

NDOT Research Report

Report No: RDT04-043

DEVELOPMENT OF A JOINT DENSITY SPECIFICATION PHASE I: LITERATURE REVIEW AND TEST PLAN

February 2004

Prepared by Research Division
Nevada Department of Transportation
1263 South Stewart Street
Carson City, Nevada 89712



This work was sponsored by the Nevada Department of Transportation. The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of Nevada at the time of publication. This report does not constitute a standard, specification, or regulation.

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. 04-043		2. Government Accession No.	3. Recipient's Catalog No.
4. Report Title DEVELOPMENT OF A JOINT DENSITY SPECIFICATION PHASE I: LITERATURE REVIEW AND TEST PLAN		5. Report Date January 24, 2004	
		6. Performing Organization Code	
7. Author(s) Peter E. Sebaaly and Juan Carlos Barrantes		8. Performing Organization Report No. 13DL-1	
9. Performing Organization Name and Address Western Regional Superpave Center Department of Civil Engineering/258 University of Nevada, Reno Reno, Nevada 89557		10. Work Unit No.	
		11. Contract or Grant No.	
12. Sponsoring Agency Name and Address Nevada Department of Transportation 1263 S. Stewart Street Carson City, NV 89712		13. Type of Report and Period Covered Interim	
		14. Sponsoring Agency Code	
15. Supplementary Notes			
16. Abstract The objective of this research study is to develop a specification for longitudinal joints on hot-mixed asphalt (HMA) pavements. The study consisted of two phases: phase 1 reviewed all current specification for longitudinal joints and Phase 2 conducts a field-testing program to identify the most effective technique under Nevada's conditions. This report summarizes the findings and recommendations of Phase I. A literature review was conducted to identify all current specifications for longitudinal joint density and to summarize all previous research efforts on the subject of longitudinal joint density. The review identified a total of ten state highway agencies and the Federal Aviation Administration (FAA) having specifications for density at the longitudinal joint. Few agencies also have specifications for the geometry of the joint. Three agencies currently implement incentives/disincentives programs based on the density of the longitudinal joint. A total of four independent research studies have been conducted to assess the various joint geometry and compaction techniques. The research studies highlighted the need for having joint density specification but they did not recommend an optimal method for joint construction. The second part of the report presents an interim joint density specification to be implemented in Nevada and a field-testing program to identify the optimal method for joint construction under Nevada's conditions.			
17. Key Words Longitudinal Joint, Joint Density, Joint Specification, Joint Compaction, Joint Geometry.		18. Distribution Statement Unrestricted. This document is available through the National Technical Information Service, Springfield, VA 21161	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. Of Pages 35	22. Price

TABLE OF CONTENT

Section	Page
Introduction	1
Review of Existing Specifications	2
DOTs Longitudinal Joint Specifications	2
Nevada DOT Longitudinal Joint Specification	5
Washoe-RTC Longitudinal Joint Specification	6
Review of Previous Research Efforts	8
National Center for Asphalt Technology (NCAT)	8
Quality Engineering Solutions	12
Texas Transportation Institute	14
New Jersey Department of Transportation	15
Summary and Findings	18
Recommendations	19
Interim Specification	19
Field-Testing Program	20

I. INTRODUCTION

Hot mixed asphalt (HMA) pavements are normally constructed with multiple passes of the paver. Typically, one lane is laid-down with each pass. Consequently, a longitudinal construction joint is formed between the constructed lanes. The density of the HMA mix at the longitudinal joint depends on the geometry of the joint and the compaction technique.

The density of the HMA mix at the longitudinal joint is usually lower than the density of the HMA mix throughout the regular mat away from the joint. This low in-place density translates into higher air-voids around the longitudinal joint leading to the penetration of moisture into the HMA mix. As the HMA pavement is subjected to environmental effects and traffic loads, the moisture-saturated mix at the joint becomes an easy target for moisture-related damages such as stripping and raveling.

Further damage of the joint allows moisture to penetrate to the base and subbase layers leading to great reduction in the strength properties of these layers. As a result of this water intrusion, the entire pavement structure weakens and failures occur under the action of repeated traffic loads and environmental factors.

One way to avoid such failures is to construct a dense longitudinal joint that would prevent the intrusion of water. Several joint geometry and compaction techniques have been recommended to optimize the density and performance of the longitudinal joint. A successful joint construction technique would provide a joint with high density and strong bond between the two paved lanes. The high-density requirement can be checked during the construction process while the strong bond requirement requires long-term performance monitoring of the pavement.

Several research studies have been conducted to assess the various geometries and compaction techniques of longitudinal joints in HMA pavements. In 2003, The Nevada Department of Transportation (NDOT) initiated a two-phase research project: a) Phase 1: to evaluate the current joint geometries and compaction techniques and to assess if the current state of knowledge is adequate to develop and implement a longitudinal joint density specification and b) Phase 2: If the current state of knowledge proved inadequate, then a field-testing program would be carried out to establish the needed knowledge base for the development and implementation of a longitudinal joint specification. This report summarizes the findings and recommendations of the first phase of the research.

II. REVIEW OF EXISTING SPECIFICATIONS

The first task of this research was to review the current specifications on the construction and density requirements for longitudinal joint of Hot Mix Asphalt (HMA) pavements. The specifications from all fifty Departments of Transportation (DOT), the local Regional Transportation Commissions, and the Federal Aviation Administration (FAA) were reviewed. The review covered the following issues:

- Joint density specifications
- Joint geometry recommendations
- Joint rolling patterns
- Joint density measurement techniques
- Joint density incentives and disincentives

II.1 DOTs Longitudinal Joint Specifications

The review process started with obtaining the specifications for HMA construction from the various agencies. The agencies specifications for mat density, joint density and joint construction techniques are summarized in Appendix A. The agencies that have joint density specifications and joint construction recommendations are presented below.

Alaska

- The density at the longitudinal joint should be a minimum of 91% of the theoretical maximum density (TMD).
- The longitudinal joint density is measured from 3 cores/5000 tons of mix.

Arizona

- The density at the longitudinal joint should be a minimum of 98% of the lab density.
- The longitudinal joint has to be tapered at 4:1 – 6:1 or hot-lapped.
- The slope has to be compacted with a pneumatic roller.
- The joint needs to be pinched during compaction, by overlapping the roller between the hot mat and the cold mat.

California

- The density at the longitudinal joint should be a minimum of 93% of the relative compaction.
- Tapered-notched joint: a ¾” top and bottom notch and a 12” taper.
- Density measurements are obtained from two cores taken every 3500 feet and nuclear measurements every 650 feet (quality control).
- Disincentives are applied for joints with densities less than 93%. The disincentive is determined by the relative compaction of the longitudinal joint section that failed the 93% relative compaction as shown in Table 1.

Table 1 California’s Disincentives Factors for the Longitudinal Joint Density.

Relative Compaction (Percent)	Disincentive Factor	Relative Compaction (Percent)	Disincentive Factor
93.0	0.000	91.4	0.062
92.9	0.002	91.3	0.068
92.8	0.004	91.2	0.075
92.7	0.006	91.1	0.082
92.6	0.009	91.0	0.090
92.5	0.012	90.9	0.098
92.4	0.015	90.8	0.108
92.3	0.018	90.7	0.118
92.2	0.022	90.6	0.129
92.1	0.026	90.5	0.142
92.0	0.030	90.4	0.157
91.9	0.034	90.3	0.175
91.8	0.039	90.2	0.196
91.7	0.044	90.1	0.225
91.6	0.050	90.0	0.300
91.5	0.056		

- If the relative compaction of day’s production is less than 90 percent, placement of the tapered notched wedge shall be suspended until the contractor demonstrates that the required relative compaction is once again accomplished.

Colorado

- The target density at the longitudinal joint should be 92% of the TMD, with a tolerance of $\pm 4\%$.
- If the mat is thinner than 1.5” a vertical joint is recommended.
- For mats thicker than 1.5”, a joint with 1.5” vertical notch followed by a 3:1 taper should be used.
- Density measurements are obtained from one 6” core for every 5000-foot pavement section. The core is obtained over the center of the longitudinal joint.

Connecticut

- For mats thicker than 1.5” the joint density should be between 90 – 97% of TMD.
- The longitudinal joint should be compacted from the cold side with 1-2” overlap and gradually shifting toward the hot side.
- Disincentives are applied as shown in Table 2.

Table 2 Connecticut’s Percent Payment based on the Longitudinal Joint Density.

Average Density (%TMD)	Percent Payment
100 – 98	97.5
97 – 90	100.0
89 – 87	97.5
86 – 84	90.0
82 or less	70.0

Idaho

- Currently, there is no density specification for longitudinal joint but measurements are being performed to ensure integrity.
- Tapered joints: 18” wide for 2.5” mat or less,
 24” wide for mat thicker than 2.5”
 24” wide for all overlays
- Density readings are collected with a nuclear gauge.

Kentucky

- The density at the longitudinal joint should be 89% - 96% of TMD.
- The specification calls for two cores at the longitudinal joint, for every 1000 tons of mix placed.
- The cores should be cut within 2.5 - 3.5” from the joint.
- Incentives and Disincentives are applied as summarized in Table 3.

Table 3 Kentucky’s Percent Payment based on the Longitudinal Joint Density.

Average Percent Density	Percent Payment
<87.0	0.75
87.0 – 87.9	0.90
88.0 – 88.9	0.95
91.0 – 96.0	1.05
89.0 – 90.9	1.00
96.1 - 96.5	0.95
96.6 – 97.0	0.90
> 97.0	0.75

Missouri

- The density at the longitudinal joint should be a minimum of 94% of Marshall density.
- Joint density is measured by nuclear gauge placed within 6” of the joint.
- Vertical face joint is specified.

Pennsylvania

- The density at the longitudinal joint should be a minimum of 90% of TMD for tapered joints.
- The longitudinal joint has to be compacted from the hot side with 1-2 inches overlap.
- Cores are used to measure the longitudinal joint density.
- A minimum of three cores per subplot or three cores per day is required. A lot is defined as the daily production of placed mix, and it is divided into three equal sublots.

Texas

- The density at the longitudinal joint should be within 48 kg/m³ of the mat density

- Nuclear gauge reading within 8” of the longitudinal joint are compared with measurement at 24” from the joint (mat readings).

Washington

- The density at the longitudinal joint should be a minimum of 91% of TMD for hot-lapped joints.

Federal Aviation Administration

- The density at the longitudinal joint should be a minimum of 92.4% of TMD
- Joint density is measured on four cores (4” or 6”) / 2000 tons of placed mix.
- Incentives and disincentives are applied as shown in Table 4.

Table 4 Federal Aviation Administration’s Percent Payment based on the Longitudinal Joint Density.

Average Percent Density	Percent Payment
Above 92.5	100
92.4	100
92.3	99.9
92.2	99.8
92.1	99.6
92.0	99.4
91.9	99.1
91.8	98.7
91.7	98.3
91.6	97.8
91.5	97.3
91.4	96.3
91.3	94.1
91.2	92.2
91.1	90.3
91.0	87.9
90.9	85.7
90.8	83.3
90.7	80.6
90.6	78.0
90.5	75.0
Below 90.5	0.0 (reject)

II.2 Nevada DOT Longitudinal Joint Specification

The current NDOT longitudinal joint density requirements are stated in Test Method: Nev. T335F and the Memorandum dated April 14, 2003. The specifications call for the following controls and measurements:

- Test Segments: 6,000 yd² for the first two days of construction and 13,000 yd² after two days of construction.
- Density measurement location: the test segment is divided into 5 subsections, and density measurements are performed at random locations within each subsection for the mat and the hot side joint (confined edge).
- Density measurement method: Nuclear gauge placed parallel to the joint and then rotated 180 degrees. The average of both readings is reported as the density of the subsection.
- Density requirements: minimum 90% of TMD (90-97% for the mat).

The NDOT longitudinal joint specification has been implemented on several projects. Table 5 summarizes the measured joint densities as they compare to the mat density on five recent NDOT projects.

Table 5 Summary of Joint and Mat Densities on NDOT Projects.

Project	Joint Density (%TMD)			Avg. Mat Density (%TMD)
	Min.	Avg.	Max.	
3140	86.6	90.3	93.4	93.2
3143	90.7	93.1	96.9	92.5
3084	80.0	89.8	93.3	93.4
3043	85.4	91.8	95.9	93.2
3127	89.5	92.1	96.2	93.2

The NDOT data showed that joint density ranges from as low as 85 percent to as high as 96 percent of TMD. In addition, on the average, joint density is within 2-3 percent of the mat density. Therefore, it can be seen that obtaining a high joint density is achievable.

II.3 Washoe-RTC Longitudinal Joint Specification

In 2002, the Washoe-RTC started implementing a shadow specification for joint density. The following is a summary of RTC's longitudinal joint density specification.

- Test Segment: 1,000 foot length.
- Density measurement: conduct nuclear density measurement every 200 feet on both sides of the joint. Identify the side with the lowest mean joint density (either hot or cold sides). Cut one core (4" or 6") at a location coinciding with the nuclear gauge measurement from the side with the lower means joint density. The center of the core should be 6" from the joint.
- Table 6 summarizes the incentives and disincentives currently used by Washoe-RTC and Table 7 summarizes the joint densities measured on RTC's projects while implementing the shadow specification.

Table 6 Incentives and Disincentives Applied to RTC Projects Based on the Longitudinal Joint Density.

Joint core results In-place air voids (%)	Incentives or disincentive factor
< 3	0 %
3 – 8	+5 %
8 – 11	0 %
11 – 14	-5 %
> 14	-50 %

Table 7 Summary of Joint and Mat Densities on RTC Projects.

Project	Cores Joint Density (%TMD)			Avg. Mat Density (%TMD)
	Min.	Avg.	Max.	
Longley Lane	88	91	94	
Baker/Coleman	87	90	93	93
Evans/Ninth	92	93	95	94
E. Prater/Howard	89	91	93	
Vista II	90	91	93	93
7 th Street	92	92	93	
Red Rock	89	91	93	
S.W. McCarran	88	91	95	

The data in Table 7 indicates that the average joint density on the majority of the projects fall within the range of 0% incentive. The minimum and maximum joint density data indicate that a large variability is encountered on most projects with percent air voids ranging from 5 to 13 percent.

III. REVIEW OF PREVIOUS RESEARCH EFFORTS

This effort reviewed the previous research studies that have been conducted to evaluate the effectiveness of the various joint geometries and compaction techniques. Most studies evaluated the impact of the various techniques on the joint density and its performance. A total of four studies were reviewed and are summarized below.

III.1 National Center for Asphalt Technology (NCAT)

In 1992, NCAT started a series of research projects for the National Asphalt Pavement Association (NAPA) to assess the most effective method to construct longitudinal joints on HMA pavements (1,2,3,4). The objectives of the studies were to compare various joint geometries and compaction techniques, and recommend the techniques that would improve long-term performance of longitudinal joints.

Field projects were constructed and evaluated in Pennsylvania, Michigan, Wisconsin, and Colorado. The data obtained from the Michigan project were unclear. For most of Michigan's sections, the density at the longitudinal joint is higher than the density of the mat, indicating that additional compaction occurred at the joint. Such pattern is not representative of a normal construction process. For this reason, the results from the Michigan project were not included in this review.

Wisconsin Project

The project in Wisconsin was constructed in October 1992 on State Route 190 (Capitol Drive) in Brookfield. Eight longitudinal joint construction techniques were evaluated. Each test section was 500 feet long. Longitudinal joint density was evaluated through cores and nuclear readings. For each section, 6 inches diameter core samples were obtained at five different locations, about 100 feet apart. Two cores were obtained at each location; one right at the joint and the other at about 2 feet away from the joint in the hot lane. No cores were obtained from the cold lane. The nuclear readings were used to supplement the limited core data. For each test section, nuclear readings were obtained at 9 locations, about 50 feet apart. At each location, nuclear density was measured at the joint, and 1 foot away from the joint on the cold side.

Colorado Project

The project in Colorado was constructed in July 1994 on Interstate 25 just north of Colorado Springs. The project consisted of a 4 inches thick wearing course. Seven longitudinal joint construction techniques were evaluated. Each test section was 500 feet long. Longitudinal joint density was evaluated from cores. For each section, 6 inches diameter core samples were obtained at six different locations. At each location 3 cores were obtained, one right at the joint and the others at about 1 foot away from the joint on either sides (cold and hot lanes).

Pennsylvania Project

The Pennsylvania project was constructed in September 1995 on State Route 441 (section 004) in Lancaster County. The project consisted of a 1.5 inches wearing course. Eight

longitudinal joint construction techniques were evaluated. Each test section was 500 feet long. Longitudinal joint density was evaluated from cores. The cores were obtained right at the joint and at about 12 inches away from the joint on the cold side. There is no record of the number of locations measured within each test section.

Field Performance

The performance of the different construction techniques was conducted through annual visual evaluations. The evaluating team consisted of at least four engineers. The overall rating considered the length of the joint with cracks, the average width of the crack, and the length and severity of the raveling observed in the mat adjacent to the joint. The observation period for the performance evaluation was not the same for all the projects.

Tables 8 and 9 summarize the compaction techniques and joint geometries that have been evaluated in the NCAT study. Table 10 summarizes the impact of the various techniques on the density and the long-term performance of the longitudinal joint.

Table 8 Description of Rolling Techniques Evaluated in the NCAT Studies.

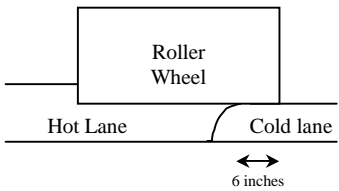
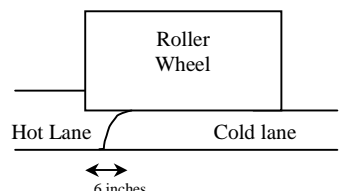
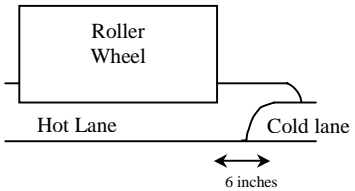
Rolling Technique	Description	Diagram
Rolling from hot side	Compaction is done from the hot side of the lane being constructed. The major portion of the roller is on the hot side, with just an overlap of about 6 inches on the cold lane.	 <p>The diagram shows a rectangular roller wheel positioned over a horizontal line representing the joint between a hot lane (left) and a cold lane (right). The roller wheel overlaps the cold lane by 6 inches, as indicated by a double-headed arrow and the text '6 inches' below the cold lane section.</p>
Rolling from cold side	Rolling is done with the major portion of the roller on the cold lane, with just an overlap of 6 inches on the hot lane. Timing is critical, because while rolling the joint from the cold side, the rest of the mat is cooling down.	 <p>The diagram shows a rectangular roller wheel positioned over a horizontal line representing the joint between a hot lane (left) and a cold lane (right). The roller wheel overlaps the hot lane by 6 inches, as indicated by a double-headed arrow and the text '6 inches' below the hot lane section.</p>
Rolling from hot side at 6 inches away from the joint	Compaction is done from the hot lane, but at a distance of 6 inches away from the joint. A pushing of the material towards the joint is achieved by this rolling procedure. It is recommended for tender mixes or thick lifts.	 <p>The diagram shows a rectangular roller wheel positioned on the hot lane, 6 inches away from the joint. A curved arrow indicates the material being pushed towards the joint. A double-headed arrow and the text '6 inches' below the hot lane section indicate the distance from the roller to the joint.</p>

Table 9 Description of Joint Geometries Evaluated in the NCAT Study.

