# Best Practices for Constructing and Specifying HMA Longitudinal Joints

## A Co-operative Effort between the Asphalt Institute and the Federal Highway Administration

**Draft Final Report**

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## ABSTRACT

"In recent years, it has become evident how critical longitudinal joint construction is to the life of the pavement structure… Many pavements have been, or are in the process of being, resurfaced as a direct or indirect result of longitudinal joint deteriorations." This statement, by the Kentucky Transportation Center in a 2002 research report (26), is not unique to Kentucky roadways. A 2009 Federal Highway Administration (FHWA) survey of their divisional offices found that roughly 50-percent of their engineers reported being unhappy with the performance of their states longitudinal joints. Burati & Elzoghbi (6) evaluated longitudinal joint densities for the Federal Aviation Administration (FAA) over 25 years ago (1984) on airport runways in New York and New Jersey. They reported longitudinal joint densities were statistically lower, and had higher variability, compared to the mat densities. Over the last 25 years there have been numerous research efforts by academia, highway agencies, industry and others. In addition, training on the placement and compaction of HMA pavements is available within the industry. Despite all of these efforts, we continue to see longitudinal joint deterioration as one of the highest listed reasons for premature failure of hot-mix asphalt (HMA) pavements. Improving longitudinal joint construction will improve density and decrease permeability. It is probably the single most important thing we can do at this time to improve the performance of pavements.

The purpose of this project was not doing additional research on longitudinal joint construction, or evaluating density and its relationship to permeability and oxidation, but rather evaluate the work that has already been done and search for consensus to make recommendations on how to construct and specify longitudinal joints in HMA pavements. The approach taken was a series of stratified steps:

- Analysis of FHWA's survey to their state Division Offices on specifications, methods and performance of longitudinal joints
- Review existing literature and research
- Identify areas where there is consensus and areas where there is not
- Conduct focused interviews with acknowledged paving experts and contractors whom recently won the prestigious annual Sheldon Hayes Award for the "best" HMA project in the United States
- Perform visits to states that have implemented a longitudinal joint specification (either minimum density or method specification) to meet with the DOT, contractors, and researchers and also to visit working projects.

After accomplishing these steps and additional review of specifications and literature, recommendations were developed that offer the best chance of specifying and constructing longitudinal joints whose performance (life) will equal the performance of the mat. This guidance includes key steps or best practices for contractors, along with specification recommendations and options for agencies. A 4-hour workshop was also developed as part of this project.


Key words: longitudinal joint, paving, density, permeability, air voids, hot-mix asphalt

# CHAPTER I. INTRODUCTION

## Definitions

A *Longitudinal Joint* is the interface between two adjacent and parallel hot-mix asphalt (HMA) mats. Premature longitudinal joint failures are the result of a combination of low density, permeability, segregation, and lack of adhesion at the interface (Figures 1 and 2).

Figure 1. Deteriorating Longitudinal Joint

Figure 2. Longitudinal Joints That Are Permeable and Failing

Inherent factors, such as the joint interface and lateral movement of the HMA mat during rolling at an unconfined edge, will typically result in lower density at the joint that can lead to premature failure at the joint (Figure 3). Cold joints are those joints that have cooled before the adjacent lane is placed. Those joints described by C. Foster as, "This then, is the problem. Rolling a bituminous surface mix in a plastic state without edge confinement cannot produce the density designed or required" (Ref. 1). Definitions of some terms related to cold joints that are used throughout this report are provided in Appendix A.

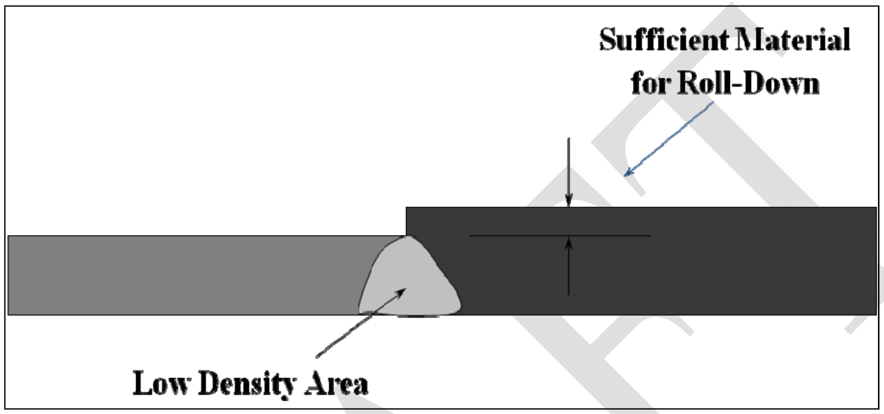


Figure 3. Longitudinal Cold Joint and Area of Low Density

Agencies and contractors can minimize the number of "cold" longitudinal joints by paving in echelon or using pavers capable of paving multiple lanes in one pass. Many pavers have the ability to pave two or more lanes with one pull. However, echelon paving and wide pavers have limited applications (new alignments, major highway reconstruction using a cross-over, airfields) because of the need to maintain traffic on the roadway. The majority of highway projects are done under traffic which requires paving one lane at a time, resulting in a "cold joint." While the use of echelon paving and wide pavers is recommended when traffic and economics permit, the remainder of this paper is focused on longitudinal cold joints, referred to herein as longitudinal joints.

Overlay projects that include milling may afford the opportunity to mill a single lane, overlay that lane, and then mill the adjacent lane; avoiding an unsupported edge. By "milling and filling" one lane at a time, the inherent difficulty of achieving adequate density at the unsupported edge can be avoided. Milling and filling one lane before proceeding to a second lane may not always be efficient, economical, or convenient. This is validated by the reality that milling operations typically complete large portions of the project before the paving operation starts. A frequent reason for this is the restriction of not opening traffic where there is uneven surface elevation of adjacent lanes. Yet, this method of milling and filling one lane at a time should be considered when feasible to avoid the unsupported edge.

Highway pavements in urban areas often have four or more lanes in each direction. The typical Interstate highway has two 12-foot lanes, one 10-foot shoulder and one 4-foot shoulder; in each case one or more longitudinal joints will be required. Paving low volume

2-lane rural roads typically require a longitudinal joint so that traffic can be maintained on the other lane. Regardless of the type of project or location, longitudinal joints will be part of most hot-mix asphalt paving projects. As such, it is important that we develop specifications and construction practices that provide long lasting, durable longitudinal joints; joints with performance periods equal to the performance periods of the mat.

**Background and Specifications**

The relationship of joint density and permeability to longitudinal joint performance dates back to the 1960's when Ernest Zube looked at permeability for the California Division of Highways (Ref. 2). The Federal Aviation Administration (FAA) was the first agency to focus on the need for a longitudinal joint specification. The FAA's focus should not come as a surprise since the width of airfield runways, even with echelon paving and wide pavers, results in numerous longitudinal joints.

Research has shown there is a relationship between density and pavement performance. Further, density (air voids) is related to permeability. Critical to the density/ permeability relationship is the size of the air voids and whether those air voids are isolated or inter-connected. Research efforts at NCAT (Ref. 3, 4) and Florida (Ref. 5) have shown that density and permeability are related to nominal maximum aggregate size (NMAS), lift thickness, compactive effort and gradation (fine graded versus coarse graded). Cooley, Prowell and Brown (Ref. 4) noted …"Density, lift thickness and permeability are all interrelated."

Agencies have adopted both method and minimum density specifications and both have successfully resulted in relatively good longitudinal joint performance. The Maryland State Highway Administration is an excellent example of an agency with a "method specification" that has proven to be effective in providing durable, long life longitudinal joints. DOTs that have a minimum density requirement at the longitudinal joint typically specify the required mat density less 2-percent, with no density less than 90% of theoretical maximum density (TMD). Some agencies accept densities as low as 88% of TMD. Agencies vary on their acceptance process as well. Some use density gauges while others rely on cores. Some vary the minimum density requirement based on whether the test location is from the cold (unsupported edge) or the hot (supported) lane. Others accept joint density based on cores taken right at the joint, or an exact offset from the joint. Frequency of tests has a wide range. Specifications also vary on how non-compliance joints are handled; some specifications stop paving after successive failing tests, others offer bonus / penalty payments.

**Project Steps**

The FHWA concern over the performance of longitudinal joints in asphalt pavements prompted them to survey their 52 Division Offices. At the same time, FHWA approached AI and issued a Task Order to take a comprehensive look at longitudinal joints across the United States.

The FHWA survey was designed to provide an overall picture of longitudinal joint specifications, construction practices and joint performance. With all 52 offices responding, the results provided a broad overview from a national perspective and identified national trends. However, the survey did not provide the detail necessary to make a thorough evaluation and offer recommendations. The project team decided to approach the Task with a very well defined, step-by-step plan.

The first step was to analyze the FHWA Division Office survey. One take away was that half the respondents were not satisfied with the overall performance of longitudinal joints in their states. Thirty-five (35) states said they had some sort of longitudinal joint specification or special provision, but only half of those states (17) reported that they had a minimum density requirement at the joint. Of those 17 states with a minimum density requirement at the joint, the value ranged from 89% to 92% TMD. Follow-up with certain states was necessary to completely understand their responses. For instance, one state reported a minimum density requirement of 92%. Yet, follow-up discussions revealed that it was 92% plus or minus 4%, essentially putting their minimum at 88%. Another finding was that only five of the respondents said they were aware of their state “trying” a joint adhesive.

The survey analysis was followed by a literature review of work dating back to the early 1960’s. Highlights are covered in Chapter 2. General consensus on many aspects of best practices to construct a longitudinal joint was found, such as the first pass of the paver must be straight to allow for a uniform overlap of the second pass. But there were other aspects that did not have a consensus, such as how to roll the supported and unsupported edges. Other areas of uncertainty included: is the notched wedge joint better than the butt joint, should the face of the joint be painted, what material (emulsion, PG-grade asphalt or a proprietary joint adhesive) should be used for painting the joint?

To resolve those differences, it was decided to conduct focused interviews with 10 well known paving experts in the industry, along with the last 10 contractors who have won the annual Sheldon Hayes Award. These interviews are covered in Chapter 3.

The completion of those interviews was followed up with visits to five states that had studied longitudinal joint performance and implemented a longitudinal joint specification. The states were chosen with geographical and environmental diversity in mind, but more importantly based on a diversity of specifications. Each state visit began with a meeting among the contractors and DOT personnel that had experience and knowledge regarding the specification, and concluded with a project visit.

In addition to the steps listed above, additional specifications and literature were reviewed, additional state contacts were made, and project visits were conducted with Sheldon Hayes Award winners. Only after the completion of all of these steps were the guidance and recommendations in this report developed. Ultimately, this paper is recommending those specifications and construction practices that offer the highest reliability to construct longitudinal joints that equal the performance of the mat. Credible alternatives are also presented.

