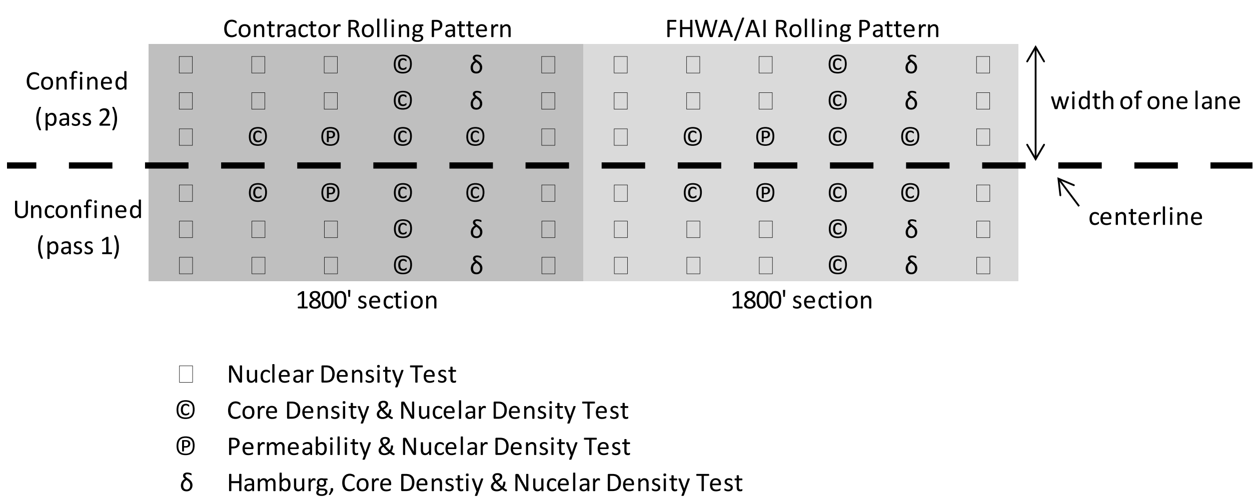


Figure 21 - Layout of cores and nuclear gauge readings per 1800' section

Thin Lift Overlay Study

Only one thin lift overlay project was available in 2015 for visit. The testing on the Thin Lift Overlay work was conducted similarly to the Longitudinal Joint portion of the study. The main difference was the addition of a thin lift nuclear density gauge. Both a standard nuclear density gauge (Model: CPN MC) used in the backscatter mode, and a thin lift gauge (Model: Troxler 3450) were used to evaluate the pavement and compare with cores.

Emphasis was given to the mainline (not the longitudinal joint), identifying the density locations similarly to WisDOT QMP specification, which are randomly distributed across the mat (Figure 9). All core locations were taken in the middle of the lane, with the exception of two cores taken on the centerline. Figure 22 shows a schematic of the thin lift testing layout. (The complete work plan can be found in Appendix D.)

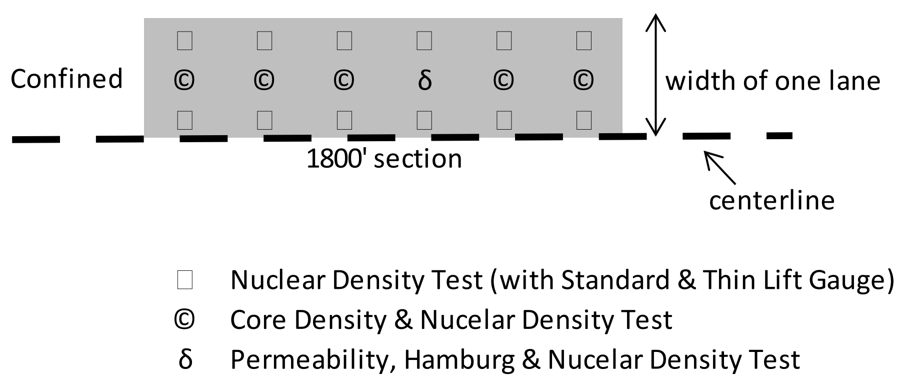


Figure 22 - Layout of Thin Lift testing

Selection of Field Projects

The selection of the field projects was separated into two categories; longitudinal joint and thin lift overlay. There was only one thin lift overly project scheduled for 2015, so that project was selected for the field visit. Regarding the longitudinal joint field projects, the intent was to find projects that would allow testing of confined and unconfined edges with varying types of longitudinal joint (See Figure 20). Originally, the work plan included a normal-vertical project and two notched wedge projects (one with a milled unconfined edge). However, at the request of a contractor and the approval of the WHRP Project Oversight Committee (POC), the work plan was modified to also include a safety edge (see Figure 3). This addition replaced a project where the notched wedge longitudinal joint (see Figure 1) was left in place, i.e., not milled out.

Longitudinal Joint Study

STH 26 – Vertical Longitudinal Joint

The first project selected was STH 26, State ID 1114-09-71, between Waupun and Rosendale in Dodge County. This project was a two-lane rural roadway closed to traffic and paved during summer of 2015. The plan required 7-inches of E-10 HMA pavement. The upper layer, 2-inches of E-10 12.5mm HMA pavement, was constructed using a vertical longitudinal joint on the surface mix. The two lower layers of E-10 19.0mm were constructed using a notched wedge longitudinal joint (see Figures 23 and 24). This project specified a centerline rubble strip. The rumble strip was milled directly over the centerline longitudinal joint (see Figure 25).

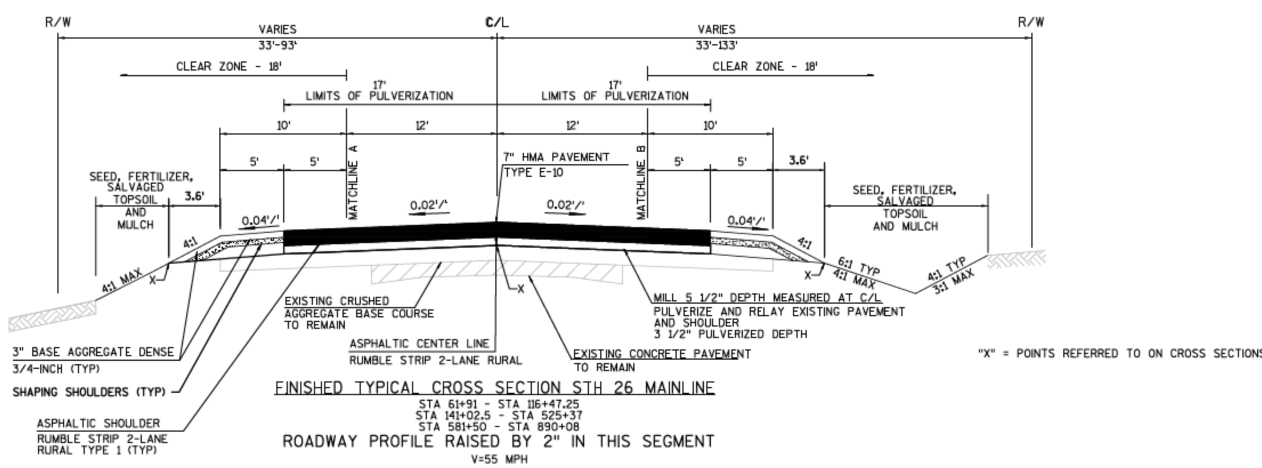


Figure 23 - STH 26 cross section

HMA PAVEMENT SHALL BE CONSTRUCTED WITH THE FOLLOWING LAYERS AND GRADATIONS
TYPE E-10

THICKNESS	LAYERS	NOM MAX SIZE GRADATION	ASPHALTIC MATERIAL
7"	ONE 2" UPPER LAYER	12.5mm	PG58-28
	TWO 2 1/2" LOWER LAYERS	19.0mm	PG58-28

Figure 24 - STH 26 plan layer thicknesses & mix types

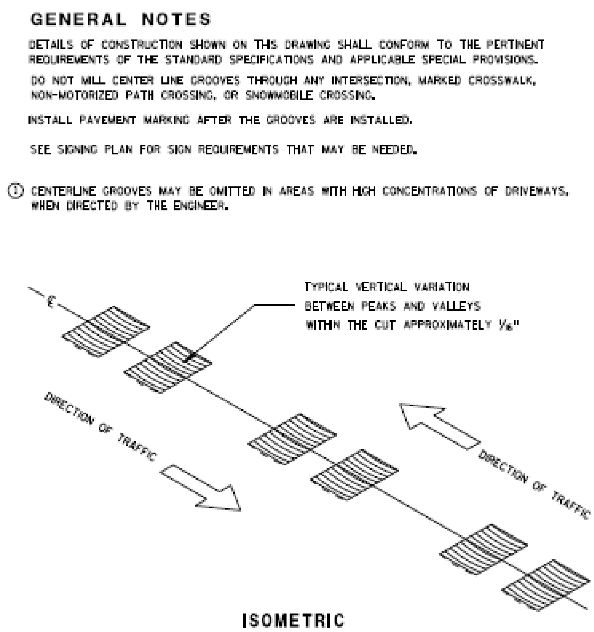


Figure 25 - Longitudinal rumble strip specification

USH 41 – Notched Wedge & Milled Longitudinal Joint

The second project selected was USH 41, State ID 1107-00-74, between Allenton and Fond Du Lac in Dodge County. This project was a four-lane roadway open to traffic and paved at night during late summer of 2015. The plan required 3.5-inches of E-30 HMA pavement. The upper and lower layers were 1.75-inches of E-30 12.5mm HMA pavement, constructed using a notched wedge longitudinal joint where the unconfined joint was milled out before placement of the confined/adjacent lane (see Figures 26 and 27).

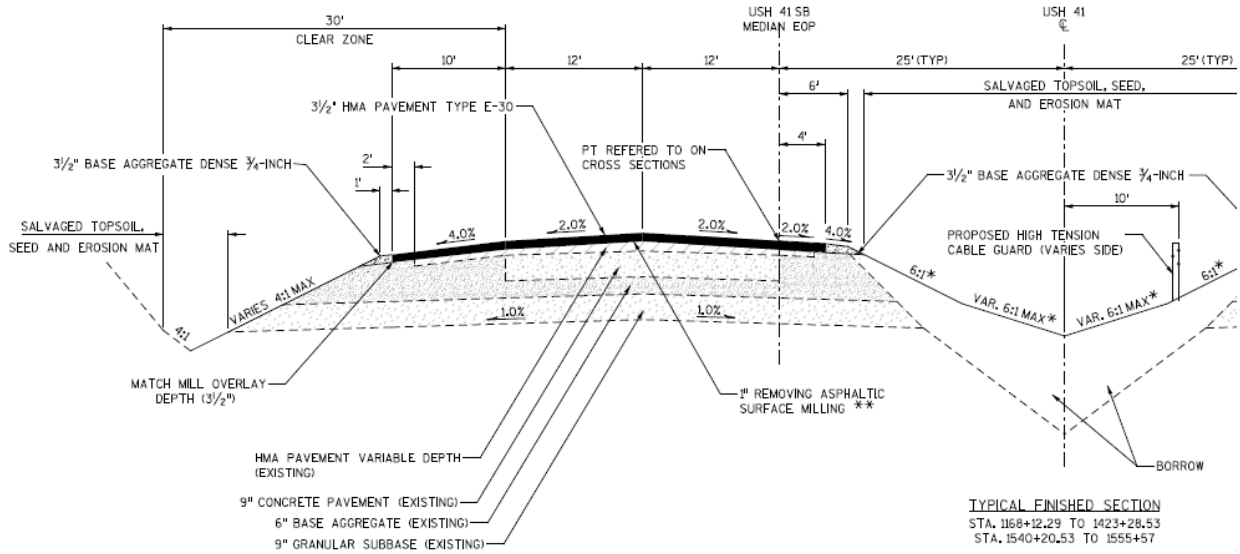


Figure 26 - USH 41 cross section

PAVEMENT LOCATION	TOTAL PAVEMENT THICKNESS	LAYERS	NOMINAL MAXIMUM SIZE GRADATION	ASPHALTIC MATERIAL
USH 41 SOUTH OF CONCRETE SECTION	3 1/2"	HMA PAVEMENT TYPE E-30 1.75" UPPER 1.75" LOWER	12.5 MM	PG 64-28 UPPER PG 58-28 LOWER

Figure 27 - USH 41 plan layer thicknesses & mix type

CTH H – Safety Edge Longitudinal

The third project selected was CTH H, State ID 5897-00-70, between Reedsburg and Wisconsin Dells in Sauk County. This project was a two-lane rural roadway open to traffic, and paved during late summer of 2015. The plan required 3.5-inches of E-3 HMA pavement. The upper and lower layers were 1.75-inches of E-3 12.5mm HMA pavement, constructed using a safety edge longitudinal joint (see Figures 28 and 29).

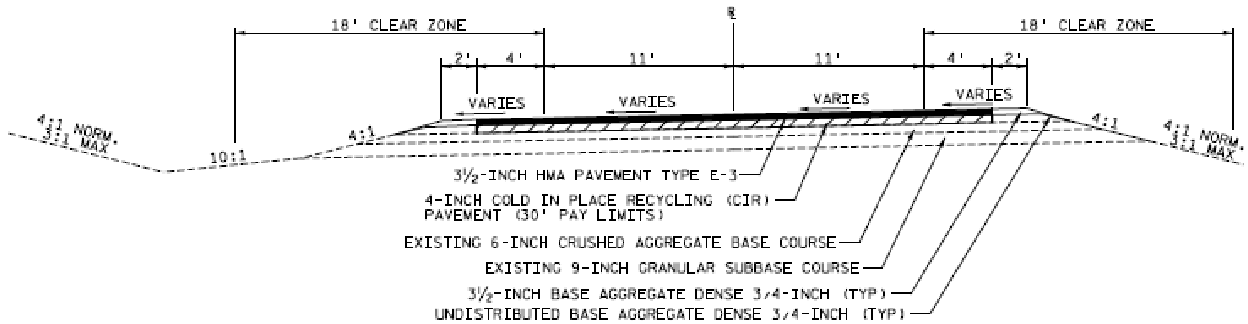


Figure 28 - CTH H cross section

HMA PAVEMENT TYPE E-3 TO BE PLACED IN TWO LAYERS. THE CONTRACTOR'S OPERATIONS SHALL BE CONSISTENT WITH THE PLAN TYPICAL SECTIONS, FOR THE 3 1/2-INCH HMA PAVEMENT. THE LAYERS SHALL BE 1 3/4-INCHES WITH NOMINAL AGGREGATE SIZE OF 12.5MM. FOR THE 4-INCH HMA PAVEMENT, THE BOTTOM LAYER SHALL BE 2 1/4-INCHES WITH NOMINAL AGGREGATE SIZE OF 19MM, AND THE TOP LAYER SHALL BE 1 3/4-INCHES WITH NOMINAL AGGREGATE SIZE

Figure 29 - CTH H layer thicknesses & mix types

Thin Lift Overlay Study

USH 8 – Thin Lift Overlay

The final project visit was the only WisDOT thin lift constructed in 2015. This took place on USH 8, State ID 1595-09-60, between Bradley and Rhinelander in Oneida County. This project was a two-lane rural roadway open to traffic, and paved during late summer of 2015. The plan required 1.25-inches of E-3 Thin Lift HMA pavement. This roadway was constructed using a vertical longitudinal joint (see Figures 30 and Figure 31). Just like the STH 26 project, the USH 8 project specified a centerline rubble strip. The rumble strip was milled directly over the centerline longitudinal joint (see Figure 32).

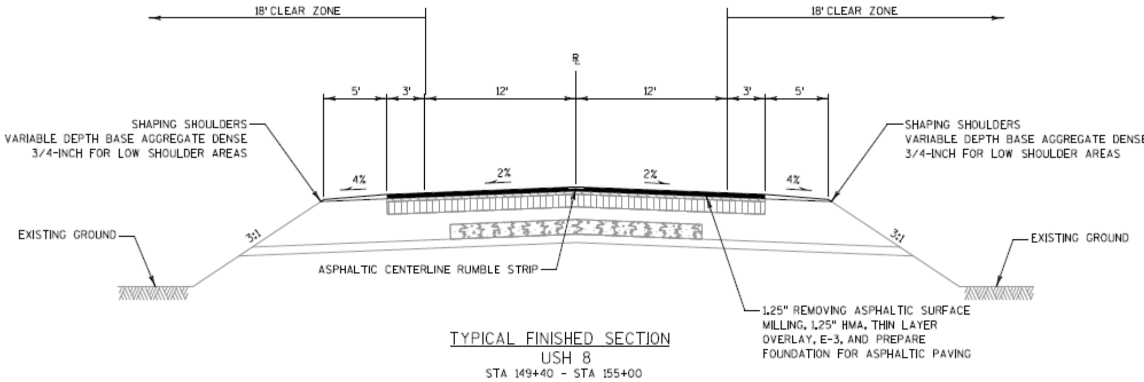


Figure 30 - USH 8 cross section

HMA, THIN LAYER OVERLAY, E-3 1.25-INCH (MAINLINE)
LAYER THICKNESS = 1.25-INCH (9.5 MM) PG58-34

Figure 31 - USH 8 layer thickness & mix type

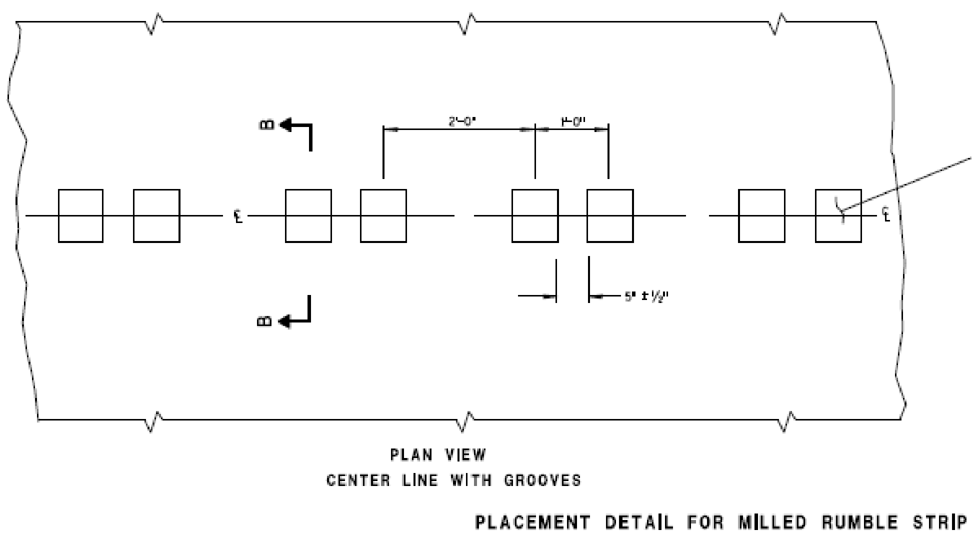


Figure 32 - USH 8 centerline rumble strip detail

Field Visits

Longitudinal Joint Study

STH 26 – Vertical Longitudinal Joint

On Tuesday July 21, 2015 a field visit was made to STH 26 in Dodge County, where the contractor, the contractor was paving an E-10 12.5mm using a vertical longitudinal joint. The day was sunny with a temperature of 75°F. STH 26 is a relatively high traffic (7,900 A.A.D.T.), rural, two-lane highway with various passing lanes, between Waupun and Oshkosh, Wisconsin. The contractor used rolling patterns summarized in Table 7.