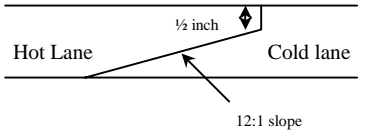
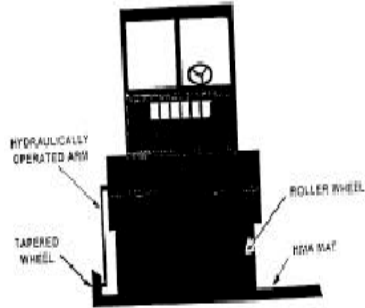
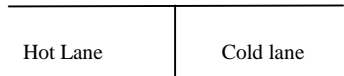

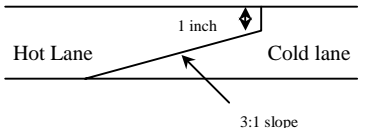
Joint Geometry	Description	Diagram
Tapered (12:1) joint with ½ inch top notch without tack coat (Michigan Wedge)	A taper is formed during the placement of the cold lane, by attaching a steel plate to the paver screed. A ½ inch notch is made at the top of the taper. The roller is kept 2 inches from the joint. The taper is compacted with a small roller attached to the paver. This tapered face is not tack coated.	
Tapered (12:1) joint with ½ inch top notch with tack coat (Michigan Wedge)	Same as the above technique with a tack coat is applied to the tapered face of the cold lane.	
Edge restraining device	This device provides lateral restraint at the edge of the cold lane, during its compaction. It consists of a hydraulically powered wheel which rolls alongside the compactor's drum simultaneously pinching the unconfined edge of the mix towards the drum providing lateral resistance. It is believed that this technique improves the density of the unconfined edge. Final compaction is performed by rolling from the hot side.	
Cut face with tack coat	The edge of the cold lane is cut to a vertical face. The cut face is tack coated before the placement of the adjacent hot lane. Compaction is performed by rolling from the hot side.	
Cut face without tack coat	Same as above, but no tack coat is apply to the vertical face.	
Joint Maker	This technique uses an automated joint construction device attached to the screed. Additional material is forced at the joint and a kicker plate attached to the paver pushes back the overlapped mix. The compaction of the joint is performed from the hot side.	
Tapered (3:1) with vertical 1.0 inch top notch	The tapered slope (3:1) and the 1.0-inch notch are formed during the placement of the cold lane, by attaching a steel plate to the paver screed. Only tack coated taper surface before the placement of the next lane. The compaction of the joint is done from the hot side.	

Table 9 Description of Joint Geometries Evaluated in the NCAT Study (continued).

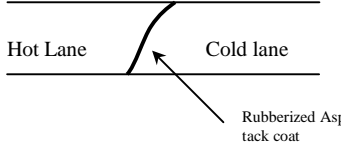
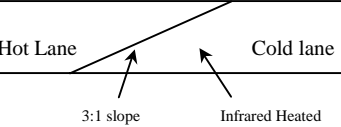
Joint Geometry	Description	Diagram
Rubberized asphalt tack coat	Any taper or special section is formed at the unconfined edge of the cold lane. A rubberized asphalt tack coat (Crafco pavement joint adhesive Part # 34524) is applied to the cold lane edge before placing the next lane. The thickness of tack coat is 1/8 in. Compaction is done from the hot side.	
New Jersey wedge	A 3:1 taper is formed by a sloping steel plate attached to the paver screed extension. During the placement of the hot lane, an infrared heater is used to heat the edge of the cold lane to a surface temperature of 93°C. The adjacent lane is placed with an overlap of 2-3 inches, it is luted back, and the compaction is done from the hot side.	

Table 10 Impact of Various Techniques on the Density and Performance of the Longitudinal Joint.

State	Joint Density		Joint Performance	
	Best	Worst	Best	Worst
Pennsylvania	Edge restraining device	New Jersey wedge 3:1	Rubberized asphalt tack coat	Rolling from the cold side
Wisconsin	Vertical face cut	Wedge Joint without tack coat	Edge restraining device	Rolling from the cold side
Colorado	Tapered 3:1 with vertical 1" offset	Rolling from the hot side	Tapered 3:1 with vertical 1" offset	Rolling from the cold or rolling from the hot side

The NCAT study presented the joint density and performance data generated by each technique (Appendix B), but it did not clearly identify the most effective technique. Their final recommendations were provided in the following general statements:

- The performance of the longitudinal joint appears to be influenced by the overall density achieved at the longitudinal joint.
- The joint density should be within 2% of the mat density.
- Cores should be used to measure joint density. Nuclear gauge is impractical.

III.2 Quality Engineering Solutions

In 2000, Quality Engineering Solutions (QES) conducted a research study for the Regional Transportation Commission (RTC) in Washoe County, Nevada (5). The objective of this research was to investigate the relationship between poor longitudinal compaction and poor joint performance.

A total of 52 longitudinal joints were evaluated on 39 different projects. The projects included new and reconstructed pavements and overlays within the Truckee Meadows. The study conducted a visual distress evaluation for the longitudinal joint and the overall pavement condition, and a nuclear density evaluation of the longitudinal joint and the pavement mat.

Twelve nuclear density measurements were taken for each of the 52 longitudinal joints studied. At each location, density readings were performed on the longitudinal joint and within the pavement mat outside the wheel-path. Two replicates were obtained for each point, and if they differed by more than 2.0 pcf, a third replicate was performed.

The distress identification evaluated the existing distress conditions of the 52 test sections. The typical joint distresses identified include:

- Open surface condition
- Surface raveling with aggregate loss
- Longitudinal joint opening and secondary cracks
- Breakup and missing material of the surface adjacent to the longitudinal joint
- Maximum width of longitudinal joint separation

Also a pavement serviceability rating was obtained while performing the density data collection.

A statistical analysis was performed to identify the differences between the longitudinal joint and the mat densities. A regression data analysis was performed, including joint deterioration value, pavement condition, age, traffic, and pavement density. This regression analysis provided strong evidence of the importance of the relationship between the joint condition and the joint density.

Some elements contributed to the high variability of the density measurements. The lack of knowledge of the exact construction technique used, as well as the impossibility to determine which was the hot or the cold side of the joint, were some of the main elements that affect negatively the data analysis.

Their analysis of the field data provided the following observations:

1. More than 80% of the longitudinal joints studied had joint densities inferior to the mat densities (i.e. less than 100% of mat density).
2. Less than 50% of all longitudinal joints studied had joint density higher than 98% of the mat density.
3. Pavements with low density are more likely to experience early joint distress.

4. Pavements with joint distress show greater variation in the measured densities than that of pavements without joint distress; both at the joint and at the mat.
5. Joint distress was observed in several relatively young sections (2 - 3 years old) showing no other appreciable roadway distress. This is considered premature joint cracking.
6. Several older sections (7 to 9 years old) exhibit almost no joint cracking and no observable joint related pavement distress.

The data generated for the research did not identify whether the density was measured on the cold or the hot side. This made it difficult to identify the source of the problem i.e. joint density or compaction technique. Figure 1 shows typical data of the ratio of the joint density over the density of the mat along the project length. This data shows high variability of joint density along the project.

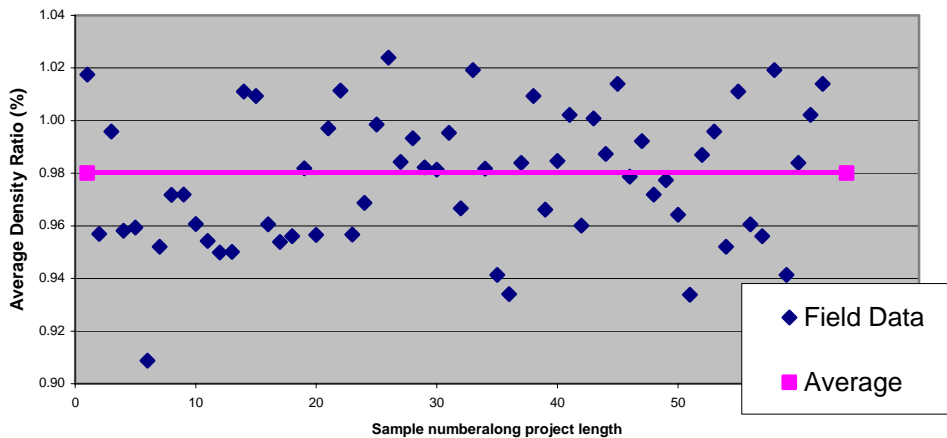


Figure 1 Ratio of joint density over mat density at various projects.

The final recommendations and conclusions of the QES study are summarized below.

1. A definite relationship exists between longitudinal joint quality, longitudinal joint distress, and the overall rate of pavement deterioration.
2. Pavement with superior joint construction result in longer pavement performance life, reduced life cycle cost, and increased cost effectiveness.
3. Sections without joint distress exhibit higher overall pavement density.
4. Sections without joint distress exhibit lower variation between joint and mat density.
5. Placement of increased emphasis on the quality of pavement joint density is warranted.
6. Both between sections and within sections variability demonstrate the current lack of emphasis on joint construction quality as measured by the joint density.

7. Commonly recognized performance factors of pavement age and traffic have a major influence on this set of pavements.

III.3 Texas Transportation Institute

In 2001, the Texas Transportation Institute of the Texas A&M University conducted a research project for the Texas Department of Transportation to evaluate the joint density of various field projects, in order to quantify the need to implement a longitudinal joint density specification in Texas. A total of thirty-four projects throughout the state of Texas, were evaluated for this research. For each project, density measurements were performed at five different locations. There is no information about the procedure used to determine these locations. All the projects correspond to overlays of 1.5 to 2 inches thick.

Nuclear density measurements were conducted using a thin lift nuclear, transversely across the paved lane at the unconfined pavement edge, 6, 12, and 24 inches away from the unconfined edge, 6 inches from the joint at both sides, on top of the joint, and in the middle of the lane. Additionally, cores were obtained near the unconfined edge and in the middle of the lane, corresponding to the nuclear reading locations. The cores were used to calibrate the nuclear readings and to evaluate their permeability.

There is no description of the longitudinal joint geometry or rolling technique applied during the construction of these field projects. Table 11 and Figure 2 summarize the differences between the density at the middle of the mat and the density at various lateral offsets from the unconfined edge.

Table 11 Differences between Mat Density and Density at Various Lateral Offsets from the Unconfined Edge in kg/cm³.

Type of Pavement\ Relative Density	A 0.5 ft from unconf. edge	B 1 ft from unconf. edge	C 2 ft from unconf Edge	D Middle of mat	E 0.5 ft from joint hot side	F on top of joint	G 0.5 ft from joint cold side
C - Limestone	-6.06	-4.92	-2.15	0.00	-3.06	-11.71	-4.91
C - Gravel	-5.32	-1.50	-0.03	0.00	-0.33	-8.03	-5.16
D	-4.49	-2.13	0.17	0.00	-0.73	-5.74	-3.63
CMHB	-5.29	-2.80	-1.24	0.00	-0.29	2.60	-5.59
Superpave	-4.02	-0.19	1.04	0.00	-2.77	-5.61	
SFA	-4.88	-3.78	-0.78	0.00	-1.70	-7.30	-4.88
SMA				0.00	0.80	-7.59	-2.90
Heavy Duty SMA		-1.48	-0.63	0.00	-1.08	-6.04	-5.51
Mean	-4.80	-1.98	-0.24	0.00	-0.87	-5.39	-4.61
Std Dev.	0.55	1.24	0.81	0.00	1.14	3.65	1.10

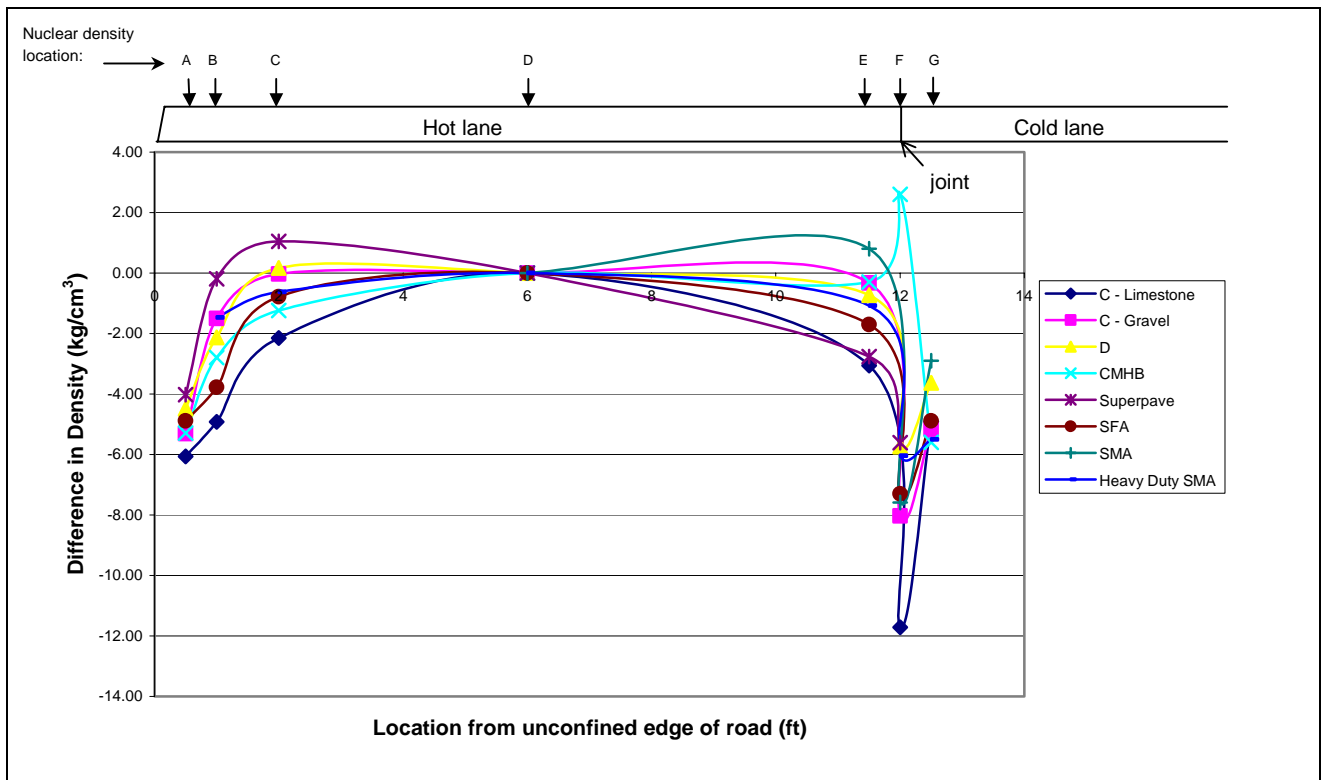


Figure 2 Relative density values obtained for the different type of pavements evaluated in Texas.

The final findings and recommendations provided by the Texas Transportation Institute were the followings:

- The study concludes the existence of a problem with the density along the longitudinal joint and that a joint density specification for HMA pavements construction is justified.
- The edge of the lane paved first (unconfined edge) corresponds to an area of consistently low density, 6 to 7 lbs per cubic ft (4 to 5 %) lower than the mat density.
- For the dense-graded mixes, the permeability was higher for the cores taken near the unconfined edge compared to those from the middle of the lane.

III.4 New Jersey Department of Transportation

In 1982, the New Jersey Department of Transportation determines the necessity of improving the longitudinal joint density and initiated this experimental project. The objective of this research was to compare the wedge joint (3:1) with the conventional angle of repose joint. Five overlay projects were selected for this density research, but just three of them included a wedge and a conventional joint. The other two evaluated the density obtained for the wedge joint configuration. The longitudinal joint density was

measured by means of nuclear readings. They were taken directly over the joint and 1 foot away from it at both sides.

The conventional (New Jersey butt-type) butted joint corresponded to the repose angle of the material, left under normal construction techniques by the paver. An overlap of 2 to 4 inches was used for the placement of the second mat. The overlapped material was pushed back, creating a bump and followed by normal compaction. The wedge joint consisted of a 3:1 inclined face, obtained by placing a sloping steel plate in the inside corner of the paver screed extension. The mat was rolled to the top of the unconfined edge, not extending more than 2 inches past the top of the unconfined edge. The inclined face was not compacted. Additionally, the wedge edge of the cold lane was softened by means of an infrared heater before the placement of the second lane (hot lane). An overlap of 2 to 3 inches was used, and the material was pushed back and compacted with no special rolling technique. Figures 3, 4, and 5 summarize the density measurements obtained for the wedge joint and the conventional butted joint, for the three field projects evaluated in this research.

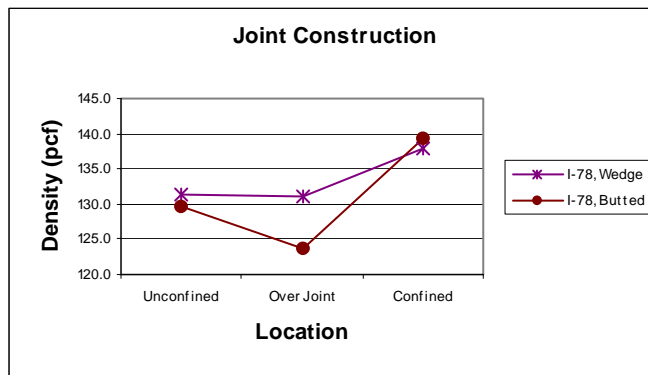


Figure 3 Comparative density measurements for route I-78, New Jersey.

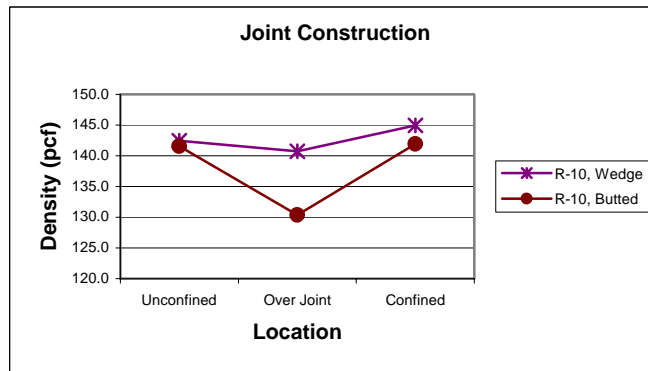


Figure 4 Comparative density measurements for route R-10, New Jersey.

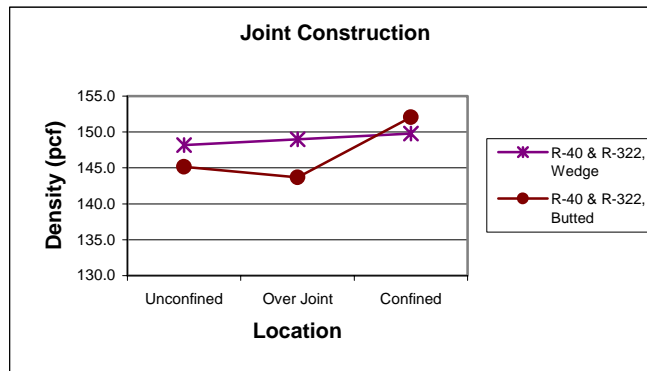


Figure 5 Comparative density measurements for routes R-40 and R-322, New Jersey.

The final conclusions obtained from this research were provided in the following statements:

- Wedge joint technique produces higher, more uniform density than the conventional butt joint technique.
- The wedge joint provides a joint more resistant to opening under the effect of traffic and weathering, because of the density improvement and the elimination of the vertical shear plane.
- After 5 years, the wedge joint construction on five projects shows none of the deterioration or raveling observed in the standard butted joint.
- The wedge joint, by eliminating the vertical plane, improves the safety of motorist lane changes.
- Additionally, supplemental heating eliminates the need to pull back the paver to avoid cold joints, increasing flexibility and production capability. It also provides a better riding quality by reducing the amount of transversal joints in the surface course.

IV. SUMMARY AND FINDINGS

The literature review conducted under this research effort covered two major categories: a) the longitudinal joint specifications of the various agencies, and b) the previous research effort on the subject of longitudinal joint density. As a result of this review the following findings can be summarized.