# CHAPTER II. LITERATURE REVIEW

## Historical Perspective

The FAA investigated the possibility of a joint density price adjustment on a paving project at the National Aviation Facilities Experiment Center (NAFEC), outside Atlantic City, NJ in 1981. That project provided insufficient data to develop a longitudinal joint price adjustment specification, but it did lead to a follow-up study. In 1984, Burati and Elzoghbi (Ref. 6) evaluated longitudinal joint densities at two airports, one in New Jersey and one in New York. In both cases they found the longitudinal joint densities to be lower than recorded mat densities. Since that time there have been numerous longitudinal joint studies. The majority of those studies reached similar conclusions: longitudinal joint densities are statistically lower than mat densities, and longitudinal joints have higher variability. Based on those studies, a reasonable specification for joint density is required Mat Density minus 2-percent, and in no case less than 90-percent of the TMD.

The permeability of longitudinal joints has also been researched extensively, and again there were common findings. Mixtures with a smaller NMAS, and a fine graded versus coarse graded mixtures of the same NMAS, can have a higher percentage of in-place air voids before the mix becomes permeable. Proper lift thickness, affording the opportunity to compact the pavement, is also a critical element of pavement impermeability. Permeability studies show that four times the NMAS should provide sufficient lift thickness to limit the number of inter-connected voids and achieve impermeability. When placing fine graded mixtures, a lift thickness of three times the NMAS may be sufficient.

## In-place Density and its Relationship to Performance

Agencies choose different ways to specify mat density requirements; most state agencies choose percent of TMD, others may choose percent of bulk density based on the lab density, while a few may choose to build a test strip and require 98-percent of the test strip density for the remainder of the project. Regardless of how the agencies specify mat density, the goal is basically the same; to end up with a minimum density of 92-percent TMD which equates to a maximum 8-percent in-place air voids. Eight percent has also generally been accepted as the point which, for practical purposes, an asphalt pavement will reach its expected design life. In-place air voids greater than eight percent result in premature aging due to oxidation and water permeability.

Figure 4 is a frequently referenced plot from a study in Washington state by Linden, Mahoney and Jackson in 1989 that shows the effect of high in-place air voids (low density, poor compaction) on overall HMA performance (Ref 7). Knowing that agencies either don't check density at the joint, or have minimum density requirements lower than 92% TMD, this plot offers an explanation why there are premature longitudinal joint failures. From Figure 1, a mat density of 92-percent TMD (8-percent air voids) suggests a HMA surface life of 98-percent of the expected life. On the other hand, longitudinal joint densities that typically range between 88 and 90-percent (10 to 12-percent air voids) can expect to have a life of only 64 to 83-percent of expected life, respectively. This is a 17 to 36-percent reduction in service life.

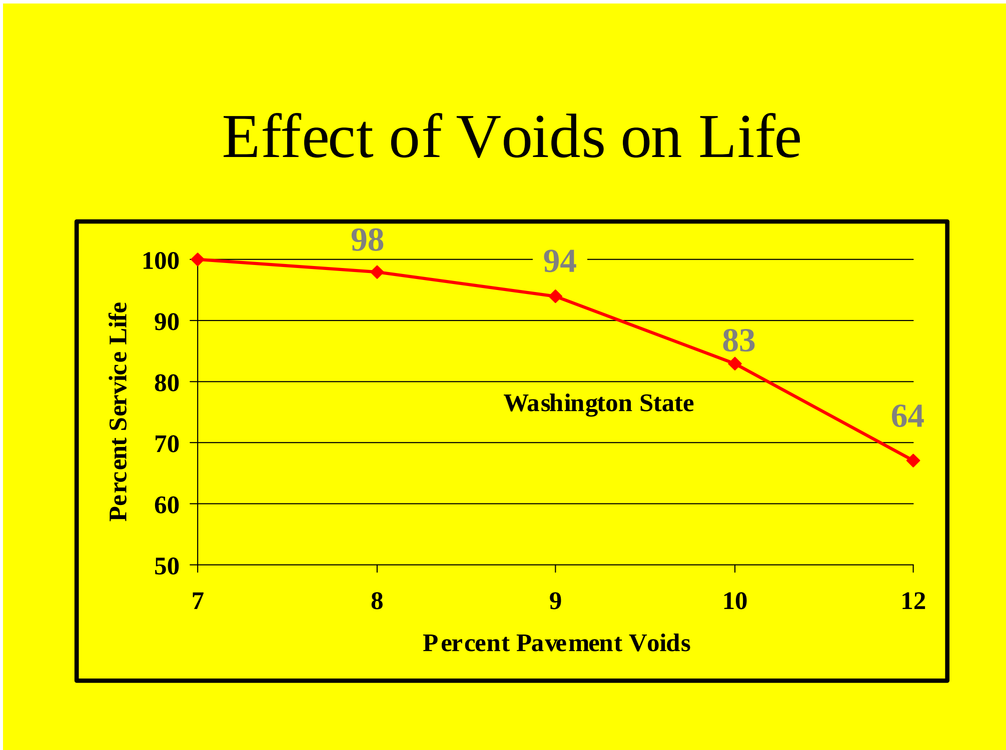


Figure 4. Low In-place Density versus Service Life (Washington Study, Ref 7)

More recent research in 2006 by Christensen on fatigue modeling supports findings reflected in Figure 1 (Ref 8). Christensen states: "For every 1% increase in in-place air voids, relative fatigue life decreases by a nearly constant amount of about 22%. This means that an increase in in-place air voids of 2% will decrease fatigue resistance by nearly 50%." Another model used by Hicks for Oregon in 1983 showed a 10% reduction in fatigue life for every 1% increase of in-place air voids (Ref 9). Whether the reduction in expected service is 17%, 44%, or 20 % is not the important point. Rather, what is important is to understand that in-place density lower than 92-percent at any location of the HMA mat, such as at longitudinal joints, will result in reduced expected service life at that location.

**Permeability and its Relationship to Performance**

An NCAT study (Ref. 3) defined field permeability as greater than $100x10^{-5}$ cm/sec. Using that as a reference point, they found, coarse graded 9.5mm and 12.5mm Superpave mixes become permeable when air voids exceed 7.7-percent. Coarse graded 19mm mixes become permeable when air voids exceed 5.5-percent and 25mm mixes at 4.4-percent (Fig. 5).

| NMAS | Average In-place Va (%) | Permeable at Va (%) | Density Required (%) |
|---|---|---|---|
| 1 " (25.0 mm) | 4 | 4.4 | 95 |
| 3/4" (19.0 mm) | 4 to 5 | 5.5 | 94 |
| 1/2" (12.5 mm) | ~6 | 7.7 | 92 |
| 3/8" ( 9.5 mm) | Below 5 | 7.7 | 92 |

Figure 5. NCAT Recommended In-place Air Voids

In 1996 the Florida DOT transitioned from Marshall mixes to coarse graded Superpave mixes. The Superpave pavements absorbed water and the water matriculated through the permeable surface mat until reaching the less permeable fine graded Marshall mixes placed on the shoulder. Stripping concerns prompted an immediate investigation. The conclusions and recommendation from that investigation (Ref 5) suggested that to achieve impermeability, air voids needed to be 6-percent or less (94% TMD). Like NCAT, they defined permeability in mixes as being greater than $100x10^{-5}$ cm/sec. Both the NCAT and Florida studies found a relationship between NMAS, lift thickness and the ability to compact the mix to achieve field impermeability ($100x10^{-5}$ cm/sec). The Florida study prompted the DOT to recommend a minimum lift thickness of 4 x NMAS.

Through 1997 Arkansas had placed 1.7 million tons of coarse graded Superpave mixtures. Reports of permeability initiated a study (Ref. 10) on 16 pavements. Four inch cores were taken from the mat. Arkansas chose $100x10^{-4}$ cm/sec as the breakpoint between permeability and impermeability. The study found that pavements with densities less than 94% of TMD were permeable and 12.5mm mixtures placed in lifts less than 2-inches thick (< 4xNMAS) were generally permeable. They further went on to suggest considering the use of 9.5mm mixtures for the wearing surface rather than the 12.5mm mix.

**Construction Practices**

There are two general types of longitudinal joints; the butt joint and the notched wedge joint (Fig 6). Butt joints can be when placed by a paver, or can be left from a milling operation or when cutting back the joint. Included later in this report is much more discussion on these different processes for creating butt joints, including proper material overlap for each. The notch wedge has several different configurations that can be used, with slopes ranging from 3:1 to 12:1. The required thickness of the top and bottom notches can also vary, but typically will be one NMAS. Which wedge configuration is used (if it is used at all), and whether or not the wedge itself gets compacted, will generally vary by state. Because the notch wedge joint can be safely traversed by vehicles, it offers the opportunity for higher daily tonnage versus the butt joint because the contractor is not required to pull the second lane up before opening to traffic. However, thin overlays do not provide sufficient thickness to create the notches at the top and bottom of the wedge. Depending on the ratio of the wedge, thick overlays may create too wide of a wedge that interferes with the adjacent traffic lane.

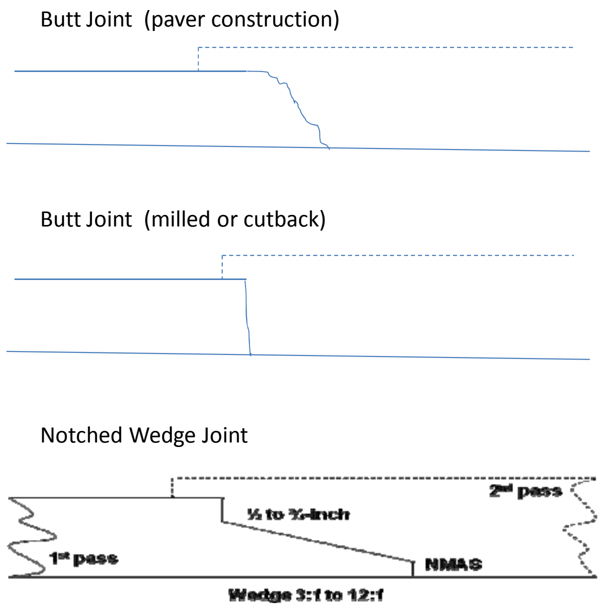


Figure 6. Butt Joint and Notch Wedge Joint

An NCAT study (Ref. 11) evaluated and ranked eight joint construction techniques over a period of six years. It is important to note the initial rankings when the joints were built looked significantly different than the final rankings 6 years later (Fig. 7). Construction techniques with high rankings early in the study dropped significantly over the course of the study. Notably, "rolling from the cold side" dropped from second to eighth, and a score of 8.8 to 4.62 (out of a possible 10).