Table 7- STH 26 - vertical unconfined rolling pattern

Unconfined Vertical Joint			
Contractor Rolling Pattern		**FHWA/AI Rolling Pattern**	
Pass #1		*Pass #1*	
12-inches away from joint (on the hot side of the mat)		Overhang 6-inches	
Pass #2		*Pass #2*	
Overhang 3-inches		On top of the joint	
Roller Types & Number of Passes			
	Hot Roller	*Intermediate Roller*	*Cold Roller*
Type of Roller	Volvo Vibratory	Rubber Tire	Sakai SW850
# of Passes	5 pass, vibe up, static back	Back and forth	7 pass, 3 vibe, 4 static

The test section was between stations 159+37 and 195+37 in the northbound lane. In this section of pavement, there is a southbound passing lane so photographs show a roadway three lanes wide. The contractor was using a material transfer device and a ski (see Figure 33(a)). In the first section from 159+37 to 177+37, the rolling pattern was not changed from the contractor's original set up. Since the contractor was using a different rolling pattern than the AI/FHWA Best Practices, the section between 177+37 and 195+37 was assigned as the AI/FHWA method.

(a) STH 26 paving train using a ski

(b) Test section divider (facing north)

(c) 3-inch overhang, pass 2, section 1

(d) AI/FHWA Section (facing south)

Figure 33 STH 26 unconfined edge

For the AI/FHWA Best Practices section, the HMA material pushed out an additional 3-inches, as measured with a ruler before and after the hot roller, when compared to the original test section (sees Figure 33 c). (Note, the contractor stated that the centerline unconfined joint was intentionally paved 0.5-inches high to help with the confined joint densities.)

Upon a second visit, on July 22, 2015, the confined longitudinal joint was tested. That day was partly cloudy with a temperature of 78°F. The contractor used rolling patterns summarized in Table 8.

Table 8 - STH 26 - vertical confined vertical rolling pattern

Confined Vertical Joint			
Contractor Rolling Pattern		**FHWA/AI Rolling Pattern**	
Pass #1		*Pass #1*	
12-inches away from joint (on the hot side of the mat)		6 to 8-inches away from the joint (on hot side)	
Pass #2		*Pass #2*	
3-inches overlap (on the cold side of the mat)		Overlap 4 to 6-inches onto the cold side	
Roller Types and Number of Passes			
	Hot Roller	*Intermediate Roller*	*Cold Roller*
Type of Roller	Volvo Vibratory	Rubber Tire	Sakai SW850
# of Passes	3 pass, all vibe	Back and forth	7 pass, 3 vibe, 4 static

The confined side test section was between stations 159+37 and 195+37 in the southbound lane, adjacent to the unconfined section. In the first section, from 159+37 to 177+37, the rolling pattern was not changed from the contractor's original set up. Since the contractor was using a different rolling pattern than the AI/FHWA Best Practices, the section between 177+37 and 195+37 was assigned as the AI/FHWA method.

(a) STH 26 confined joint

(c) 3-inch overlap, pass 2, section 2

(b) 12-inches away, pass 1, section 2

(d) STH 26 finished joint

Figure 34 STH 26 confined edge

STH 26 was visited a third time on March 31, 2016, to observe the longitudinal joint after one winter. The joint was still very tight and performing well. Figure 35 was taken in the first test section facing northbound.

Figure 35 - STH 26 longitudinal joint, photographed 3/31/16

(Please note the exceptionally straight/linear longitudinal joint.)   Figures 34 & 35 show a straight line between the confined and unconfined sides of the joint. The practice of using a string-line during paving can help with the linearity of the longitudinal joint and such consistency likely contributed to the high joint densities achieved on this project.

USH 41 – Notched Wedge Longitudinal Joint

On Tuesday (night) September 1, 2015 the USH 41 project in Dodge County was visited, where the contractor, was paving an E-30 12.5mm using a notched wedge longitudinal joint. It was humid with a temperature of 76°F. USH 41 is a heavily trafficked four-lane highway between Milwaukee and Fond Du Lac, Wisconsin. On this project, one lane was paved while the adjacent lane remained open to traffic. This first field visit to USH 41 was to test the unconfined longitudinal joint of this first lane. The contractor used rolling patterns summarized in Table 9.

Table 9 - USH 41 – notched wedge unconfined rolling pattern

Unconfined Notched Wedge Joint			
Contractor Rolling Pattern		**FHWA/AI Rolling Pattern**	
Pass #1		*Pass #1*	
12-inches away from joint (on the hot side of the mat)		Overhang 6-inches	
Pass #2		*Pass #2*	
Overhang 3-inches		On top of the joint	
Roller Types & Number of Passes			
	Hot Roller	*Intermediate Roller*	*Cold Roller*
Type of Roller	Sakai	Hamm HD 120	Rubber Tire
# of Passes	5 pass, vibe up, static back	5 pass – all static	Back and forth

The unconfined test section was from station 1423+28 to 1387+28 in the southbound driving lane. The first half of the test section (1423+28 to 1405+28), the rolling pattern followed the procedure in Table 9. Since the contractor was using a different rolling pattern than the AI/FHWA Best Practices, the second half (1405+28 to 1387+28), was assigned as the AI/FHWA method. Photos are not available due to the night operations.

On the second visit, Sunday (night) September 13, 2015, the confined longitudinal joint was tested. The weather had slight wind and a temperature of 73°F. The contractor used rolling patterns as summarized in Table 10.

Table 10 USH 41 notched wedge confined rolling pattern

Confined Notched Wedge Joint			
Contractor Rolling Pattern		**FHWA/AI Rolling Pattern**	
Pass #1		*Pass #1*	
12-18-inches away from joint (on the hot side of the mat)		6 to 8-inches away from the joint (on hot side)	
Pass #2		*Pass #2*	
Overlap 6-inches off joint (onto the cold side of the mat)		Overlap 4 to 6-inches onto the cold side	
Roller Types & Number of Passes			
	Hot Roller	*Intermediate Roller*	*Cold Roller*
Type of Roller	Sakai	--	Ingersoll DD 130
# of Passes	5 pass, all vibe	--	5 – pass static

This test section was again between stations 1423+28 and 1459+28, directly adjacent to the measured unconfined section, in the southbound passing lane. In this section, the initial unconfined edge of the notched wedge joint was milled out, resulting in a confined milled longitudinal joint. The first half of the test section (1423+28 to 1441+28), the contractor used the rolling pattern outlined in Table 9. Since the contractor was using a different rolling pattern than the AI/FHWA Best Practices, the section between 1441+28 and 1459+28 was assigned as the AI/FHWA method.

USH 41 was visited a third time on March 31, 2016, to observe the longitudinal joint after one winter. The joint appeared tight and to be performing well. The scrape marks on the confined side of the longitudinal joint (visible in Figure 36) may be attributed to a snow plow. Unfortunately, the pavement was exhibiting reflective transverse cracking. Figure 36 was taken from the STH 67 Bridge facing south. Figure 37 was taken in the median of the southbound lane, facing south.

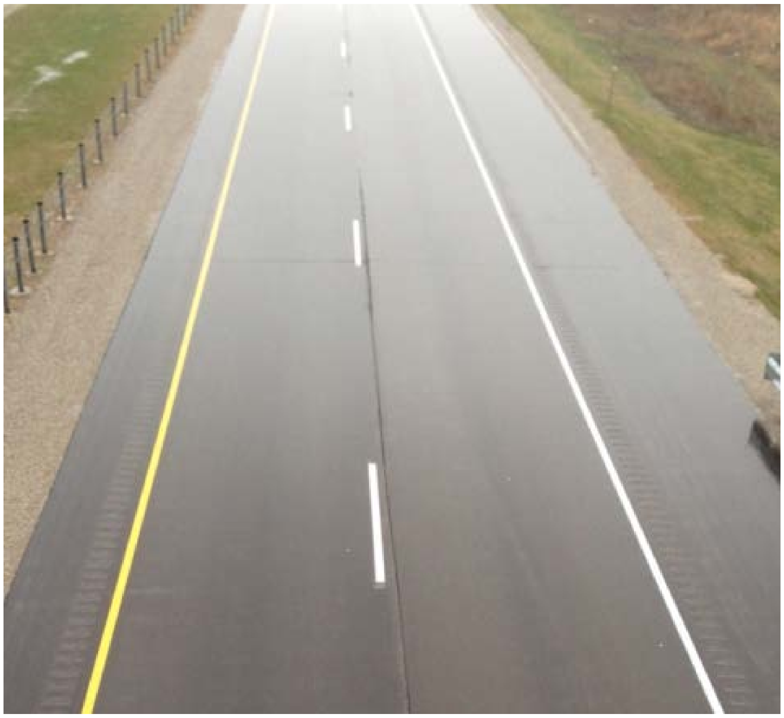


Figure 36- USH 41 joint photographed 3/31/16

Figure 37 - USH 41 longitudinal joint 3/31/16

CTH H – Safety Edge Longitudinal Joint

On Thursday September 10, 2015 the CTH H project in Sauk County was visited, where the contractor was paving an E-3 12.5mm using a safety edge longitudinal joint. CTH H is a rural two-lane highway just south of Wisconsin Dells. On the day of the field visit, the weather was cloudy and 66°F. The contractor was paving one lane and using traffic control to allow traffic on the other lane. This first field visit to CTH H was to test the unconfined longitudinal joint. The contractor used the following rolling patterns:

Table 11 - CTH E safety edge unconfined rolling pattern

Unconfined Safety Edge Joint			
Contractor Rolling Pattern		**FHWA/AI Rolling Pattern**	
Pass #1		*Pass #1*	
Overhang 6-inches		Overhang 6-inches	
Pass #2		*Pass #2*	
On top of joint		On top of the joint	
Roller Types & Number of Passes			
	Hot Roller	*Intermediate Roller*	*Cold Roller*
Type of Roller	Dynapac	none	Hamm
# of Passes	5 – pass vibe	none	5 – pass static

The test section was between stations 462+05 and 480+05 in the southbound lane. Since the contractor was following the AI/FHWA best practices, only one test section was evaluated per visit. Upon the second visit, Friday September 11, 2015, the confined longitudinal joint was tested. Weather was partly cloudy with a temperature of 76°F. The contractor used the following rolling patterns:

Table 12 - CTH E safety edge confined rolling pattern

Confined Safety Edge Joint			
Contractor Rolling Pattern		***FHWA/AI Rolling Pattern***	
Pass #1		*Pass #1*	
6 to 8-inches away from the joint (on hot side)		6 to 8-inches away from the joint (on hot side)	
Pass #2		*Pass #2*	
Overlap 4 to 6-inches onto the cold side		Overlap 4 to 6-inches onto the cold side	
Rolling Pattern			
	Hot Roller	*Intermediate Roller*	*Cold Roller*
Type of Roller	Dynapac	none	Hamm
# of Passes	5 – pass vibe	none	5 – pass static

(a) CTH H paver set up

(b) rolling unconfined joint

(c) - safety edge up close

Figure 38 – CTH H

CTH H was visited a third time on March 31, 2016, to observe the longitudinal joint after one winter. The joint appeared to be performing well. The picture in Figure 39 was taken near Oak Hill Road facing north.


Figure 39 - CTH H photographed 03/31/16

Thin Lift Overlay Study

USH 8 – Thin Lift Project

On Tuesday September 16, 2015 the USH 8 project in Oneida County was visited. The contractor, was paving an E-3 9.5mm thin lift mix, and one lane was open to traffic. Weather was cloudy with a temperature of 67°F. Table 13 outlines the rolling pattern used by the contractor.

Table 13 - USH 8 Thin Lift rolling pattern

Roller Types & Number of Passes		
	Hot Roller	*Cold Roller*
Type of Roller	Ingersoll Rand	Hypac
# of Passes	5 – pass	7 – pass
Static or vibe?	vibe up, static back	static
Temperature zone	270°F	140°F - 130°F

Cores were taken in the middle of the lane and also at the centerline of the roadway. The thin lift gauge and standard gauge were each tested in the parallel and perpendicular orientations.

[Note, the project engineer mentioned that the grooves left from the mill were deep, and there was discussion by the contractor to bring out a mill with smaller teeth. Though, considering the tack was placed sufficiently, it is plausible that the larger grooves in the milled pavement may help to bind and lock the thin lift in place. There is no evidence that the mill or teeth were replaced.]

(a) Large teeth on mill

(b) Sufficient tack

(c) Material that was underneath the core taken directly on the centerline joint

Figure 40 – USH 8

Figure 40 (c) pertains to the longitudinal joint of the existing pavement over which the thin lift was placed. A core was taken directly on the longitudinal joint of the thin lift pavement and also the layer below. Typically, a lower layer core will either remain connected to the upper layer, indicating a good tack bond, or de-bond from the upper layer and remain in the pavement. In the case of the centerline cores taken on USH 8, the lower (existing) layer did not resemble a core but rather looked like loose aggregate/particles (see Figure 41 (c)). The material underneath the centerline core was no longer intact pavement; it was a badly deteriorated longitudinal joint. The condition of the underlying longitudinal joint is a concern for the life of this thin lift overlay.

As of this report, a follow-up visit has not been made since the time of milling the centerline rumble strips to confirm or reject the concern regarding this thin lift performance and longevity.

CHAPTER 5: ANALYSIS OF FIELD VISIT DENSITY & CORE DATA

The 2014 density data collection and the subsequent 2015 field visits resulted in over 1900 density data sets. A data set for the 2014 density study is defined as a mainline sublot average with a corresponding joint density test. A data set for the 2015 field visits is defined as a single test location, usually encompassing multiple tests (see work plan - Figures 21 and 22). Table 14 lists the number of data sets for each layer, ESAL and joint type.

Table 14 - 2014 and 2015 summary of data collection

	Upper Layer	Lower Layer	E-1	E-3	E-10/30	Notch Wedge	Normal Vertical	Milled	Thin Lift Overlay	Safety Edge
2014 Density Validation Study	1252	193	282	460	898	865	633	176	--	--
	87%	*13%*	*17%*	*28%*	*55%*	*52%*	*38%*	*11%*	*--*	*--*
2015 Field Project Visits	227	.--	--	78	150	39	72	39	39	39

For the 2015 field visits, cores were taken to validate the 2014 density data collected. The density of the cores was calculated using Gmm provided by the contractor during the field visit and AASHTO T-166 to determine the bulk specific gravity (Gmb). The strongest correlation to core densities is when the nuclear density gauge is in the parallel orientation as this resulted in 82.5% correlation to core values in comparison to 67.0% for the perpendicular orientation shown in Table 15.

Table 15 - Correlation of density to cores

Parallel	0.825
Perpendicular	0.670
Average of Both	0.745

The parallel orientation of the nuclear density gauge overestimates density 78.1% of the time; while it underestimates density the remaining 10.9% of the time, see Figures 41 and 42.

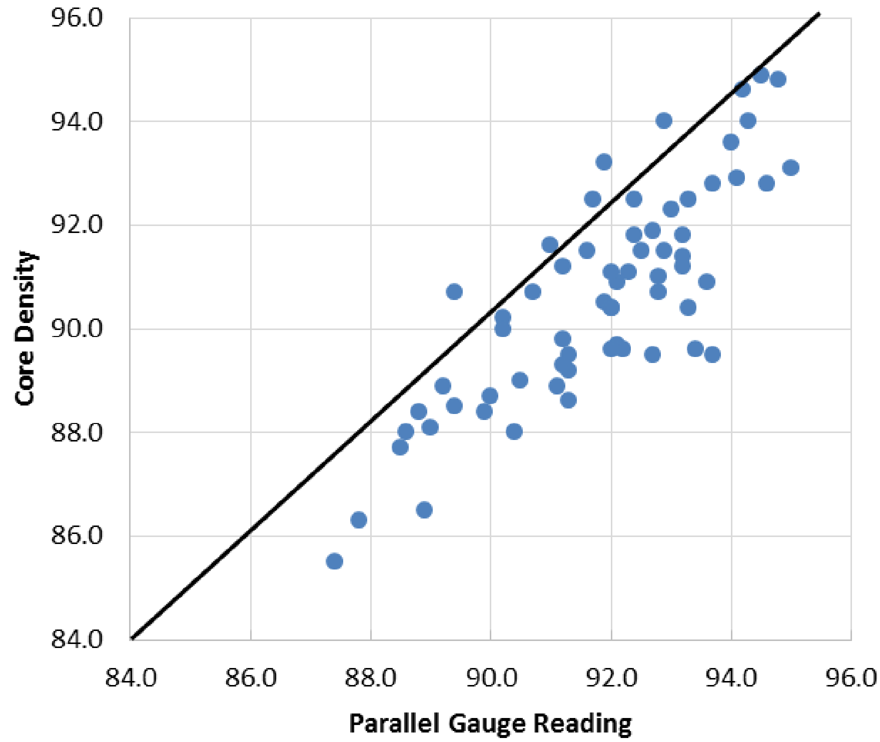


Figure 41 - Parallel correlation to cores

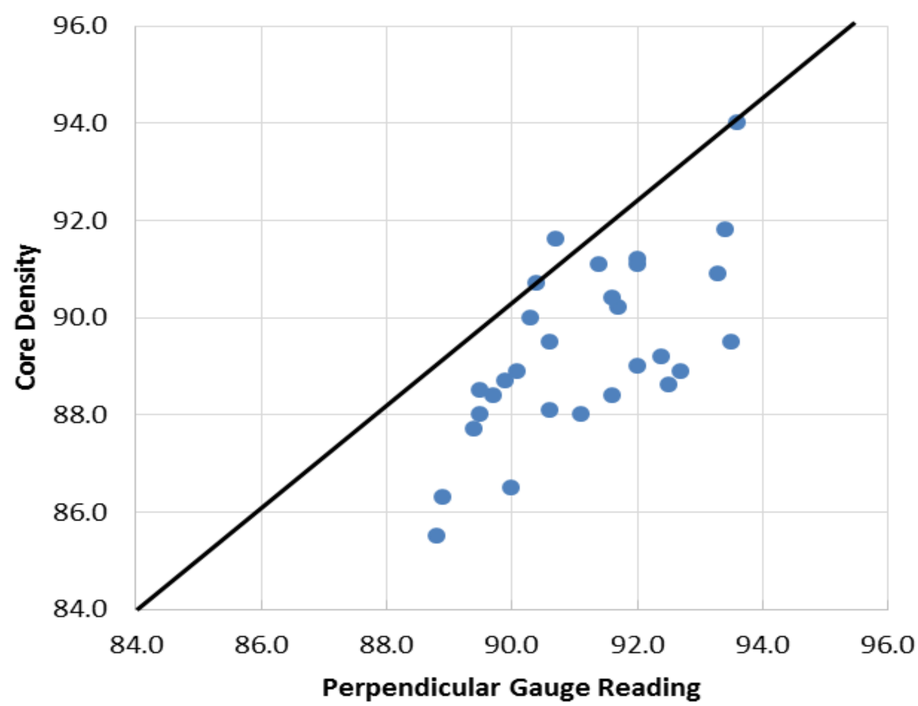


Figure 42 - Perpendicular correlation cores

Figures 41 through 43 compile core data with nuclear density data in the parallel and perpendicular orientations. On average, the parallel orientation will overestimate density by 1.7% for all data and 1.8% for joints only, while the perpendicular orientation will overestimate density by 1.0% for mainline and 2.5% for joints only. It is recommended to use the orientation that is closer to the actual value and resulted in a higher correlation to core measurements, which is the parallel. However, a nuclear/core correlation is needed to establish a true offset to account for the overestimation as mentioned.