Agencies Specifications

- Ten state highway agencies and the FAA have formal specifications for longitudinal joint density.
- The majority of the current longitudinal joint density specifications call for either a percent of theoretical maximum density or a relative density.
- Only four highway agencies specify the longitudinal joint geometry.
- Only three highway agencies specify the compaction technique at the longitudinal joint.
- Only three highway agencies apply incentives/disincentives based on the density of the longitudinal joint.

Previous Research Efforts

- Numerous longitudinal joint geometries were evaluated through field studies conducted by the National Center for Asphalt Technology. However, the research did not identify an optimal method for joint construction.
- The studies conducted by Quality Engineering Solutions in Nevada and the Texas Transportation Institute in Texas identified the urgent need for specifications on the longitudinal joint density.
- The study conducted by the New Jersey DOT showed that the wedge geometry of the longitudinal joint would provide better performance than the vertical face geometry.

V. RECOMMENDATIONS

Based on the review of the specifications currently used by the various agencies and the previous research efforts, the following two recommendations were made.

- Implement an interim longitudinal joint specification on some current NDOT projects.
- Conduct a field experimental program to evaluate the longitudinal joint geometry and compaction techniques under Nevada's conditions.

V.1 Interim Specification

Based on the review of the available longitudinal joint specifications and research studies on this subject, the following interim specification was recommended.

- Follow the normal procedure for measuring the mat density: a) use a test segment of 6,000 yd², b) subdivide the segment into five subsections, and c) select a random location for mat density measurement.
 - Measure the longitudinal joint density at the same random location selected for the mat density:
 - Use the nuclear density gauge to measure the density at both the hot and cold sides of the longitudinal joint.
 - For density measurements calculations: a) for the hot side, use the maximum theoretical density (TMD) corresponding to the hot mat location and b) for the cold side, use the TMD corresponding to the station on the cold mat location.
 - Conduct two nuclear gauge density measurements on the hot and cold sides of the joint. The two measurements should be parallel to the joint and 180 degrees apart. Average the two density measurements from each side and record them as the hot-side and cold-side densities, respectively.
 - Identify the joint side (e.g. hot side or cold side) with the lower nuclear density.
 - Cut a core (4" or 6") from the joint side with the lower density.
 - Measure the density of the core.
 - Check the density of the core against the following limits:
 - Maximum of 2% less than the corresponding mat density.
- AND**
- Minimum of 90% of theoretical maximum density at the specific location.

The researchers recommended that NDOT implements this interim joint density specification on several HMA construction projects and start collecting joint density data as prescribed in this interim specification. The implementation of the recommended interim specification will provide valuable data on the density of the cold joint, the comparison of the nuclear density and core density, and the ability of the contractors to meet the specification limits using conventional construction practice.

V.2 Field-Testing Program

The objective of this field-testing program is to evaluate the effectiveness of the various joint geometries and compaction techniques in increasing the joint density and providing improved performance. The proposed field-testing program calls for the evaluation of five joint geometries and two compaction techniques. The following presents a description of the techniques recommended for field evaluation. The lane paved first is referred as the “cold side” and the lane paved second is referred to as the “hot side”

Joint Geometry

The joint geometry will be formed during the construction of the first lane. A total of five joint geometries are recommended for field evaluation. Each joint geometry will be constructed over a minimum of 700 feet long test section. The following represents a description of the recommended joint geometries.

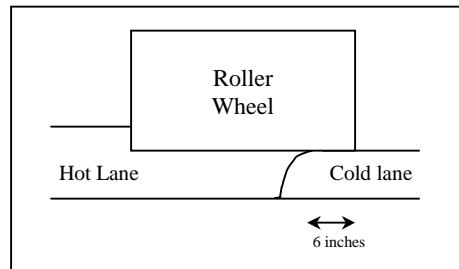
- ***Natural Slope:*** the HMA mix is left on its natural angle of repose as is achieved by the paving process.
- ***Edge Restraining Device:*** this device provides lateral support at the edge of the first paving lane during compaction. It consists of a hydraulically powered wheel which rolls alongside the compactor’s drum simultaneously pinching the unconfined edge of the mix towards the drum and provides lateral support. Previous experience with this technique showed it to provide high joint density. The cost of the equipment and installation will be around \$8500. It is recommended that a technical representative of the equipment manufacturer be present at the site during the construction of the test section.
- ***Cut Edge with Rubberized Asphalt Tack Coat:*** the edge of the first paving lane is cut to a vertical face after the compaction of the mat is completed. In this technique, the vertical cut face is tack coated with rubberized asphalt. Previous experience with this technique provided good joint performance. The rubberized asphalt has an estimated cost of \$0.61/lb. The supplier suggested an application of 0.62lb/ft. The total cost of the rubberized asphalt for the four projects will be around \$1500. It is recommended that technical representatives from the equipment manufacturer and the rubberized tack coat supplier be present at the site during the construction of the test section.

- ***Cut Edge without Rubberized Asphalt Tack Coat:*** the edge of the first paving lane is cut to a vertical face after the compaction of the mat is completed. In this technique, the vertical cut face is not tack coated. It is recommended that a technical representative of the equipment manufacturer be present at the site during the construction of the test section.
- ***Tapered Joint at 3:1:*** the edge of the first paving lane is tapered at a 3:1 slope with a ½” notch at the end of the taper. The taper is achieved through a steel plate connected to the paver. No special compaction effort is placed on the tapered edge. Previous experience with this technique showed good performance. It is recommended that a technical representative of the equipment manufacturer be present at the site during the construction of the test section.

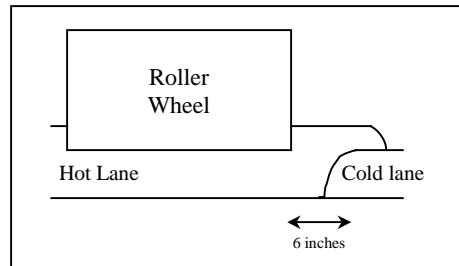
Joint Compaction Technique

The joint compaction technique will be followed during the construction of the second lane. Two joint compaction techniques will be evaluated on each of the five joint geometries. The following represents a brief description of the joint compaction techniques recommended for evaluation.

- ***Pattern I - Rolling from the Hot Side with 6” Overlap on the Cold Side:*** as shown below, compaction is started from the hot side of the joint (i.e. first pass). The major portion of the roller is on the hot side with just an overlap of about 6” on the cold side.



- ***Pattern II – Rolling from the Hot Side at 6” away from the Joint:*** as shown below, compaction is started from the hot side of the joint (i.e. first pass). The roller is kept at 6” away from the joint. This rolling procedure tends to push the loose HMA mix towards the joint.



Compaction of the First-Paved Lane

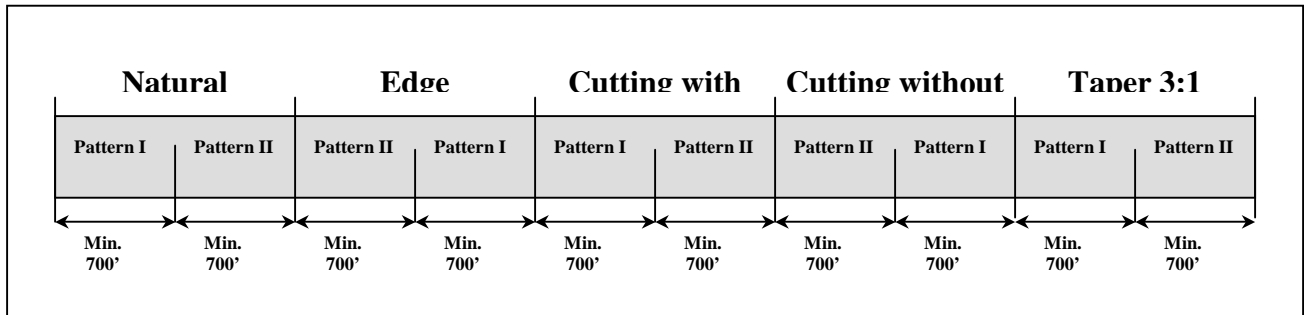
The first-paved lane will include an unsupported edge at the location where it will meet the second-paved lane forming the longitudinal joint. The first-paved lane should be compacted with the roller having 2" hang over the unsupported edge.

Sections Layout

Total number of sections: 5 (joint geometry) x 2 (compaction techniques) = 10.

Section length: Minimum 700 feet or a half-day production. The exact length of the section will be decided once a field project is selected.

Layout of Test Sections



Number of Projects

It is recommended to implement the testing plan on a minimum of two projects: one in the north and one in the south. The two projects will ensure the implementation under the various materials and environmental conditions throughout the state.

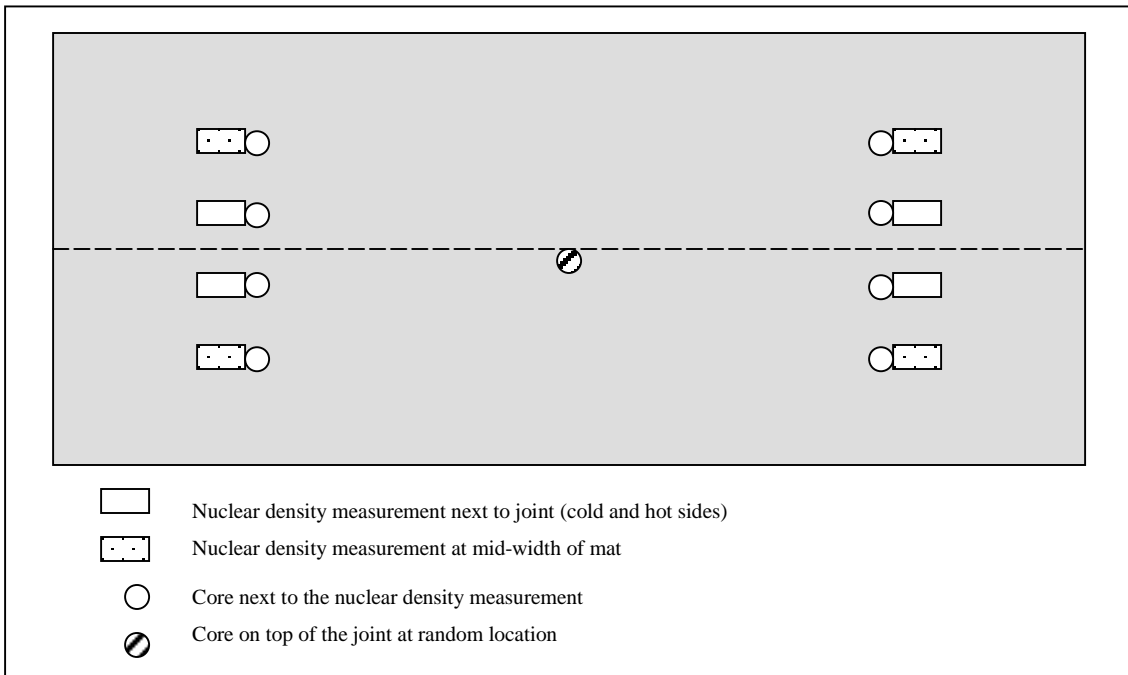
Density Measurements

The density of the joint achieved during the construction of the test sections will be used to assess the effectiveness of the various techniques. The long-term performance of the joint also will be used to evaluate the long-term effectiveness of the techniques. The following density measurement plan is recommended for the field sections.

- Conduct nuclear density measurement at the cold side and hot side of the joint at 10 locations within each test section. At each side, take two readings parallel to the joint and 180 degrees apart. Average both readings and record them as the hot and cold side densities. The nuclear gauge should be placed as close to joint as possible.
- Conduct nuclear density measurement at the mid-width of the cold side and hot side of the mat at the same 10 locations where the joint densities are measured. At each location take four readings 90 degrees apart. Report the average of the four readings as the density of the cold and hot sides.

- Cut a 4” core at each location that a nuclear density measurement is taken (i.e. at both the joint and the mid-width of the mat). A total of 40 cores will be obtained from each section.
- Cut a core (4” or 6”) on top of the joint at three random locations within each section.

Density Measurement Diagram



VI. REFERENCES

1. Kandhal, Prithvi S. and Rao, Shrinidhar S. *Evaluation of Longitudinal Joint Construction Techniques for Asphalt Pavements (Michigan and Wisconsin Projects – Interim Report)*. National Center for Asphalt Technology. Report No. 94-1. January 1994.
2. Kandhal, Prithvi S. and Mallick, Rajib B. *A Study of Longitudinal Construction Techniques in HMA Pavements (Interim Report – Colorado Project)*. National Center for Asphalt Technology. Report No. 96-3. February 1996.
3. Kandhal, Prithvi S. and Mallick, Rajib B. *Longitudinal Joint Construction Techniques for Asphalt Pavements*. National Center for Asphalt Technology. Report No. 97-4. August 1997.
4. Kandhal, Prithvi S.; Ramirez, Timothy L.; and Ingram, Paul M. *Evaluation of Eight Longitudinal Joint Construction Techniques for Asphalt Pavements in Pennsylvania*. National Center for Asphalt Technology. Report No. 2002-03. February 2002.
5. Morian, Deniss A.; Frith, Douglas J.; and Stoffels, Shelley M. *Longitudinal Asphalt Pavement Joint Construction Effect on Pavement Performance*. Developed for the Regional Transportation Commission of Washoe County. July 2000.

APPENDIX A

STATE HIGHWAY AGENCIES HMA DENSITY SPECIFICATION

Agency	Density Specifications		Construction Specifications		
	Mat	Longitudinal Joint	General	Geometry	Compaction
Alabama	Target density is 94% of theoretical maximum density.		1) Longitudinal joints in the wearing surface shall conform to the edges of proposed traffic lanes 2) Any necessary longitudinal joints in underlying layers shall be offset so as to be at least 6 inches (150 mm) from the joint in the next overlying layer.	Angle of repose of 1:1.	The longitudinal joint shall be rolled in the first pass.
Alaska	Target value is 94% of the maximum specific gravity	Above 91% of maximum specific gravity	1) Offset the longitudinal joints in one layer from the joint in the layer immediately below by at least 6 inches. Align the joints of the top layer at the centerline or lane lines.		
Arizona	The target is 98% of lab density.	The density required on the tapered joint is the same as for the rest of the mat.	Longitudinal joints of each course shall be staggered a minimum of 300 millimeters with relation to the longitudinal joint of any immediate underlying course.	Joints shall be formed by a slope shoe or hot lapped. The tapered joint is formed with a shoe attached to the end of the screed to form a slope of about 4:1 to 6:1 beyond the screed	1) The sloped edge has to be compacted using a pneumatic roller. Steel rollers cannot compact the taper. 2) The joint should be pinched while rolling so that there is overlap by the roller between the hot mat and the cold mat.
Arkansas	Compliance Limits: 92.0% to 96.0% of the theoretical density.		The longitudinal joint in one layer shall offset that in the layer immediately below by approximately 6". The longitudinal joint in the top layer shall be at the centerline or at the lane line.		1) When paving in echelon or abutting a previously placed mat, the longitudinal joint shall be rolled first followed by the regular rolling procedure. 2) The slight excess of asphalt at a longitudinal joint, generated by overlapping during placement of an adjacent mat to a previous mat, shall not be scattered across the mat. This material shall be stacked over the joint and pinched into the joint by the first pass of a steel wheel roller running with all but 150 mm to 200 mm (6" to 8") of the drum on the cold mat. Vibrating rollers shall operate in the static mode during this operation.
California (draft specs)	96% of relative compaction	93% of relative compaction	The tapered portion of the mat shall be constructed by use of an approved strike-off device that will provide a uniform slope and will not restrict the main screed. The adjacent mat shall be paved within one working, unless delayed by inclement weather.	Recommended tapered notched joint. The tapered notched wedge shall be 12" wide and with a vertical notched 3/4" at the top and bottom.	
Colorado	92 - 96 percent of the maximum theoretical density	Target density of 92% of the max specific gravity, tolerance: ± 4 percent	The longitudinal joint shall offset the joint in the layer immediately below by 6 inches. The joints in any pavement layer shall not fall in a wheel path. The joints in the top layer of pavement shall be located as follows: (1) For 2-lane roadways, offset 6 to 12 inches from the center of pavement and from the outside edge of travel lanes. (2) For roadways of more than 2 lanes, offset 6 to 12 inches from lane lines and outside edge of travel lanes.	Mat thickness < 1.5 inches - vertical exposed joint. If the thickness is > 1.5 inches, the top 1.5" shall be vertical and, below tapered (Minimum 3:1)	

Agency	Density Specifications		Construction Specifications		
	Mat	Longitudinal Joint	General	Geometry	Compaction
Connecticut	The in-place density: 92 - 97 percent of the maximum theoretical density.	90 - 97 percent of the maximum theoretical density, for layers of 1.5" or thicker.	The longitudinal joint in one layer shall offset the previous joint in the layer immediately below by approximately 6" however, the joint in the top layer shall be at the centerline of the pavement if the roadway comprises two-lane width, or at lane lines if the roadway is more than two lanes in width.		In compacting the joint, the steel-wheel roller shall be shifted onto the cold mat so that only 1 to 2 inches of the drive wheel extends over the uncompacted material. The steel-wheel roller shall continue to roll along this line and its position shifted gradually across the joint until the joint has been rolled with the entire width of the drive wheel. Rolling with steel-wheel and pneumatic-tired rollers shall be continued until a thoroughly compacted, neat joint is obtained. When the vibratory roller is used for breakdown rolling, compacting the joint shall be accomplished with the roller on the hot mat shifted 1 to 2 inches across the joint onto the cold mat.
Delaware	Minimum of 92% of the theoretical maximum density		The material being placed in the abutting lane shall be tightly compacted against the vertical face of the cold mat. The finishing machine shall be positioned so that the spread material overlaps the edge of the cold mat by 1 to 2", and is left sufficiently high to allow for compaction. Before rolling, the material overlapping the joint shall be carefully deposited adjacent to the joint of the hot mat with a lute. When the abutting lane is not placed the same day, or the joint is distorted by traffic or other means, the edge shall be carefully trimmed to line and coated uniformly with tack material. The longitudinal joint in any layer shall offset that in the layer immediately below by approximately 6". However, the joints in the completed surfacing shall be at the lane line.	Vertical face	Longitudinal joints shall be rolled directly behind the laying operations.
Florida	Average in-place lot density of at least 98% of the control strip density.		For all layers of pavement except the leveling course, place each layer so that longitudinal construction joints are offset 6 to 12 inches laterally between successive layers. The Engineer may waive this requirement where offsetting is not feasible due to the sequence of construction.		Where the lane being placed is adjacent to a previously placed lane, pinch or roll the center joint prior to the rolling of the rest of the hot mat.
Georgia	Maximum Air Voids of 7.8%.		Arrange the width of the individual lifts so that the longitudinal joints of each successive lift are offset from the previous lift at least 1 ft. This requirement does not apply to the lift immediately over thin lift leveling courses.		
Hawaii	91 - 96% of theoretical maximum density, for pavement courses of 1-1/2 in or thicker.		The longitudinal joint in one layer shall offset that in the layer immediately below by approximately six inches; however, the joint in the top layer shall be at the centerline of the pavement if the roadway comprises two lanes of width, or are lane lines if the roadway is more than two lanes in width.		When paving in echelon or abutting a previously placed lane, the Contractor shall roll the longitudinal joint first followed by the regular rolling procedures.