*Kandhal, Ramirez, & Ingram*

**Table 3. Yearly Rankings of Joint Construction Techniques[a]**

| 1997 (July) | 1998 (July) | 2000 (October) | 2001 (July) |
|---|---|---|---|
| 1. Rolling hot side (9.8) | 1. Rubberized joint material (9.8) | 1. Cutting wheel (9.0) | 1. Rubberized joint material (9.88) |
| 2. Rolling cold side (8.8) | 2. Cutting wheel (9.4) | 2. Rubberized joint material (7.75) | 2. Cutting wheel (9.12) |
| 3. Rubberized joint material (8.2) | 3. Rolling from hot side (8.8) | 3. N.J. wedge (7.5) | 3. Rolling hot side 152 mm (8.75) |
| 4. Joint maker (8.0) | 4. Rolling from hot side 152 mm away (8.4) | 4. Rolling from hot side 152 mm (7.25) | 4. N.J. wedge (7.75) |
| 5. Cutting wheel (7.8) | 5. Joint maker (7.8) | 5. Edge restraining device (6.5) | 5. Edge restraining device (6.75) |
| 6. Rolling hot side 152 mm (7.0) | 6. Edge restraining device (6.4) | 6. Joint maker (4.5) | 6. Joint maker (5.50) |
| 7. Edge restraining device (6.5) | 7. Rolling from cold side (6.0) | 7. Rolling from hot side (4.25) | 7. Rolling from hot side (4.75) |
| 8. N.J. wedge (4.0) | 8. N.J. wedge (5.6) | 8. Rolling from cold side (3.0) | 8. Rolling from cold side (4.62) |

[a] Evaluations were conducted by 4 to 5 evaluators, average ratings are given in parenthesis (Scale of rating: 0 = unacceptable; 2 = poor; 4 = fair; 6 = good; 8 = very good; and 10 = excellent

Figure 7. Ranking of Joint Construction Techniques in NCAT Study (Ref 11)

During the 2007 TRB Symposium titled, "Building Quality HMA Longitudinal Joints – Point: Counterpoint," it was clear that while there is a solid agreement on certain aspects of joint construction, other aspects definitely having opposing views. Experts agreed that the first pass of the paver must be straight so that a uniform overlap can be achieved with the second pass of the paver. There was general agreement the overlap should be 1-inch +/- 0.5-

inch, but differences existed on what to do with that overlap. Should the overlapped material be luted back to the joint, removed with a flat bottom shovel or left alone and rolled?

An Airport Asphalt Pavement Technology Program (AAPTP) project developed guidelines for improved construction and performance of longitudinal joints on asphalt airfield pavements (Ref 12). In their 2007 report, Mallick et al recommends a minimum density spec where acceptance for joint density and mat density is based on PWL for each lot. The recommended minimum spec limits were 92.8% TMD for mat density and 90.5% TMD for joint density. Best practices for constructing conventional longitudinal joints are also discussed and are similar to the recommendations in this report. Echelon paving is preferred in order to minimize the number of longitudinal joints. When echelon paving is not possible, the following four practices are recommended in decreasing order of preference (each in combination with a minimum density spec).

1. Notched wedge joint (1:12 taper) with rubberized joint adhesive (JA) on notch and at least top 3-4 inches of wedge
2. Rubberized JA applied to entire face of butt joint
3. Notched wedge with conventional tack on entire face of notch and wedge
4. Cutting wheel technique that removes 2-6 inches of the unconfined edge (low density material) while the mix is warm and plastic.

Tennessee evaluated 7 different joint construction techniques on a project in 2008 (Ref 13). These techniques were divided into three major categories: painting the unconfined face with 4 products (1 unmodified emulsion, 2 modified emulsions and 1 rubberized joint adhesive), sealing the finished joint at the surface with two types of penetrating sealers, and using an infrared joint heater to heat the cold joint just prior to laying the hot side of the joint. While these projects will continue to be monitored, the initial results showed the infrared heater to have provided the best results in terms highest density and lowest permeability. In 2009, TN DOT started monitoring longitudinal joint density by cutting cores (4-6 inches in diameter) at random locations in each sublot directly over the joint. For sublots that fall below the required minimum of 89% TMD, there is no pay penalty, but the contractor must at his expense improve the quality of the joint by applying a surface seal to the longitudinal joints. The sealer material must be an emulsion or rejuvenator product approved by TNDOT. It is sprayed or squeegee applied with the addition of angular sand and is placed one-foot wide on either side of the joint.

In the United Kingdom, TRL published Road Note 42 in 2008 that gives guidance on the procedures for maximizing the durability of asphalt pavements (Ref 14). Their recommendations on longitudinal joints include:

- Minimize number of joints as much as possible because it’s an inherent weakness
- Avoid placing longitudinal joint in wheel paths
- Stagger the joints for multiple lifts to avoid water traveling through pavement
- Paint all exposed vertical faces with binder (not emulsion) to enhance adhesion to the newly laid hot mix. Do not seal the joint face of open-graded mixtures.
- Seal the surface of a completed joint on underlying layers with a bitumen sealer

- On dense graded surface lifts where traffic can be controlled, consider cutting back the unconfined edge (while warm) with a cutting wheel a distance equal to the lift thickness.  Water added to the wheel helps obtain a clean cut.

Cutting wheels used in the United Kingdom appear to be more sophisticated than in the U.S. (Figures 8 and 9).  In the United Kingdom, best practices call for the cut face to be painted with a 50 pen bitumen binder.


Figure 8.  Cutting Wheel Fixed to Roller in the United Kingdom
(www.highwaysmaintenance.com/kraktext.htm)

Figure 9.  Cutting Wheel Attached to Grader for Airfield Project in U.S. (Prowell photo)

# CHAPTER III. EXPERT INTERVIEWS

## Overview

Despite having the FHWA survey and the literature review completed, questions still remained. It was decided to conduct a series of focused interviews with acknowledged paving experts and recent Sheldon Hayes Award winners, people who have spent most or all their careers building longitudinal joints. The Sheldon Hayes Award is the National Asphalt Pavement Associations (NAPA) highest award, presented annually to the best paving project is the United States. The 2-page, 19 question interview sheet was sent to each expert 2 to 3 weeks before the actual face-to-face or phone interview in order that they could have sufficient time to think about the questions ahead of the interview. Each question was designed to look at specific points in the longitudinal joint construction process that may relate to performance. The question order roughly follows the sequence of constructing a joint. The interviews averaged roughly 60 minutes. The experts were allowed time to expand their answers into areas outside the questions. The ultimate goal of the interviews was to find agreement on as many questions as possible, and clearly define the differences on the other questions.

Ten consultants or equipment manufacturers were selected. They were well-recognized experts in the asphalt industry. The individual's names and companies are listed in the SPONSORS AND ACKNOWLEDGEMENTS section. Initial thought was to also have the same number of contractors, but it was difficult to narrow down the list to 10 across the nation using some type of objective criteria. It was decided to invite the 10 most recent Sheldon Hayes Award winners to participate. Because Lindy Paving had won the award three times in the past 10 years, and one of the winners was not able to respond, we ended up interviewing 7 contractors. These individuals and their companies are also listed under SPONSORS AND ACKNOWLEDGEMENTS.

In the section below, the exact wording of the question is first shown in italics, followed by a discussion of the responses for that question, then a brief takeaway developed from those responses. This is done for each of the 19 questions. Each expert was interviewed by going through these questions, so any question that may have been confusing could be explained. The discussion from those interviews, along with discussions taking place during the state visits (and subsequent jobsite visits), influenced the summaries and takeaways written here. If there was a noticeable difference between how the majority of contractors answered a question versus the majority of consultants, the difference was noted in the summary.

All the responses for each question are compiled in Appendix B.

## Questions, Summaries and Takeaways

*Q 1) First pass must be as straight as possible. How do you accomplish that?*

There was unanimous consensus that a stringline (or similar reference) should be used to assure the first pass of the paver is as straight as possible. Some suggested painting over the stringline in case wind or traffic might disturb the stringline. At least one contractor sends a survey crew out to set the line. An important comment was that the “dump person” is critical to getting the truck properly lined up with the paver (assuming a Material Transfer Vehicle is not being used). Failure to do so will force the paver off the stringline.

Takeaway: Use a stringline to assure the first pass is straight.

*Q 2) Do you prefer a*

- *a) Notched wedge joint*
- *b) Butt Joint*

A butt joint was preferred over the notched wedge by a very slim margin. No preference was also a comment.

Takeaway: The type of joint is not as critical to longitudinal joint performance as good construction practices.

*Q 3) Do you use paver automation (yes) or (no). Your preference is*

- *a) Joint Matcher*
- *b) Ski*

Consultants and contractors agreed that paver automation (versus manual operation) offers the best opportunity to construct a durable longitudinal joint. Almost all the consultants favored using the joint matcher over the ski; while the contractors were split on preferring the joint matcher versus the ski. Further discussion revealed that the ski is typically preferred when the focus is on ride quality, and the joint matcher is preferred when the focus is on the longitudinal joint. The joint matcher, placed immediately ahead of the auger, does the best job of getting sufficient material at the joint because it measures the HMA thickness required at precise locations; while the ski averages the thickness of HMA required over the length of the ski (30-40 ft) and may not always provide the optimum amount for the joint. Those choosing the ski typically do so because the project has a ride specification and not a longitudinal joint specification, or the penalty/bonus for ride quality outweighs the penalty/bonus for joint density.

Takeaway: Use of a joint matcher on the longitudinal joint is the best option (versus the ski) to assure sufficient material at the joint. Smoothness is best accomplished with a ski. Multiple lifts provide the opportunity to use a ski to get a smooth ride first and then use a joint matcher on the final lift to get the best joint.

*Q 4) Do you roll the unsupported edges by:*

- *a) Staying back 6-inches from the edge*
- *b) Overhang the edge of the mat by 6-inches*
- *c) Other* ______________________________

There was an even split of those interviewed on how to roll the unsupported edge. Roughly half preferred the method where the 1st pass of the roller overhangs the unsupported edge about 6 inches, and the other half preferred the method of staying back 6 inches from the unsupported edge on first pass, then overlapping 6 inches on second pass. The main concern with the overlap method is lateral movement of the mat (especially for lifts greater than 2 inches), while the predominant concern with staying back slightly off the edge is the possibility of a stress crack occurring at the edge of the roller drum from the first pass. This type of cracking occurs parallel to the longitudinal joint and may not develop immediately, but years later.

Take away: While opinions were pretty evenly split, the method where the 1st pass of the roller overhangs the unsupported edge about 6 inches is recommended. The alternative method of staying 6 inches back from the unsupported edge at first roller pass should not be used unless the paving crew has used the specific mix at the specific temperature and not experienced cracking at the roller drum's edge. Even with this experience, mix gradations vary and mix temperatures fluctuate so monitoring for this type of cracking is prudent.

*Q 5) When using a wedge joint do you tack the notch & wedge (yes) or (no) if yes, with*

*a) Emulsion*
*b) PG-grade Asphalt*
*c) Other _______________If yes, complete wedge or portion. Any, problems?*

With only two exceptions, those interviewed thought painting the notched wedge joint was a good idea. Emulsions were mostly mentioned for tacking the notched wedge, but typically it's whatever material is used to tack the roadway mat. PG grade asphalt was also listed by some consultants and contractors.

Take away: The notched wedge joint should be painted. Typically it's painted with whatever material is used for tacking the mat.

*Q 6) When using a butt joint do you tack the vertical face (yes) or (no) if yes, with*

*a) Emulsion*
*b) PG-grade Asphalt*
*c) Other _____________ If yes, complete wedge or portion. Any problems?*

All but one of the experts recommended painting the face of the butt joint. Again emulsions were mostly mentioned for tacking the butt joint, but typically it's whatever material is used to tack the roadway mat. The contractors seemed to prefer tacking the butt (or wedge) joint with emulsion as opposed to a PG asphalt.

Take away: The butt joint should typically be painted with whatever material is used for tacking the mat.