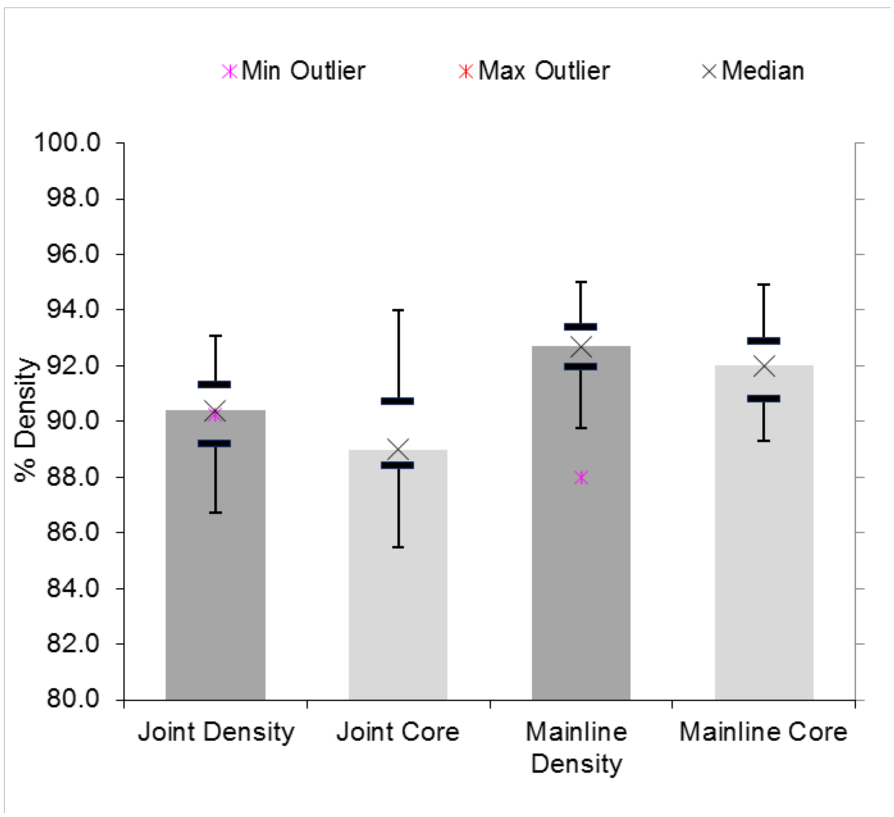


Figure 43 - Core data vs nuclear density data (parallel orientation)

Table 16 - Analysis of data for Figure 43 box and whisker plot

Labels	Joint Density	Joint Core	Mainline Density	Mainline Core
Min	87.4	85.5	88.0	89.3
Q_1	89.2	88.4	92.0	90.8
Median	90.4	89.0	92.7	92.0
Q_3	91.3	90.7	93.4	92.9
Max	93.7	94.0	95.0	94.9
IQR	2.1	2.3	1.5	2.0
Upper Outliers	0	0	0	0
Lower Outliers	17	0	3	0

Due to having the highest correlation to core measurements, the parallel orientation is used for the remainder of this report.

STH 26 – Vertical Longitudinal Joint

The average mainline lot densities of STH 26 were similar to the 2014 E-10 mixes in terms of mean and variance. However, when comparing the mainline parallel joint density of STH 26 E-10 to 2014 E-10, STH 26 was similar. When isolating 2014 vertical joint E-10 projects; that is, STH 26 joint density is 1.2% higher than 2014 projects.

Since most of this research combines E-10 and E-30 mixes, Figure 45 compares STH 26 data to E-10/E-30 dataset. Similar trends remain true. While the contractor achieved similar average mainline densities, they were able to achieve higher than average joint densities (Figure 45).

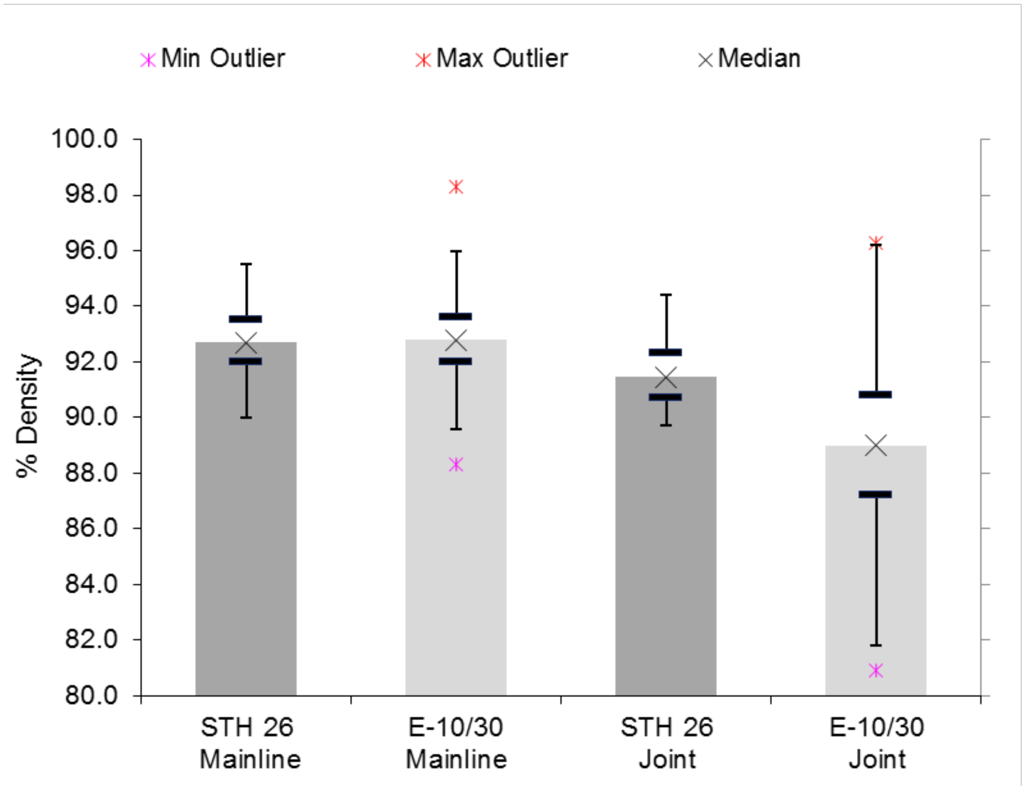


Figure 44 – Nuclear density data (parallel) - STH 26 vs 2014 E-10 vertical joint projects

Table 17 - Data included in Figure 44 box and whisker plot

Labels	STH 26 Mainline	E-10/30 Mainline	STH 26 Joint	E-10/30 Joint
Min	90.0	88.3	89.7	80.9
Q_1	92.0	92.0	90.7	87.2
Median	92.7	92.8	91.5	89.0
Q_3	93.5	93.6	92.3	90.8
Max	95.5	98.3	94.4	96.3
IQR	1.5	1.6	1.6	3.6
Upper Outliers	0	8	0	1
Lower Outliers	0	10	0	2
ST DEV	1.2	1.3	1.3	2.6

When comparing the rolling pattern used by the contractor and AI/FHWA rolling pattern, the two data sets are statistically different, where the contractor's standard rolling pattern produced a mean density 0.5% higher than the AI/FHWA recommended rolling pattern. However, when distinguishing between confined and unconfined, the standard rolling pattern and the AI/FHWA sections are not statistically different. The contractor's rolling pattern was different from the AI/FHWA rolling pattern on the unconfined side of the joint, where the contractor was maintaining 12-inches away from the joint on the first pass, rather than overhanging 6-inches as suggested by AI/FHWA. The rolling patterns for the confined side were similar, where the contractor stays 12-inches (AI/FHWA calls for 6-8-inches) away from the joint for the first pass and overlaps 3-inches (AI/FHWA calls for 4-6-inches) for the second pass.

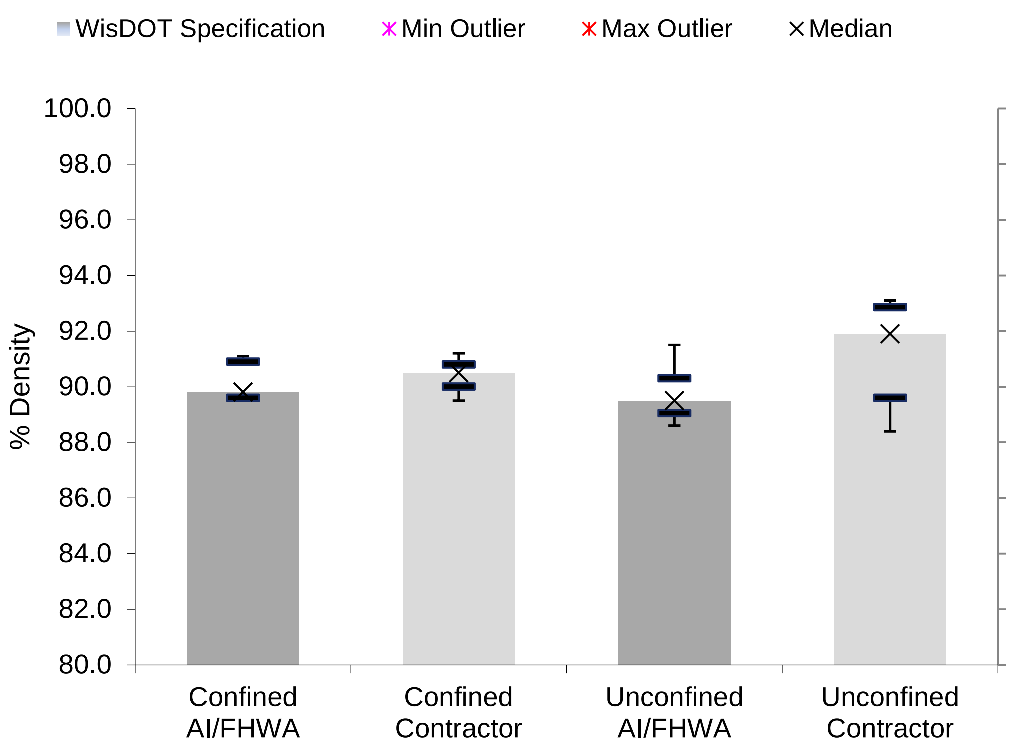


Figure 45 –Nuclear data STH 26 - FHWA recommended vs. contractor practice rolling pattern

Table 18 - Data used for Figure 44 box and whisker plot

Labels	Confined AI/FHWA	Confined Contractor	Unconfined AI/FHWA	Unconfined Contractor
Min	89.5	89.5	88.6	88.4
Q_1	89.6	90.0	89.1	89.6
Median	89.8	90.5	89.5	91.9
Q_3	90.9	90.8	90.3	92.9
Max	91.1	91.2	91.5	93.1
IQR	1.3	0.8	1.3	3.3
Upper Outliers	0	0	0	0
Lower Outliers	0	0	0	0
ST DEV	0.7	0.6	1.1	2.0

The mix pushed/shoved out on the first pass of the unconfined edge when the roller hung over the joint. The data shows that staying 12-inches away from the joint on the first pass for an unconfined edge of a vertical joint increases compaction for this mix. However, as stated in the AI/FHWA study, there is concern for a potential stress crack parallel to the longitudinal joint when using this technique.

USH 41– Notched Wedge Longitudinal Joint / Milled

There is not a statistically significant difference between the average mainline lot densities of USH 41 and 2014 E-30 mixes. However, when comparing to notched wedge projects, USH 41 was over 1% lower than jobs of 2014. The difference between confined (milled) and unconfined (notched wedge) joints is not statistically significant.

Figure 46 compares USH 41 data to the E-10/E-30 dataset; both the notched wedged and milled longitudinal joints. While the contractor achieved similar/lower average mainline densities, they were able to achieve higher than average joint densities on the unconfined notch wedge joint. The milled confined joint densities on USH 41 were lower than average.

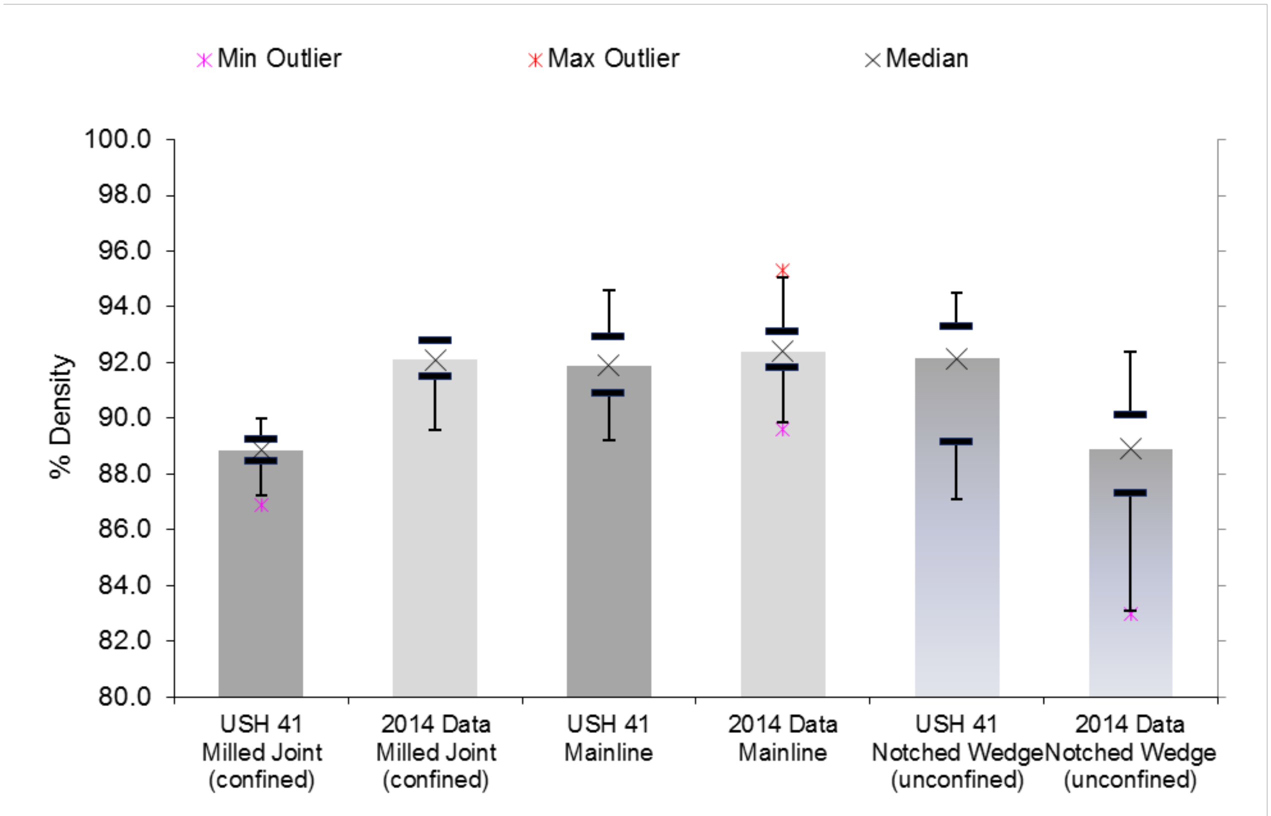


Figure 46 - Nuclear data - USH 41 vs. 2014 notched wedge & milled projects

Table 19 - Data used in Figure 46 box and whisker plot

Labels	USH 41 Milled Joint (confined)	2014 Data Milled Joint (confined)	USH 41 Mainline	2014 Data Mainline	USH 41 Notched Wedge (unconfined)	2014 Data Notched Wedge (unconfined)
Min	86.9	89.6	89.2	89.6	87.1	83.0
Q_1	88.5	91.5	90.9	91.8	89.2	87.3
Median	88.9	92.1	91.9	92.4	92.2	88.9
Q_3	89.3	92.8	92.9	93.1	93.3	90.1
Max	90.0	92.9	94.6	95.3	94.5	92.4
IQR	0.8	1.3	2.0	1.3	4.1	2.8
Upper Outliers	0	0	0	2	0	0
Lower Outliers	1	0	0	1	0	1
ST DEV	0.8	1.0	1.5	1.0	2.3	1.9

In looking at rolling patterns, the rolling pattern used by the contractor and the AI/FHWA rolling pattern did not result in a statistically significant difference (Figure 47).

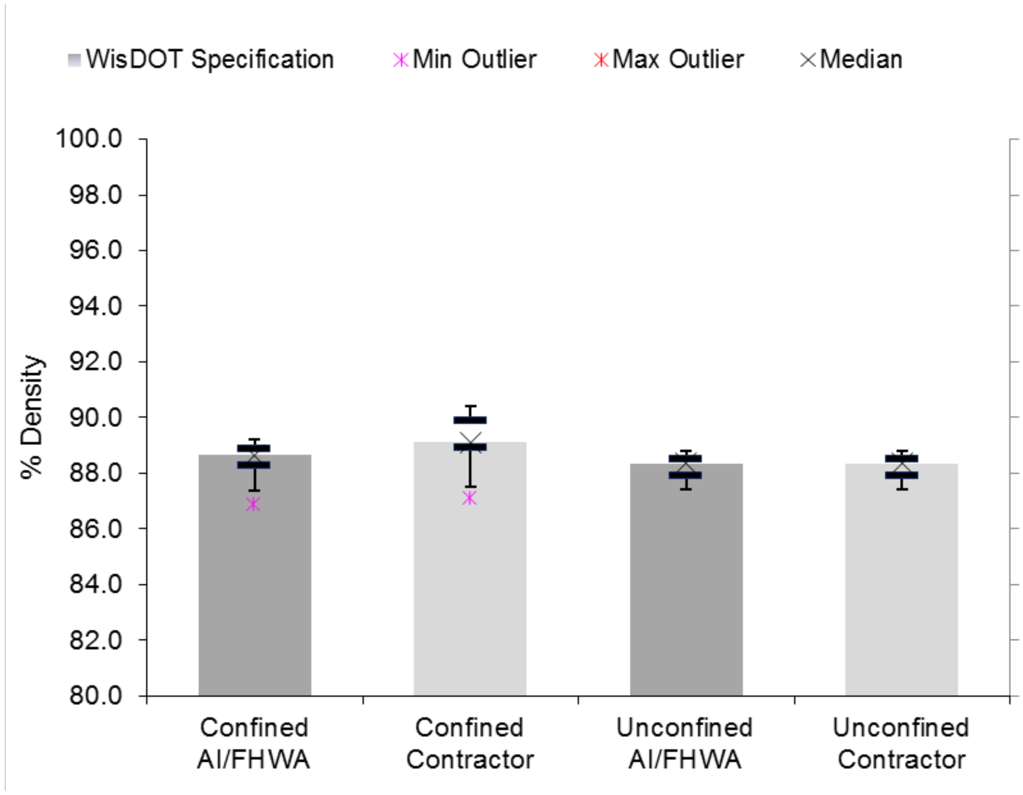


Figure 47 –Nuclear data USH 41- FHWA recommended vs. contractor practice rolling pattern

Table 20 - Data used in Figure 47 box and whisker plot

Labels	Confined AI/FHWA	Confined Contractor	Unconfined AI/FHWA	Unconfined Contractor
Min	86.9	87.1	87.4	87.4
Q_1	88.3	88.9	87.9	87.9
Median	88.7	89.1	88.4	88.4
Q_3	88.9	89.9	88.5	88.5
Max	89.2	90.4	88.8	88.8
IQR	0.6	0.9	0.6	0.6
Upper Outliers	0	0	0	0
Lower Outliers	1	1	0	0
ST DEV	0.8	1.2	0.5	0.5

CTH H– Safety Edge Longitudinal Joint

CTH H mainline lot densities were almost 1% lower than 2014 E-3 mixes, with the CTH H mean at 93.0% and 2014 E-3 mean at 93.8%. However, when comparing average joint density of CTH H E-3 to 2014 E-3 joint density, CTH H is statistically similar. While the contractor achieved lower than average mainline densities, they were able to achieve average joint densities (Figure 48).