Agency	Density Specifications		Construction Specifications		
	Mat	Longitudinal Joint	General	Geometry	Compaction
Idaho	92.0 - 95.0 percent of Maximum Specific Gravity	Density tests may be taken at longitudinal joints to ensure the integrity of material in the joint area.	One cold longitudinal joint will be allowed. On the top course, it shall be at the centerline of the traveled way; on the lower courses it shall be staggered and offset 6 inches to 1 ft from the centerline of the traveled way. The amount of overlap of the new mix on the cold mat should be 1 to 2 inches. Prior to rolling, the overlap shall be bumped back or trimmed back to the joint line.	Tapered joint: The taper shall be 1.47 ft wide for depths 0.2 ft or less. For depths greater than 0.2 ft, the taper shall be 1.96 ft wide. On all pavement overlays, the taper shall be 1.96 ft wide.	When paving in echelon abutting a previously placed lane, the longitudinal joint should be rolled first, followed by the regular rolling procedure.
Illinois	Class I, Type 1 (Min. Stability 2000lb): 92.0 - 96.0 percent of the theoretical maximum density Class I, Type 2 (Min. Stability 1700lb): 93.0 - 97.0 percent of the theoretical maximum density		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. 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 inches. When pavement is placed at a greater width than 12 ft, the profile will be taken 3 ft from and parallel to each edge and each side of the planned longitudinal joint.		When laying the bituminous mixture adjacent to the cold mat, the first pass of the roller shall be along the longitudinal joint on the hot mat with the compression wheel not more than 6 inches from the joint. The second pass of the roller shall overlap the longitudinal joint not more than 12 inches on the cold mat after which the rolling shall proceed from the low side of the transverse slope to the high side, overlapping uniformly.
Indiana	The target is 94.0 ± 2.0 of the Maximum Specific Gravity.		Longitudinal joints in the surface shall be at the lane lines of the pavement. Longitudinal joints below the surface shall be offset from previously constructed joints by approximately 150 mm (6 in.), and be located within 300 mm (12 in.) of the lane line.		Longitudinal joints shall be compacted in accordance with the following: (a) For confined edges, the first pass adjacent to the confined edge, the compaction equipment shall be entirely on the hot mat, 6 inches from the confined edge. (b) For unconfined edges, the compaction equipment shall extend 6 inches beyond the edge of the hot mat.
Iowa	Class IA (intermediate and surface courses for the traffic lanes of Interstate highways): minimum of 96% of laboratory density. Class IB (Interstate and Primary bases, Primary travel lanes intermediate and surface courses): minimum of 95% of laboratory density.		Longitudinal joints for courses on resurfacing projects shall be constructed directly above the longitudinal joint in the existing pavement. The offset distance between longitudinal joints in succeeding courses of full depth HMA paving shall be not more than 3 inches.		

Agency	Density Specifications		Construction Specifications		
	Mat	Longitudinal Joint	General	Geometry	Compaction
Kentucky	The Contract will state the compaction values to be used. Compaction should be between 92 - 96% of the Theoretical Maximum Specific Gravity.	89 - 96% of the Theoretical Maximum Specific Gravity	Correct irregularities in alignment of the outside edge or edges of longitudinal joints by adding or removing material before compacting the edges. When the pavement construction consists of 2 or more courses, offset the longitudinal joint a minimum of 6 inches. Place the longitudinal joint in the final surface course along the dividing line between the lanes.		Clean adjacent surfaces of all loose materials so the joint shall receive full compaction from the rollers.
Louisiana	Minimum of 92.0% of the Theoretical Maximum Specific Gravity		Longitudinal joints shall offset those in the layer below by a minimum of 3 inches. In the top layer it shall be offset 3 - 6 inches, from the centerline of pavement or from lane lines. Longitudinal joints shall be constructed by setting the screed to allow approximately 25 percent fluff and also overlapping the paver approximately 2 inches onto the adjacent pass. Prior to rolling, the overlapped mix shall be pushed back to the uncompacted side, without scattering loose material over the hot mat, to form a vertical edge above the joint. The vertical edge shall then be compacted by rolling to form a smooth, sealed joint.		
Maryland	In place density of 92.0 to 97.0 percent of the theoretical maximum density.		Longitudinal joints shall be staggered a minimum of 6 in. and shall be arranged so that the longitudinal joint in the top course shall be within 6 in. of the line dividing the traffic lanes.		Steel wheel rollers shall be used for the first rolling of all joints and edges, the initial breakdown rolling, and the finish rolling.
Massachusetts	Not less than 95% of the Laboratory compacted density.		The longitudinal joints for the top course shall be cut back to expose the full depth of the course and, when the laying of the course is resumed, the exposed edge of the joint shall be treated with a hot pured rubberized asphalt sealant.	Vertical face	To prevent "rolloff" of the pavement edges and longitudinal joints on deep lift pavement, the outer 8 inches of the deep lift mixture shall be left unrolled until the temperature of the mix ranges between, 149°F and 176°F, whereupon it shall be compacted by the steel roller.
Michigan	Average of the density values should be equal to or greater than 92.0 percent of the Maximum Specific Gravity		When placing the uppermost leveling and top course, the longitudinal joint shall coincide with the proposed painted lane lines. Longitudinal joints shall be either vertical or tapered.	Vertical or tapered (1:12 slope and a notch of 0.5 to 1 inch at the top of the taper)	When compacting an adjoining lane and not restricted by traffic, the vertical longitudinal bumped joint shall be rolled first with the roller supported mainly on the cold mat with only 2 to 6 inches of the roller extending onto the hot mat.
Minnesota	Mimimum of 95 percent of the Marshall density.		In multiple lift construction, the longitudinal joints shall be constructed not less than 6 inches measured transversely from the longitudinal joints in the previously placed lift. For wearing course, the longitudinal joint shall be on the centerline of the road, provided that no joint is located in the wheel path area of a traffic lane. At longitudinal joints formed by placing multiple strips, the adjoining surface being laid shall, after final compacting, be slightly higher (but not to exceed 1/8 inch) than the previously placed strip.		When a longitudinal joint is formed by adjoining strips, the first pass of the roller shall be over that joint.

Agency	Density Specifications		Construction Specifications		
	Mat	Longitudinal Joint	General	Geometry	Compaction
Missouri	Minimum density of 98 percent of a laboratory specimen made in the proportions of the job-mix formula in accordance with AASHTO T 167 or 96 percent of a laboratory specimen made in the proportions of the job-mix formula in accordance with AASHTO T 245,	Not less than 2.0 percent below the specified density (within 6 inches of a longitudinal joint)	The longitudinal joint shall offset that in the layer immediately below by approximately 6 inches. The joints in the completed surfacing shall be at the lane lines or outside the travel lane. Longitudinal joints shall be formed by the use of an edging plate fixed on both sides of the finishing machine. The inside plate, or that placing material for the longitudinal joint, shall be normal to the roadbed. When placing the first lane, if the mixture at the longitudinal joint tends to slump, it shall be set up to a vertical edge by light compaction with the back of a rake.	Vertical face	
Nebraska	Average Density (5 Samples, Percent of Voidless Density) should be greater than 92.4%		An intended lap of 1 inch with a variance of ½ inch will normally be the optimum overlap for longitudinal joint construction. If thickness is insufficient prior to rolling, joint will usually be smooth in appearance but lack density because of inadequate compaction. Make sure density is checked along the joints.	Vertical face	When paving adjacent to a previously placed lane, the last pass of the roller in which the full roller width is entirely on the hot mat shall be kept approximately 6 inches from the existing facility. The final pass of the roller shall then be made over the remaining uncompacted 6 inches strips, tucking the material into the joint.
New Hampshire	Minimum density of 95 percent of laboratory specimens, made by the AASHTO T 245 method in the proportions of the job mix formula.		The longitudinal wearing course joint shall be in the center of the pavement, and joints of other courses shall be offset approximately 6 inches. A tapered overlapping joint may be used on all longitudinal joints provided that the adjacent lane can be placed when the existing surface temperature is above 50 °F. 1) An inclined face (3:1) on the joint shall be formed in the first bituminous mat placed. The inclined face may be for the entire height or an inclined face with a 1/2 inch maximum vertical face at the top of the mat. 2) After the initial mat is placed, the mat shall be rolled to the edge of the unconfined face. 3) When the hot mat is placed the initial longitudinal wedge shall be either treated with an approved bonding agent or heated to a temperature that facilitates bonding of the joint with an approved heating device. 4) Luting the joint after placement of the hot mat will not be required unless necessary to correct surface irregularities.	Tapered joint with inclined face of 3:1. Allows a 1/2 inch notch.	When paving in echelon or abutting a previously placed lane, the longitudinal joint shall be rolled first followed by the regular rolling procedure.

Agency	Density Specifications		Construction Specifications		
	Mat	Longitudinal Joint	General	Geometry	Compaction
New Jersey	Each mixture in a given lot shall be compacted so that the combined percentage of material below 2.0 percent voids or above 8.0 percent voids shall be no more than ten percent.		<p>HMA pavers shall be equipped with a sloped plate to produce a wedge edge at longitudinal joints. The sloped plate shall be attached to the paver screed extension. The sloped plate shall produce a wedge edge having a face slope of 1V:3H. The plate shall be so constructed as to accommodate compacted layer thickness from 40 to 100 millimeters. The bottom of the sloped plate shall be mounted 10 to 13 millimeters above the existing surface. The plate shall be interchangeable on either side of the screed.</p> <p>For surface layers, HMA pavers shall also be equipped with infrared heater(s) to heat the longitudinal edge of the previously placed layer</p> <p>The longitudinal joint in one layer shall offset that in the layer immediately below by approximately 150 millimeters. However, the joint in the surface course shall be at the lane lines.</p>	Tapered joint	When compacting the longitudinal edge of the first lanes placed using the wedge joint, the breakdown roller shall not extend more than 50 millimeters over the top of the sloped face of the wedge joint. When paving in echelon, rollers shall not compact within 150 millimeters of an edge where an adjacent lane is to be placed.
New Mexico	The mean density shall be at least 93% of the theoretical maximum density. In addition, individual test value shall be at least 90% of the theoretical maximum density and shall not exceed 98% of the theoretical maximum density. QC/QA: target density for acceptance will be 95% of the theoretical maximum density.		<p>Longitudinal joints shall be staggered at least 6 inches relative to longitudinal joints of the underlying course. Longitudinal joints shall have at least a 1 ft minimum taper.</p> <p>Tapered longitudinal joints from previous operations shall be cleaned and tack coated. The surface of each course at all joints shall be smooth and shall not show deviations in excess of 3/16 inch when tested with a 10 ft straightedge in any direction.</p>	Tapered joint not steeper than 6:1	
New York	Density specs are included in the contract proposal.	Contract proposal include longitudinal joint density spec.	<p>In the formation of all joints, the exposed edge of the existing layer that will become part of the joint shall be the full thickness of the layer and straight.</p> <p>The pavement of successive courses shall be such that all joints are offset at least 6 inches from the joint of the lower pavement course.</p>	Vertical face	

Agency	Density Specifications		Construction Specifications		
	Mat	Longitudinal Joint	General	Geometry	Compaction
North Carolina	Minimum of 92% of the Maximum Specific Gravity		Tack the exposed edge of all longitudinal joints prior to placing the adjoining pavement. Form longitudinal joints by allowing the paver to deposit the mixture adjacent to the joint to such depth that maximum compaction can be obtained along the joint. Pinch the joint by rolling immediately behind the paver. Offset the longitudinal joints in each layer from that in the layer immediately below by approximately 6 inches. Construct the joints in the final layer between designated travel lanes of the final traffic pattern.		
North Dakota	The average density shall be at least 91% of the daily average Maximum Theoretical Density. Each individual subplot shall have a minimum average density of 89% of the daily average Maximum Theoretical Density.		Joints shall be tacked and constructed with adequate bond on abutting surfaces. Vertical construction joints in successive courses shall be placed so the joints do not fall in the same vertical plane.		When paving in echelon or abutting a previously placed lane, the longitudinal joint should be rolled first followed by the regular rolling procedure.
Ohio	In place density of 93.0 to 97.0 percent of the maximum theoretical density.		Seal all cold longitudinal joints on surface courses, by coating the vertical face of the cold joint with asphalt material, applied at a rate of 0.25 gallon per square yard.	Tapered joint, the maximum slope is 3 to 1.	Where a longitudinal joint is being made, roll the joint then follow the applicable rolling procedure. For continuous lanes, one ahead of the other, do not allow rollers performing the initial rolling operation in one lane closer than 12 inches to the longitudinal joint until the adjacent lane is placed. Compact all cold longitudinal joints on intermediate and surface courses using a three-wheel roller.
Oregon	Minimum density of 98.0% of the target density, obtain from the Moving Average Maximum Density (MAMD) Method. Lower MAMD applicable: 91% for low volume roads.		Offset the longitudinal joints in one layer by at least 6 inches from the longitudinal joints in the layer immediately below. (1) Base Course - Place base course longitudinal joints within 12 inches of the edge of a lane, or within 12 inches of the center of a lane, except in irregular areas, unless otherwise shown. (2) Wearing Course - Longitudinal joints shall not occur within the width of a traffic lane. They shall be located at either skip lines or fog lines unless approved by the Engineer. On median lanes and on shoulder areas the joints shall occur only at lane lines or at points of change in the transverse slopes.		When paving in echelon, or when abutting a previously placed lane, roll the longitudinal joint first, followed by the regular rolling pattern.

Agency	Density Specifications		Construction Specifications		
	Mat	Longitudinal Joint	General	Geometry	Compaction
Pennsylvania	Field density between 92% and 97% of Theoretical Maximum Density	For Notched wedge: minimum of 90% of the theoretical maximum density.	Offset the longitudinal joint in one layer from the joint in the layer immediately below by approximately 6 inches. However, align the joint in the top layer at the approximate pavement centerline, if the roadway is two lanes wide; or at approximate lane lines, if the roadway is more than two lanes wide. Operate the paver so that, in spreading, the material overlaps the edge of the lane previously placed by approximately 1-1/2 inches.	Tapered -notched or vertical joint	Immediately compact fresh mix directly behind the paver at the longitudinal joint. When compacting the joint, use a vibratory roller for breakdown rolling, shift the roller on the hot mat 1inch or 2 inches across the joint onto the cold mat. Make the first pass in the vibratory mode. Roll with steel-wheel and pneumatic-tire rollers until a thoroughly compacted neat joint is obtained.
Rhode Island	Minimum density of 95 percent of the density of laboratory Marshall specimens made in the proportions of the job-mix formula.		Longitudinal joints shall be staggered a minimum of 6-inches and shall be arranged so that the longitudinal joint in the top course being constructed shall be at the location of the line dividing the traffic lanes. The edge of the old pavement or the cold mat, shall be cut back a sufficient distance to expose a fresh, full thickness, vertical face. To obtain a well bonded joint, this face shall be brush-painted or pressure sprayed with a bituminous tack coat, after which the hot bituminous mixture shall be placed in contact with it and raked to a proper depth and grade.	Vertical face	
South Carolina	Average minimum density of 96.5% of the average daily field laboratory density as determined by the Marshall Method of test, but not exceeding 98.5%.		The longitudinal joints of each successive course have to be offset from the joints of the previous course at least 6 inches where practicable. The width of each lane in the top layer shall be the width of the design travel lanes.		Longitudinal joints shall be rolled directly behind the paver. The paver shall overlaps the edge of the cold mat by 1 to 2 inches. The loose material shall be left high enough to allow for compaction to the depth of the cold mat. The overlapped material shall be pushed back by means of lutes or other suitable tools to the edge of the cold mat.
South Dakota	High Volume Traffic: 92.0 to 96% of the lot average maximum specific gravity. Low and Medium Volume Traffic: 91 - 96% of the lot average maximum specific gravity.		The center joints of succeeding lifts shall be offset approximately six inches. The center joint of the top lift shall be located on centerline. Longitudinal joints other than at the lane lines will not be permitted in the top lift. A shoe attachment may be used to match the longitudinal joint(s) on the final paver pass(es) of the top lift unless otherwise directed by the Engineer. A shoe attachment on the paver shall be used to automatically match the elevation of asphalt concrete shoulders with concrete pavements.		When abutting a previously laid lane, compaction of the longitudinal joint should be accomplished by rolling from the hot lane.
Tennessee	Average of not less than 92 % of maximum theoretical density with no individual test falling below 90 % of maximum theoretical density.		Where multi-course pavements are placed, the longitudinal joint in one layer shall offset that in the layer immediately before by approximately one foot; however, the joint in the top layer shall be at the center-line of the pavement if the roadway comprises two lanes of width, or at lane lines if the roadway is more than two lanes in width.		When paving in echelon or abutting a previously placed lane, the longitudinal joint shall be rolled first, followed by the regular rolling procedure. When paving in echelon, rollers shall not compact within six inches of an edge where an adjacent lane is to be placed.

Agency	Density Specifications		Construction Specifications		
	Mat	Longitudinal Joint	General	Geometry	Compaction
Texas	In place air-voids between 4.5 - 9%.	If difference in density at both sides of the joint is more than 48 kilogram per cubic meter, the production is discontinued until this difference is corrected.	Construction joints of successive courses of asphaltic material shall be offset at least 6 inches. Construction joints on surface courses shall coincide with lane lines or shall be as directed by the Engineer.		
Utah	The target density is 93.5 percent of maximum theoretical density for overlay thickness greater than 2 inches. For overlay thickness is 2 inches or less, target density is 92.5 percent of maximum theoretical density. Lower Limit: Target Value - 2.0% Upper Limit: Target Value + 3.0%		Offset longitudinal joints 6 to 12 inches in succeeding courses. Place top course joint within one foot of the centerline or lane line. If the previous pass has cooled below 175°F, tack the longitudinal edge before placing the adjacent pass.	Tapered joint, 3:1	
Virginia	98.0 - 102.0 percent of the Target Control Strip density. Courses not having sufficient quantity of material to run a nuclear density roller pattern and control strip shall be compacted to a minimum density of 91.5 percent of the theoretical maximum density.		A short ski or shoe shall be used to match the grade of the cold mat on all primary, interstate and designated secondary routes. Unless otherwise directed by the Engineer, a 24 foot minimum automatic grade control ski shall be used on all asphalt mixtures on all divided highways, with the exception of less than full width overlays and the first course of asphalt base mixtures over aggregate subbases.		When abutting a previously placed lane, the longitudinal joint shall be rolled first, followed by the regular rolling procedure.
Washington	Minimum of 91.0 percent of the reference maximum density (moving average of the most recent five determinations for the lot of asphalt concrete being placed)	For hot-lap joints, require the same minimum compacted density as in the rest of the pavement mat.	The longitudinal joint in any one layer shall be offset from the layer immediately below by not more than 6 inches nor less than 2 inches. All longitudinal joints constructed in the top layer shall be at a lane line or edge line of the traveled way.		If a hot-lap joint is allowed, two paving machines shall be used; a minimum compacted density, as in the rest of the pavement, shall be achieved throughout the traffic lane; and construction equipment shall not impact any uncompacted mix.