*Q 7) Have you ever used a proprietary joint adhesive, (yes) or (no), if yes*

*a) Was it practical? (yes) or (no)*
*b) Did it improve the performance of the joint? (yes) or no)*

None of the contractors interviewed had ever used a rubberized joint adhesive to paint the face of the joint, even though our review of the literature led us to believe it was a growing and favorable practice. A majority of the consultants interviewed responded that they had used rubberized joint adhesives, and the majority of those thought their use was practical and effective.

Take away: While it seems intuitive that painting the face of a joint with rubberized joint adhesive generally should provide extended pavement life, there does not seem to be enough experience in the industry to say it is always cost-effectiveness.

*Q 8) Have you ever cut the cold joint back prior to placing the adjacent lane? (yes) or (no)*

*a) Was it practical? (yes) or (no)*
*b) Did it improve the performance of the joint? (yes) or (no)*

Fifteen of 17 had cut back the unsupported edge of the joint, but few felt this practice was practical. Despite this, consultants by a 5:2 margin thought cutting the joint back was effective in improving joint density. The cutting wheel is highly operator dependant to cut a straight edge (remember the stringline in Q1).

Take away: Reports show cutting the joint back has improved joint density, but there are concerns over the ability to make a straight cut and also in creating too smooth an interface for adhesion. In addition, there are typically traffic control and safety issues with this practice on roadways that are not typically present on airfields (where this practice is commonplace).

*Q 9) Have you ever used an infra-red heater on a longitudinal joint? (yes) or (no)*

*a) Was it practical? (yes) or (no)*
*b) Did it improve the performance of the joint? (yes) or (no)*

Ten of the 17 experts said they had used an infrared heater on a longitudinal joint. Only one of those 10 thought it to be practical and effective. Negative responses focused on the inability to coordinate heater speed with paver speed. If the paving operation slows down, the heater may overheat the material; if the paver speeds up, the joint may not be sufficiently heated.

Take away: Historically, there is not a consistently high success rate with using infrared heaters to improve joint performance. That said, there have been some major improvements to joint heater equipment that includes longer, more efficient heaters, and automation with paver speed that greatly minimizes over and under-heating. Recent longitudinal joint studies in Canada, New England and Tennessee have shown that infrared heaters can increase longitudinal joint density by 1-2%.

*Q 10) How much do you overlap the hot material onto the cold material?*

*a)* ______________________________________

There is general agreement on the correct amount of overlap of mix onto the cold lane. Fifteen of the 17 responses fell in the range of 0.5 to 1.5 inches.

Take away: Overlap of 1-inch +/- 0.5 inches is desired.

*Q 11) What do you do with the overlap material?*

*a) Push it back to the joint*
*b) Do nothing*
*c) Other ______________________________*

Eleven of 17 responses said to “do nothing” with the overlap, 4 chose to push (lute) the overlap back to the joint, and 2 chose to remove with a shovel. If consistently done properly, gently “bumping the joint” by pushing the overlapped material just off the cold mat and barely onto the hot side of the joint should improve density and performance. However, too often the luting is done incorrectly by pushing the overlap material across the hot mat resulting in insufficient material at the joint. This is often referred to as a “starved joint.” The result is the hot side of the joint being starved or deprived of material, and then the roller drum bridging across from the edge of the cold mat across to the hot mat. The outcome is low joint density and a joint destined to failure. Also, when the material is broadcast across the hot mat, it typically gets segregated, which provides another obstacle for achieving density and a well-performing joint. Finally, there is a safety concern on roadways with a lute person being exposed to traffic in the passing lane.

Take away: Assuming a proper overlap 1-inch +/- 0.5-inch, the overlap material should be left alone and not bumped back with a lute. If for some reason the overlap exceeds this, then remove the excess with a shovel, allowing recommended overlap to remain.

*Q 12) How do you first roll the second pass?*

*a) From the hot side overlapping onto the cold*
*b) From the cold side overlapping onto the hot*
*c) Make the first pass staying back from the joint and overlapping onto the cold with the second pass*
*d) Start rolling on the outside edge and working into the joint*
*e) Other ______________________________*

Experts interviewed varied widely in their opinions on how to first roll the supported edge. Four favored “hot overlapping onto the cold”, 4 favored “cold overlapping onto the hot, 7 preferred making the first pass with the roller on the hot mat, but staying slightly back from the joint, and 2 liked to begin on the outside edge and work their way toward the joint (allowing time for the cold side to heat up and soften). The majority preferred staying slightly off the joint on the first pass. The biggest advantage to this method is that most think it will minimize any bridging effect of the roller being supported by the cold lane. It can also provide a slight excess of material at the joint when material is pushed into the joint during the first roller pass (depending on mix stiffness and lateral movement). In addition, this method puts the entire drum on the mat when hottest. The concern with this method is the chance of stress cracks forming at the drum’s edge on first pass (see Question 4 summary).

Take away:  Like question 4, the varying opinions suggest the best option may be mix specific and paving crew preference.  We agree with the majority and recommend first using the method of rolling from the hot side, staying back from the joint 6 to 8-inches, and then overlapping onto the cold method on the second pass.  With this method, superintendants and roller operators should be vigilant in monitoring the compacted mat for the first sign of these cracks (they can show up later).  If there is a history of these cracks, then we believe the next best option is to roll on the hot side and overlap onto the cold lane by 2-4 inches with the first pass.  With this method, care must be taken to ensure there is always sufficient material placed at the joint to avoid bridging during the process of compaction.  Densification will cease at the joint, no matter how many passes occur, if there is bridging of the roller.

*Q 13) Do you monitor the longitudinal joint density (yes) or (no), if yes, how*

*a) Nuclear gage or similar device*
*b) Cores*
*c) Other* ________________________________

Sixteen of 17 experts said they monitor joint density.  Nuclear gauge is the overwhelming method to monitor joint density.  The only no response highlighted the inability to get the gauge to seat properly if trying to straddle the joint.  Most choose to take density readings parallel to the joint and slightly off the joint’s center.

Take away:  Overlapping the joint combined with not luting the material off the joint makes it difficult, if not impossible, to get the gauge properly seated directly over the joint for an accurate density reading. However, contractors should monitor joint density slightly off and parallel to the joint with a density gauge for consistency (and density) as part of their Quality Control program.  Cores are taken to correlate with the gauge.

*Q 14) Which type of specification offers the best chance to long term joint performance?*

*a) Method*
*b) Minimum percent density,   What is the practical minimum?* _______*%*
*c) No specification*

Thirteen of 17 experts felt specifying a minimum density specification, versus a method specification, gave the best chance for long-term joint performance.  Of those 13, the practical minimum density value most mentioned was 90% TMD, with a few saying it was 91% TMD.  A few also stated the practical minimum joint density level in terms of mat density (i.e. mat density minus 1% or 2%).  No one gave a practical minimum joint density requirement that was less than 90% TMD.

Take away:  Most agree that a minimum longitudinal joint density spec of 90% TMD is the best way to ensure long-term joint performance.

*Q 15) Does a fine 9.5mm mix have a better chance for good performance than a 12.5mm*

*a) Yes*
*b) No*

Most experts felt a fine 9.5mm mix offered a better chance of good performing joints relative to a 12.5mm mix.

Take away: Use the smallest NMAS you feel comfortable with, considering traffic loads, percentage of trucks, etc. Most important is having proper lift thickness (4 times NMAS for coarse graded mixes, and 3 times NMAS for fine graded mixes) for both mat and joint compaction.

*Q 16) Does a 9.5mm mix with a design asphalt content of 6.2% asphalt have a better chance for good performance than that same mix at 5.7% asphalt?*

*a) Yes*
*b) No*

Most experts felt a 9.5mm mix with a 6.2% design asphalt content was better in terms of joint performance than a 9.5mm mix with a 5.7% design asphalt content.

Take away: While adding asphalt to a mix will improve the ability of a mix to compact and increase joint density, it could have other consequences, such as bleeding and rutting. Proper lift thickness (see above take away) is critical.

*Q 17) Could I do anything additional in "late season" paving to improve joint performance?*

*a)* ____________________________________________________________

Most of the expert's recommendations for late season paving revolved around mix temperature and paver/ roller coordination. Some said additional rollers may be needed. There were a few suggestions to use "warm mix" and joint heaters.

Take away: Late season paving and cool temperatures mandate that "best practices" be followed. Most important is maintaining a proper and consistent mix temperature and a paver speed that allows the rollers to stay very close to the paver.

*Q 18) Have you ever been required to seal the surface of a longitudinal joint as part of the contract? (yes) or (no). If yes, what did you use to seal the joint?*

*a) The material was* _____________________________________________
*b) The width of the seal was* ______ *-inches*

Only four of the experts had ever been required to seal the surface of a longitudinal joint as part of a paving contract, two using PG-graded asphalt. Width ranged from 4 to 12 inches. Note: The process of sealing the surface of a completed joint is referred to as "overbanding" in this report, in order to distinguish from "sealing" the joint, which is done on the open face of a cold joint.

Take away: Overbanding the surface of a joint is not a common method used on paving projects at this time.

*Q 19) What are the other "Tips that make the difference"? List as many as you like.*

Additional comments not already covered –

- Must plan for the longitudinal joint, it cannot be an afterthought
- Make sure tack extends full paving width, perhaps extend beyond
- Make sure joint is clean and tack is cured
- Echelon paving when possible
- Vibratory screed needs to always be on
- Set end gate properly, down on existing pavement surface
- Extend augers and tunnels to within 12-18 inches from end gate to ensure sufficient fresh material is carried (not pushed) to joint. Not doing this will create an overload, cascaded and tapered flow of material causing segregation at the joint area. Uniform head of material across entire screed is necessary to provide consistency at joint.
- Always use a rubber tire roller
- Periodically have someone from outside the company review paving operation, they may spot any bad habits that have evolved over time
- Training, training, training. Set standards for paving crew and insist they are met
- Sufficient rollers to stay close to paver
- Never starve the joint
- Best joint must sacrifice ride and sometimes yield. Control overlap and depth

## CHAPTER IV. STATE VISITS AND SPECIFICATIONS

State visits were made in Texas, Colorado, Connecticut, Maryland and Pennsylvania. Each state had researched longitudinal joints and implemented a longitudinal joint specification. Visits included a meeting with the agency and their contractors, as well as a project visit(s). Texas, Colorado and Connecticut accept longitudinal joints based on minimum density, but that is where the similarity stopped. Maryland and Pennsylvania both had method specifications, and no density requirements. Following here is a brief description of each state's spec and some of the significant notes from the visits.

### Texas

TXDOT evaluated their joint densities in 2001 and found that the average difference in density between the unconfined edges compared to the middle of the lane was 4-5% lower, with greater differences in some pavements (Ref 15). Citing that study, the Texas DOT implemented a longitudinal joint spec in 2004. In 2006, another study was performed which concluded that a significant improvement in joint density occurred since the new spec, reporting that on some projects the difference between joint and mat density was less than 1% (Ref 16).

The spec requires a joint density evaluation be performed for each sublot. Acceptance is based on density gauge readings. Minimum joint density is a relative density compared to the mat density. Joint density is accepted when the joint density (from gauge) is not lower than 3 pounds per cubic foot (pcf) from the corresponding mat density taken at same station. If difference is greater than 3 pcf, then the joint density is calculated (correlated with mat cores). If this correlated joint density is less than 90% TMD, then the joint density is considered failing at this location. Two successive failures require stopping the operation and solving the problem. There is no bonus/penalty pay schedule.