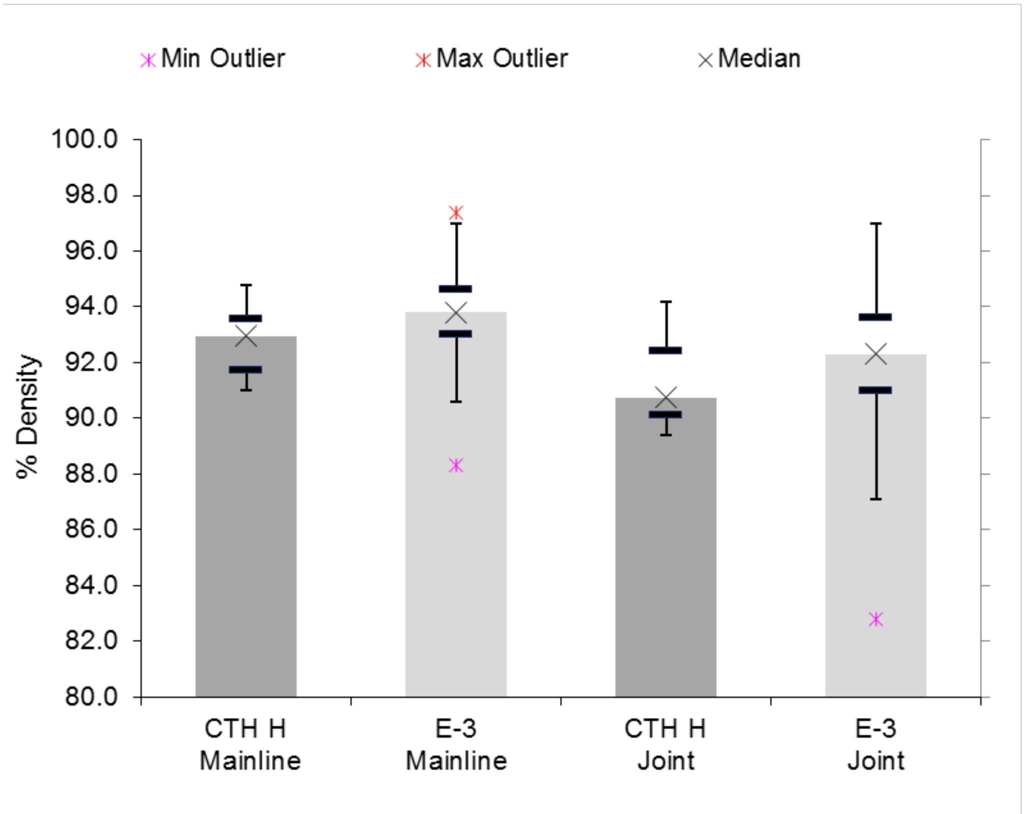


Figure 48 - Nuclear density (parallel) CTH H vs 2014 E-3 safety edge projects

Table 21 - Data used in Figure 48 box and whisker plot

Labels	CTH H Mainline	E-3 Mainline	CTH H Joint	E-3 Joint
Min	91.0	88.3	89.4	82.8
Q_1	91.7	93.0	90.1	91.0
Median	93.0	93.8	90.8	92.3
Q_3	93.6	94.6	92.4	93.6
Max	94.8	97.4	94.2	97.0
IQR	1.9	1.6	2.3	2.6
Upper Outliers	0	1	0	0
Lower Outliers	0	8	0	10
ST DEV	1.1	1.4	1.5	2.3

USH 8– Thin Lift Project

On USH 8, both a thin lift and standard nuclear density gauge were used to determine densities. When comparing all gauge data to cores, there is no significant difference. However, when isolating gauge type, the thin lift gauge underestimates the core densities by over 2% and the standard gauge overestimates the core densities by more than 2% (Figure 49).

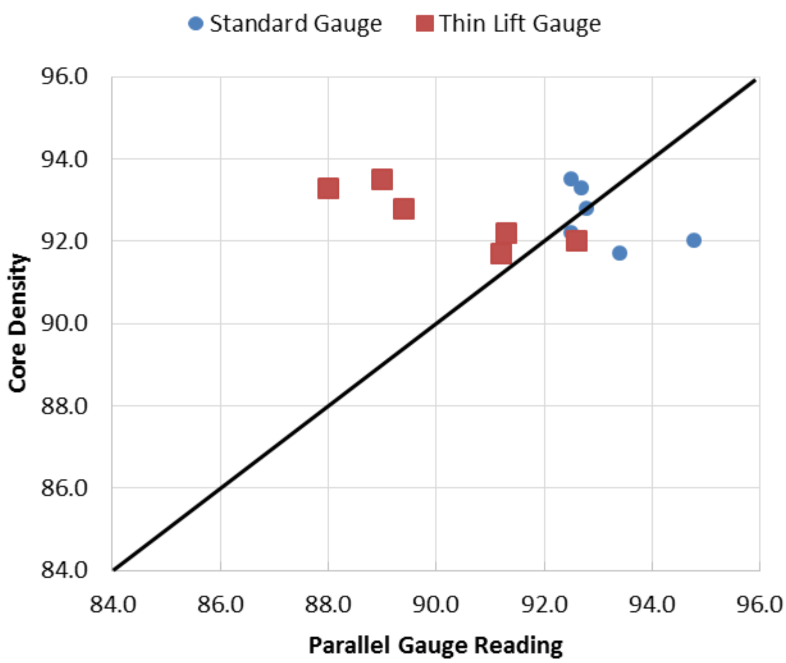


Figure 49 - Parallel nuclear vs. cores for standard and thin lift gauge

While the USH 8 project specified 1.25-inches, the core thickness varied from 1.27 to 3.15-inches. The thickest cores were found at the centerline. The USH 8 mainline lot densities were almost 2% lower than 2014 E-3 mixes, with USH 8 mean at 91.9% and 2014 E-3 mean mainline density at 93.7% (Figure 50).

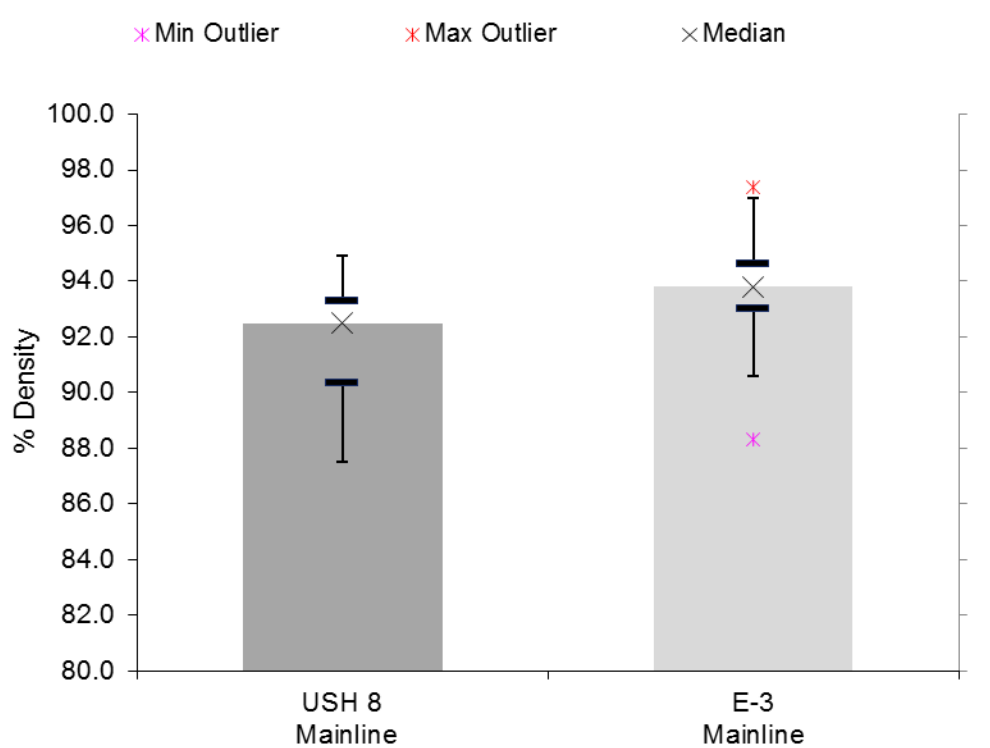


Figure 50 - Nuclear density (parallel) - USH 8 vs 2014 E-3 density data

Table 22 - Data used in Figure 50 box and whisker plot

Labels	CTH H Confined	CTH H Unconfined
Min	89.8	89.4
Q_1	91.5	89.9
Median	92.4	90.3
Q_3	92.8	90.5
Max	94.2	91.0
IQR	1.3	0.5
Upper Outliers	0	0
Lower Outliers	0	0
ST DEV	1.5	0.6

Hamburg and Permeability Data

The original work plan included Hamburg and NCAT Permeability tests. Initially the field visits were to include all E-10 and E-30 designs. Unfortunately, the safety edge longitudinal joint and thin lift overlay projects were only available using E-3 designs. Therefore, the resultant dataset includes two E-10/30 designs and two E-3 designs, intended slight deviation from initially planned.

Hamburg Data

Hamburg tests were conducted on mainline core samples from each 2015 project. The Hamburg test method followed AASHTO T-324, where two HMA samples (or cores) are placed in 50°C water. A loaded steel wheel (158.0 +/- 1.0 lb) passes over the specimen repeatedly and deformation is measured. The test is complete when the specimen reaches 12.5mm of rut depth. This test is to measure rutting resistance and moisture susceptibility of an HMA specimen (Figure 51). A greater number of passes before reaching a certain rut depth indicates a higher rutting/moisture resistant mixture.

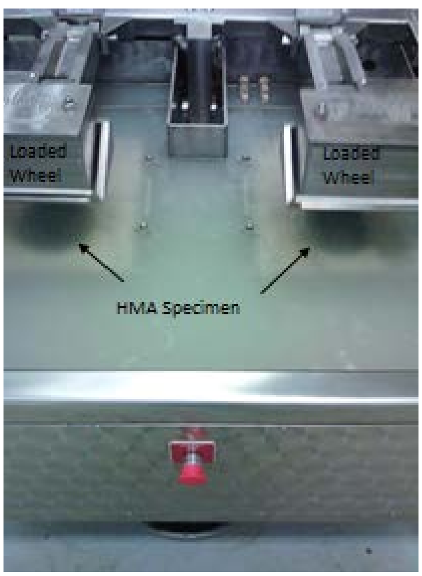


Figure 51 - Hamburg test (AASHTO T-324)

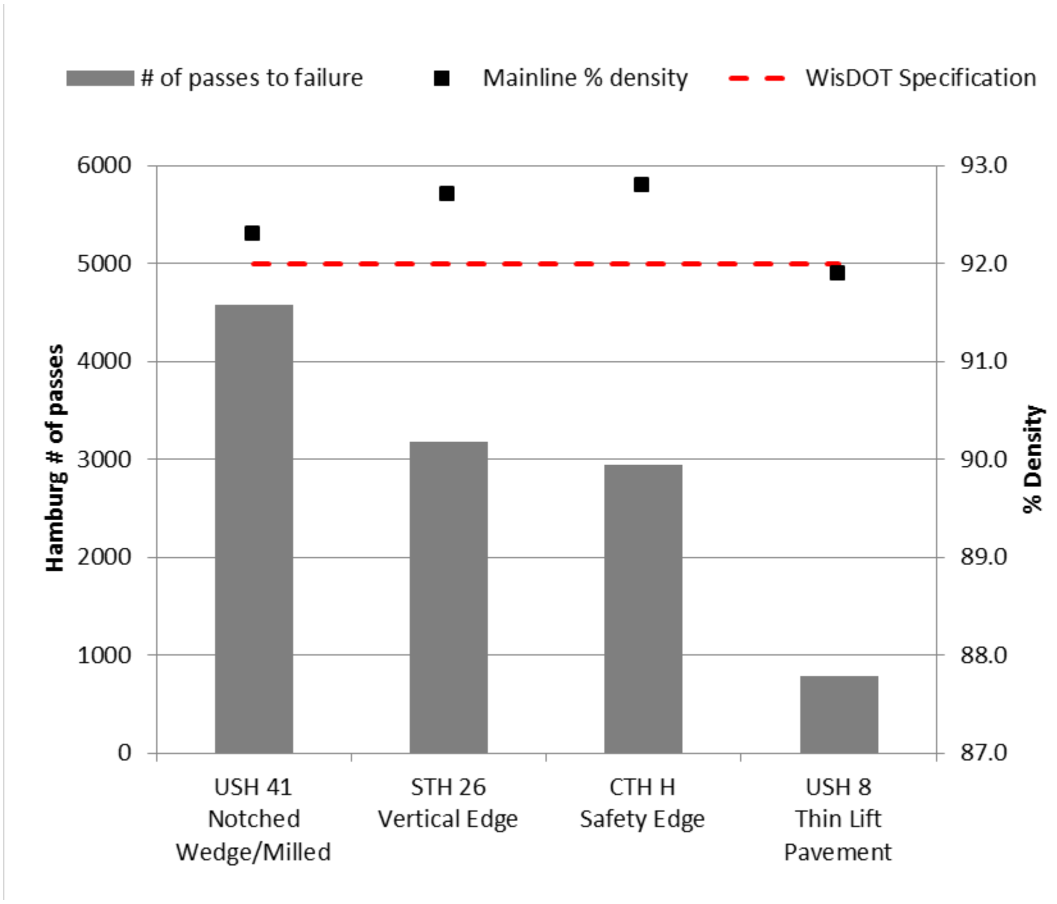


Figure 52 -Hamburg & density vs WisDOT proposed specification requirement

Figure 52 shows that all projects tested failed prior to 5,000 passes (> 12.5mm rut depth). Additionally, there was large variability in Hamburg results than density for each pavement tested. Even though USH 41 (notched wedge/milled) and STH 26 (vertical) projects used similar mix designs, with the slight difference being an E-30 versus E-10 respectively, the Hamburg failed almost 1400 passes sooner for the E-10 of STH 26.

While the Hamburg test was included to provide additional distinction amongst data collected, the dataset was smaller than anticipated and results were inconclusive.

NCAT Permeability Data

Permeability tests were conducted using the NCAT Permeameter. The NCAT Permeameter is a falling-head permeameter which uses Darcy's Law to determine the rate of water flow (cm/s) through compacted HMA pavements. Figure 53 is a picture of the NCAT Permeameter being used on STH 26. The permeameter is adhered to the HMA pavement, and filled with water. Once filled, the rate of outflow into the pavement is measured by timing the flow of water between markings on the side of the cylinder.

Figure 53 - NCAT permeameter photographed on STH 26

The NCAT Permeability proved to be a difficult field test to conduct, in that the adhesion of the permeameter to the pavement was non-uniform, inconsistent, and sometimes ineffective. [For example, when testing the unconfined side of CTH H, the difficulties with the permeameter resulted in early termination of testing because traffic control needed to advance with the paving train.]

Permeability was tested at the joint (in the same locations as the nuclear density gauge) for USH 41, STH 26, and CTH H. It was tested on the mainline for the USH 8 thin lift overlay project.

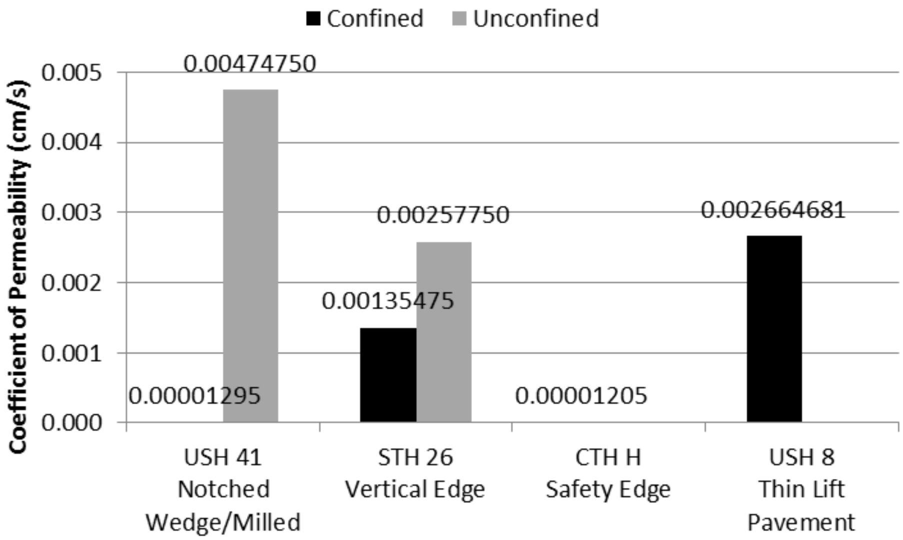


Figure 54 - Permeability using the NCAT permeameter

When comparing unconfined to confined (Figure 54), for the USH 41, STH 26, and CTH H projects, the largest difference occurred on USH 41, which is the notched wedge longitudinal joint / milled project. The permeability of the confined edge of the milled notched wedge joint and the safety edge joint were virtually zero. The permeability of the USH 8 thin lift pavement was similar to that of the unconfined side of the vertical longitudinal joint.

Albeit interesting, this data is incomplete, and will need additional testing to draw decisive conclusions.