Agency	Density Specifications		Construction Specifications		
	Mat	Longitudinal Joint	General	Geometry	Compaction
West Virginia	92 to 96% of the theoretical maximum density of the approved mix design.		The longitudinal joint in any layer shall offset that in the layer immediately below by approximately six inches; however, the joint in the top layer shall be at the centerline of the pavement if the roadway comprises two lanes of the width, or at lane lines if the roadway is more than two lanes in width.		
Wisconsin	Compacted to a density not less than the percentage of the Target Maximum Density: 92% for High volume (> 3E6 ESALS), and 91.5% for < 3E6 ESALS.				
FAA	93.9 - 96 % of the Theoretical Maximum Density.	Above 92.4 % of the Theoretical Maximum Density.	The longitudinal joint in one course shall offset the longitudinal joint in the course immediately below by at least 1 foot; however, the joint in the surface top course shall be at the centerline of the pavement. Longitudinal joints which are irregular, damaged, uncompacted, cold, or otherwise defective, shall be cut back a minimum of 2 inches from the edge with a cutting wheel to expose a clean, sound vertical surface for the full depth of the course. All contact surfaces shall be given a light tack coat of asphalt material prior to placing any fresh mixture against the joint.	Vertical face	

**DEVELOPMENT OF A JOINT DENSITY SPECIFICATION
PHASE I: LITERATURE REVIEW AND TEST PLAN**

**NEVADA DEPARTMENT OF TRANSPORTATION
Construction Division
1263 S. Stewart St.
Carson City, Nevada 89712**

**Research Report No. 13DL-1
January, 2004**

**UNIVERSITY
OF NEVADA
RENO**

Pavements/Materials Program

**Department of Civil Engineering
College of Engineering
University of Nevada
Reno, Nevada 89557**

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.		2. Government Accession No.	3. Recipient's Catalog No.
4. Report Title DEVELOPMENT OF A JOINT DENSITY SPECIFICATION PHASE I: LITERATURE REVIEW AND TEST PLAN		5. Report Date January 24, 2004	
		6. Performing Organization Code	
7. Author(s) Peter E. Sebaaly and Juan Carlos Barrantes		8. Performing Organization Report No. 13DL-1	
9. Performing Organization Name and Address Western Regional Superpave Center Department of Civil Engineering/258 University of Nevada, Reno Reno, Nevada 89557		10. Work Unit No.	
		11. Contract or Grant No.	
12. Sponsoring Agency Name and Address Nevada Department of Transportation 1263 S. Stewart Street Carson City, NV 89712		13. Type of Report and Period Covered Interim	
		14. Sponsoring Agency Code	
15. Supplementary Notes			
16. Abstract The objective of this research study is to develop a specification for longitudinal joints on hot-mixed asphalt (HMA) pavements. The study consisted of two phases: phase 1 reviewed all current specification for longitudinal joints and Phase 2 conducts a field-testing program to identify the most effective technique under Nevada's conditions. This report summarizes the findings and recommendations of Phase I. A literature review was conducted to identify all current specifications for longitudinal joint density and to summarize all previous research efforts on the subject of longitudinal joint density. The review identified a total of ten state highway agencies and the Federal Aviation Administration (FAA) having specifications for density at the longitudinal joint. Few agencies also have specifications for the geometry of the joint. Three agencies currently implement incentives/disincentives programs based on the density of the longitudinal joint. A total of four independent research studies have been conducted to assess the various joint geometry and compaction techniques. The research studies highlighted the need for having joint density specification but they did not recommend an optimal method for joint construction. The second part of the report presents an interim joint density specification to be implemented in Nevada and a field-testing program to identify the optimal method for joint construction under Nevada's conditions.			
17. Key Words Longitudinal Joint, Joint Density, Joint Specification, Joint Compaction, Joint Geometry.		18. Distribution Statement Unrestricted. This document is available through the National Technical Information Service, Springfield, VA 21161	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. Of Pages	22. Price

TABLE OF CONTENT

Section	Page
Introduction	1
Review of Existing Specifications	2
DOTs Longitudinal Joint Specifications	2
Nevada DOT Longitudinal Joint Specification	5
Washoe-RTC Longitudinal Joint Specification	6
Review of Previous Research Efforts	8
National Center for Asphalt Technology (NCAT)	8
Quality Engineering Solutions	12
Texas Transportation Institute	14
New Jersey Department of Transportation	15
Summary and Findings	18
Recommendations	19
Interim Specification	19
Field-Testing Program	20

I. INTRODUCTION

Hot mixed asphalt (HMA) pavements are normally constructed with multiple passes of the paver. Typically, one lane is laid-down with each pass. Consequently, a longitudinal construction joint is formed between the constructed lanes. The density of the HMA mix at the longitudinal joint depends on the geometry of the joint and the compaction technique.

The density of the HMA mix at the longitudinal joint is usually lower than the density of the HMA mix throughout the regular mat away from the joint. This low in-place density translates into higher air-voids around the longitudinal joint leading to the penetration of moisture into the HMA mix. As the HMA pavement is subjected to environmental effects and traffic loads, the moisture-saturated mix at the joint becomes an easy target for moisture-related damages such as stripping and raveling.

Further damage of the joint allows moisture to penetrate to the base and subbase layers leading to great reduction in the strength properties of these layers. As a result of this water intrusion, the entire pavement structure weakens and failures occur under the action of repeated traffic loads and environmental factors.

One way to avoid such failures is to construct a dense longitudinal joint that would prevent the intrusion of water. Several joint geometry and compaction techniques have been recommended to optimize the density and performance of the longitudinal joint. A successful joint construction technique would provide a joint with high density and strong bond between the two paved lanes. The high-density requirement can be checked during the construction process while the strong bond requirement requires long-term performance monitoring of the pavement.

Several research studies have been conducted to assess the various geometries and compaction techniques of longitudinal joints in HMA pavements. In 2003, The Nevada Department of Transportation (NDOT) initiated a two-phase research project: a) Phase 1: to evaluate the current joint geometries and compaction techniques and to assess if the current state of knowledge is adequate to develop and implement a longitudinal joint density specification and b) Phase 2: If the current state of knowledge proved inadequate, then a field-testing program would be carried out to establish the needed knowledge base for the development and implementation of a longitudinal joint specification. This report summarizes the findings and recommendations of the first phase of the research.

II. REVIEW OF EXISTING SPECIFICATIONS

The first task of this research was to review the current specifications on the construction and density requirements for longitudinal joint of Hot Mix Asphalt (HMA) pavements. The specifications from all fifty Departments of Transportation (DOT), the local Regional Transportation Commissions, and the Federal Aviation Administration (FAA) were reviewed. The review covered the following issues:

- Joint density specifications
- Joint geometry recommendations
- Joint rolling patterns
- Joint density measurement techniques
- Joint density incentives and disincentives

II.1 DOTs Longitudinal Joint Specifications

The review process started with obtaining the specifications for HMA construction from the various agencies. The agencies specifications for mat density, joint density and joint construction techniques are summarized in Appendix A. The agencies that have joint density specifications and joint construction recommendations are presented below.

Alaska

- The density at the longitudinal joint should be a minimum of 91% of the theoretical maximum density (TMD).
- The longitudinal joint density is measured from 3 cores/5000 tons of mix.

Arizona

- The density at the longitudinal joint should be a minimum of 98% of the lab density.
- The longitudinal joint has to be tapered at 4:1 – 6:1 or hot-lapped.
- The slope has to be compacted with a pneumatic roller.
- The joint needs to be pinched during compaction, by overlapping the roller between the hot mat and the cold mat.

California

- The density at the longitudinal joint should be a minimum of 93% of the relative compaction.
- Tapered-notched joint: a ¾” top and bottom notch and a 12” taper.
- Density measurements are obtained from two cores taken every 3500 feet and nuclear measurements every 650 feet (quality control).
- Disincentives are applied for joints with densities less than 93%. The disincentive is determined by the relative compaction of the longitudinal joint section that failed the 93% relative compaction as shown in Table 1.

Table 1 California’s Disincentives Factors for the Longitudinal Joint Density.

Relative Compaction (Percent)	Disincentive Factor	Relative Compaction (Percent)	Disincentive Factor
93.0	0.000	91.4	0.062
92.9	0.002	91.3	0.068
92.8	0.004	91.2	0.075
92.7	0.006	91.1	0.082
92.6	0.009	91.0	0.090
92.5	0.012	90.9	0.098
92.4	0.015	90.8	0.108
92.3	0.018	90.7	0.118
92.2	0.022	90.6	0.129
92.1	0.026	90.5	0.142
92.0	0.030	90.4	0.157
91.9	0.034	90.3	0.175
91.8	0.039	90.2	0.196
91.7	0.044	90.1	0.225
91.6	0.050	90.0	0.300
91.5	0.056		

- If the relative compaction of day’s production is less than 90 percent, placement of the tapered notched wedge shall be suspended until the contractor demonstrates that the required relative compaction is once again accomplished.

Colorado

- The target density at the longitudinal joint should be 92% of the TMD, with a tolerance of $\pm 4\%$.
- If the mat is thinner than 1.5” a vertical joint is recommended.
- For mats thicker than 1.5”, a joint with 1.5” vertical notch followed by a 3:1 taper should be used.
- Density measurements are obtained from one 6” core for every 5000-foot pavement section. The core is obtained over the center of the longitudinal joint.

Connecticut

- For mats thicker than 1.5” the joint density should be between 90 – 97% of TMD.
- The longitudinal joint should be compacted from the cold side with 1-2” overlap and gradually shifting toward the hot side.
- Disincentives are applied as shown in Table 2.

Table 2 Connecticut’s Percent Payment based on the Longitudinal Joint Density.

Average Density (%TMD)	Percent Payment
100 – 98	97.5
97 – 90	100.0
89 – 87	97.5
86 – 84	90.0
82 or less	70.0

Idaho

- Currently, there is no density specification for longitudinal joint but measurements are being performed to ensure integrity.
- Tapered joints: 18” wide for 2.5” mat or less,
 24” wide for mat thicker than 2.5”
 24” wide for all overlays
- Density readings are collected with a nuclear gauge.

Kentucky

- The density at the longitudinal joint should be 89% - 96% of TMD.
- The specification calls for two cores at the longitudinal joint, for every 1000 tons of mix placed.
- The cores should be cut within 2.5 - 3.5” from the joint.
- Incentives and Disincentives are applied as summarized in Table 3.

Table 3 Kentucky’s Percent Payment based on the Longitudinal Joint Density.

Average Percent Density	Percent Payment
<87.0	0.75
87.0 – 87.9	0.90
88.0 – 88.9	0.95
91.0 – 96.0	1.05
89.0 – 90.9	1.00
96.1 - 96.5	0.95
96.6 – 97.0	0.90
> 97.0	0.75

Missouri

- The density at the longitudinal joint should be a minimum of 94% of Marshall density.
- Joint density is measured by nuclear gauge placed within 6” of the joint.
- Vertical face joint is specified.

Pennsylvania

- The density at the longitudinal joint should be a minimum of 90% of TMD for tapered joints.
- The longitudinal joint has to be compacted from the hot side with 1-2 inches overlap.
- Cores are used to measure the longitudinal joint density.
- A minimum of three cores per subplot or three cores per day is required. A lot is defined as the daily production of placed mix, and it is divided into three equal sublots.

Texas

- The density at the longitudinal joint should be within 48 kg/m³ of the mat density

- Nuclear gauge reading within 8” of the longitudinal joint are compared with measurement at 24” from the joint (mat readings).

Washington

- The density at the longitudinal joint should be a minimum of 91% of TMD for hot-lapped joints.

Federal Aviation Administration

- The density at the longitudinal joint should be a minimum of 92.4% of TMD
- Joint density is measured on four cores (4” or 6”) / 2000 tons of placed mix.
- Incentives and disincentives are applied as shown in Table 4.

Table 4 Federal Aviation Administration’s Percent Payment based on the Longitudinal Joint Density.

Average Percent Density	Percent Payment
Above 92.5	100
92.4	100
92.3	99.9
92.2	99.8
92.1	99.6
92.0	99.4
91.9	99.1
91.8	98.7
91.7	98.3
91.6	97.8
91.5	97.3
91.4	96.3
91.3	94.1
91.2	92.2
91.1	90.3
91.0	87.9
90.9	85.7
90.8	83.3
90.7	80.6
90.6	78.0
90.5	75.0
Below 90.5	0.0 (reject)

II.2 Nevada DOT Longitudinal Joint Specification

The current NDOT longitudinal joint density requirements are stated in Test Method: Nev. T335F and the Memorandum dated April 14, 2003. The specifications call for the following controls and measurements:

- Test Segments: 6,000 yd² for the first two days of construction and 13,000 yd² after two days of construction.
- Density measurement location: the test segment is divided into 5 subsections, and density measurements are performed at random locations within each subsection for the mat and the hot side joint (confined edge).
- Density measurement method: Nuclear gauge placed parallel to the joint and then rotated 180 degrees. The average of both readings is reported as the density of the subsection.
- Density requirements: minimum 90% of TMD (90-97% for the mat).

The NDOT longitudinal joint specification has been implemented on several projects. Table 5 summarizes the measured joint densities as they compare to the mat density on five recent NDOT projects.

Table 5 Summary of Joint and Mat Densities on NDOT Projects.

Project	Joint Density (%TMD)			Avg. Mat Density (%TMD)
	Min.	Avg.	Max.	
3140	86.6	90.3	93.4	93.2
3143	90.7	93.1	96.9	92.5
3084	80.0	89.8	93.3	93.4
3043	85.4	91.8	95.9	93.2
3127	89.5	92.1	96.2	93.2

The NDOT data showed that joint density ranges from as low as 85 percent to as high as 96 percent of TMD. In addition, on the average, joint density is within 2-3 percent of the mat density. Therefore, it can be seen that obtaining a high joint density is achievable.

II.3 Washoe-RTC Longitudinal Joint Specification

In 2002, the Washoe-RTC started implementing a shadow specification for joint density. The following is a summary of RTC's longitudinal joint density specification.

- Test Segment: 1,000 foot length.
- Density measurement: conduct nuclear density measurement every 200 feet on both sides of the joint. Identify the side with the lowest mean joint density (either hot or cold sides). Cut one core (4" or 6") at a location coinciding with the nuclear gauge measurement from the side with the lower means joint density. The center of the core should be 6" from the joint.
- Table 6 summarizes the incentives and disincentives currently used by Washoe-RTC and Table 7 summarizes the joint densities measured on RTC's projects while implementing the shadow specification.

Table 6 Incentives and Disincentives Applied to RTC Projects Based on the Longitudinal Joint Density.

Joint core results In-place air voids (%)	Incentives or disincentive factor
< 3	0 %
3 – 8	+5 %
8 – 11	0 %
11 – 14	-5 %
> 14	-50 %

Table 7 Summary of Joint and Mat Densities on RTC Projects.

Project	Cores Joint Density (%TMD)			Avg. Mat Density (%TMD)
	Min.	Avg.	Max.	
Longley Lane	88	91	94	
Baker/Coleman	87	90	93	93
Evans/Ninth	92	93	95	94
E. Prater/Howard	89	91	93	
Vista II	90	91	93	93
7 th Street	92	92	93	
Red Rock	89	91	93	
S.W. McCarran	88	91	95	

The data in Table 7 indicates that the average joint density on the majority of the projects fall within the range of 0% incentive. The minimum and maximum joint density data indicate that a large variability is encountered on most projects with percent air voids ranging from 5 to 13 percent.

III. REVIEW OF PREVIOUS RESEARCH EFFORTS

This effort reviewed the previous research studies that have been conducted to evaluate the effectiveness of the various joint geometries and compaction techniques. Most studies evaluated the impact of the various techniques on the joint density and its performance. A total of four studies were reviewed and are summarized below.

III.1 National Center for Asphalt Technology (NCAT)

In 1992, NCAT started a series of research projects for the National Asphalt Pavement Association (NAPA) to assess the most effective method to construct longitudinal joints on HMA pavements (1,2,3,4). The objectives of the studies were to compare various joint geometries and compaction techniques, and recommend the techniques that would improve long-term performance of longitudinal joints.

Field projects were constructed and evaluated in Pennsylvania, Michigan, Wisconsin, and Colorado. The data obtained from the Michigan project were unclear. For most of Michigan's sections, the density at the longitudinal joint is higher than the density of the mat, indicating that additional compaction occurred at the joint. Such pattern is not representative of a normal construction process. For this reason, the results from the Michigan project were not included in this review.

Wisconsin Project

The project in Wisconsin was constructed in October 1992 on State Route 190 (Capitol Drive) in Brookfield. Eight longitudinal joint construction techniques were evaluated. Each test section was 500 feet long. Longitudinal joint density was evaluated through cores and nuclear readings. For each section, 6 inches diameter core samples were obtained at five different locations, about 100 feet apart. Two cores were obtained at each location; one right at the joint and the other at about 2 feet away from the joint in the hot lane. No cores were obtained from the cold lane. The nuclear readings were used to supplement the limited core data. For each test section, nuclear readings were obtained at 9 locations, about 50 feet apart. At each location, nuclear density was measured at the joint, and 1 foot away from the joint on the cold side.

Colorado Project

The project in Colorado was constructed in July 1994 on Interstate 25 just north of Colorado Springs. The project consisted of a 4 inches thick wearing course. Seven longitudinal joint construction techniques were evaluated. Each test section was 500 feet long. Longitudinal joint density was evaluated from cores. For each section, 6 inches diameter core samples were obtained at six different locations. At each location 3 cores were obtained, one right at the joint and the others at about 1 foot away from the joint on either sides (cold and hot lanes).

Pennsylvania Project

The Pennsylvania project was constructed in September 1995 on State Route 441 (section 004) in Lancaster County. The project consisted of a 1.5 inches wearing course. Eight

longitudinal joint construction techniques were evaluated. Each test section was 500 feet long. Longitudinal joint density was evaluated from cores. The cores were obtained right at the joint and at about 12 inches away from the joint on the cold side. There is no record of the number of locations measured within each test section.

Field Performance

The performance of the different construction techniques was conducted through annual visual evaluations. The evaluating team consisted of at least four engineers. The overall rating considered the length of the joint with cracks, the average width of the crack, and the length and severity of the raveling observed in the mat adjacent to the joint. The observation period for the performance evaluation was not the same for all the projects.

Tables 8 and 9 summarize the compaction techniques and joint geometries that have been evaluated in the NCAT study. Table 10 summarizes the impact of the various techniques on the density and the long-term performance of the longitudinal joint.

Table 8 Description of Rolling Techniques Evaluated in the NCAT Studies.

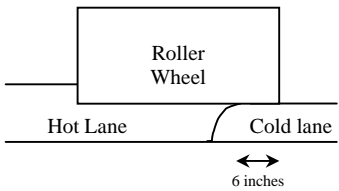
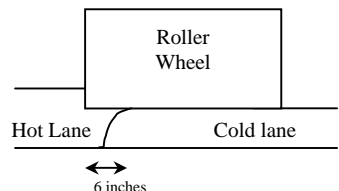
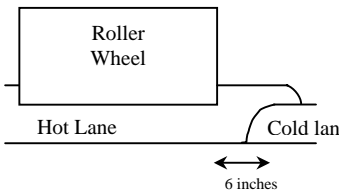
Rolling Technique	Description	Diagram
Rolling from hot side	Compaction is done from the hot side of the lane being constructed. The major portion of the roller is on the hot side, with just an overlap of about 6 inches on the cold lane.	 <p>The diagram shows a rectangular roller wheel positioned over a horizontal line representing the joint between a hot lane (left) and a cold lane (right). The roller wheel overlaps the cold lane by 6 inches, as indicated by a double-headed arrow and the text '6 inches' below the cold lane section.</p>
Rolling from cold side	Rolling is done with the major portion of the roller on the cold lane, with just an overlap of 6 inches on the hot lane. Timing is critical, because while rolling the joint from the cold side, the rest of the mat is cooling down.	 <p>The diagram shows a rectangular roller wheel positioned over a horizontal line representing the joint between a hot lane (left) and a cold lane (right). The roller wheel overlaps the hot lane by 6 inches, as indicated by a double-headed arrow and the text '6 inches' below the hot lane section.</p>
Rolling from hot side at 6 inches away from the joint	Compaction is done from the hot lane, but at a distance of 6 inches away from the joint. A pushing of the material towards the joint is achieved by this rolling procedure. It is recommended for tender mixes or thick lifts.	 <p>The diagram shows a rectangular roller wheel positioned on the hot lane, 6 inches away from the joint. A curved arrow indicates the material being pushed towards the joint. A double-headed arrow and the text '6 inches' below the hot lane section indicate the distance from the roller to the joint.</p>

Table 9 Description of Joint Geometries Evaluated in the NCAT Study.