The Texas approach to monitoring joint density offers no extra testing other than 2 gauge readings next to the core taken in the mat and another gauge reading taken 8 inches off the joint (never straddle the joint). Joint density tests average 1 per 250 tons of production. Gauge readings are taken parallel to the longitudinal joint, but it was not clear which side of the joint, hot or cold, the gauge readings should be taken from.

The type of joint (butt or wedge) is decided upon either by the Districts or left up to the contractor. Thin lifts typically use butt joints and thick lifts typically use wedge joints. Construction practices identified by the DOT and contractors as key to achieving density at the joint are similar to those discussed in the previous section. Everyone seemed to first roll the unsupported edge by overlapping 6 inches, and tack the entire wedge with emulsion. Both groups felt the biggest challenge with building a good quality joint was night-time paving, where it is difficult to see if the correct depth and overlap of material is being placed. Another item of interest was that about half the dense graded jobs used a rubber tire roller for intermediate rolling. Also stated by the contractors was if the TXDOT ride incentive schedule was in place on a job, they would use a 40-foot ski for maximum smoothness.

The TX joint density spec has changed very little since being implemented in 2004 because TXDOT feels it is working; bringing more attention to the joints by contractors and resulting in relatively good joint performance.

**Colorado**

Believing they had a large longitudinal joint problem, Colorado DOT installed an "informational only" longitudinal joint density spec in 2001. In 2003, they converted it to an incentive/disincentive spec. The target density of the spec is 92% TMD, +/- 4%. Acceptance is based on 6-inch cores centered on the visible joint (+/- 1-inch). Percent-within-limits are calculated based on the lower limit of 88-percent. Note: We initially thought Colorado had the highest minimum density criteria in their spec at 92%, but learned through this visit that the actual minimum density was 88% (92% - 4% = 88%). Average density measurements reported by the DOT for the construction season went from 89.5% TMD in both 2001 & 2002 to between 90.0% and 90.7% in subsequent years. Additional joint spec details in Colorado include:

- PWL is based on 88% lower limit; with $\geq$80% PWL = 100% Pay.
- There is also up to a 5% bonus.
- L-joint payment is 15% of total payment, and mat is 35% of total payment.
- Joint density spec is applied to all lifts.
- A sublot is 5,000 linear feet linear feet (lf) and a lot is 3 sublots.
- One core on joint per sublot required for Quality Assurance.
- Quality Control testing twice the frequency of QA, so one core per 2,500 lf.
- Density calculations based on $G_{mm}$ which is the average of both sides of joint.

The type of joint (butt or wedge) is left up to the contractor for lifts greater than an inch. While any wedge configuration can be used to meet the safety requirement that traffic can't cross over a lip greater than 1" high, most wedges had a 3:1 slope, with a notch at the top and none at the bottom. For thin lifts one inch or less, a butt joint is required.

There has been a distinct trend by the DOT to go with finer and smaller size mixes to provide less segregation and improved density. The majority of their wearing surfaces placed are fine 9.5mm mixes. There was the comment that the SMA mixes provided a higher probability of receiving a bonus versus dense-graded mixes because the SMA does not move under the rollers as much. It was stated that rubber tire rollers are used on all projects, except when using polymer modified asphalt (PMA). There was a consensus that it is more difficult to get full pay when using PMA. Colorado pays for the tack as a separate pay item rather than incidental to the paving, with the idea that will better promote the proper application rate

Overall, the contractors seemed to like the spec because it offers up to a 5% bonus. The core location (centered on the joint, +/- 1-inch) was tightened in the spec because it was too vague to just say over the joint. Another important note is that tack coat is paid as a separate bid item in CO, so comments were made that the mat and joints receive sufficient tack (emulsion). The following were stated as changes seen since the spec was implemented: more training for the crew, better equipment, more frequent use of best practices, more attention to detail, and just overall more focus on the joint. Overall, both industry and the

DOT strongly felt the quality of the joints improved significantly with implementation of the spec.

**Connecticut**

At the time of the visit in 2010, joint density acceptance was based on nuclear gauge readings with the gauge placed 6-inches from the joint (update for 2011 is provided at the end of this section). Gauge value was based on correction factor based on minimum of 5 cores to gauge readings. Full payment for joint density required 92% TMD, but only the hot, supported edge, is tested. This side will typically have higher density measurements versus the cold, unsupported side. There was no requirement in CT to test the cold, unsupported side of the joint. Joint density represented 30% of payment, mat density was 20% of payment, and material properties were the other 50% of payment. There was a bonus for joint and mat density, but the penalty payments were skewed versus the bonus.

Connecticut evaluated the notch wedge joint in 2006-2007 and now requires it on lift thicknesses equal to or between 1.5 and 3.0-inches (Ref 17). The required taper of the wedge is somewhere between 8:1 and 12:1, contractor option. The required top notch is between 0.5 and 1.0-inch, and the bottom notch can be between 0.0 and 0.5-inch. Contractors commented that they try to leave 0.5-inch notch on the bottom notch because of raveling concerns. The spec requires that the wedge be compacted in some manner; the majority of contractors use the CEM attachment that makes the wedge and compacts with vibration, while a few others use a tow-behind roller. Tacking (with emulsion) under the full width of the wedge was deemed very important to limit movement of the unsupported edge. In addition, the wedge itself also gets tacked full width (including the notch) as a separate pass before the mat gets tacked. It was felt by both agency and contractors that the notch wedge joint resulted in higher and more uniform density across the joint than the butt joint.

Rubber tire rollers were typically not used by contractors. In 2010, Connecticut was transitioning towards acceptance based on cores, versus using density gauges. The general consensus of contractors and agency is that implementation of the longitudinal joint density spec has improved joint performance.

Note: In 2011, Connecticut has revised their longitudinal joint specification to acceptance based on density of 6-inch cores centered on the wedge. Their minimum density for full pay has been lowered to 91% of TMD at the joint, and 92% of TMD within the mat.

**Maryland**

Maryland is known for having a history of durable longitudinal joints, and builds exclusively butt joints. Maryland uses a method specification for the longitudinal joints, clearly defining the placement and rolling procedures for the joint. It is important to note that prior to implementing their method specification, they took 4-inch joint cores (centered 5-inches off the joint) from both the supported and unsupported edges. Those cores averaged 92.5% and 91.4% TMD respectively, so the MD FHA deemed that this method specification provided acceptable joint densities. Highlights of the Maryland method include:

- Assure a true line when paving, use a stringline or other reference
- Roll the unsupported edge with the drum extending beyond the unsupported edge
- When placing hot lane adjacent to cold lane, overlap onto the cold 1.5-inches
- Assure sufficient depth in hot lane to account for ¼-inch per inch roll down
- Do not bump back the overlapped material
- When compacting supported edge, keep first roller pass back from the joint 6-12 inches. On second pass overlap the drum onto the cold lane.

**Pennsylvania**

Pennsylvania started evaluating joint construction methods in 2006 and began gathering data on joint density (Ref 18). As part of this effort, they traveled to Maryland to discuss the "Maryland Method" and visited on-going projects and projects that were five or more years old. Pennsylvania returned and constructed projects that compared the "Maryland Method" to normal construction practices in Pennsylvania. In 2008, Pennsylvania implemented a longitudinal joint method specification, appropriately named the "Maryland Method". In this spec, Pennsylvania allows the contractor the option of building either a butt or notched wedge joint, but prescribed the method of building the joint.

Beginning in 2007, a joint density baseline was established to track the progress and improvements that resulted from using these best practices and increased training and scrutiny on joint construction. Average joint and mat density from 2007-2009 in PA was reported per Figure 10 (Ref 19):

| Longitudinal Joint Data Summary | | | |
|---|---|---|---|
| Year | # of Projects | Avg Joint Density | Avg Mat Density |
| 2007 | 18 | 87.8% | 93.9% |
| 2008 | 43 | 88.9% | 94.1% |
| 2009 | 29 | 89.2% | 94.1% |
| 2010 | Contractors gathering data for PWT spec | | |

Figure 10. Joint and Mat Densities in PA

Results indicate that following the "Maryland Method", Pennsylvania's average joint density increased approximately 1.4-percent from 2007 to 2009.

Because the data showed many projects were still not achieving optimal joint density, Pennsylvania transitioned in 2010 from their method specification to a minimum density spec based on 6-inch cores. The incentive/ disincentive payment schedule is based on a statistical approach of calculating percent within tolerance (PWT), using 80% PWT. The lower spec limit was set at 89% TMD, with plans to increase that limit to 90% TMD in later years. The incentive/ disincentive schedule for year 2010 is shown in Figure 11, with plans in 2011 to double the incentive/disincentive amounts. Additionally, lots with average densities lower than 88% TMD require a corrective action of overbanding the joint with PG-graded asphalt. The band width is 4-inches, centered on the visible joint. This spec only applies to surface courses and newly constructed joints where mats on both sides of the joint were placed as part of the contract.

For a lot with a PWT ≥ 81, the Contractor will receive a prorated positive incentive payment up to a maximum of $2,500 calculated according to Table A.

For a lot with a PWT < 50, the Contractor will receive a prorated negative adjustment (disincentive) up to a maximum of $6,000 for the longitudinal joint lot calculated according to Table A.

Costs associated with providing joint pavement cores will not be paid for separately and will be considered incidental to the construction items for the wearing courses eligible for the longitudinal joint evaluation. Costs associated with corrective action such as traffic control or other costs will not be paid for separately.

**TABLE A**

Lot by Lot Payment Schedule for Longitudinal Joint Incentive/Disincentive

| Lot PWT | Amount |
|---|---|
| PWT ≥ 81 | (PWT -80)/20 x $2,500<br><br>(Incentive) |
| PWT = 50 to 80 | $0 |
| PWT ≤ 49 | (50-PWT)/50 x $6,000<br><br>(Disincentive) |

Figure 11. Incentive/Disincentive Schedule for Year 1 in PA

The core location is dependent on the type of joint. Butt joint cores are centered on the visible joint, meaning 3 inches of the core's surface will be on the hot side and 3 inches on the cold side. Wedge joint cores are centered at the middle of the wedge to obtain roughly half of the mix from the hot side and half of the mix from the cold side. This location results in the core being centered typically 3-inches off the wedge's upper notch (wedge being under the core surface).

### General Comments

Joint configurations varied with each state. Texas preferred the wedge joint as did Colorado and Connecticut. Maryland builds butt joints and Pennsylvania allows the contractor the option to build butt or notched wedge joints. Wedge joint configurations varied ranging from 3:1 to 12:1. Some states used rubber tired rollers for intermediate rolling of the joint, but only at the confined joint. Rubber tire rollers at the unconfined joint will push the material away from the joint. Joint overlap was consistent: 1.5-inches +/- 0.5-inches and in every state the overlap material was not pushed back. Contractors felt that both echelon paving and the method of milling one lane at a time to eliminate unsupported edges would improve longitudinal joints, but these methods were not practical in most cases. Every state visited had reached the same conclusion (agency and industry); implementing their longitudinal joint specification increased attention to the placement and compaction of the joint, which resulted in improved performance.