Cores on the longitudinal joint

As presented thus far, all cores and density tests were taken *near* the longitudinal joint (see Figure 9) or on the mainline. It was suggested to include a core directly on the longitudinal joint on one of the field visits (Figure 54). From that point forward, cores were also taken directly on the centerline of the longitudinal joint. However, STH 26 was already completed, so no cores were collected from the centerline of the longitudinal joint for that project.

When a core is taken directly on the centerline of the longitudinal joint, it will encompass both sides of the joint. These centerline cores were collected for USH 41, CTH H, and USH 8. Bulk densities of said cores were calculated from each side of the joint using the average Gmm. Figure 55 shows the relative location of the cores. Cores locations 2-inches away from the centerline were also tested with a nuclear density gauge in the parallel and perpendicular position prior to coring.

Figure 55 - Centerline of CTH H

The motivation behind taking a core directly on the centerline was to determine if centerline joint density was accurately represented by adjacent unconfined and confined measurements. Four centerline cores were taken on USH 41, and two centerline cores were taken on each USH 8 and CTH H. Figure 56 displays the relative density of the longitudinal joint on either side of the centerline, as well as the density of the centerline joint. Pictures of the centerline cores are displayed below each corresponding bar graph.

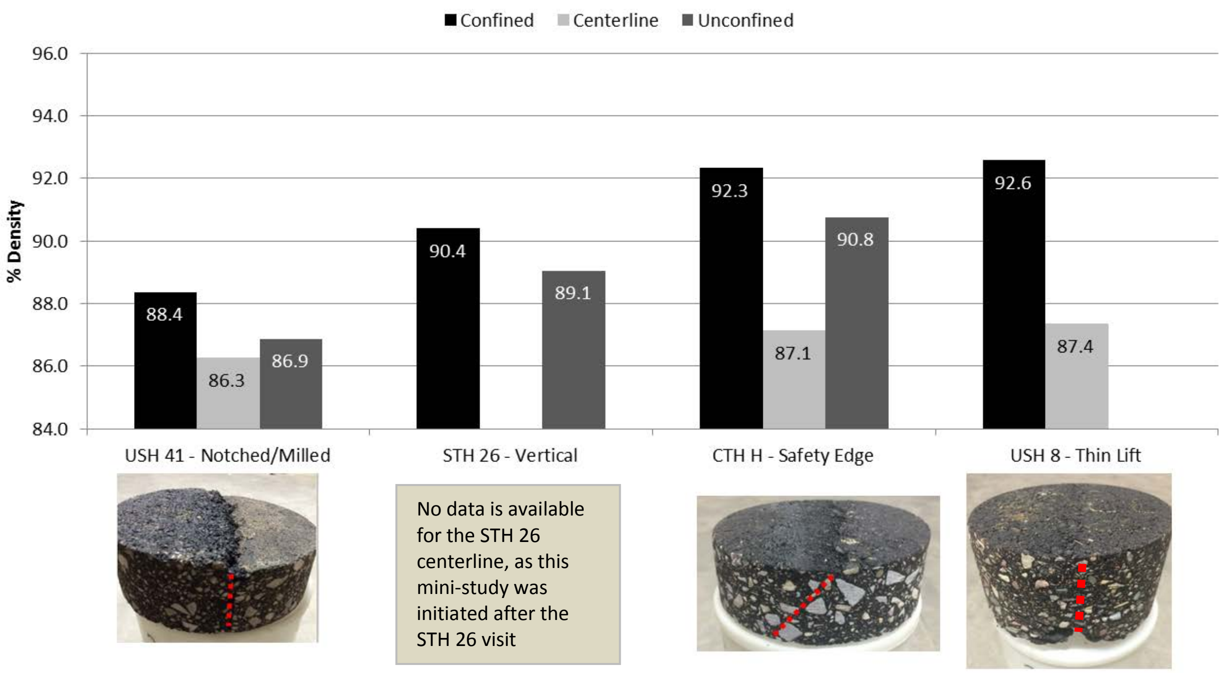


Figure 56 - Centerline cores vs. adjacent confined and unconfined cores

The density of cores taken on the centerline joint are much lower than the density of the cores taken on either side of the longitudinal joint. The differences between the centerline cores and the average of cores on either side of the centerline vary for each joint type. The notched wedge / milled longitudinal joint centerline core densities are relatively close at 1.4% below the average of adjacent cores tested 2 inches off the centerline. The safety edge centerline cores are 4.5% lower than the average of adjacent cores. The thin lift centerline cores are 5.2% lower than the average of adjacent cores. The thin lift project, as already mentioned, had a suspect existing longitudinal joint which likely contributed to the low density.

The difference in the centerline cores and adjacent cores could be attributed to joint type, achieved densities on confined and unconfined sides, or even the varying joint types/geometries resulting in uneven proportions of confined and unconfined lanes/mix represented within the core, but further investigation would be needed to determine specifics.

CHAPTER 6: CONCLUSIONS

Density Validation:

Results showed that the measurement of density using a nuclear density gauge best correlate when using a standard nuclear density gauge in the parallel position. However, the nuclear density gauge overestimates in place density 78% of the time. For the thin lift project on USH 8, it was found that while the standard nuclear density gauge overestimated density, and the thin lift gauge underestimated density. Therefore a nuclear/core correlation is recommended for all projects, regardless of gauge type, in order to determine an appropriate offset or correction factor between the gauge and cores of a specific pavement.

On average, the parallel orientation will overestimate density by 1.7% for all data and 1.8% for joints only, while the perpendicular orientation will overestimate density by 1.0% for mainline and 2.5% for joints only.

Longitudinal Joint Type

When analyzing the 2014 nuclear density data (specifically the data from parallel orientation), there is a significant difference between the confined and unconfined sides of a longitudinal joint. It was found that joint density is on average 2% lower than mainline density. Average longitudinal joint densities listed from highest to lowest are as following:

1. Milled confined (92.5%)
2. Safety Edge confined (92.4%)
3. Notched Wedge confined (92.2%)
4. Notched Wedge unconfined (91.0%)
5. Safety Edge unconfined (90.3%)
6. Vertical confined (90.7%)

7. Vertical unconfined (89.3%)

All joint density averages decreased as ESAL designation of the pavement increased (Figure 13). The safety edge resulted in higher joint densities than the confined edge of the notched wedge and both the confined and unconfined edges of vertical projects (Figure 15); however there was only one safety edge project evaluated for comparison. Additional data should be gathered before drawing any definitive conclusions, though the safety edge shows potential to improve longitudinal joint density.

Rolling Pattern

Rolling pattern was only found to be a statistically significant factor in achieving density on one project – the vertical longitudinal joint of STH 26. On this project, the contractor's standard rolling pattern achieved higher densities than the FHWA/AI best practices for the unconfined edge. The unconfined longitudinal joint pushed out 3-inches when the roller hung over the edge in the FHWA/AI section. This phenomenon may be attributed to specific HMA mix type and can reduce density, which could explain why the contractor's standard rolling patterns involved the roller stay away from the vertical edge on the first pass. While staying away on the first pass may create a stress crack adjacent to the joint as indicated by AI/FHWA, it may also be necessary to achieve increased longitudinal joint density, as seen on STH 26.

All other rolling patterns were not statistically significant in increasing or decreasing the density of the longitudinal joint on the projects visited.

Density Targets

Some consideration should be given to increasing the mainline density target, as that lends itself to increased joint density as well when additional compactive effort is applied to the entire lane width. Other studies have suggested mainline density be no less than 92% Gmm (*1*)

(*2*). Current WisDOT mainline specifications range from 90.5 to 92.0%. The 2014 density data shows that average mainline density was 93.1%.

Figure 14 illustrates the upper and lower layer densities where all averages are above 92.0%. The lowest average density (92.7%) occurred on the E-10/30 Upper Layer, which already requires 92.0% density. While the lower layer was only 13% of the data, that 13% is comprised of 193 datasets ranging over E-1, E-3, E-10 and E-30 mixes. All the data collected for this research indicates there is not a need to separate density targets based on layer.

The literature recommendations for minimum compaction of the longitudinal joint vary from 89.0 to 91.0 % (*3*) (*4*). The 2014 density data average longitudinal joint densities (regardless of joint type) were as follows (See Figure 13):

1. E-1 joint – 92.7%
2. E-3 joint – 92.3%
3. E-10/E-30 joint – 89.1%

This data suggests a target of 90% is achievable for E-1 and E-3 mixes, but less so for E-10 and E-30 mixes. That being said, the joint densities achieved on E-10 and E-30 field projects of 2015 were higher than 2014 average joint densities, demonstrating that it may be possible to improve longitudinal joint densities. As determined in the Pennsylvania study (*9*), heightened awareness, best practices documentation, and the new PWL specification increased joint density by 1.1% statewide. After analyzing all data collected for this research study, the recommended longitudinal joint density for Wisconsin is 90.0%.

Figure 57 applies a suggested density target to the mainline and longitudinal joint density of 92.0 and 90.0%, respectively.

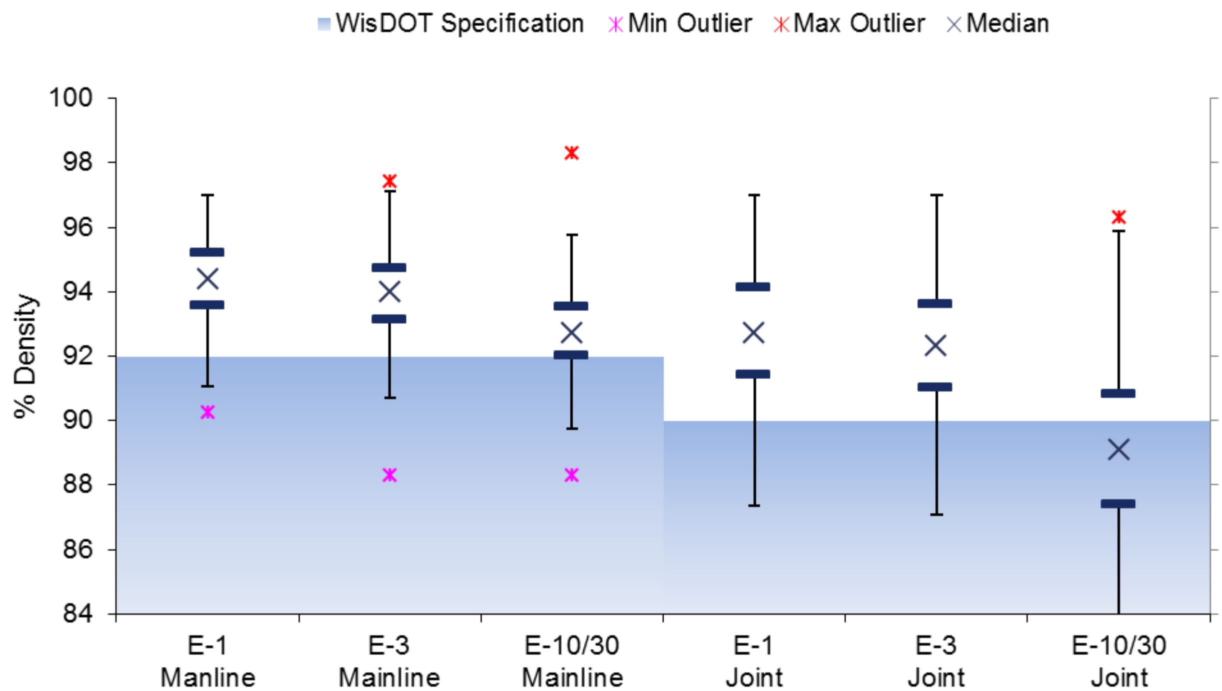


Figure 57 - Mainline – 2014 nuclear parallel mainline and joint density, with suggested specifications

Table 23 - Analysis of data for Figure 58 box and whisker plot

Labels	E-1 Manline	E-3 Mainline	E-10/30 Mainline	E-1 Joint	E-3 Joint	E-10/30 Joint
Min	90.25	88.3	88.3	83.9	82.8	80.9
Q_1	93.55	93.1	92	91.4	91	87.4
Median	94.4	94	92.7	92.7	92.3	89.1
Q_3	95.2	94.7	93.5	94.1	93.6	90.8
Max	97	97.4	98.3	97	97	96.3
IQR	1.65	1.6	1.5	2.7	2.6	3.4
Upper Outliers	0	1	9	0	0	2
Lower Outliers	9	9	17	9	10	3
ST DEV	1.3	1.4	1.2	2.1	2.3	2.5
SPEC	92	92	92	90	90	90

Figure 57 above, is an alternate view of data presented in Figure 13, grouping mainline density with longitudinal joint density. The suggested targets for mainline density (92.0% average) and longitudinal joint density (90.0%) are indicated by the shaded regions on the graph. All but E-10/30 longitudinal joints already achieved the suggested specification of 90.0%.

Since Figure 57 includes all joint types within each ESAL category, Figure 58 shows the resultant joint density for the E-10/30 mixes when only the notched wedge (unconfined) and milled (confined) data are used, as suggested in the previous section of this report.

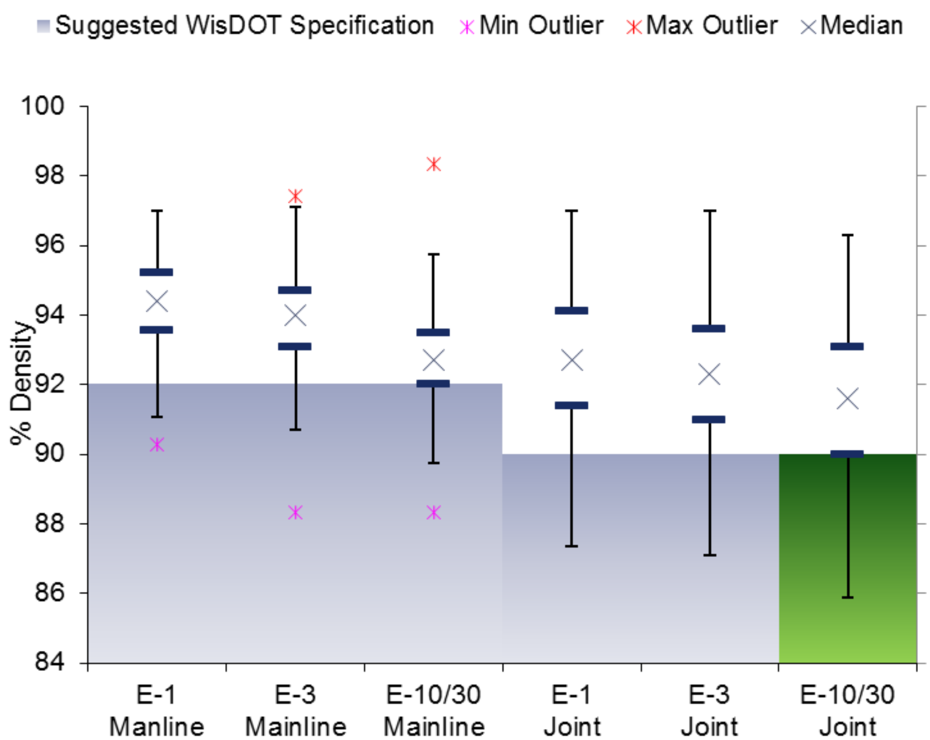


Figure 58 - Mainline and joint density, parallel (all data) - E-10/30 filtered

Table 24 - Analysis of data for Figure 59 box and whisker plot

Labels	E-1 Manline	E-3 Mainline	E-10/30 Mainline	E-1 Joint	E-3 Joint	E-10/30 Joint
Min	90.25	88.3	88.3	83.9	82.8	85.9
Q_1	93.55	93.1	92	91.4	91	90
Median	94.4	94	92.7	92.7	92.3	91.6
Q_3	95.2	94.7	93.5	94.1	93.6	93.1
Max	97	97.4	98.3	97	97	96.3
IQR	1.65	1.6	1.5	2.7	2.6	3.1
Upper Outliers	0	1	9	0	0	0
Lower Outliers	9	9	17	9	10	0
ST DEV	1.3	1.4	1.2	2.1	2.3	2.0

Figure 58 now indicates that when notched wedge (unconfined) and milled (confined) longitudinal joint type is used for E-10/30 mixes, a 90.0% density target is achievable. Furthermore, in both high ESAL projects evaluated, STH 26 (vertical) and USH 41 (notched wedge/mill), the contractor achieved below average density on the mainline and above average density on the joints.

CHAPTER 7: RECOMMENDATIONS

Density Validation:

i. Continue to collect daily nuclear density data using a standard nuclear density gauge in the parallel orientation for conventional thickness HMA and thin lift over lay projects

ii. Use cores to establish a nuclear density / core correlation during a test strip

iii. Adjust the density targets to account for nuclear gauge offsets

All nuclear density data collected in Wisconsin for this study, for previous studies and for the Quality Management Program have been using a standard nuclear density gauge in the parallel position. The data validates current practice showing that parallel orientation correlates better to cores than perpendicular orientation. On average, the nuclear density readings, in the parallel orientation, are overestimated by 0.7% for the mainline and 2.0% for the joint. While a nuclear / core correlation is needed to report the true pavement density, the current targets (and recommended targets in this study) and acceptance is based on gauge readings. More cores may be needed to validate the nuclear gauge offset from cores, and the specification should be adjusted to account for the desired target based on pavement density as determined from cores.

Longitudinal Joint Type:

i. Enforce the current standard to require the notched wedge longitudinal joint on all projects, unless echelon paving is possible

ii. For E-10 and E-30 mixes, additionally require milling of the unconfined notched wedge longitudinal joint when paving the adjacent lane (the data shows this is not needed to achieve density on lower ESAL mixes)

The notched wedge longitudinal joint produced the second highest densities and the milled longitudinal joint produced the highest joint density. The notched wedge longitudinal joint provides a viable choice for safety reasons, as well as density. The notch provides safe vehicle lane changes without a significant drop off, and the presence of the wedge helps confine the mix during rolling. Because milling the unconfined notched wedge would result in added expense, it is only recommended where the data deems it necessary, that is on E-10 and E-30 mixes. The 2014 density data shows that vertical longitudinal joint results in the lowest density.

Appendices E and F provide a specification and case study for paving wider than called for by plan and milling off the extra width before placing the adjacent lane. The case study looked at a 50 gyration recycled surface mix which was paved 4-inches wider and then milled. Average longitudinal joint densities were 93.3 and 93.0% for the confined and unconfined sides, respectively. There were also cores taken directly on the centerline which averaged 92.0% density.

Density Targets:

i. A minimum of 90.0% density for longitudinal joints

ii. A minimum of 92.0% density for all ESAL type mainline

iii. Remove any distinction between upper and lower layer density

Please note: these density target recommendations are based on parallel nuclear gauge data. If Wisconsin adopts the nuclear / core correlation, these targets may need to be adjusted.

The recommendation is to set all minimum mainline density in Wisconsin at 92.0%, since the data shows it is achievable.

Historically, the lower layer nuclear density targets were reduced to account for the backscatter mode of the nuclear gauge over aggregate base. A nuclear / core correlation will eliminate the need for a reduced lower layer density target. Additionally, the data showed no distinction between upper layer and lower layer densities obtained. However, increasing the compaction target of the lower layer of HMA assumes that the subgrade and base material are strictly addressed to ensure proper compaction throughout the pavement structure.