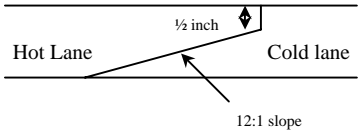
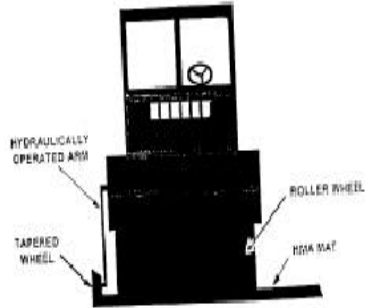
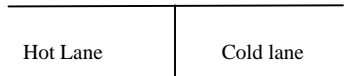
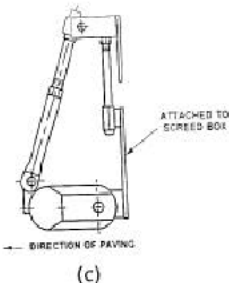
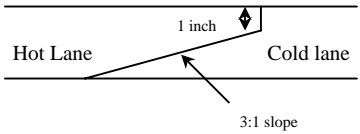
Joint Geometry	Description	Diagram
Tapered (12:1) joint with ½ inch top notch without tack coat (Michigan Wedge)	A taper is formed during the placement of the cold lane, by attaching a steel plate to the paver screed. A ½ inch notch is made at the top of the taper. The roller is kept 2 inches from the joint. The taper is compacted with a small roller attached to the paver. This tapered face is not tack coated.	
Tapered (12:1) joint with ½ inch top notch with tack coat (Michigan Wedge)	Same as the above technique with a tack coat is applied to the tapered face of the cold lane.	
Edge restraining device	This device provides lateral restraint at the edge of the cold lane, during its compaction. It consists of a hydraulically powered wheel which rolls alongside the compactor's drum simultaneously pinching the unconfined edge of the mix towards the drum providing lateral resistance. It is believed that this technique improves the density of the unconfined edge. Final compaction is performed by rolling from the hot side.	
Cut face with tack coat	The edge of the cold lane is cut to a vertical face. The cut face is tack coated before the placement of the adjacent hot lane. Compaction is performed by rolling from the hot side.	
Cut face without tack coat	Same as above, but no tack coat is apply to the vertical face.	
Joint Maker	This technique uses an automated joint construction device attached to the screed. Additional material is forced at the joint and a kicker plate attached to the paver pushes back the overlapped mix. The compaction of the joint is performed from the hot side.	
Tapered (3:1) with vertical 1.0 inch top notch	The tapered slope (3:1) and the 1.0-inch notch are formed during the placement of the cold lane, by attaching a steel plate to the paver screed. Only tack coated taper surface before the placement of the next lane. The compaction of the joint is done from the hot side.	

Table 9 Description of Joint Geometries Evaluated in the NCAT Study (continued).

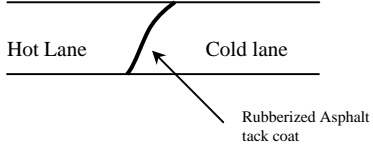
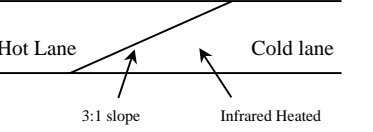
Joint Geometry	Description	Diagram
Rubberized asphalt tack coat	Any taper or special section is formed at the unconfined edge of the cold lane. A rubberized asphalt tack coat (Crafco pavement joint adhesive Part # 34524) is applied to the cold lane edge before placing the next lane. The thickness of tack coat is 1/8 in. Compaction is done from the hot side.	
New Jersey wedge	A 3:1 taper is formed by a sloping steel plate attached to the paver screed extension. During the placement of the hot lane, an infrared heater is used to heat the edge of the cold lane to a surface temperature of 93°C. The adjacent lane is placed with an overlap of 2-3 inches, it is luted back, and the compaction is done from the hot side.	

Table 10 Impact of Various Techniques on the Density and Performance of the Longitudinal Joint.

State	Joint Density		Joint Performance	
	Best	Worst	Best	Worst
Pennsylvania	Edge restraining device	New Jersey wedge 3:1	Rubberized asphalt tack coat	Rolling from the cold side
Wisconsin	Vertical face cut	Wedge Joint without tack coat	Edge restraining device	Rolling from the cold side
Colorado	Tapered 3:1 with vertical 1" offset	Rolling from the hot side	Tapered 3:1 with vertical 1" offset	Rolling from the cold or rolling from the hot side

The NCAT study presented the joint density and performance data generated by each technique (Appendix B), but it did not clearly identify the most effective technique. Their final recommendations were provided in the following general statements:

- The performance of the longitudinal joint appears to be influenced by the overall density achieved at the longitudinal joint.
- The joint density should be within 2% of the mat density.
- Cores should be used to measure joint density. Nuclear gauge is impractical.

III.2 Quality Engineering Solutions

In 2000, Quality Engineering Solutions (QES) conducted a research study for the Regional Transportation Commission (RTC) in Washoe County, Nevada (5). The objective of this research was to investigate the relationship between poor longitudinal compaction and poor joint performance.

A total of 52 longitudinal joints were evaluated on 39 different projects. The projects included new and reconstructed pavements and overlays within the Truckee Meadows. The study conducted a visual distress evaluation for the longitudinal joint and the overall pavement condition, and a nuclear density evaluation of the longitudinal joint and the pavement mat.

Twelve nuclear density measurements were taken for each of the 52 longitudinal joints studied. At each location, density readings were performed on the longitudinal joint and within the pavement mat outside the wheel-path. Two replicates were obtained for each point, and if they differed by more than 2.0 pcf, a third replicate was performed.

The distress identification evaluated the existing distress conditions of the 52 test sections. The typical joint distresses identified include:

- Open surface condition
- Surface raveling with aggregate loss
- Longitudinal joint opening and secondary cracks
- Breakup and missing material of the surface adjacent to the longitudinal joint
- Maximum width of longitudinal joint separation

Also a pavement serviceability rating was obtained while performing the density data collection.

A statistical analysis was performed to identify the differences between the longitudinal joint and the mat densities. A regression data analysis was performed, including joint deterioration value, pavement condition, age, traffic, and pavement density. This regression analysis provided strong evidence of the importance of the relationship between the joint condition and the joint density.

Some elements contributed to the high variability of the density measurements. The lack of knowledge of the exact construction technique used, as well as the impossibility to determine which was the hot or the cold side of the joint, were some of the main elements that affect negatively the data analysis.

Their analysis of the field data provided the following observations:

1. More than 80% of the longitudinal joints studied had joint densities inferior to the mat densities (i.e. less than 100% of mat density).
2. Less than 50% of all longitudinal joints studied had joint density higher than 98% of the mat density.
3. Pavements with low density are more likely to experience early joint distress.

4. Pavements with joint distress show greater variation in the measured densities than that of pavements without joint distress; both at the joint and at the mat.
5. Joint distress was observed in several relatively young sections (2 - 3 years old) showing no other appreciable roadway distress. This is considered premature joint cracking.
6. Several older sections (7 to 9 years old) exhibit almost no joint cracking and no observable joint related pavement distress.

The data generated for the research did not identify whether the density was measured on the cold or the hot side. This made it difficult to identify the source of the problem i.e. joint density or compaction technique. Figure 1 shows typical data of the ratio of the joint density over the density of the mat along the project length. This data shows high variability of joint density along the project.

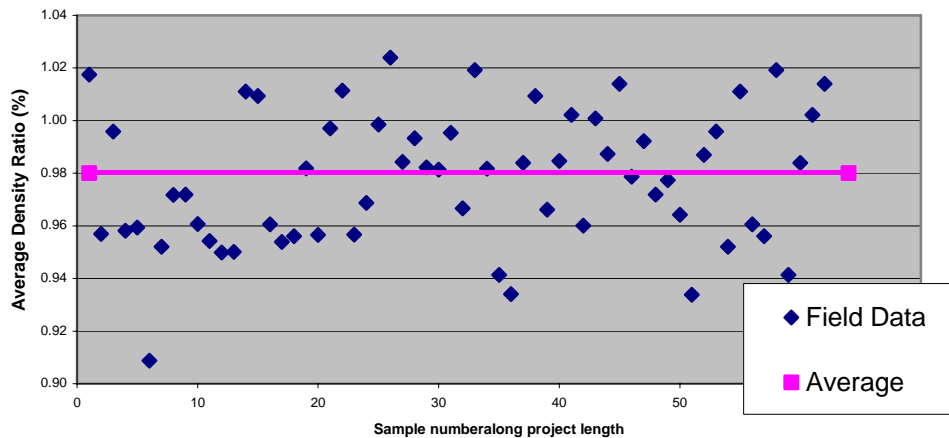


Figure 1 Ratio of joint density over mat density at various projects.

The final recommendations and conclusions of the QES study are summarized below.

1. A definite relationship exists between longitudinal joint quality, longitudinal joint distress, and the overall rate of pavement deterioration.
2. Pavement with superior joint construction result in longer pavement performance life, reduced life cycle cost, and increased cost effectiveness.
3. Sections without joint distress exhibit higher overall pavement density.
4. Sections without joint distress exhibit lower variation between joint and mat density.
5. Placement of increased emphasis on the quality of pavement joint density is warranted.
6. Both between sections and within sections variability demonstrate the current lack of emphasis on joint construction quality as measured by the joint density.

7. Commonly recognized performance factors of pavement age and traffic have a major influence on this set of pavements.

III.3 Texas Transportation Institute

In 2001, the Texas Transportation Institute of the Texas A&M University conducted a research project for the Texas Department of Transportation to evaluate the joint density of various field projects, in order to quantify the need to implement a longitudinal joint density specification in Texas. A total of thirty-four projects throughout the state of Texas, were evaluated for this research. For each project, density measurements were performed at five different locations. There is no information about the procedure used to determine these locations. All the projects correspond to overlays of 1.5 to 2 inches thick.

Nuclear density measurements were conducted using a thin lift nuclear, transversely across the paved lane at the unconfined pavement edge, 6, 12, and 24 inches away from the unconfined edge, 6 inches from the joint at both sides, on top of the joint, and in the middle of the lane. Additionally, cores were obtained near the unconfined edge and in the middle of the lane, corresponding to the nuclear reading locations. The cores were used to calibrate the nuclear readings and to evaluate their permeability.

There is no description of the longitudinal joint geometry or rolling technique applied during the construction of these field projects. Table 11 and Figure 2 summarize the differences between the density at the middle of the mat and the density at various lateral offsets from the unconfined edge.

Table 11 Differences between Mat Density and Density at Various Lateral Offsets from the Unconfined Edge in kg/cm³.

Type of Pavement\ Relative Density	A 0.5 ft from unconf. edge	B 1 ft from unconf. edge	C 2 ft from unconf Edge	D Middle of mat	E 0.5 ft from joint hot side	F on top of joint	G 0.5 ft from joint cold side
C - Limestone	-6.06	-4.92	-2.15	0.00	-3.06	-11.71	-4.91
C - Gravel	-5.32	-1.50	-0.03	0.00	-0.33	-8.03	-5.16
D	-4.49	-2.13	0.17	0.00	-0.73	-5.74	-3.63
CMHB	-5.29	-2.80	-1.24	0.00	-0.29	2.60	-5.59
Superpave	-4.02	-0.19	1.04	0.00	-2.77	-5.61	
SFA	-4.88	-3.78	-0.78	0.00	-1.70	-7.30	-4.88
SMA				0.00	0.80	-7.59	-2.90
Heavy Duty SMA		-1.48	-0.63	0.00	-1.08	-6.04	-5.51
Mean	-4.80	-1.98	-0.24	0.00	-0.87	-5.39	-4.61
Std Dev.	0.55	1.24	0.81	0.00	1.14	3.65	1.10

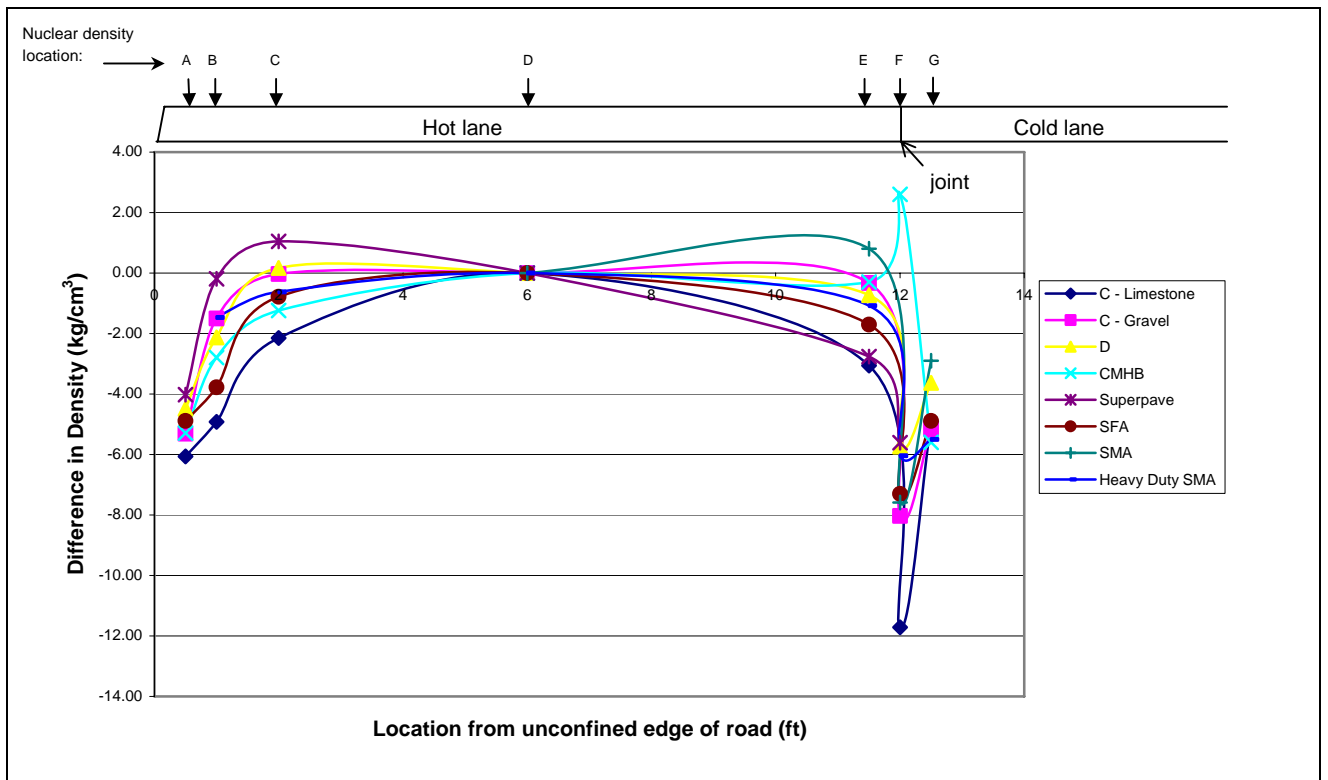


Figure 2 Relative density values obtained for the different type of pavements evaluated in Texas.

The final findings and recommendations provided by the Texas Transportation Institute were the followings:

- The study concludes the existence of a problem with the density along the longitudinal joint and that a joint density specification for HMA pavements construction is justified.
- The edge of the lane paved first (unconfined edge) corresponds to an area of consistently low density, 6 to 7 lbs per cubic ft (4 to 5 %) lower than the mat density.
- For the dense-graded mixes, the permeability was higher for the cores taken near the unconfined edge compared to those from the middle of the lane.

III.4 New Jersey Department of Transportation

In 1982, the New Jersey Department of Transportation determines the necessity of improving the longitudinal joint density and initiated this experimental project. The objective of this research was to compare the wedge joint (3:1) with the conventional angle of repose joint. Five overlay projects were selected for this density research, but just three of them included a wedge and a conventional joint. The other two evaluated the density obtained for the wedge joint configuration. The longitudinal joint density was

measured by means of nuclear readings. They were taken directly over the joint and 1 foot away from it at both sides.

The conventional (New Jersey butt-type) butted joint corresponded to the repose angle of the material, left under normal construction techniques by the paver. An overlap of 2 to 4 inches was used for the placement of the second mat. The overlapped material was pushed back, creating a bump and followed by normal compaction. The wedge joint consisted of a 3:1 inclined face, obtained by placing a sloping steel plate in the inside corner of the paver screed extension. The mat was rolled to the top of the unconfined edge, not extending more than 2 inches past the top of the unconfined edge. The inclined face was not compacted. Additionally, the wedge edge of the cold lane was softened by means of an infrared heater before the placement of the second lane (hot lane). An overlap of 2 to 3 inches was used, and the material was pushed back and compacted with no special rolling technique. Figures 3, 4, and 5 summarize the density measurements obtained for the wedge joint and the conventional butted joint, for the three field projects evaluated in this research.

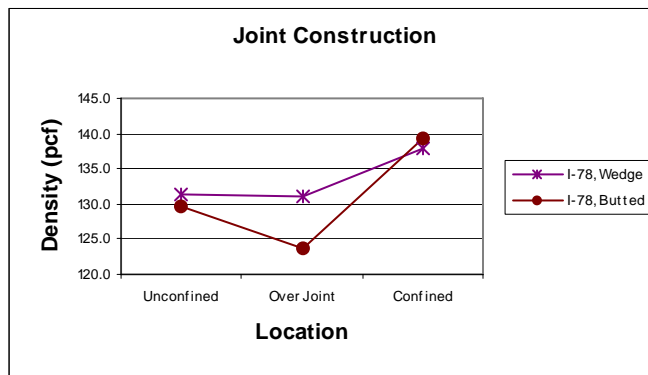


Figure 3 Comparative density measurements for route I-78, New Jersey.

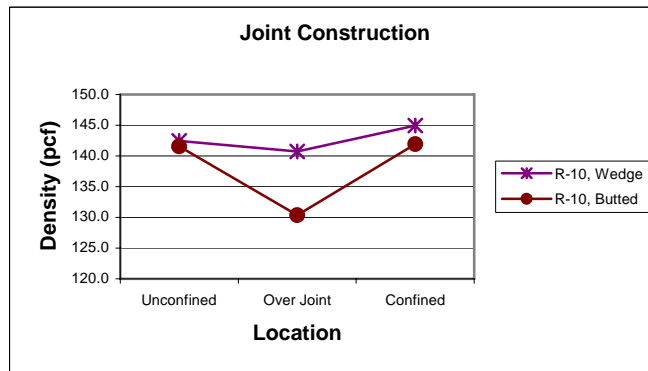


Figure 4 Comparative density measurements for route R-10, New Jersey.

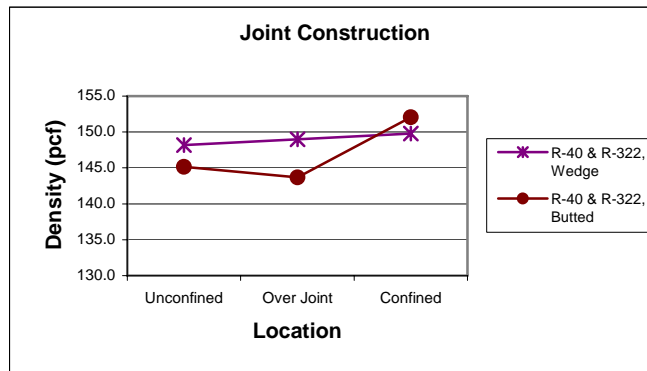


Figure 5 Comparative density measurements for routes R-40 and R-322, New Jersey.

The final conclusions obtained from this research were provided in the following statements:

- Wedge joint technique produces higher, more uniform density than the conventional butt joint technique.
- The wedge joint provides a joint more resistant to opening under the effect of traffic and weathering, because of the density improvement and the elimination of the vertical shear plane.
- After 5 years, the wedge joint construction on five projects shows none of the deterioration or raveling observed in the standard butted joint.
- The wedge joint, by eliminating the vertical plane, improves the safety of motorist lane changes.
- Additionally, supplemental heating eliminates the need to pull back the paver to avoid cold joints, increasing flexibility and production capability. It also provides a better riding quality by reducing the amount of transversal joints in the surface course.

IV. SUMMARY AND FINDINGS

The literature review conducted under this research effort covered two major categories: a) the longitudinal joint specifications of the various agencies, and b) the previous research effort on the subject of longitudinal joint density. As a result of this review the following findings can be summarized.