# CHAPTER V. RECOMMENDATIONS

The following recommendations were developed from the literature review, expert interviews, state visits and subsequent follow-up activities. They are divided into various categories relating to longitudinal joints.

## Mix Selection and Design Considerations for Improving Longitudinal Joint Performance

- Use the smallest NMAS mix that is appropriate for the application. This will aid in obtaining the necessary density and also a more impermeable surface. Smaller size mixes are less permeable at a given in-place air void level.

- Use a gradation that favors the fine side of the .45 power curve, as finer mixes are generally easier to compact.

- Consider including permeability as one of the factors for approving the mix design. This approval would be based on a laboratory test and not a pavement test. The purpose would be to demonstrate that when properly compacted, the mix would meet the agency's permeability requirements.

- Use a lift thickness that is at least 4 times the NMAS for coarse gradations and 3 times the NMAS for fine gradations. Coarse gradations are defined as those that pass below the Primary Control Sieve (PCS) control point in Table 4 of AASHTO M 323. Fine gradations are defined as those that pass above the PCS control point. Adequate lift thickness will facilitate compaction and maximize density.

- Consider use of the notch wedge joint (versus butt) for lift thicknesses equal to or between 1 and 3 inches. Pennsylvania, Colorado, Connecticut, Kentucky and Colorado found the notch wedge joint to provide higher densities than the butt joint. Pike Industries (Ref 21) found the density of the notch wedge joint to be an average of 1% higher than the butt joint. Mallick (Ref 12) recently recommended the notch wedge for airfield paving ahead of cutting the joint back because it provides a better opportunity for higher density. The safety and production advantage offered by the wedge allows the contractor to continue paving in one lane without an edge drop-off. For butt joints, the maximum allowable drop-off while keeping traffic open is typically 1.5 to 2.0-inches. For mats thicker than this, contractors have to stop midway and regroup the paving train to level up the adjacent lane, costing production time. Wedge joints eliminate this issue. Regarding compaction of the wedge, methods vary from hand vibratory plates to small tow behind rollers to commercially available paver attachments that shape and compact the wedge through vibration. Opinions vary as to their effectiveness of increasing density, but Connecticut requires some type of compaction on the wedge to prevent loose aggregate when opened to traffic.

- Pay for tack as a separate bid item (as opposed to being an incidental requirement) to facilitate using the proper application rate. Texas and Colorado were two states we visited that do this. Each felt it was a big advantage in terms of producing a quality joint (and mat).

**Planning**

- Include longitudinal joint construction as a topic for the pre-paving meeting; type of joint to be used, sequence of lane placement, and role each paving crew member has in achieving good joint density. Plan construction sequence so that any overlap of material at the joint does not impede the flow of water (hot side of joint may be slightly higher than cold side).

- When placing multiple lifts, the longitudinal joints should be offset horizontally between layers by at least 6-inches.

- Consider the use of infrared joint heaters, especially in cold weather paving. This method ranked first among seven joint treatments evaluated in Tennessee (Ref 13). Pochily (Ref 21) reported a "steady and solid 2% increase when using the infrared device." While the experts interviewed generally did not find the use of heaters to be practical or effective, there have been equipment improvements that include longer and more efficient infrared heaters and automation with paver speed that minimizes overheating and under-heating of the joint.

- The use of rubber tire rollers is encouraged at the confined joint. Rubber tired rollers should not be operated close to the unsupported edge to avoid excessive lateral movement. Zube (Ref 2) noted the importance of using rubber tired rollers to knead (tighten) the surface. Brown (Ref. 22) cited the value of rubber tire rollers when constructing longitudinal joints, noting: "A rubber tire roller is very good for rolling longitudinal joints since the rubber tires provide a kneading action and can reach down into localized low spots to help provide compaction." The state visit to Colorado found the contractor using a rubber tired roller for the intermediate rolling and the quality control technician pointed out that "joint density would probably not be achieved without the rubber tired roller". The Alaska DOT, with a target density of 91-92% TMD, does not require but favors the use of rubber tired rollers.

- As part of the contractor's quality control program, density gauges should be used to monitor the relative density on both sides of the longitudinal joint. Gauges should be set parallel to the longitudinal joint, with the edge of the gauge offset 2-inches from the joint. Gauges should not be placed directly over the joint because the surface is typically not flush at the joint, so the gauge cannot be seated properly, leading to an inaccurate reading. The density measurement should be an average of two (or four) 1-minute readings, rotating the gauge 180 degrees between readings. Gauges should be calibrated and a correlation factor calculated based on core densities taken from the mat, not closer than 2 feet from the joint. Guidance on gauge types is as follows (Ref 23):
    - for lifts <1 inch thick, use a thin lift nuclear gauge or a nonnuclear gauge.
    - for lifts 1-2 inches thick, use a thin lift nuclear gauge.

   - for lifts 2-3 inches thick, use any nuclear gauge set to the general backscatter mode.

- Constructing improved longitudinal joints requires a total effort, from the mix designer to the contractor's gauge technician checking density behind the last roller as part of quality control. Everyone needs to understand their role. Designers need to calculate tonnage based on sufficient lift thicknesses with respect to NMAS, mix designs need to be selected with permeability in mind, and contractors need to think about the placement and compaction procedures discussed in this report. Training should be conducted with all involved parties in the same classroom so that everyone understands their role and how everyone's role fits together.

**Alternative Techniques and Materials for Consideration**

- Evaluate project and traffic control requirements to see if echelon paving could be utilized in any facet of paving to minimize the number of cold joints.

- For mill and fill jobs, evaluate traffic flow requirements to require the contractor to mill and fill one lane at a time; meaning mill one lane, then pave that lane, before milling an adjacent second lane. This eliminates unconfined edges.

- Assess project and traffic control requirements for the practicality of a test project to evaluate the method of cutting back the joint. Cutting back the joints is done routinely on airfield projects in the U.S., which have a long history of obtaining higher joint densities. Bognacki (Ref 20) reported that cutting back the joint 6-8 inches resulted in an improvement in longitudinal density by 2-4% TMD. Alaska contractors, while not required, routinely cut or mill back the unsupported edge to achieve the target density of 91% TMD. This method is also used in the United Kingdom on roadways. Safety issues related to traffic control may be hampering the utilization of this method in the U.S. Another issue is that cutting a straight line can be difficult, yet is very important to getting the proper overlap when the joint is completed.

- Evaluate the use of joint adhesives (JAs), which are hot applied rubberized asphalt, to seal the face of all open unconfined joints. Proprietary JAs are routinely used in New Jersey and Alaska, and were ranked #1 by Kandhal (Ref 11) as shown in Figure 7. Mallick (12) also strongly recommended them for all types of joints. While not commonplace yet, use of this material appears to improve the adhesion and sealing of the joint. Note: When paving on super elevation, consideration should be given to eliminating the JA on any vertical joint face that could dam water that permeates and flows through the mix. This is especially true for permeable mixes, but has also been found to be an issue on dense mixes that were unintentionally permeable.

- Evaluate the use of surface sealers after the joint has been constructed. Tennessee requires this on joints that do not meet their minimum density requirement. Application widths are typically 1 to 2 feet. A question to this method is the long-term effectiveness of making the pavement impermeable.

**Specifications**

The FHWA survey showed that roughly two-thirds of states had some type of specification or provision that directly addresses longitudinal joints. About half (17) of those states said they had a minimum density requirement in their longitudinal joint spec. Whether including a minimum density requirement or not, these specs take very different approaches, along with different types of testing and criteria. The overwhelming feeling from both the contractors and state agencies that we visited was that implementing the longitudinal joint specification chosen for their state resulted in increased attention to the joint, which has improved the performance of joints.

C. Bognacki (Ref 20) found longitudinal joint density improved when the NY Port Authority changed from a method specification to a percent-within-limits specification. The clear majority of experts (13 of 17) that we interviewed felt that a minimum density spec offered the best chance of achieving long term joint performance. Among those 13 experts, the practical minimum density value cited most frequently was 90% TMD, with no one citing less than 90% TMD.

As the first two chapters discussed, density at the joint commonly falls below 90% TMD. The literature is also clear that the critical in-place air void level, where the HMA becomes permeable, starts between 7-8%, or even lower, depending on the NMAS and gradation (Ref 2, 3, 4, 5 and 10). This 7-8% air void level equates to an in-place density of 92-93% TMD. The literature also shows that expected performance life of HMA starts to exponentially drop when in-place density falls below 92% TMD (Ref 7, 8, 9). This is no surprise since densities below this level result in HMA layers that are permeable, causing premature oxidation, striping, raveling, etc.

Despite the need to achieve a minimum joint density of 92% TMD to assure that the longitudinal joint performs as long as the mat, research has shown that the combination of an unsupported edge and the joint interface make it very difficult to achieve this level of density consistently using conventional methods. A Connecticut study concluded that "It is unreasonable to expect the average density of the longitudinal joint to achieve a density of 92-percent as currently required" (Ref. 17). Other research in the literature agrees, and recommends a minimum density requirement at a level of 90% TMD, or 2% lower than the required mat density. Examples include:

- "The evaluation is considered failing if the joint density is more than 3.0 pcf below the density taken at the core random sample location and the correlated joint density is less than 90%." Texas Transportation Institute (Ref. 16)
- "It is recommended to specify minimum compaction level at the longitudinal joint (generally two percent lower than that specified for the mat away from the joint)." NCAT / PaDOT (Ref. 11)
- "Joint density, 2% less than mat density, is achievable when measured with cores." NCAT (Ref. 13)
- "Maximum of 2% less than the corresponding mat density and minimum of 90% of theoretical maximum density at the specific location." Nevada (Ref. 24)

Williams (Ref 25) for Arkansas compared many methods of evaluating longitudinal joint quality and recommended determining the in-place density of cores using the vacuum sealing method. Brown suggested the vacuum sealing method (AASHTO T 331) be used (versus AASHTO T 166) when the water absorption of the core exceeds 1-percent (Ref. 22). Determining $G_{mm}$ and TMD from AASHTO T 331 versus AASHTO T 166 will yield slightly higher in-place air voids.

Maryland chooses not to incorporate a minimum longitudinal joint density into their specifications. Instead, they use a method specification which clearly defines the joint construction process. Maryland is an example which highlights that good longitudinal joint performance can be achieved without requiring a minimum joint density specification. It is important to note that Maryland's method specification was evaluated by taking 4-inch cores 5-inches off the visible joint on both the hot and cold sides. Those cores averaged 92.5% and 91.4% respectively. States that choose to use a method specification should evaluate their joint densities during construction on a random basis and monitor joint performance in later years. Small states where most asphalt paving is done by a relatively small number of contractors may be more appropriate for a method spec than a larger state with many paving contractors.

It is clear that a variety of alternative approaches have been successfully utilized by agencies in improving the quality of longitudinal joints. This report has covered many of these. Each agency and project has its own unique set of circumstances. While there is not be a single approach best suited for every agency or application, the following specification requirements are provided as a starting point for agencies looking to change their specifications to improve longitudinal joint performance. These recommendations are based on the information collected during this project. Agencies may choose to incorporate some and not all of the elements presented below.