Further Recommendations Based on Observations

i. Do not construct centerline rumble strips directly over the longitudinal joint, instead place them on either side of the longitudinal joint
ii. Review the selection process of thin lift overlay projects, and include the existing longitudinal joint as a criterion
iii. Look into the use of a void reducing membrane to fill the longitudinal joint from underneath
iv. Consider a topical joint sealer in lieu of a monetary penalty for substandard longitudinal joints
v. Use a joint heater when possible, but disseminate updated WisDOT SPV or STSP to include latest language and have the inspector verify temperature range is met

The research shows there is a large difference between cores taken on the centerline of the longitudinal joint and those taken 2-inches offset from the joint. For this reason, it is recommended to mill the rumble strips at a 2-inch offset, on each side of the longitudinal joint, instead of directly on top of it.

Special effort should be made in selecting a thin lift overlay project, as it was observed that the existing longitudinal joint was severely deteriorated which will likely negatively affect the overall performance of the pavement.

Further research should include the evaluation of various joint sealers. New products include a void reducing asphalt membrane that is applied before paving to fill the void spaces in the longitudinal joint from the bottom up. Appendix G is the Illinois Department of Transportation (IDOT) Void Reducing Asphalt Membrane specification.

Also, in lieu of a monetary penalty, the research team recommends requiring the application of a top-applied joint sealer, at the contractor's expense, when the contractor does not achieve compaction of the longitudinal joint.

Heated joints resulted in higher densities for all joint types where data was available. Heated joints increased densities by 0.7, 1.2 and 1.5% for milled, vertical, and notched wedge, respectively.

CHAPTER 8: WISDOT SPECIFICATION RECOMMENDATIONS

Below are exact excerpts from various WisDOT documents. The blue underlined items are new text and a recommend change. The red struck-through items are current WisDOT language and a recommended change.

Facility Development Manual

Section 14-10-1 General

5.11 Edge and End Joints

Attachment 5.5 shows the notched wedge longitudinal joint, the standard joint to be used at HMA pavement centerlines and lane lines. However, a longitudinal butt joint should typically be used for single layer HMA overlays and for SMA pavements. The notched wedge longitudinal joint should be constructed by tapering the edges of the HMA pavement layers. The taper shall include a notch at the top of the layer and have a 12:1 slope for the remaining layer depth below the notch. The notch wedge longitudinal joint shall be milled out before placing the adjacent (confined) lane for E-10 and E-30 pavements. A vertical longitudinal joint is not recommended for high ESAL projects.

Standardized Special Provision

Milling and Removing Temporary Joint Special

Item SPV.0105.06.

A Description

This special provision describes the milling and removing of the upper and lower layer HMA wedge joint and any other temporary longitudinal or transverse joints, including sweeping and cleaning of the affected area prior to the abutting pavement placement.

B (Vacant)

C Construction

Immediately prior to the placement of the adjoining lane, mill ~~any temporary~~the notched wedge joint to a true line with a face perpendicular to the surface of the existing asphaltic surface pavement.

2016 Standard Specifications

Part 4: Pavements

Section 450 General Requirements for Asphaltic Pavements

450.3.2.8 Jointing

(1) Place all layers as continuously as possible without joints. Do not roll over an unprotected end of freshly laid mixture unless interrupting placement long enough for the mixture to cool. If interrupting placement, ensure proper bond with the new surface. Form joints by cutting back on the previous run to expose the full depth of the layer. After resuming placement, place the fresh mixture against the joint to form intimate contact and be co-planar with the previously completed work after consolidation.

(2) If an asphaltic mat adjoins an older high-type asphaltic mat, cut back the old mat on a straight line to form a butt joint for over full depth of the new mat.

(3) Construct notched wedge longitudinal joints for all mainline paving if the pavement thickness conforms to the minimums specified in 460.3.2~~, unless the engineer directs or allows an alternate joint~~. Taper each layer at a slope no greater than 12:1. Extend the taper beyond the

normal lane width, or as the engineer directs. Ensure that tapers for all layers directly overlap and slope in the same direction.

(4) Place a ~~1/2~~half to one inch vertical notch after compaction at the top of tapers on all layers. Place the finished longitudinal joint line of the upper layer at the pavement centerline for 2-lane roadways, or at the lane lines if the roadway has more than 2 lanes.

(5) Construct the tapered portion of each layer using an engineer-approved strike-off device that will provide a uniform slope and will not restrict the main screed. Apply a weighted steel side roller wheel, as wide as the taper, to the tapered section. Compact the initial taper section to as near the final density as possible. Apply a tack coat to the taper surface before placing the adjacent lane.

(6) Clean longitudinal and transverse joints coated with dust and, if necessary, paint with hot asphaltic material, a cutback, or emulsified asphalt to ensure a tightly bonded, sealed joint.

2016 Standard Specifications

Part 4: Pavements

Section 460 Hot Mix Asphalt Pavement

460.3.3 HMA Pavement Density Maximum Density Method

460.3.3.1 Minimum Required Density

(1) Compact all layers of HMA mixture to the density table 460-3 shows for the applicable mixture, location, and layer.

TABLE 460-3 MINIMUM REQUIRED DENSITY~~[1]~~

LOCATION	~~LAYER~~	PERCENT OF TARGET MAXIMUM DENSITY		
		MIXTURE TYPE		
		~~E-0.3, E-1, & E-3~~	~~E-10, E-30 & E-30x~~ LT, MT, HT	SMA~~[5]~~ ~~[3]~~
TRAFFIC LANES[1] [2]	~~LOWER~~	~~91.5[3]~~	~~92.0[4]~~	--
	~~UPPER~~	~~91.5~~	92.0	--
SIDE ROADS, CROSSOVERS, TURN LANES, & RAMPS[1]	~~LOWER~~	~~91.5[3]~~	~~92.0[4]~~	--
	~~UPPER~~	~~91.5~~	92.0	--
SHOULDERS & APPURTENANCES[1]	~~LOWER~~	~~89.5~~	~~89.5~~	--
	~~UPPER~~	~~90.5~~	90.5	--
LONGITUDINAL JOINT[4]			90.0	--

[1] These ~~table~~ values are for average lot density. If any individual test results falls more than 3.0 percent below the minimum required target maximum density, the engineer may investigage the accepability of that material.

[2] Includes parking lanes as determined by the engineer.

~~[3] Minimum reduced by 2.0 percent for lower layer constructed directly on crushed aggregate or recycled base courses.~~

~~[4] Minimum reduced by 1.0 percent for lower layer constructed directly on crushed aggregate or recycled base courses.~~

[5] [3] Minimum required densities for SMA mixtures are determined according to CMM 8-15.

[4] These values are for average sublot density taken within 2-inches of the longitudinal joint

460.5.2.2 Disincentive for HMA Pavement Density

(1) The department will administer density disincentives under the Disincentive Density HMA Pavement and the Disincentive Density Asphaltic Material administrative items. If the lot density is less than the specified minimum in table 460-3, the department will reduce pay based on the contract unit price for both the HMA Pavement and Asphaltic Material bid items for that lot as follows:

DISINCENTIVE PAY REDUCTION FOR HMA PAVEMENT DENSITY

PERCENT LOT DENSITY BELOW SPECIFIED MINIMUM	PAYMENT FACTOR (percent of contract price)
From 0.5 to 1.0 inclusive	98
From 1.1 to 1.5 inclusive	95
From 1.6 to 2.0 inclusive	91
From 2.1 to 2.5 inclusive	85
From 2.6 to 3.0 inclusive	70
More than 3.0[1]	____

[1] Remove and replace the lot with a mixture at the specified density. When acceptably replaced, the department will pay for the replaced work at the contract unit price. Alternatively the engineer may allow the nonconforming material to remain in place with a 50 percent payment factor.

(2) Each longitudinal joint sublot shall be evaluated individually (i.e. no averaging within a lot). If a longitudinal joint sublot average density is less than the specified minimum in table 460-3, the contractor shall perform one of the following for the full length of the sublot in which the tests fall, up to 1500-feet, at no additional cost to the department:

- Unconfined joint: apply 0.070 gallons per square yard of tack at joint
- Confined joint: apply a joint sealant to the completed joint

~~(2)~~ (3) The department will not assess density disincentives for pavement placed in cold weather because of a department-caused delay as specified in 450.5(5).

Construction and Materials Manual

Chapter 8 Materials Testing, Sampling, Acceptance

Section 15 Density Testing

8-15.5 Nuclear Density Testing HMA

8-15.5.1 General

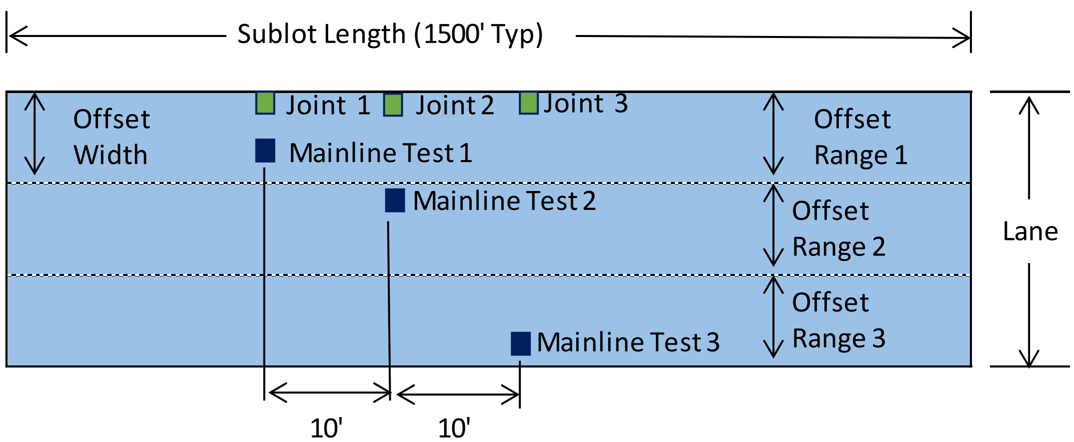
During tests, the gauge must be kept the following minimum distances from:

— Pavement transverse construction joints .... 20 feet
— Bridge deck expansion joints .... 20 feet
— Operator .... 3 feet
— Bystanders .... 15 feet
— Equipment, manholes, etc. .... 15 feet
— Other nuclear devices .... 30 feet
— Unrestricted edge of pavement .... 1.5 feet

— Restricted edge of pavement .... 1 foot
— Longitudinal joint (unconfined and confined)...........2 inches

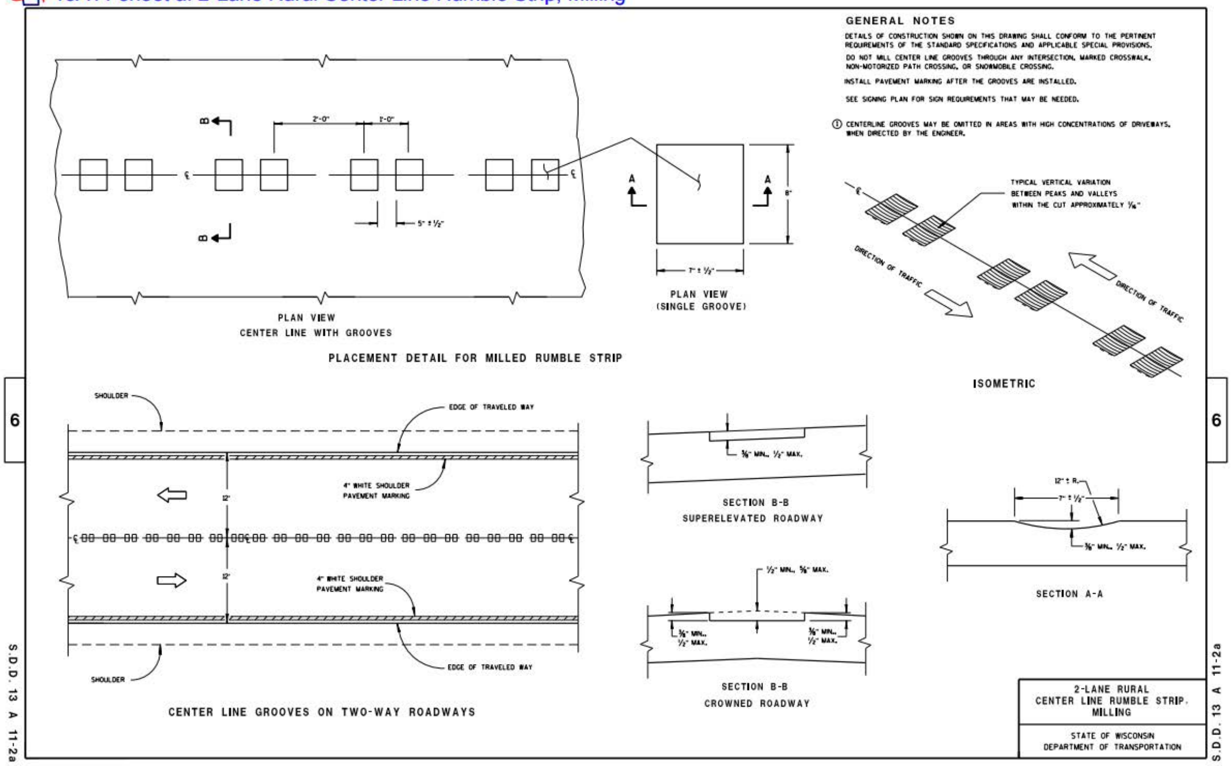
8-15.10.2.1 Determining Test Locations Using Linear Sublots

Figure 1 Linear and Longitudinal Joint Sublot Layout

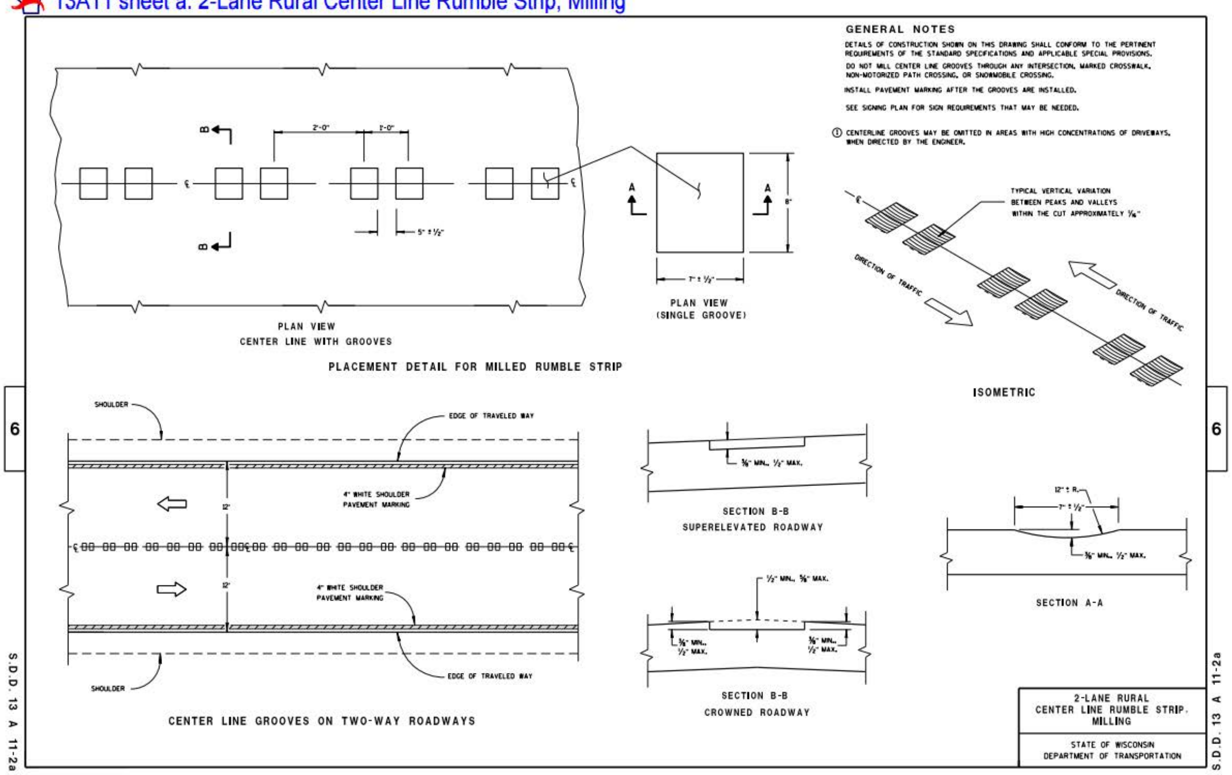


13A11 sheet a: 2-Lane Rural Center Line Rumble Strip, Milling

13A11 sheet a: 2-Lane Rural Center Line Rumble Strip, Milling



13A11 sheet a: 2-Lane Rural Center Line Rumble Strip, Milling



Consider milling a rumble strip on each side of the longitudinal joint, at a 2-inch offset.

WORKS CITED

(*1*) Brown, E. Ray. 1990. Density of Asphalt Concrete - How Much Is Needed? Washington, DC: TRB, 1990. NCAT Report No. 90-3.

(*2*) NCHRP. 2011. A Manual for Design of Hot Mix with Commentary. 2011. 673.

(*3*) MI-DOT. 2011. Extending the Life of Asphalt Pavements. s.l. : Michigan DOT, 2011.

(*4*) University, Purdue. www.engineering.purdue.edu. [Online] https://engineering.purdue.edu/NCSC/library/Longitudinal%20Joint%20in%20Asphalt%20Pavement.pdf. Longitudinal Joint in Asphalt Pavement.

(*5*) Counts, FHWA Every Day. 2015. Safety Edge. [Online] October 21, 2015.

(6) Williams, Stacy G., Ph.D., P.E. 2011. HMA Longitudinal Joint Evaluation and Construction. s.l. : University of Arkansas, 2011. TRC-0801.

(*7*) Kandhal, Prithvi S. 1994. Evaluation of Longitudinal Joint Construction Techniques for Asphalt Pavements (Michigan and Wisconsin Project - Interim Report). s.l. : NCAT, 1994.

(*8*) Mallick, Kandhal and. 1997. Longtitudinal Joint Construction Techniques for Asphalt Pavements. Auburn, AL : NCAT, 1997. 97-4.

(*9*) New Longitudinal Joint Gets Results in Pennsylvania. Garth Bridenbaugh, PE. 2012. September / October , s.l. : Asphalt Pavement Magazine, 2012.

(*10*) AI/FHWA. 2012. Best Practices for Constructing and Specifying HMA Longitudinal Joints. 2012.

(*11*) Crovetti, Robert Schmitt and James. 2007. Development of In-Place Permeability Criteria for HMA Pavement in Wisconsin. s.l. : Wisconsin Highway Research Program, 2007. SPR#0092-06-02.

(*12*) 2014. Thin Asphalt Concrete Overlays. A Synthsis of Highway Practice. Washington DC : TRB, 2014. Vols. 20-05, 44-07 Synthesis 464

(*13*) Troxler. 2007. Nucelar Moisture Density Gauge. www.troxlerlabs.com. [Online] September 2007. http://www.troxlerlabs.com/downloads/pdfs/3440/3440appbrief.pdf.