Agencies Specifications

- Ten state highway agencies and the FAA have formal specifications for longitudinal joint density.
- The majority of the current longitudinal joint density specifications call for either a percent of theoretical maximum density or a relative density.
- Only four highway agencies specify the longitudinal joint geometry.
- Only three highway agencies specify the compaction technique at the longitudinal joint.
- Only three highway agencies apply incentives/disincentives based on the density of the longitudinal joint.

Previous Research Efforts

- Numerous longitudinal joint geometries were evaluated through field studies conducted by the National Center for Asphalt Technology. However, the research did not identify an optimal method for joint construction.
- The studies conducted by Quality Engineering Solutions in Nevada and the Texas Transportation Institute in Texas identified the urgent need for specifications on the longitudinal joint density.
- The study conducted by the New Jersey DOT showed that the wedge geometry of the longitudinal joint would provide better performance than the vertical face geometry.

V. RECOMMENDATIONS

Based on the review of the specifications currently used by the various agencies and the previous research efforts, the following two recommendations were made.

- Implement an interim longitudinal joint specification on some current NDOT projects.
- Conduct a field experimental program to evaluate the longitudinal joint geometry and compaction techniques under Nevada's conditions.

V.1 Interim Specification

Based on the review of the available longitudinal joint specifications and research studies on this subject, the following interim specification was recommended.

- Follow the normal procedure for measuring the mat density: a) use a test segment of 6,000 yd², b) subdivide the segment into five subsections, and c) select a random location for mat density measurement.
- Measure the longitudinal joint density at the same random location selected for the mat density:
 - Use the nuclear density gauge to measure the density at both the hot and cold sides of the longitudinal joint.
 - For density measurements calculations: a) for the hot side, use the maximum theoretical density (TMD) corresponding to the hot mat location and b) for the cold side, use the TMD corresponding to the station on the cold mat location.
 - Conduct two nuclear gauge density measurements on the hot and cold sides of the joint. The two measurements should be parallel to the joint and 180 degrees apart. Average the two density measurements from each side and record them as the hot-side and cold-side densities, respectively.
 - Identify the joint side (e.g. hot side or cold side) with the lower nuclear density.
 - Cut a core (4" or 6") from the joint side with the lower density.
 - Measure the density of the core.
- Check the density of the core against the following limits:
 - Maximum of 2% less than the corresponding mat density.

AND

- Minimum of 90% of theoretical maximum density at the specific location.

The researchers recommended that NDOT implements this interim joint density specification on several HMA construction projects and start collecting joint density data as prescribed in this interim specification. The implementation of the recommended interim specification will provide valuable data on the density of the cold joint, the comparison of the nuclear density and core density, and the ability of the contractors to meet the specification limits using conventional construction practice.

V.2 Field-Testing Program

The objective of this field-testing program is to evaluate the effectiveness of the various joint geometries and compaction techniques in increasing the joint density and providing improved performance. The proposed field-testing program calls for the evaluation of five joint geometries and two compaction techniques. The following presents a description of the techniques recommended for field evaluation. The lane paved first is referred as the “cold side” and the lane paved second is referred to as the “hot side”

Joint Geometry

The joint geometry will be formed during the construction of the first lane. A total of five joint geometries are recommended for field evaluation. Each joint geometry will be constructed over a minimum of 700 feet long test section. The following represents a description of the recommended joint geometries.

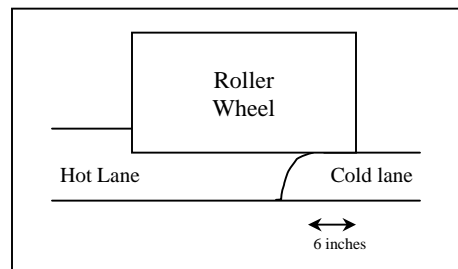
- ***Natural Slope:*** the HMA mix is left on its natural angle of repose as is achieved by the paving process.
- ***Edge Restraining Device:*** this device provides lateral support at the edge of the first paving lane during compaction. It consists of a hydraulically powered wheel which rolls alongside the compactor’s drum simultaneously pinching the unconfined edge of the mix towards the drum and provides lateral support. Previous experience with this technique showed it to provide high joint density. The cost of the equipment and installation will be around \$8500. It is recommended that a technical representative of the equipment manufacturer be present at the site during the construction of the test section.
- ***Cut Edge with Rubberized Asphalt Tack Coat:*** the edge of the first paving lane is cut to a vertical face after the compaction of the mat is completed. In this technique, the vertical cut face is tack coated with rubberized asphalt. Previous experience with this technique provided good joint performance. The rubberized asphalt has an estimated cost of \$0.61/lb. The supplier suggested an application of 0.62lb/ft. The total cost of the rubberized asphalt for the four projects will be around \$1500. It is recommended that technical representatives from the equipment manufacturer and the rubberized tack coat supplier be present at the site during the construction of the test section.

- ***Cut Edge without Rubberized Asphalt Tack Coat:*** the edge of the first paving lane is cut to a vertical face after the compaction of the mat is completed. In this technique, the vertical cut face is not tack coated. It is recommended that a technical representative of the equipment manufacturer be present at the site during the construction of the test section.
- ***Tapered Joint at 3:1:*** the edge of the first paving lane is tapered at a 3:1 slope with a 1/2" notch at the end of the taper. The taper is achieved through a steel plate connected to the paver. No special compaction effort is placed on the tapered edge. Previous experience with this technique showed good performance. It is recommended that a technical representative of the equipment manufacturer be present at the site during the construction of the test section.

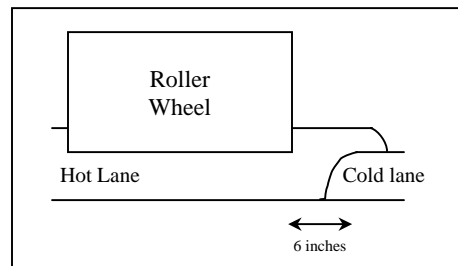
Joint Compaction Technique

The joint compaction technique will be followed during the construction of the second lane. Two joint compaction techniques will be evaluated on each of the five joint geometries. The following represents a brief description of the joint compaction techniques recommended for evaluation.

- ***Pattern I - Rolling from the Hot Side with 6" Overlap on the Cold Side:*** as shown below, compaction is started from the hot side of the joint (i.e. first pass). The major portion of the roller is on the hot side with just an overlap of about 6" on the cold side.



- ***Pattern II – Rolling from the Hot Side at 6" away from the Joint:*** as shown below, compaction is started from the hot side of the joint (i.e. first pass). The roller is kept at 6" away from the joint. This rolling procedure tends to push the loose HMA mix towards the joint.



Compaction of the First-Paved Lane

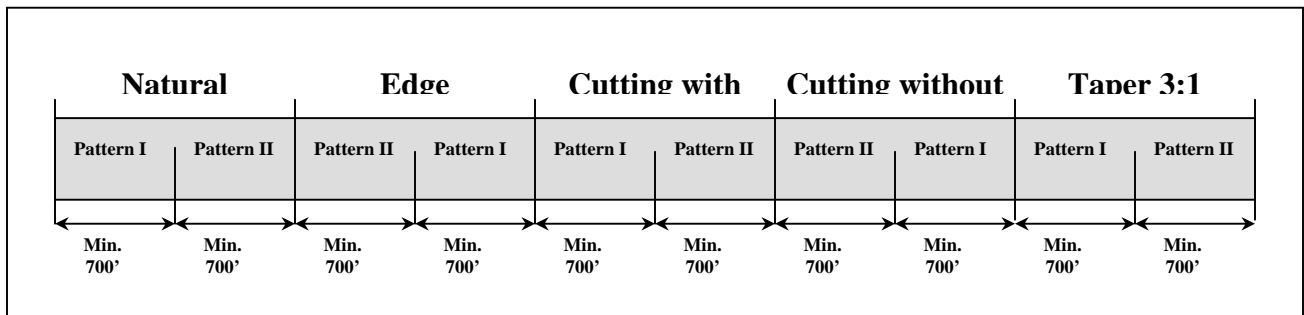
The first-paved lane will include an unsupported edge at the location where it will meet the second-paved lane forming the longitudinal joint. The first-paved lane should be compacted with the roller having 2" hang over the unsupported edge.

Sections Layout

Total number of sections: 5 (joint geometry) x 2 (compaction techniques) = 10.

Section length: Minimum 700 feet or a half-day production. The exact length of the section will be decided once a field project is selected.

Layout of Test Sections



Number of Projects

It is recommended to implement the testing plan on a minimum of two projects: one in the north and one in the south. The two projects will ensure the implementation under the various materials and environmental conditions throughout the state.

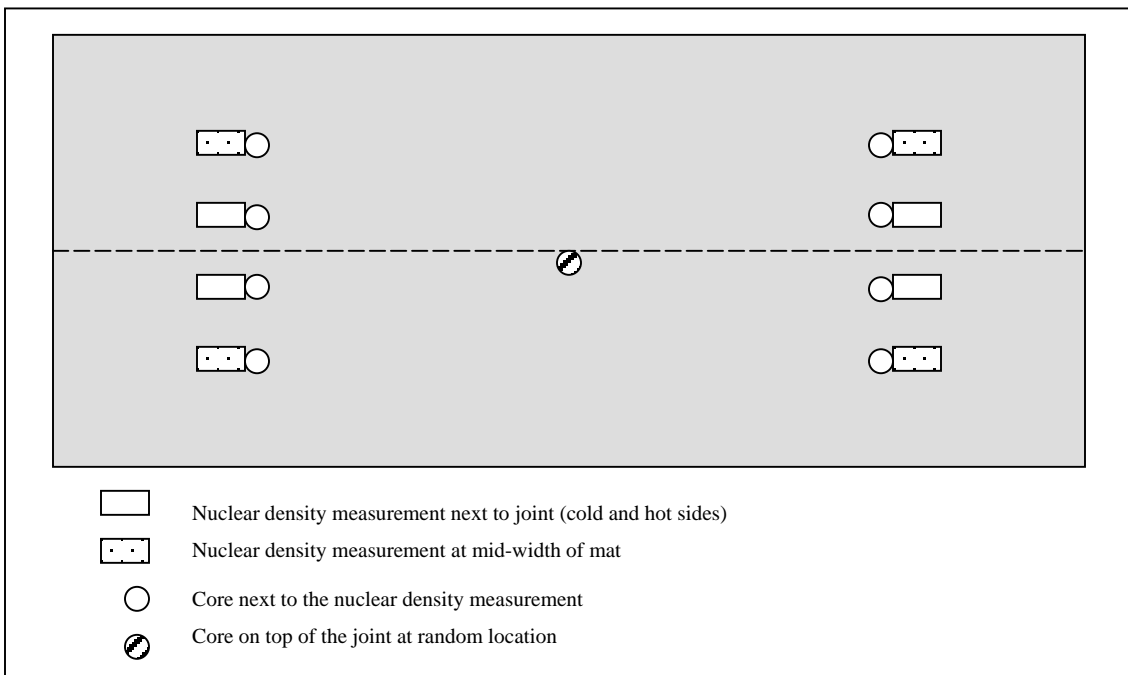
Density Measurements

The density of the joint achieved during the construction of the test sections will be used to assess the effectiveness of the various techniques. The long-term performance of the joint also will be used to evaluate the long-term effectiveness of the techniques. The following density measurement plan is recommended for the field sections.

- Conduct nuclear density measurement at the cold side and hot side of the joint at 10 locations within each test section. At each side, take two readings parallel to the joint and 180 degrees apart. Average both readings and record them as the hot and cold side densities. The nuclear gauge should be placed as close to joint as possible.
- Conduct nuclear density measurement at the mid-width of the cold side and hot side of the mat at the same 10 locations where the joint densities are measured. At each location take four readings 90 degrees apart. Report the average of the four readings as the density of the cold and hot sides.

- Cut a 4” core at each location that a nuclear density measurement is taken (i.e. at both the joint and the mid-width of the mat). A total of 40 cores will be obtained from each section.
- Cut a core (4” or 6”) on top of the joint at three random locations within each section.

Density Measurement Diagram



VI. REFERENCES

1. Kandhal, Prithvi S. and Rao, Shrinidhar S. *Evaluation of Longitudinal Joint Constructions Techniques for Asphalt Pavements (Michigan and Wisconsin Projects – Interim Report)*. National Center for Asphalt Technology. Report No. 94-1. January 1994.
2. Kandhal, Prithvi S. and Mallick, Rajib B. *A Study of Longitudinal Construction Techniques in HMA Pavements (Interim Report – Colorado Project)*. National Center for Asphalt Technology. Report No. 96-3. February 1996.
3. Kandhal, Prithvi S. and Mallick, Rajib B. *Longitudinal Joint Construction Techniques for Asphalt Pavements*. National Center for Asphalt Technology. Report No. 97-4. August 1997.
4. Kandhal, Prithvi S.; Ramirez, Timothy L.; and Ingram, Paul M. *Evaluation of Eight Longitudinal Joint Construction Techniques for Asphalt Pavements in Pennsylvania*. National Center for Asphalt Technology. Report No. 2002-03. February 2002.
5. Morian, Deniss A.; Frith, Douglas J.; and Stoffels, Shelley M. *Longitudinal Asphalt Pavement Joint Construction Effect on Pavement Performance*. Developed for the Regional Transportation Commission of Washoe County. July 2000.

APPENDIX A

STATE HIGHWAY AGENCIES HMA DENSITY SPECIFICATION

Agency	Density Specifications		Construction Specifications		
	Mat	Longitudinal Joint	General	Geometry	Compaction
Alabama	Target density is 94% of theoretical maximum density.		1) Longitudinal joints in the wearing surface shall conform to the edges of proposed traffic lanes 2) Any necessary longitudinal joints in underlying layers shall be offset so as to be at least 6 inches (150 mm) from the joint in the next overlying layer.	Angle of repose of 1:1.	The longitudinal joint shall be rolled in the first pass.
Alaska	Target value is 94% of the maximum specific gravity	Above 91% of maximum specific gravity	1) Offset the longitudinal joints in one layer from the joint in the layer immediately below by at least 6 inches. Align the joints of the top layer at the centerline or lane lines.		
Arizona	The target is 98% of lab density.	The density required on the tapered joint is the same as for the rest of the mat.	Longitudinal joints of each course shall be staggered a minimum of 300 millimeters with relation to the longitudinal joint of any immediate underlying course.	Joints shall be formed by a slope shoe or hot lapped. The tapered joint is formed with a shoe attached to the end of the screed to form a slope of about 4:1 to 6:1 beyond the screed	1) The sloped edge has to be compacted using a pneumatic roller. Steel rollers cannot compact the taper. 2) The joint should be pinched while rolling so that there is overlap by the roller between the hot mat and the cold mat.
Arkansas	Compliance Limits: 92.0% to 96.0% of the theoretical density.		The longitudinal joint in one layer shall offset that in the layer immediately below by approximately 6". The longitudinal joint in the top layer shall be at the centerline or at the lane line.		1) When paving in echelon or abutting a previously placed mat, the longitudinal joint shall be rolled first followed by the regular rolling procedure. 2) The slight excess of asphalt at a longitudinal joint, generated by overlapping during placement of an adjacent mat to a previous mat, shall not be scattered across the mat. This material shall be stacked over the joint and pinched into the joint by the first pass of a steel wheel roller running with all but 150 mm to 200 mm (6" to 8") of the drum on the cold mat. Vibrating rollers shall operate in the static mode during this operation.
California (draft specs)	96% of relative compaction	93% of relative compaction	The tapered portion of the mat shall be constructed by use of an approved strike-off device that will provide a uniform slope and will not restrict the main screed. The adjacent mat shall be paved within one working, unless delayed by inclement weather.	Recommended tapered notched joint. The tapered notched wedge shall be 12" wide and with a vertical notched 3/4" at the top and bottom.	
Colorado	92 - 96 percent of the maximum theoretical density	Target density of 92% of the max specific gravity, tolerance: ± 4 percent	The longitudinal joint shall offset the joint in the layer immediately below by 6 inches. The joints in any pavement layer shall not fall in a wheel path. The joints in the top layer of pavement shall be located as follows: (1) For 2-lane roadways, offset 6 to 12 inches from the center of pavement and from the outside edge of travel lanes. (2) For roadways of more than 2 lanes, offset 6 to 12 inches from lane lines and outside edge of travel lanes.	Mat thickness < 1.5 inches - vertical exposed joint. If the thickness is > 1.5 inches, the top 1.5" shall be vertical and, below tapered (Minimum 3:1)	

Agency	Density Specifications		Construction Specifications		
	Mat	Longitudinal Joint	General	Geometry	Compaction
Connecticut	The in-place density: 92 - 97 percent of the maximum theoretical density.	90 - 97 percent of the maximum theoretical density, for layers of 1.5" or thicker.	The longitudinal joint in one layer shall offset the previous joint in the layer immediately below by approximately 6" however, the joint in the top layer shall be at the centerline of the pavement if the roadway comprises two-lane width, or at lane lines if the roadway is more than two lanes in width.		In compacting the joint, the steel-wheel roller shall be shifted onto the cold mat so that only 1 to 2 inches of the drive wheel extends over the uncompacted material. The steel-wheel roller shall continue to roll along this line and its position shifted gradually across the joint until the joint has been rolled with the entire width of the drive wheel. Rolling with steel-wheel and pneumatic-tired rollers shall be continued until a thoroughly compacted, neat joint is obtained. When the vibratory roller is used for breakdown rolling, compacting the joint shall be accomplished with the roller on the hot mat shifted 1 to 2 inches across the joint onto the cold mat.
Delaware	Minimum of 92% of the theoretical maximum density		The material being placed in the abutting lane shall be tightly compacted against the vertical face of the cold mat. The finishing machine shall be positioned so that the spread material overlaps the edge of the cold mat by 1 to 2", and is left sufficiently high to allow for compaction. Before rolling, the material overlapping the joint shall be carefully deposited adjacent to the joint of the hot mat with a lute. When the abutting lane is not placed the same day, or the joint is distorted by traffic or other means, the edge shall be carefully trimmed to line and coated uniformly with tack material. The longitudinal joint in any layer shall offset that in the layer immediately below by approximately 6". However, the joints in the completed surfacing shall be at the lane line.	Vertical face	Longitudinal joints shall be rolled directly behind the laying operations.
Florida	Average in-place lot density of at least 98% of the control strip density.		For all layers of pavement except the leveling course, place each layer so that longitudinal construction joints are offset 6 to 12 inches laterally between successive layers. The Engineer may waive this requirement where offsetting is not feasible due to the sequence of construction.		Where the lane being placed is adjacent to a previously placed lane, pinch or roll the center joint prior to the rolling of the rest of the hot mat.
Georgia	Maximum Air Voids of 7.8%.		Arrange the width of the individual lifts so that the longitudinal joints of each successive lift are offset from the previous lift at least 1 ft. This requirement does not apply to the lift immediately over thin lift leveling courses.		
Hawaii	91 - 96% of theoretical maximum density, for pavement courses of 1-1/2 in or thicker.		The longitudinal joint in one layer shall offset that in the layer immediately below by approximately six inches; however, the joint in the top layer shall be at the centerline of the pavement if the roadway comprises two lanes of width, or are lane lines if the roadway is more than two lanes in width.		When paving in echelon or abutting a previously placed lane, the Contractor shall roll the longitudinal joint first followed by the regular rolling procedures.