*Preferred Specification with Cores*

- Quality Control
    - Construct test strip that includes a longitudinal joint
    - Determine optimum roller pattern for density at the joint
    - Monitor joint density (for each lane) with gauge
- Quality Acceptance
    - Cut 6-inch cores directly over the joint for butt type, and centered on the wedge for notched wedge types. Determine the average % TMD of these cores. Use the following pay scale for joints (if agency pays incentives/disincentives):
    - ≥ 92% TMD, pay maximum bonus
    - 90 – 92% TMD, Pay 100% plus pro-rated bonus
    - < 90% TMD, reduced payment
- In addition, for joints < 92% TMD, require contractor to seal, at no additional cost, the surface of completed longitudinal joints by overbanding with PG binder at a width

of 4 inches, $\pm$ 1 inch, centered on the visible joint. If there is a concern about skid resistance, the overband can be sanded.

The requirement to overband the joint with a PG binder may seem a bit unusual or extreme, but it is based on research that says HMA with density less than 92% TMD will be permeable, oxidize prematurely and likely have a shortened life. Overbanding is intended to decrease both oxidation and permeability. This is a requirement in Alaska DOT's standard HMA spec where the average joint density of a lot falls below 90% TMD. Overbanding is also required frequently by the Pennsylvania Turnpike Authority and some of the Pa DOT Districts. The photos in Figure 12 show a contractor, three-time winner of NAPA's Sheldon Hayes Award, overbanding joints. It should also be noted that overbanding the edges around patching is considered best practice.

Regarding the preferred location of cores taken to assess joint density, there is not a clear consensus, particularly when using the notched wedge joint. To best assess the density right at the joint, and not slightly on the confined (hot) side or slightly on the unconfined (cold) side, the cores need to be taken directly over the joint. To assume an equal split of material from the hot side and the cold side (for proper $G_{mm}$ calculations), it is recommended that the core be taken directly over the joint for butt type, and centered on the wedge for notched wedge types. When coring a wedge joint, the core should be centered a distance from the visible joint equal to the length of the wedge / 2. This allows for $G_{mm}$ to be based on the average of the two $G_{mm}$ values (one from the hot side and one from the cold side).

Figure 12. Overbanding Longitudinal Joints 4-inches Wide with PG Binder

*Alternative Specification with Gauges*

While it's preferred to use cores versus gauges for density measurements for acceptance, some agencies use density gauges because they want to eliminate the patching required to fill the core hole. The same guidelines for using gauges under quality control, outlined earlier in this chapter must be followed (see last bullet, Planning section). The specification could be the same as above, except that instead of taking 6-inch cores over the joint, density gauge readings would be taken on each side of, parallel to, and offset by 2-inches from the visible joint. Joint density readings taken across the joint will be inaccurate due to improper seating. Also, the gauge should use a correlation factor based on comparisons with mat cores. The Texas longitudinal joint specification (covered in Chapter IV) is an example of using gauges to monitor joint density.

*Steps in Implementation*

Implementation of a minimum joint density specification should be a series of steps best done with agency and industry working in partnership. As an example:

1. Offer training in longitudinal joint construction and factors affecting performance.
2. Establish baseline of existing joint densities by randomly selecting projects.
3. Consider evaluating through a series of trials some of the recommendations listed earlier in this chapter:
    - Mix selection and design considerations
    - Planning
    - Alternative techniques and materials (echelon paving, mill and fill one lane at a time, cutting back joint, JAs, surface sealers, etc.
4. Implement specification, but with a lower minimum density requirement (say 89% TMD) for first year, OR implement spec and show bonus/penalty but do not add or subtract dollars.
5. Incrementally increase the minimum density requirement to reach 90% TMD, or possibly higher as it can be shown to be accomplished on a regular basis. This is where offering pay incentives (bonuses) is very helpful, to see what is realistic.

**Construction Best Practices**

The following summarizes the necessary steps to best construct a longitudinal joint to optimize long-term joint performance. For most of these steps, a more detailed discussion is provided elsewhere in this report (such as the interview questions in Chapter III). References to these locations are made as appropriate.

- Follow best practices to avoid mix segregation (loading trucks, dumping paver hopper wings, use of material transfer vehicles, etc.).

- Use stringline guide for paver operator to make straight pass (Q 1, Ch3).

- Tack coat uniformly applied to full width of paving lane (Q 19, Ch 3).

- Ensure vibrator screed is turned on all the time (Q 19, Ch 3).

- Extend augers and tunnels to within 12 to 18-inches of the end gate to ensure a continual supply of fresh material is carried (not pushed) to the joint (Q19, Ch 3).

- Set end gate properly to firmly seat on existing surface for clean joint (Q19, Ch 3).

- Coordinate paver and auger speed to allow for a uniform head of material across the entire width of the paver. Maintain paver and auger speed.

- Use paver automation. A critical element to getting joint density is having sufficient depth of material at the longitudinal joint. The "joint matcher", set immediately adjacent to the end gate, provides the best opportunity to get that sufficient depth. The use of a ski, versus the joint matcher, will normally result in a pavement with a better International Roughness Index (smoother pavement), but not necessarily the optimum depth of HMA for the best joint (Q 3, Ch 3).

- When allowed by the specification, construct a notched wedge joint for the wearing course when the lift thickness is between 1.5 and 3 inches ($4^{th}$ bullet, Mix Selection and Design Considerations, this chapter).

- Compact unsupported edge of mat with the first pass of vibratory roller drum extended out over the edge of the mat approximately 6-inches. This is to avoid the stress cracks from the roller edge discussed earlier. One concern with this method is that if the roller gets too far over the edge on first pass, the edge may breakdown, especially for lifts greater than 2 inches. An alternative method is to make the first pass of vibratory roller back 6-inches from the unsupported edge, and then extend the drum out over the unsupported edge on the second pass. Advocates of this method believe the non-rolled 6-inch strip provides some confinement for the mix under the drum, and this strip can then be rolled on second pass. With this method, watch for stress cracks that may develop parallel to the joint. This alternate method should only be used if the paving crew has experience with the specific mix and has not had a problem (Q 4, Ch 3).

- Monitor relative density of unsupported joint using a density gauge ($4^{th}$ bullet, Planning, this chapter) (Q 13, Ch 3).

- Tack the existing face of the joint with the material (emulsion or asphalt cement) being used to tack the mat (Q 5 and Q 6, Ch 3). Alternatively, consider using a proprietary joint adhesive as research indicates it improves joint performance ($4^{th}$ bullet, Alternative Techniques and Materials for Consideration, this chapter).

- Overlap the existing lane (of a butt joint constructed with the paver, or a notched wedge joint) 1-inch +/- 0.5-inch (Q 9). When the butt joint is constructed by milling or cutting back the existing lane, the overlap should be approximately ½-inch. (See Figure 6).

- Do not lute (push back) the overlapped material, assuming the proper overlap was placed (see previous bullet). If the overlap exceeds 1.5 inches, carefully remove the excess with a flat-end shovel (Q 11, Ch 3).

- Compact the supported edge of joint with the first pass of the vibratory roller drum on the hot mat staying back from the joint 6 to 8-inches. The second pass should then overlap onto the cold mat 4 to 6-inches. With this method, watch for any stress cracks developing in the mat that are parallel and 6 to 8-inches off the joint. An alternative method is to have the first pass of the vibratory roller on the hot mat overlapping 4 to 6-inches onto the cold mat. A major concern with this method is that if an insufficient depth of HMA is placed next to the cold mat, the roller will bridge over and not compact the hot material completely (Q 12, Ch 3) (Bridenbaugh - Ref 18, Williams - Ref 25, Estakhri - Ref 16).

- When the joint is completed, the overlap should be 0.1-inch higher to ensure no bridging of the roller ever occurred.

- Monitor the relative density of the supported joint using a density gauge (4th bullet, Planning, this chapter) (Q 13, Ch 3).

- Cut a 6-inch quality control core(s) and measure density prior to next paving day.

**Summary**

Fifty plus years of research have confirmed the importance of a properly compacted asphalt pavement. Research in the early 1960s looked at compaction as it related to permeability. Subsequent research, particularly with the introduction of Superpave, looked at air voids as they related to permeability. Additional studies have evaluated the relationship between air voids and asphalt pavement performance. Improper compaction, and the resulting high air void content, leads to premature pavement failure due to increased permeability and an increased rate of oxidation. While these studies have shown the desired air void content varies with the Nominal Maximum Aggregate Size (NMAS) and gradation (coarse vs fine), they suggest air voids in the 7 - 8% range should be the maximum air voids for most surface courses.

This Task Order brought another important factor to light. Current construction practices have a difficult, some say impossible, time achieving the suggested air void content at the longitudinal joint. While in-place air voids for the mat typically range between 4 and 8%, longitudinal joint air voids tend to range between 10 -12%. The inability to compact the longitudinal joint to 8% or less air voids provides the explanation for why there is a significant difference in the performance of the mat versus the longitudinal joint. The saying goes, “a chain is only as strong as the weakest link”; paraphrasing that, “the performance period (and ultimately the life-cycle) of an asphalt pavement is controlled by the longitudinal joint”.

This Task Order did not involve new research, but rather, it reviewed the research conducted over the past 50+ years, picked the brains of some of the U.S.’s finest paving consultants and paving contractors, and visited states that had researched and implemented longitudinal joint specifications. Only after the completion of all of those steps were the recommendations made in this report.

The construction best practices are a compilation of field paving and compaction procedures that offer the best chance of achieving desired joint density levels and optimize joint performance. While these field best practices are desired, they are not always followed, even though they generally do not require an extensive amount of additional expense or elaborate equipment.

States that have implemented joint density specifications have seen improved performance. Connecticut and Pennsylvania are two recent examples of states that researched the issue, made incremental improvements in their methods and specifications over a number of years, and reported average joint densities in 2011 slightly above 91%. In the years (2003 – 2007) after Colorado implemented their joint density specification, they reported average joint densities above 90%. While these are excellent results, they still do not reach the necessary 8% or less air void level to avoid premature oxidation and permeability. Thus, this report includes a recommendation to overband longitudinal joints which fail to meet the 92% TMD (8-percent air voids). Alaska and Pennsylvania are examples of states where the practice of overbanding longitudinal joints is used. Tennessee uses joint surface sealers on joints that do not meet a minimum density.

Longitudinal joint performance is a high priority item for the FHWA and many state highway agencies. Contractors, equipment manufacturers and material suppliers continue to explore new methods and materials. Ultimately, the goal is to approach the same level of compaction in the longitudinal joint as we see in the mat. The recommendations in this report should be an important step in that journey.