(*14*) NAPA. 2009. Thin Asphalt Overlays for Pavement Preservation. 2009. 135.

APPENDIX A – WISDOT LONGITUDINAL JOINT DENSITY DATA COLLECTION PROCEDURE

WisDOT Longitudinal Joint Density Data Collection Procedure

Background:

In an attempt to investigate the long term performance of longitudinal joints in asphalt pavements, the Wisconsin Department of Transportation is collecting compaction data of the pavement at the longitudinal joint during construction. This data recorded as % density will be based off the Target Maximum Density of the mixture, which is equated by multiplying the G_{mm} of the mixture times the unit weight of water (62.24 lb/ft^3).

Procedure:

Under the current density STSP (460-020) data is collected for pay in 1500' sublots. The goal of this procedure is to collect as much data as possible, in order to do so the frequency of the joint density measuring will be kept the same as the current STSP 460-020. In lieu of calculating additional random numbers for this testing, this procedure will use the locations that have already been predetermined prior to construction (see Figure 1 below).

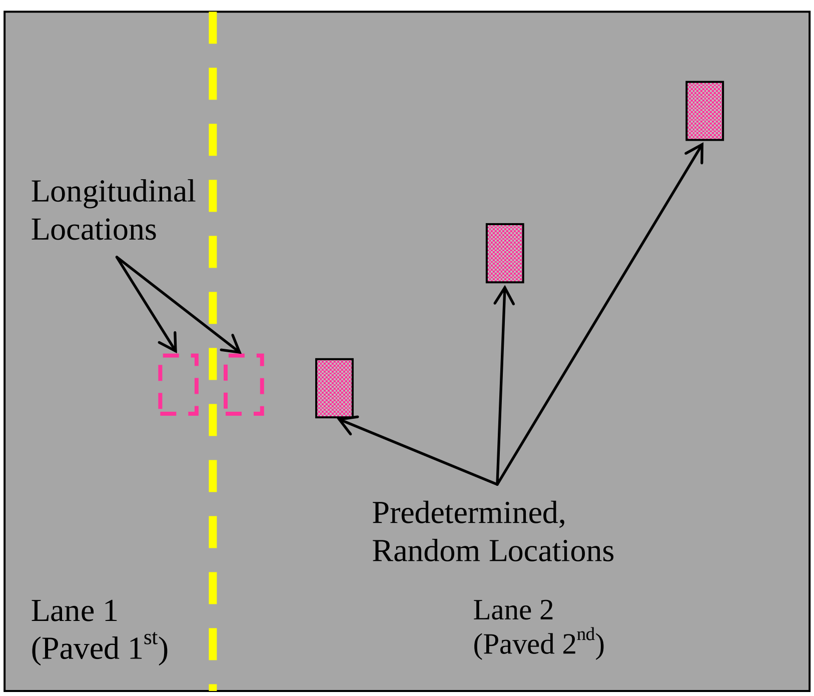


Figure 1

Steps for conducting the longitudinal joint density tests (Unconfined Longitudinal Joint)

1. Determine the location of the longitudinal joint density tests to be taken (location will correspond with the predetermined random location per STSP 460-020)
2. Place the gauge parallel to the longitudinal joint (unconfined as shown in Figure 2 below or confined as shown in Figure 3 below) and within a 1/2" of the top edge of the joint without touching, straddling or overhanging the adjacent lane.

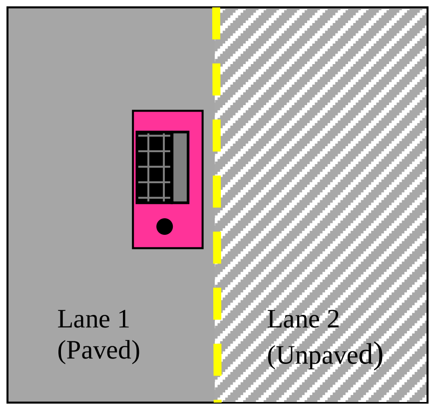


Figure 2: Unconfined Situation

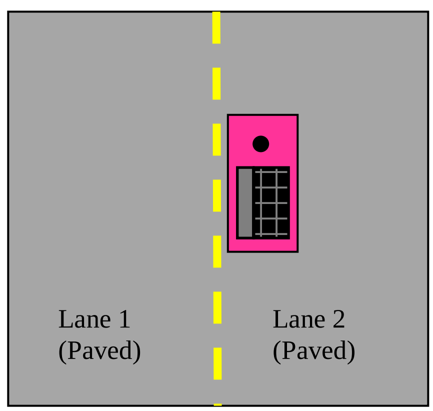


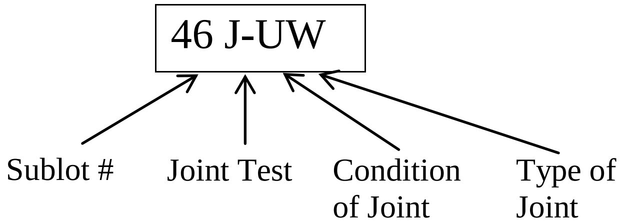
Figure 3: Unconfined Situation

3. Set the gauge up to record a 60 second test (if using a Seaman gauge, the test length will be a total of 2 minute; 60 seconds contact, 60 seconds air gap)
4. Start the test and record the bulk density (lb/ft^3) along with the % density.
5. Label the test result by the random sublot, followed by the appropriate combination of coding listed below.
    a. The type of joint constructed will be coded as follows;
        i. Notched Wedge joint = W
        ii. Vertical joint = V
        iii. Milled joint = M
    b. The type of joint tested will be coded as follows;

i. Unconfined = U

ii. Confined = C

c. Therefore as example,



- The above coding would signify testing done in sublot 46 for lane 1 (Figure 2: Unconfined Situation) for a notched wedge joint.

6. Rotate the gauge 90° (transverse to the lane and direction of travel) and slide the front edge of the gauge within a 1/2" of the top edge of the joint without touching, straddling or overhanging the adjacent lane (see Figure 4 & Figure 5 below).

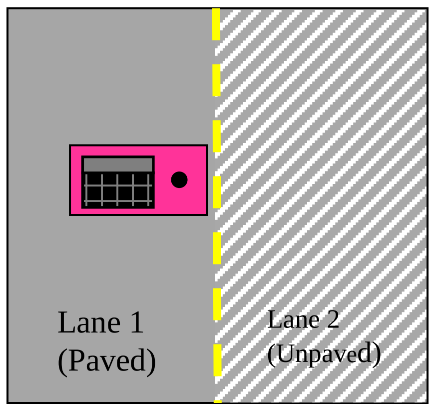


Figure 4: Unconfined Situation (Gauge Rotated 90°)

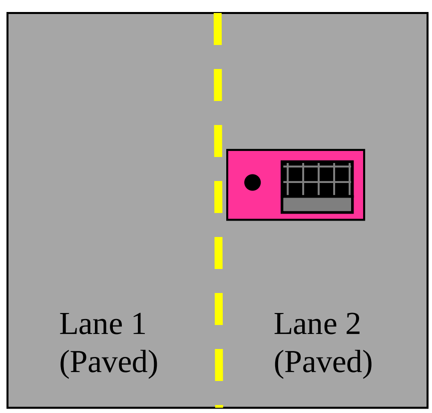
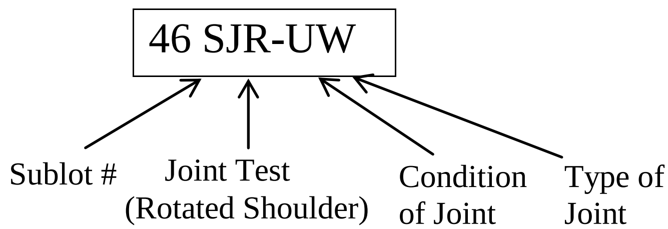


Figure 5: Confined Situation (Gauge Rotated 90°)

7. Set the gauge up to record a 60 second test (if using a Seaman gauge, the test length will be a total of 2 minute; 60 seconds contact, 60 seconds air gap)

8. Start the test and record the bulk density (lb/ft^3) along with the % density.

9. Label the test result by the random sublot followed by the appropriate combination of coding listed above with an R which stands for Rotated (e.g. for a confined milled joint in sublot 46 the coding would be 46 JR-CM).
10. The steps outlined above are shown for centerline longitudinal joint, however, the process should be repeated for multi-lane highways as well as shoulder longitudinal joints that are not paved integrally with the mainline. Test results for shoulder joint testing will be labeled with an S and followed by the appropriate combination described above (e.g. for a confined vertical joint in sublot 46 the coding would be 46 SJ-CV and/or 46 SJR-CV).
    a. Therefore as example,



- The above coding would signify testing done in sublot 46 for lane 1 (Figure 2: Unconfined Situation) for a notched wedge joint.

11. All longitudinal joint density results will be recorded on a QMP density worksheet, form WS4607 and will remain separate from that of the QMP documentation. The longitudinal joint density results recorded as part of this procedure will not affect payment. Documentation of the longitudinal joint density will be turned into the department at the completion of paving.

APPENDIX B – SURVEY OF CURRENT PAVING PRACTICES & OPINIONS

Wisconsin Highway Research Program (0092-15-09)

Research Survey: Field Density Validation

This survey is being used to supplement the density data collected for the HMA Technical Team Longitudinal Joint study initiated in 2014. The Longitudinal Joint information collected was primarily joint "Method" type. The intent of this inquiry is to gather information to identify "Best Practices" currently used in the field, as well as opinions from construction professionals. All information provided is considered confidential.

Question 1:

<table>
<tr><th colspan="2">Please list whether the information provided in this survey is tied to a specific project OR if the information provided in this survey is considered a "Best Practice" for your company.</th></tr>
<tr><td rowspan="3">□ The information provided in this survey is for a Specific Project:

Project Name:___________________________

Project Location:_________________________

State ID:________________________________

Construction Year:________________________

For this project - were Longitudinal Joint Densities recorded and submitted as part of the 2014 Longitudinal Joint Study?

□ YES □ NO</td><td>□ The information provided in this survey is the summary of the Best Practices used in the field:

Company Name:_________________________

Regional Area:___________________________</td></tr>
<tr><td>OPTIONAL INFORMATION:</td></tr>
<tr><td>Your Name:_____________________________

Company:__________________________

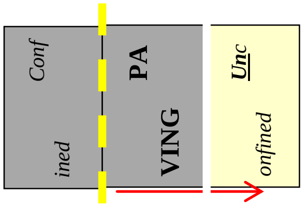
Title:___________________________________</td></tr>
</table>

Question 2:

<table>
<tr><th colspan="2">Please rank from most important to least important (1 being the most important)
First, when constructing a Longitudinal Joint, which "Method" do <u>you</u> feel produces the best joint? And, second, which "Method" is most practical for most (greater than 50%) of your paving projects? (Check only one box per side)</th></tr>
<tr><td><u>Method that produces the BEST joint:</u>
____ Eschelon
____ Joint Heater
____ Joint Tack
____ Notched Wedge
____ Milled Joint
____ Pavement thickness at least ___Xs NMAS
____ Other______________________________</td><td><u>The most practical Method in the field:</u>
____ Eschelon
____ Joint Heater
____ Joint Tack
____ Notched Wedge
____ Milled Joint
____ Pavement thickness at least ___Xs NMAS
____ Other________________________________</td></tr>
</table>

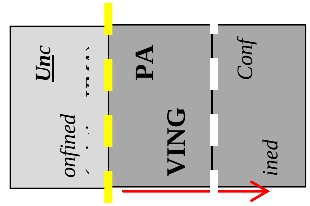
Question 3:

For each of the scenarios below (or the scenarios that apply to your project), please check the box that describes how the Roller Operator sets up the first pass of the Rolling Pattern:



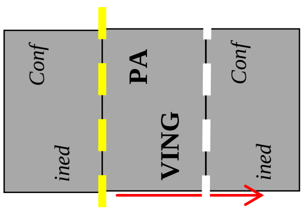
Scena
rio #1:
Confined /
Unconfined
Slope

FIRST pass:
□ Roll confined joint first
□ Roll unconfined joint first
□ Roll High Side to Low Side
□ Roll Low Side to High Side
□ Roll joint after rolling mat
□ Other________________________________



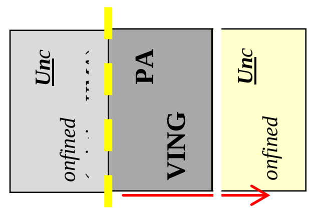
Scena
rio #2:
Unconfined /
Confined
Slope

FIRST pass:
□ Roll confined joint first
□ Roll unconfined joint first
□ Roll High Side to Low Side
□ Roll Low Side to High Side
□ Roll joint after rolling mat
□ Other________________________________



Scena
rio #3:
Confined /
Confined
Slope

FIRST pass:
□ Roll High Side to Low Side
□ Roll Low Side to High Side
□ Roll joint after rolling mat
□ Other______________________________



Scena
rio #4:
Unconfined /
Unconfined
Slope

FIRST pass:
□ Roll High Side to Low Side
□ Roll Low Side to High Side
□ Roll joint after rolling mat
□ Other________________________________

Question 4:

Please list below the rolling method used when rolling both the Unconfined and Confined joint: (check any/all that apply):

Unconfined Joint:
FIRST PASS:
□ Roll _____" away from the edge (on the mat)
□ Overhang _____" off the edge
SECOND PASS:
□ Roll _____" away from the edge (on the mat)
□Overhang _____" off the edge
OR / ADDITIOINALLY:
□ Use an extra cold roller on the joint only
□ Wait until a lower temperature ______°F
□ Other________________________________
____

Confined Joint:
FIRST PASS:
□ Roll _____" away from the joint (on the mat)
□ Overhang _____" off the joint
SECOND PASS:
□ Roll _____" off the joint (on the mat)
□ Overhang _____" off the joint
OR / ADDITIONALLY:
□ Use an extra cold roller on the joint only
□ Wait until a lower temperature ______°F
□ Other________________________________
____

Question 5:

Please list below the "Best Practices" used by the paving crew for a Longitudinal Joint (check any/all that apply):	
Unconfined Joint: □ Lute back onto mat – "raking" □ Lute vertical edge - "bump" □ No Luting Confined Joint: □ Lute back onto mat – "raking" □ Lute - "scrape and leave a lip" □ Overlap by ____" □ No Luting	Paving Set up: □ Stringline □ Skis □ Paver Automation □ Heated Screed □ End Gates no more than _____" from auger Other_________________________________ ____

Question 6:

Please rank from most important to least important (1 being the most important) the factors that affect the long term quality of a Longitudinal Joint:
____ Joint Method - (______________ Method is the best (options listed in Question #2 above)) ____ Rolling ____ Paver Set up ____ Quality Specifications / Inspection ____ Prepave meetings / Communication between Project Staff and Contractors ____ Mix Type (______ NMAS) ____ Pavement Thickness (______ times the NMAS) ____ Traffic Control ____ Segregation Control

Question 7:

Please Briefly explain how you train and reinforce joint construction practices within your firm or on your project? Please add any additional comments you would like to add to the above boxes, and reference which question you are referring to.
____ ____ ____ ____

Question 8 (LAST QUESTION!):

<table>
<tr><td colspan="2">Is there an HMA project in Wisconsin, that you would like to point out to this research team, which is exhibiting an exceptionally GOOD performing Longitudinal Joint and/or a BAD performing Longitudinal Joint?</td></tr>
<tr><td><u>GOOD Performing:</u>

Project Name:____________________________

Project Location:__________________________

Year Constructed: _________________________

Joint Method (if known):___________________</td><td><u>BAD Performing:</u>

Project Name:____________________________

Project Location:__________________________

Year Constructed: _________________________

Joint Method (if known):___________________</td></tr>
<tr><td colspan="2">Please list below any additional pertinent information (if any) regarding these pavements, or (if you are so inclined) list more GOOD/BAD pavements you would like to highlight.</td></tr>
<tr><td colspan="2">____
____
____
____
____
____
____
____
____
____
____
____</td></tr>
</table>

Please email or mail this Survey back to the following address:

Signe Reichelt
Behnke Materials Engineering
3621 E Hart Road
Beloit, WI 53149
smreichelt@behnkematerialsengineering.com

Thank you for your help!

Appendix C – Longitudinal Joint Study Work Plan

Wisconsin Highway Research Program (0092-15-09)

Work Plan: Field Density Validation

Below is a Work Plan outlining the project matrix and anticipated testing for each project visit.

PROJECT PARAMETERS:

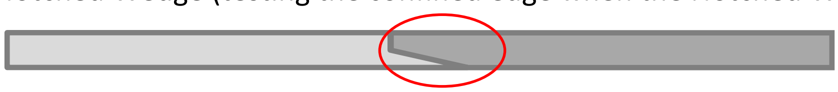
- E-10 or E-30 12.5mm mix
- No warm mix / compaction additives
- Minimum of 3600' test section (for each specified joint method – see below)
- Flexible traffic control to allow for testing

JOINT METHOD:

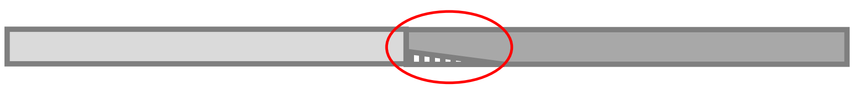
The following are the Joint Methods we would like to study. If possible we would like to combine as many of the Joint Methods in one visit.

1. Notched Wedge (testing the unconfined edge)

2. Notched Wedge (testing the confined edge when the Notched Wedge was left in place)

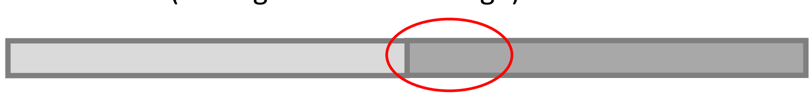


3. Notched Wedge (testing the confined edge when the Notched Wedge was milled out)



4. Vertical Joint (testing the unconfined edge)

5. Vertical Joint (testing the confined edge)



The original Work Plan estimated 6 site visits which have been distributed between 1 Thin Lift Overlay job, and 5 Longitudinal Joint jobs. If we are able to test more than one Joint Method (i.e. testing the confined and unconfined in the same visit), we will be able to add more projects. In that case, we will continue the list as follows:

6. Safety Edge Longitudinal Joint (testing the unconfined edge)
7. Safety Edge Longitudinal Joint (testing the confined edge)

TEST SECTIONS:

For each Joint Method (1 – 5 above) the following test section will be set up:

Standard Rolling Pattern						Best Practices Rolling Pattern					
X^J	X^J C	X^J P	X^J C	X^J C	X^J	X^J	X^J C	X^J P	X^J C	X^J C	X^J
X^M	X^M	X^M	X^M C	X^M H	X^M	X^M	X^M	X^M	X^M C	X^M H	X^M
X^M	X^M	X^M	X^M C	X^M H	X^M	X^M	X^M	X^M	X^M C	X^M H	X^M

X^J – Joint Nuclear Density (Parallel & Perpendicular)
X^M – Mainline Density, taken randomly across the mainline
C – Joint Core to Validate Density Readings
H – Mainline Core for Hamburg
P – Permeability Tests

Example Lot set up:

Standard Rolling Pattern						Best Practices Rolling Pattern					
Lot 1S	Lot 2S	Lot 3S	Lot 4S	Lot 5S	Lot 6S	Lot 1BP	Lot 2BP	Lot 3BP	Lot 4BP	Lot 5BP	Lot 6BP

0+00 3+00 6+00 9+00 12+00 15+00 18+00 21+00 24+00 27+00 30+00 33+00 36+00

Testing Totals:

Nuclear Density Lots: 12 Lots (6 in each section)
NCAT Permeameter: 2 tests (one in each section)
Cores: 10 Cores for Density Validation (5 in each section)
Cores for Hamburg: 4 cores to equal 2 Hamburg Tests (one in each section)

Best Practices – Rolling Pattern:

Confined Edge:

1st Pass – Stay on the hot side, 6" – 12" away from the cold joint
2nd Pass – Move 6" -12" onto the cold side of the mat
Paver – leave a lip of material of 0.5" – 1"
No Luting

Unconfined Edge:

1st Pass – Extend the roller 6" - 12" out over the edge of the mat (hanging off the edge)
2nd Pass – Roll right on the confined edge

Best Practices are modified from the Best Practices for Constructing and Specifying HMA Longitudinal Joints – A Co-operative Effort between the Asphalt Institute and the Federal Highway Administration Final Report dated July 1, 2012.