Agency	Density Specifications		Construction Specifications		
	Mat	Longitudinal Joint	General	Geometry	Compaction
Idaho	92.0 - 95.0 percent of Maximum Specific Gravity	Density tests may be taken at longitudinal joints to ensure the integrity of material in the joint area.	One cold longitudinal joint will be allowed. On the top course, it shall be at the centerline of the traveled way; on the lower courses it shall be staggered and offset 6 inches to 1 ft from the centerline of the traveled way. The amount of overlap of the new mix on the cold mat should be 1 to 2 inches. Prior to rolling, the overlap shall be bumped back or trimmed back to the joint line.	Tapered joint: The taper shall be 1.47 ft wide for depths 0.2 ft or less. For depths greater than 0.2 ft, the taper shall be 1.96 ft wide. On all pavement overlays, the taper shall be 1.96 ft wide.	When paving in echelon abutting a previously placed lane, the longitudinal joint should be rolled first, followed by the regular rolling procedure.
Illinois	Class I, Type 1 (Min. Stability 2000lb): 92.0 - 96.0 percent of the theoretical maximum density Class I, Type 2 (Min. Stability 1700lb): 93.0 - 97.0 percent of the theoretical maximum density		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. 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 inches. When pavement is placed at a greater width than 12 ft, the profile will be taken 3 ft from and parallel to each edge and each side of the planned longitudinal joint.		When laying the bituminous mixture adjacent to the cold mat, the first pass of the roller shall be along the longitudinal joint on the hot mat with the compression wheel not more than 6 inches from the joint. The second pass of the roller shall overlap the longitudinal joint not more than 12 inches on the cold mat after which the rolling shall proceed from the low side of the transverse slope to the high side, overlapping uniformly.
Indiana	The target is 94.0 ± 2.0 of the Maximum Specific Gravity.		Longitudinal joints in the surface shall be at the lane lines of the pavement. Longitudinal joints below the surface shall be offset from previously constructed joints by approximately 150 mm (6 in.), and be located within 300 mm (12 in.) of the lane line.		Longitudinal joints shall be compacted in accordance with the following: (a) For confined edges, the first pass adjacent to the confined edge, the compaction equipment shall be entirely on the hot mat, 6 inches from the confined edge. (b) For unconfined edges, the compaction equipment shall extend 6 inches beyond the edge of the hot mat.
Iowa	Class IA (intermediate and surface courses for the traffic lanes of Interstate highways): minimum of 96% of laboratory density. Class IB (Interstate and Primary bases, Primary travel lanes intermediate and surface courses): minimum of 95% of laboratory density.		Longitudinal joints for courses on resurfacing projects shall be constructed directly above the longitudinal joint in the existing pavement. The offset distance between longitudinal joints in succeeding courses of full depth HMA paving shall be not more than 3 inches.		

Agency	Density Specifications		Construction Specifications		
	Mat	Longitudinal Joint	General	Geometry	Compaction
Kentucky	The Contract will state the compaction values to be used. Compaction should be between 92 - 96% of the Theoretical Maximum Specific Gravity.	89 - 96% of the Theoretical Maximum Specific Gravity	Correct irregularities in alignment of the outside edge or edges of longitudinal joints by adding or removing material before compacting the edges. When the pavement construction consists of 2 or more courses, offset the longitudinal joint a minimum of 6 inches. Place the longitudinal joint in the final surface course along the dividing line between the lanes.		Clean adjacent surfaces of all loose materials so the joint shall receive full compaction from the rollers.
Louisiana	Minimum of 92.0% of the Theoretical Maximum Specific Gravity		Longitudinal joints shall offset those in the layer below by a minimum of 3 inches. In the top layer it shall be offset 3 - 6 inches, from the centerline of pavement or from lane lines. Longitudinal joints shall be constructed by setting the screed to allow approximately 25 percent fluff and also overlapping the paver approximately 2 inches onto the adjacent pass. Prior to rolling, the overlapped mix shall be pushed back to the uncompacted side, without scattering loose material over the hot mat, to form a vertical edge above the joint. The vertical edge shall then be compacted by rolling to form a smooth, sealed joint.		
Maryland	In place density of 92.0 to 97.0 percent of the theoretical maximum density.		Longitudinal joints shall be staggered a minimum of 6 in. and shall be arranged so that the longitudinal joint in the top course shall be within 6 in. of the line dividing the traffic lanes.		Steel wheel rollers shall be used for the first rolling of all joints and edges, the initial breakdown rolling, and the finish rolling.
Massachusetts	Not less than 95% of the Laboratory compacted density.		The longitudinal joints for the top course shall be cut back to expose the full depth of the course and, when the laying of the course is resumed, the exposed edge of the joint shall be treated with a hot pured rubberized asphalt sealant.	Vertical face	To prevent "rolloff" of the pavement edges and longitudinal joints on deep lift pavement, the outer 8 inches of the deep lift mixture shall be left unrolled until the temperature of the mix ranges between, 149°F and 176°F, whereupon it shall be compacted by the steel roller.
Michigan	Average of the density values should be equal to or greater than 92.0 percent of the Maximum Specific Gravity		When placing the uppermost leveling and top course, the longitudinal joint shall coincide with the proposed painted lane lines. Longitudinal joints shall be either vertical or tapered.	Vertical or tapered (1:12 slope and a notch of 0.5 to 1 inch at the top of the taper)	When compacting an adjoining lane and not restricted by traffic, the vertical longitudinal bumped joint shall be rolled first with the roller supported mainly on the cold mat with only 2 to 6 inches of the roller extending onto the hot mat.
Minnesota	Mimumum of 95 percent of the Marshall density.		In multiple lift construction, the longitudinal joints shall be constructed not less than 6 inches measured transversely from the longitudinal joints in the previously placed lift. For wearing course, the longitudinal joint shall be on the centerline of the road, provided that no joint is located in the wheel path area of a traffic lane. At longitudinal joints formed by placing multiple strips, the adjoining surface being laid shall, after final compacting, be slightly higher (but not to exceed 1/8 inch) than the previously placed strip.		When a longitudinal joint is formed by adjoining strips, the first pass of the roller shall be over that joint.

Agency	Density Specifications		Construction Specifications		
	Mat	Longitudinal Joint	General	Geometry	Compaction
Missouri	Minimum density of 98 percent of a laboratory specimen made in the proportions of the job-mix formula in accordance with AASHTO T 167 or 96 percent of a laboratory specimen made in the proportions of the job-mix formula in accordance with AASHTO T 245,	Not less than 2.0 percent below the specified density (within 6 inches of a longitudinal joint)	The longitudinal joint shall offset that in the layer immediately below by approximately 6 inches. The joints in the completed surfacing shall be at the lane lines or outside the travel lane. Longitudinal joints shall be formed by the use of an edging plate fixed on both sides of the finishing machine. The inside plate, or that placing material for the longitudinal joint, shall be normal to the roadbed. When placing the first lane, if the mixture at the longitudinal joint tends to slump, it shall be set up to a vertical edge by light compaction with the back of a rake.	Vertical face	
Nebraska	Average Density (5 Samples, Percent of Voidless Density) should be greater than 92.4%		An intended lap of 1 inch with a variance of ½ inch will normally be the optimum overlap for longitudinal joint construction. If thickness is insufficient prior to rolling, joint will usually be smooth in appearance but lack density because of inadequate compaction. Make sure density is checked along the joints.	Vertical face	When paving adjacent to a previously placed lane, the last pass of the roller in which the full roller width is entirely on the hot mat shall be kept approximately 6 inches from the existing facility. The final pass of the roller shall then be made over the remaining uncompacted 6 inches strips, tucking the material into the joint.
New Hampshire	Minimum density of 95 percent of laboratory specimens, made by the AASHTO T 245 method in the proportions of the job mix formula.		The longitudinal wearing course joint shall be in the center of the pavement, and joints of other courses shall be offset approximately 6 inches. A tapered overlapping joint may be used on all longitudinal joints provided that the adjacent lane can be placed when the existing surface temperature is above 50 °F. 1) An inclined face (3:1) on the joint shall be formed in the first bituminous mat placed. The inclined face may be for the entire height or an inclined face with a 1/2 inch maximum vertical face at the top of the mat. 2) After the initial mat is placed, the mat shall be rolled to the edge of the unconfined face. 3) When the hot mat is placed the initial longitudinal wedge shall be either treated with an approved bonding agent or heated to a temperature that facilitates bonding of the joint with an approved heating device. 4) Luting the joint after placement of the hot mat will not be required unless necessary to correct surface irregularities.	Tapered joint with inclined face of 3:1. Allows a 1/2 inch notch.	When paving in echelon or abutting a previously placed lane, the longitudinal joint shall be rolled first followed by the regular rolling procedure.

Agency	Density Specifications		Construction Specifications		
	Mat	Longitudinal Joint	General	Geometry	Compaction
New Jersey	Each mixture in a given lot shall be compacted so that the combined percentage of material below 2.0 percent voids or above 8.0 percent voids shall be no more than ten percent.		<p>HMA pavers shall be equipped with a sloped plate to produce a wedge edge at longitudinal joints. The sloped plate shall be attached to the paver screed extension. The sloped plate shall produce a wedge edge having a face slope of 1V:3H. The plate shall be so constructed as to accommodate compacted layer thickness from 40 to 100 millimeters. The bottom of the sloped plate shall be mounted 10 to 13 millimeters above the existing surface. The plate shall be interchangeable on either side of the screed.</p> <p>For surface layers, HMA pavers shall also be equipped with infrared heater(s) to heat the longitudinal edge of the previously placed layer</p> <p>The longitudinal joint in one layer shall offset that in the layer immediately below by approximately 150 millimeters. However, the joint in the surface course shall be at the lane lines.</p>	Tapered joint	<p>When compacting the longitudinal edge of the first lanes placed using the wedge joint, the breakdown roller shall not extend more than 50 millimeters over the top of the sloped face of the wedge joint.</p> <p>When paving in echelon, rollers shall not compact within 150 millimeters of an edge where an adjacent lane is to be placed.</p>
New Mexico	<p>The mean density shall be at least 93% of the theoretical maximum density. In addition, individual test value shall be at least 90% of the theoretical maximum density and shall not exceed 98% of the theoretical maximum density.</p> <p>QC/QA: target density for acceptance will be 95% of the theoretical maximum density.</p>		<p>Longitudinal joints shall be staggered at least 6 inches relative to longitudinal joints of the underlying course. Longitudinal joints shall have at least a 1 ft minimum taper.</p> <p>Tapered longitudinal joints from previous operations shall be cleaned and tack coated. The surface of each course at all joints shall be smooth and shall not show deviations in excess of 3/16 inch when tested with a 10 ft straightedge in any direction.</p>	Tapered joint not steeper than 6:1	
New York	Density specs are included in the contract proposal.	Contract proposal include longitudinal joint density spec.	<p>In the formation of all joints, the exposed edge of the existing layer that will become part of the joint shall be the full thickness of the layer and straight.</p> <p>The pavement of successive courses shall be such that all joints are offset at least 6 inches from the joint of the lower pavement course.</p>	Vertical face	

Agency	Density Specifications		Construction Specifications		
	Mat	Longitudinal Joint	General	Geometry	Compaction
North Carolina	Minimum of 92% of the Maximum Specific Gravity		Tack the exposed edge of all longitudinal joints prior to placing the adjoining pavement. Form longitudinal joints by allowing the paver to deposit the mixture adjacent to the joint to such depth that maximum compaction can be obtained along the joint. Pinch the joint by rolling immediately behind the paver. Offset the longitudinal joints in each layer from that in the layer immediately below by approximately 6 inches. Construct the joints in the final layer between designated travel lanes of the final traffic pattern.		
North Dakota	The average density shall be at least 91% of the daily average Maximum Theoretical Density. Each individual subplot shall have a minimum average density of 89% of the daily average Maximum Theoretical Density.		Joints shall be tacked and constructed with adequate bond on abutting surfaces. Vertical construction joints in successive courses shall be placed so the joints do not fall in the same vertical plane.		When paving in echelon or abutting a previously placed lane, the longitudinal joint should be rolled first followed by the regular rolling procedure.
Ohio	In place density of 93.0 to 97.0 percent of the maximum theoretical density.		Seal all cold longitudinal joints on surface courses, by coating the vertical face of the cold joint with asphalt material, applied at a rate of 0.25 gallon per square yard.	Tapered joint, the maximum slope is 3 to 1.	Where a longitudinal joint is being made, roll the joint then follow the applicable rolling procedure. For continuous lanes, one ahead of the other, do not allow rollers performing the initial rolling operation in one lane closer than 12 inches to the longitudinal joint until the adjacent lane is placed. Compact all cold longitudinal joints on intermediate and surface courses using a three-wheel roller.
Oregon	Minimum density of 98.0% of the target density, obtain from the Moving Average Maximum Density (MAMD) Method. Lower MAMD applicable: 91% for low volume roads.		Offset the longitudinal joints in one layer by at least 6 inches from the longitudinal joints in the layer immediately below. (1) Base Course - Place base course longitudinal joints within 12 inches of the edge of a lane, or within 12 inches of the center of a lane, except in irregular areas, unless otherwise shown. (2) Wearing Course - Longitudinal joints shall not occur within the width of a traffic lane. They shall be located at either skip lines or fog lines unless approved by the Engineer. On median lanes and on shoulder areas the joints shall occur only at lane lines or at points of change in the transverse slopes.		When paving in echelon, or when abutting a previously placed lane, roll the longitudinal joint first, followed by the regular rolling pattern.

Agency	Density Specifications		Construction Specifications		
	Mat	Longitudinal Joint	General	Geometry	Compaction
Pennsylvania	Field density between 92% and 97% of Theoretical Maximum Density	For Notched wedge: minimum of 90% of the theoretical maximum density.	Offset the longitudinal joint in one layer from the joint in the layer immediately below by approximately 6 inches. However, align the joint in the top layer at the approximate pavement centerline, if the roadway is two lanes wide; or at approximate lane lines, if the roadway is more than two lanes wide. Operate the paver so that, in spreading, the material overlaps the edge of the lane previously placed by approximately 1-1/2 inches.	Tapered -notched or vertical joint	Immediately compact fresh mix directly behind the paver at the longitudinal joint. When compacting the joint, use a vibratory roller for breakdown rolling, shift the roller on the hot mat 1inch or 2 inches across the joint onto the cold mat. Make the first pass in the vibratory mode. Roll with steel-wheel and pneumatic-tire rollers until a thoroughly compacted neat joint is obtained.
Rhode Island	Minimum density of 95 percent of the density of laboratory Marshall specimens made in the proportions of the job-mix formula.		Longitudinal joints shall be staggered a minimum of 6-inches and shall be arranged so that the longitudinal joint in the top course being constructed shall be at the location of the line dividing the traffic lanes. The edge of the old pavement or the cold mat, shall be cut back a sufficient distance to expose a fresh, full thickness, vertical face. To obtain a well bonded joint, this face shall be brush-painted or pressure sprayed with a bituminous tack coat, after which the hot bituminous mixture shall be placed in contact with it and raked to a proper depth and grade.	Vertical face	
South Carolina	Average minimum density of 96.5% of the average daily field laboratory density as determined by the Marshall Method of test, but not exceeding 98.5%.		The longitudinal joints of each successive course have to be offset from the joints of the previous course at least 6 inches where practicable. The width of each lane in the top layer shall be the width of the design travel lanes.		Longitudinal joints shall be rolled directly behind the paver. The paver shall overlaps the edge of the cold mat by 1 to 2 inches. The loose material shall be left high enough to allow for compaction to the depth of the cold mat. The overlapped material shall be pushed back by means of lutes or other suitable tools to the edge of the cold mat.
South Dakota	High Volume Traffic: 92.0 to 96% of the lot average maximum specific gravity. Low and Medium Volume Traffic: 91 - 96% of the lot average maximum specific gravity.		The center joints of succeeding lifts shall be offset approximately six inches. The center joint of the top lift shall be located on centerline. Longitudinal joints other than at the lane lines will not be permitted in the top lift. A shoe attachment may be used to match the longitudinal joint(s) on the final paver pass(es) of the top lift unless otherwise directed by the Engineer. A shoe attachment on the paver shall be used to automatically match the elevation of asphalt concrete shoulders with concrete pavements.		When abutting a previously laid lane, compaction of the longitudinal joint should be accomplished by rolling from the hot lane.
Tennessee	Average of not less than 92 % of maximum theoretical density with no individual test falling below 90 % of maximum theoretical density.		Where multi-course pavements are placed, the longitudinal joint in one layer shall offset that in the layer immediately before by approximately one foot; however, the joint in the top layer shall be at the center-line of the pavement if the roadway comprises two lanes of width, or at lane lines if the roadway is more than two lanes in width.		When paving in echelon or abutting a previously placed lane, the longitudinal joint shall be rolled first, followed by the regular rolling procedure. When paving in echelon, rollers shall not compact within six inches of an edge where an adjacent lane is to be placed.

Agency	Density Specifications		Construction Specifications		
	Mat	Longitudinal Joint	General	Geometry	Compaction
Texas	In place air-voids between 4.5 - 9%.	If difference in density at both sides of the joint is more than 48 kilogram per cubic meter, the production is discontinued until this difference is corrected.	Construction joints of successive courses of asphaltic material shall be offset at least 6 inches. Construction joints on surface courses shall coincide with lane lines or shall be as directed by the Engineer.		
Utah	The target density is 93.5 percent of maximum theoretical density for overlay thickness greater than 2 inches. For overlay thickness is 2 inches or less, target density is 92.5 percent of maximum theoretical density. Lower Limit: Target Value - 2.0% Upper Limit: Target Value + 3.0%		Offset longitudinal joints 6 to 12 inches in succeeding courses. Place top course joint within one foot of the centerline or lane line. If the previous pass has cooled below 175°F, tack the longitudinal edge before placing the adjacent pass.	Tapered joint, 3:1	
Virginia	98.0 - 102.0 percent of the Target Control Strip density. Courses not having sufficient quantity of material to run a nuclear density roller pattern and control strip shall be compacted to a minimum density of 91.5 percent of the theoretical maximum density.		A short ski or shoe shall be used to match the grade of the cold mat on all primary, interstate and designated secondary routes. Unless otherwise directed by the Engineer, a 24 foot minimum automatic grade control ski shall be used on all asphalt mixtures on all divided highways, with the exception of less than full width overlays and the first course of asphalt base mixtures over aggregate subbases.		When abutting a previously placed lane, the longitudinal joint shall be rolled first, followed by the regular rolling procedure.
Washington	Minimum of 91.0 percent of the reference maximum density (moving average of the most recent five determinations for the lot of asphalt concrete being placed)	For hot-lap joints, require the same minimum compacted density as in the rest of the pavement mat.	The longitudinal joint in any one layer shall be offset from the layer immediately below by not more than 6 inches nor less than 2 inches. All longitudinal joints constructed in the top layer shall be at a lane line or edge line of the traveled way.		If a hot-lap joint is allowed, two paving machines shall be used; a minimum compacted density, as in the rest of the pavement, shall be achieved throughout the traffic lane; and construction equipment shall not impact any uncompacted mix.

Agency	Density Specifications		Construction Specifications		
	Mat	Longitudinal Joint	General	Geometry	Compaction
West Virginia	92 to 96% of the theoretical maximum density of the approved mix design.		The longitudinal joint in any layer shall offset that in the layer immediately below by approximately six inches; however, the joint in the top layer shall be at the centerline of the pavement if the roadway comprises two lanes of the width, or at lane lines if the roadway is more than two lanes in width.		
Wisconsin	Compacted to a density not less than the percentage of the Target Maximum Density: 92% for High volume (> 3E6 ESALS), and 91.5% for < 3E6 ESALS.				
FAA	93.9 - 96 % of the Theoretical Maximum Density.	Above 92.4 % of the Theoretical Maximum Density.	The longitudinal joint in one course shall offset the longitudinal joint in the course immediately below by at least 1 foot; however, the joint in the surface top course shall be at the centerline of the pavement. Longitudinal joints which are irregular, damaged, uncompacted, cold, or otherwise defective, shall be cut back a minimum of 2 inches from the edge with a cutting wheel to expose a clean, sound vertical surface for the full depth of the course. All contact surfaces shall be given a light tack coat of asphalt material prior to placing any fresh mixture against the joint.	Vertical face	



Kenny C. Guinn, Governor

Jeff Fontaine, P.E. Director
Prepared by Research Division
Tie He, Research Division Chief
(775) 888-7803
the@dot.state.nv.us
1263 South Stewart Street
Carson City, Nevada 89712