APPENDIX D – THIN LIFT STUDY WORK PLAN

Wisconsin Highway Research Program (0092-15-09)

Work Plan: Field Density Validation – Thin Lift Overlay

Below is a Work Plan outlining the project matrix and anticipated testing for each project visit.

PROJECT PARAMETERS:

- Thin Lift Overlay
- Minimum of 3600' test section (for each specified joint method – see below)
- Flexible traffic control to allow for testing

TEST SECTIONS:

The following test section will be set up:

Standard Rolling Pattern						Best Practices Rolling Pattern					
X X C X	X X C X	X X C X	X X H P X	X X C X	X X C X	X X C X	X X C X	X X C X	X X H P X	X X C X	X X C X

X –Density, taken randomly across the mainline (test with Standard CPN nuclear density gauge & a Thin Lift Nuclear density gauge)

C – Core to Validate Density Readings

H – Mainline Core for Hamburg

P – Permeability Tests

Example Lot set up:

Standard Rolling Pattern						Best Practices Rolling Pattern					
Lot 1S	Lot 2S	Lot 3S	Lot 4S	Lot 5S	Lot 6S	Lot 1BP	Lot 2BP	Lot 3BP	Lot 4BP	Lot 5BP	Lot 6BP

0+00 3+00 6+00 9+00 12+00 15+00 18+00 21+00 24+00 27+00 30+00 33+00 36+00

Testing Totals:

Nuclear Density Lots: 12 Lots (6 in each section)

NCAT Permeameter: 2 tests (one in each section)

Cores: 10 Cores for Density Validation (5 in each section)

Cores for Hamburg: 4 cores to equal 2 Hamburg Tests (one in each section)

Best Practices – Rolling Pattern:

Use the Thin Lift Nuclear Density gauge to set up a rolling pattern that will result in a passing density, per WisDOT 460 specification. Only allow a Steel Wheel (no vibe) and a Rubber Tire (if available) roller.

Best Practices are loosely based on the National Cooperative Highway Research Program (NCHRP) Synthesis 464 – Thin Asphalt Concrete Overlays, A Synthesis of Highway Practice.

APPENDIX E – IDOT DISTRICT 4 NOTCH WEDGE / MILL SPEC

CONSTRUCTION SEQUENCE FOR MILLING AND PAVING (3P)

The following is the sequence for milling and paving:

1. Mill both lanes for the entire project.
2. Place leveling binder on both lanes of the entire project.
3. Place the Hot-Mix Asphalt (HMA) Prime Coat and Surface Course 6" wider than the centerline when paving the first lane.
4. After surfacing the first lane and prior to priming and start of surfacing on the adjacent lane, mill the 6" of the unconfined surface to the centerline. The milling equipment must be capable of producing a straight line. The depth of the milling must be controlled so as not to gouge the underlying leveling binder lift. The intent is to create a vertical face at the centerline and provide a lateral confinement for the adjacent lane surface course. Skid-steer mounted mills will not be allowed.
5. Clean and prepare the surface of the remaining lane as per Article 406.05 of the Standard Specification prior to the placement of the HMA Surface. The HMA Prime Coat shall be sprayed the full width of the lane and also lapped onto the adjacent lane a distance not to exceed 4". This additional width is to ensure the vertical face of the adjacent mat is adequately covered with prime coat.
6. Placement of this HMA Surface shall require the use of a joint-matching device in lieu of a longitudinal averaging ski. The compacted height of this lane shall be exactly flush, or not more than 1/32" higher, to the adjacent lane to ensure the joint has sufficient material for adequate compaction. During placement, the side plate of the screed shall not exceed ½" overlap onto the adjacent lane.

The milling of the 6" extra width at the centerline will be paid for at the contract unit price per Square Yard for HOT-MIX ASPHALT SURFACE REMOVAL – SPECIAL. The extra HMA prime coat will be paid for at the contract unit price per Ton for POLYMERIZED BITUMINOUS MATERIAL (PRIME COAT). The extra HMA surface course will be paid for at the contract unit price per Ton for HOT-MIX ASPHALT SURFACE COURSE, MIX _, N__. All other extra work will not be paid for separately, but shall be included in the unit bid price of the various pay items and no other compensation will be allowed.

Centerline Joint Investigation

(Surface Only)

Contract	Contractor	Location	Offset	Hot Side Mat Core	Hot Side Joint	Centerline Joint	Cold Side Joint	Closest Cold Side Mat Core	Location	Offset	All Longitudinal Joint Cores
		21+77	4.3	91.4	92.9		93.7	95.4	23+08	0.9	
68981		72+85	3.6	94.1	93.0		91.8	94.3	68+48	1.3	
IL 91 Toulon	AAC	102+16	6.2	93.3	93.3		92.1	95.2	106+66	6.9	
PFP		236+66	4.8	95.5	95.3		92.5	94.7	235+64	3.3	
		260+46	4.5	95.1	95.0		93.1	91.4	259+24	6.6	
		274+02	9.1	95.0	93.7		93.9	95.2	269+19	5.7	
		Averages		94.1	93.9		92.9	94.4			93.1
68B24		60+80	3.6	93.7	92.4	92.8	93.0	95.0	64+67	11.4	
IL 116 Benson	AAC	118+23	2.7	96.1	93.2	91.4	94.3	94.8	111+99	3.5	
QCP		208+23	7.5	94.9	93.4	91.5	91.3	90.9	210+03	5.1	
		261+41	0.6	94.2	92.8	90.5	90.1	92.7	261+86	3.1	
		Averages		94.7	93.0	91.6	92.2	93.4			N/A
		816+10	1.1	94.5	94.3	92.3	92.3	94.3	810+90	2.7	
		824+52	5.5	93.0	92.3		94.3	94.5	824+91	1.2	
		841+51	5.2	95.6	92.6		93.2	94.2	837+84	6.3	
68A78		893+88	6.3	93.5	92.0		92.3	92.7	894+55	2.6	
IL 116 Farmington	UCM	1033+63	7.4	94.3		93.8		93.8	1031+06	9.9	
PFP		1040+51	5.4	95.0	94.1		94.2	95.4	1036+59	6.9	
		1066+28	9.8	94.5		91.8		95.4	1065+63	3.0	
		1083+57	5.2	93.8	95.9		94.5	95.3	1083+25	3.2	
		1096+95	3.0	93.7	92.0		93.0	93.3	1095+93	10.3	
		1113+87	7.8	93.9	91.5		94.8	95.5	1107+42	8.7	
		Averages		94.2	93.1	92.6	93.6	94.4			91.8
	Overall Averages			94.3	93.3	92.0	93.0	94.2			

All 3 Projects were places on 4.75 LB and were an N50 Recycled Surface. The surface on the first lane paves was placed 4" wider than the proposed width. This 4" milled off prior to placing the adjacent lane.

Centerline Joint Investigation

(Surface Only)

Contract	Contractor	Location	Offset	Hot Side Mat Core	Hot Side Joint	Centerline Joint	Cold Side Joint	Closest Cold Side Mat Core	Location	Offset	All Longitudinal Joint Cores
		21+77	4.3	91.4	92.9		93.7	95.4	23+08	0.9	
68981		72+85	3.6	94.1	93.0		91.8	94.3	68+48	1.3	
IL 91 Toulon	AAC	102+16	6.2	93.3	93.3		92.1	95.2	106+66	6.9	
PFP		236+66	4.8	95.5	95.3		92.5	94.7	235+64	3.3	
		260+46	4.5	95.1	95.0		93.1	91.4	259+24	6.6	
		274+02	9.1	95.0	93.7		93.9	95.2	269+19	5.7	
		Averages		94.1	93.9		92.9	94.4			93.1
68B24		60+80	3.6	93.7	92.4	92.8	93.0	95.0	64+67	11.4	
IL 116 Benson	AAC	118+23	2.7	96.1	93.2	91.4	94.3	94.8	111+99	3.5	
QCP		208+23	7.5	94.9	93.4	91.5	91.3	90.9	210+03	5.1	
		261+41	0.6	94.2	92.8	90.5	90.1	92.7	261+86	3.1	
		Averages		94.7	93.0	91.6	92.2	93.4			N/A
		816+10	1.1	94.5	94.3	92.3	92.3	94.3	810+90	2.7	
		824+52	5.5	93.0	92.3		94.3	94.5	824+91	1.2	
		841+51	5.2	95.6	92.6		93.2	94.2	837+84	6.3	
68A78		893+88	6.3	93.5	92.0		92.3	92.7	894+55	2.6	
IL 116 Farmington	UCM	1033+63	7.4	94.3		93.8		93.8	1031+06	9.9	
PFP		1040+51	5.4	95.0	94.1		94.2	95.4	1036+59	6.9	
		1066+28	9.8	94.5		91.8		95.4	1065+63	3.0	
		1083+57	5.2	93.8	95.9		94.5	95.3	1083+25	3.2	
		1096+95	3.0	93.7	92.0		93.0	93.3	1095+93	10.3	
		1113+87	7.8	93.9	91.5		94.8	95.5	1107+42	8.7	
		Averages		94.2	93.1	92.6	93.6	94.4			91.8
		Overall Averages		94.3	93.3	92.0	93.0	94.2			

All 3 Projects were places on 4.75 LB and were an N50 Recycled Surface. The surface on the first lane paves was placed 4" wider than the proposed width. This 4" milled off prior to placing the adjacent lane.

APPENDIX G – IDOT JOINT SEALANT SPECIFICATION

HOT-MIX ASPHALT – LONGITUDINAL JOINT SEALANT

Effective: March 1, 2016
Revised: March 2, 2016

Add the following to Article 406.02 of the Standard Specifications.

"(d) Longitudinal Joint Sealant (LJS) (Note 2.)

Note 2. The bituminous material used for the LJS shall be according to the following table. Elastomers shall be added to a base asphalt and shall be either a styrene-butadiene diblock or triblock copolymer without oil extension, or a styrene-butadiene rubber. Air blown asphalt, acid modification, or other modifiers will not be allowed. LJS in the form of pre-formed rollout banding may also be used.

Test	Test Requirement	Test Method
Dynamic shear @ 82°C (unaged), G*/sin δ, kPa	1.00 min.	AASHTO T 315
Creep stiffness @ -18°C (unaged), Stiffness (S), MPa m-value	300 max. 0.300 min.	AASHTO T 313
Ash, %	6.0 max.	AASHTO T 111
Elastic Recovery, 100 mm elongation, cut immediately, 25°C, %	58 min.	ASTM D 6084 (Procedure A)
Separation of Polymer, Difference in °C of the softening point (ring and ball)	3 max.	ITP Separation of Polymer from Asphalt Binder"

Add the following to Article 406.03 of the Standard Specifications.

"(j) Longitudinal Joint Sealant (LJS) Pressure Distributor (Note 2.)
(k) Longitudinal Joint Sealant (LJS) Melter Kettle (Note 3.)

Note 2. When a pressure distributor is used to apply the LJS, the distributor shall be equipped with a heating and recirculating system along with a functioning auger agitating system or vertical shaft mixer in the hauling tank to prevent localized overheating.

Note 3. When a melter kettle is used to transport and apply the LJS longitudinal joint sealant, the melter kettle shall be an oil jacketed double-boiler with agitating and recirculating systems. Material from the kettle may be dispensed through a pressure feed wand with an applicator shoe or through a pressure feed wand into a hand-operated thermal push cart."

Revise Article 406.06(g)(2) of the Standard Specifications to read:

"(2) Longitudinal Joints. Unless prohibited by stage construction, any HMA lift shall be complete before construction of the subsequent lift. The longitudinal joint in all lifts shall be at the centerline of the pavement if the roadway comprises two lanes in width, or at lane width if the roadway is more than two lanes in width.

When stage construction prohibits the total completion of a particular lift, the longitudinal joint in one lift shall be offset from the longitudinal joint in the preceding lift by not less than 3 in. (75 mm). The longitudinal joint in the surface course shall be at the centerline of the pavement if the roadway comprises two lanes in width, or at lane width if the roadway is more than two lanes in width.

A notched wedge longitudinal joint shall be used between successive passes of HMA binder course that has a difference in elevation of greater than 2 in. (50 mm) between lanes on pavement that is open to traffic.

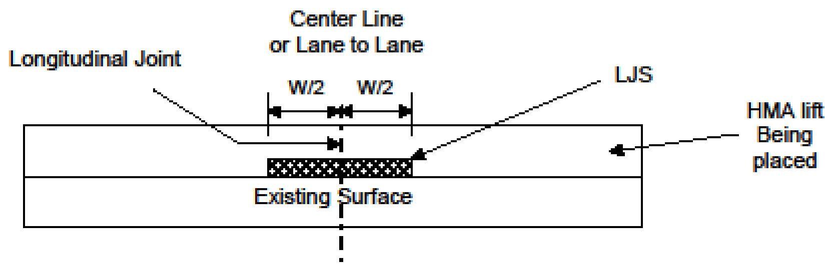
The notched wedge longitudinal joint shall consist of a 1 to 1 1/2 in. (25 to 38 mm) vertical notch at the lane line, a 9 to 12 in. (230 to 300 mm) wide uniform taper sloped toward and extending into the open lane, and a second 1 to 1 1/2 in. (25 to 38 mm) vertical notch at the outside edge.

The notched wedge longitudinal joint shall be formed by the strike off device on the paver. The wedge shall then be compacted by the joint roller.

When using a notched wedge joint, the bituminous material specified for the mainline tack coat shall be applied to the entire face of the longitudinal joint immediately prior to placing the adjacent lift of binder. The material shall be uniformly applied at a rate of 0.05 to 0.1 gal/sq yd (0.2 to 0.5 L/sq m).

When the use of longitudinal joint sealant (LJS) is specified, it shall be applied for all lifts of paving excluding lifts of IL-4.75 mm mixtures. The surface to which the LJS is applied shall be dry and cleaned of all dust, debris, and any substances that will prevent the LJS from adhering. Cleaning shall be accomplished by means of a sweeper/vacuum truck, power broom, air compressor or by hand. The LJS may be placed before or after the tack or prime coat. When placed after the tack or prime coat, the tack or prime shall be fully cured prior to placement of the LJS.

The LJS application shall be centered under the joint of the HMA lift being constructed within 2 in. (50 mm) of the joint.



The width and minimum application rate shall be according to the following table:

LJS Application Rate Table		
Overlay Thickness in. (mm)	LJS Width "W" in. (mm)	Application Rate [1/] lb/ft (kg/m)
HMA Mixtures [2/]		
3/4 (19)	18 (450)	0.88 (1.31)
1 (25)	18 (450)	1.15 (1.71)
1 1/4 (32)	18 (450)	1.31 (1.95)
1 1/2 (38)	18 (450)	1.47 (2.19)
1 3/4 (44)	18 (450)	1.63 (2.43)
2 (50)	18 (450)	1.80 (2.68)
2 1/4 (60)	18 (450)	1.96 (2.92)
2 1/2 (63)	18 (450)	2.12 (3.16)
2 3/4 (70)	18 (450)	2.29 (3.41)
3 (75)	18 (450)	2.45 (3.65)
3 1/4 (83)	18 (450)	2.61 (3.89)
3 1/2 (90)	18 (450)	2.78 (4.14)
3 3/4 (95)	18 (450)	2.94 (4.38)
4 (100)	18 (450)	3.10 (4.62)
SMA Mixtures [2/]		
1 1/2 (38)	12 (300)	0.83 (1.24)
1 3/4 (44)	12 (300)	0.92 (1.37)
2 (50)	12 (300)	1.00 (1.49)

1/ The application rate has a surface demand for liquid included within it. The nominal thickness of the LJS may taper from the center of the application to a lesser thickness on the edge of the application. The width and weight/foot (mass/meter) shall be maintained.

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

The Contractor shall furnish to the Engineer a bill of lading for each tanker supplying material to the project. The application rate of LJS will be verified within the first 1000 ft (300 m) of the day's scheduled application length and every 6000 ft (1800 m) the remainder of the day. For projects less than 3000 ft (900 m), the rate will be verified once. A suitable paper or pan shall be placed at a random location in the path of the placement for the LJS. After application of the LJS, the paper or pan shall be picked up and weighed. The weight per foot will be calculated. The tolerance from the plan target weight/foot (mass/meter) from the LJS Application Rate Table shall be ± 15 percent. The Contractor shall replace the LJS in the area where the sample was taken.

The LJS shall be applied in a single pass with a pressure distributor, melter kettle, or hand applied from a roll. At the time of installation the pavement surface temperature and the ambient temperature shall be a minimum of 40 °F (4 °C) and rising.

When starting another run of LJS placement, suitable release paper shall be placed over the previous application of LJS to prevent doubling up of thickness of LJS.

The LJS shall be suitable for construction traffic to drive on without pickup or tracking of the LJS within 30 minutes of placement. If pickup or tracking occurs, LJS placement shall stop and damaged areas shall be repaired.

Prior to start of paving of pavement course, ensure the paver end plate and grade control device is adequately raised above the finished height of the LJS.

If the LJS flushes to the surface of the HMA lift being placed, the excess LJS shall be removed."

Add the following paragraph after the second paragraph of Article 406.13(b) of the Standard Specifications.

"Bituminous material for longitudinal joint sealant will be measured for payment in place in feet (meters)."

Add the following paragraph after the first paragraph of Article 406.14 of the Standard Specifications.

"Longitudinal joint sealant will be paid for at the contract unit price per foot (meter) for LONGITUDINAL JOINT SEALANT."

When the LJS is specified, the longitudinal joint density testing for QC/QA, QCP, or PFP will not be required on the joint(s) with the LJS and the pay adjustments will not be applied.