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## Appendix A

# Definitions

**Cold Lane** is the first lane paved and will have one or two unsupported edges
**Hot Lane** will have at least one edge that is placed against an existing lane or shoulder
**Hot Longitudinal Joint** is formed when two pavers are used in echelon and the longitudinal joint is completed before the material in the cold lane has had a chance to cool.
**Cold Longitudinal Joint** is one where the first lane paved previous day / night or the time between the first and second pass of the paver is such that the first pass has cooled
**Theoretical Maximum Density** (TMD) is the weight of asphalt and aggregate mixture divided by the volume of the asphalt coated particles (0.00% air voids)
**Bulk Density** is the mass of asphalt and aggregate divided by the bulk volume (i.e., volume of the asphalt, aggregate, and air).
**Nominal Maximum Aggregate Size** (NMAS) is one sieve size larger than the first sieve to retain more than 10-percent of the material
**Fine Gradation** when plotted on the 0.45 power gradation graph, falls mostly above the maximum density line
**Coarse Gradation** when plotted on the 0.45 power gradation graph, falls mostly below the maximum density line
**Density Gauge** is nuclear or non-nuclear gauge used to measure the in-place hot-mix asphalt density

## Appendix B

# Complete Set of Interview Responses

**1) The first pass must be as straight as possible. How do you accomplish that?**

| | Answer | Comment(s) |
|---|---|---|
| Consultant 1 | Stringline | ----- |
| Consultant 2 | Stringline | Drop down chain as guide |
| Consultant 3 | Stringline | Use of laser or GPS |
| Consultant 4 | ----- | Experienced operator, pre-construction preparation |
| Consultant 5 | Stringline | ----- |
| Consultant 6 | Stringline | Skip paint stringline |
| Consultant 7 | Stringline | Skip paint stringline |
| Consultant 8 | Stringline | Or other reference point |
| Consultant 9 | Stringline | Or other reference point |
| Consultant 10 | Reference & Guide bar | Rod positioned at leading edge of paver, easy for operator to see |

| | Answer | Comment(s) |
|---|---|---|
| Contractor A | Stringline | ----- |
| Contractor B | Stringline | ----- |
| Contractor C | Stringline | Important to get truck lined up properly |
| Contractor D | Stringline | Use survey crew to set stringline skip paint stringline |
| Contractor E | Stringline | ----- |
| Contractor F | Stringline | and marking paint |
| Contractor G | Stringline | paint, if windy |

**2) Do you prefer a notched wedge joint or a butt joint?**

| | Answer | Comment(s) |
|---|---|---|
| Consultant 1 | Butt | Better ride on "ride spec" job. notched wedge can be a good joint |
| Consultant 2 | No preference | Correct notch profile after rolling don't starve the joint |
| Consultant 3 | Notched wedge | ----- |
| Consultant 4 | Notched wedge | ----- |
| Consultant 5 | Butt | Notched wedge works |
| Consultant 6 | Notched wedge | Minimum lift thickness 1.5 to 2" butt joint works too |
| Consultant 7 | Butt | ----- |
| Consultant 8 | No preference | ----- |
| Consultant 9 | Butt | Wedge joint tough to get compacted |
| Consultant 10 | No preference | |

| | Answer | Comment(s) |
|---|---|---|
| Contractor A | Butt | However, DOT requires notched wedge. |
| Contractor B | Butt | ----- |
| Contractor C | Notched wedge | Butt better durability if roll out notch Important in multiple lifts to reverse the direction of the wedge |
| Contractor D | Butt | ----- |
| Contractor E | No preference | Lift thickness may limit the ability to use the notched wedge |
| Contractor F | No preference | |
| Contractor G | Notched wedge | |

**2b) Do you compact the notched wedge?**

| | Answer |
|---|---|
| Consultant 1 | ----- |
| Consultant 2 | ----- |
| Consultant 3 | ----- |
| Consultant 4 | ----- |
| Consultant 5 | Yes |
| Consultant 6 | ----- |
| Consultant 7 | ----- |
| Consultant 8 | Yes |
| Consultant 9 | ----- |
| Consultant 10 | Yes |

| | Answer |
|---|---|
| Contractor A | Yes, with a rubber tired roller |
| Contractor B | When we build wedge we use a small roller on wedge |
| Contractor C | Yes, roll wedge with a weighted single tire attached to paver |
| Contractor D | N/A |
| Contractor E | ----- |
| Contractor F | No |
| Contractor G | No |

**3) Do you use the paver automation? If yes, your preference, Joint Matcher or Ski?**

| | Answer |
|---|---|
| Consultant 1 | Yes, joint matcher |
| Consultant 2 | Yes, joint matcher |
| Consultant 3 | Yes, joint matcher |
| Consultant 4 | Yes, joint matcher |
| Consultant 5 | Yes, joint matcher |
| Consultant 6 | Yes, joint matcher |

| | |
|---|---|
| Consultant 7 | No |
| Consultant 8 | Yes, joint matcher |
| Consultant 9 | Yes, joint matcher |
| Consultant 10 | Yes, joint matcher |
| | **Answer** |
| Contractor 1 | Yes, ski |
| Contractor 2 | Yes, ski |
| Contractor 3 | Yes, joint matcher |
| Contractor 4 | Yes, joint matcher |
| Contractor 5 | Yes, ski |
| Contractor 6 | Yes, joint matcher |
| Contractor 7 | Yes, joint matcher |

**4) Do you roll the unsupported edge by:**

| | |
|---|---|
| | **Answer** |
| Consultant 1 | Overhang the edge by 6-inches |
| Consultant 2 | Overhang the edge by 6-inches (static on first pass) |
| Consultant 3 | Stay back from the edge 6-inches |
| Consultant 4 | Stay back from the edge 6-inches |
| Consultant 5 | Stay back from the edge 6-inches |
| Consultant 6 | Overhang the edge by 6-inches |
| Consultant 7 | Overhang the edge by 6-inches |
| Consultant 8 | High stability hang over, low stability mix stay back |
| Consultant 9 | Overhang the edge by 6-inches |
| Consultant 10 | Stay back from the edge 6-inches |
| | **Answer** |
| Contractor 1 | Overhang the edge of the mat 6-inches |
| Contractor 2 | Stay back from the edge 6-inches |
| Contractor 3 | Overhang the edge of the mat 6-inches |
| Contractor 4 | Stay back from the edge 6-inches |
| Contractor 5 | ----------------- |
| Contractor 6 | Overhang the edge of the mat 6-inches |
| Contractor 7 | Stay back from the edge 6-inches |

**5) When using a wedge joint to you tack the notch & wedge? If yes, with**

| | |
|---|---|
| | **Answer** |
| Consultant 1 | Yes, emulsion |
| Consultant 2 | Yes, emulsion (double tack) |
| Consultant 3 | No |
| Consultant 4 | Yes, emulsion |
| Consultant 5 | Yes, PG-grade |
| Consultant 6 | Yes, emulsion |
| Consultant 7 | No |
| Consultant 8 | Yes, emulsion |

| | |
|---|---|
| Consultant 9 | Yes, same material as roadway |
| Consultant 10 | Yes, emulsion |
| | **Answer** |
| Contractor 1 | Yes, emulsion |
| Contractor 2 | Yes, emulsion |
| Contractor 3 | Yes, emulsion (double tack) |
| Contractor 4 | --------------- |
| Contractor 5 | Yes, emulsion |
| Contractor 6 | Yes, emulsion or PG-grade |
| Contractor 7 | Yes, emulsion or PG-grade |

**6) When using a butt joint do you tack the vertical face? If yes, with**

| | **Answer** |
|---|---|
| Consultant 1 | Yes. emulsion |
| Consultant 2 | Yes, emulsion (double tack) |
| Consultant 3 | Yes, PG-grade |
| Consultant 4 | Yes, PG-grade |
| Consultant 5 | Yes, emulsion |
| Consultant 6 | Yes, emulsion |
| Consultant 7 | No |
| Consultant 8 | Yes, emulsion |
| Consultant 9 | Yes, same material as roadway tack |
| Consultant 10 | Yes, emulsion |
| | **Answer** |
| Contractor 1 | Yes, emulsion |
| Contractor 2 | Yes, emulsion |
| Contractor 3 | Yes, emulsion |
| Contractor 4 | Yes, emulsion |
| Contractor 5 | Yes, emulsion |
| Contractor 6 | Yes, emulsion or PG-grade, same as roadway |
| Contractor 7 | Yes, emulsion or PG-grade, same as roadway |

**7) Have you ever used proprietary joint adhesive? If yes, was it practical, did it improve performance?**

| | **Answer** |
|---|---|
| Consultant 1 | Yes, not practical, improved performance |
| Consultant 2 | Yes, was practical, improved performance |
| Consultant 3 | Yes, was practical, improved performance |
| Consultant 4 | No |
| Consultant 5 | Yes, was practical, improved performance |
| Consultant 6 | -------------- |
| Consultant 7 | No |
| Consultant 8 | Yes, was practical, ? |
| Consultant 9 | Yes, was practical, improved performance |

| | |
|---|---|
| Consultant 10 | Yes, -----, ------ |
| | **Answer** |
| Contractor 1 | No |
| Contractor 2 | No |
| Contractor 3 | No |
| Contractor 4 | No |
| Contractor 5 | No |
| Contractor 6 | No |
| Contractor 7 | No |

**8) Have you ever cold the cold joint back, prior to placing adjacent lane? If yes, was it practical, did it improve performance?**

| | |
|---|---|
| | **Answer** |
| Consultant 1 | Yes, not practical, did not improve performance |
| Consultant 2 | No |
| Consultant 3 | Yes, not practical, improved performance |
| Consultant 4 | Yes, not practical, ? |
| Consultant 5 | Yes, not practical, improved performance |
| Consultant 6 | Yes, practical, improved performance |
| Consultant 7 | No |
| Consultant 8 | Yes, ?, improved performance |
| Consultant 9 | Yes, practical, improved performance |
| Consultant 10 | Yes, not practical, did not improve performance |
| | **Answer** |
| Contractor 1 | Yes, not practical, did not improve performance |
| Contractor 2 | Yes, not practical, did not improve performance |
| Contractor 3 | Yes, not practical, improved performance |
| Contractor 4 | Yes, practical, improved performance (mill rather than cut) |
| Contractor 5 | Yes, not practical, did not improve performance |
| Contractor 6 | Yes, not practical, did not improve performance |
| Contractor 7 | Yes, not practical, did not improve performance |

**9) Have you ever used an infra-red heater on longitudinal joint? If yes, was it practical, did it improve performance?**

| | |
|---|---|
| | **Answer** |
| Consultant 1 | Yes, not practical, did not improve performance |
| Consultant 2 | No |
| Consultant 3 | No |
| Consultant 4 | Yes, not practical, ? |
| Consultant 5 | Yes, ?, improved performance |
| Consultant 6 | --------- |
| Consultant 7 | Yes, not practical, did not improve performance |
| Consultant 8 | --------- |
| Consultant 9 | Yes, ?, ? |

| | Answer |
|---|---|
| Consultant 10 | Yes, not practical, did not improve performance (hard to control heat) |

| | **Answer** |
|---|---|
| Contractor 1 | No |
| Contractor 2 | Yes, not practical, ? |
| Contractor 3 | Yes, not practical, improved performance |
| Contractor 4 | No |
| Contractor 5 | Yes, not practical, did not improve performance |
| Contractor 6 | Yes, ? ? |
| Contractor 7 | No |

**10) How much do you overlap the hot material onto the cold material?**

| | **Answer** |
|---|---|
| Consultant 1 | 1.5 to 2.0-inches |
| Consultant 2 | 0.5-inch |
| Consultant 3 | 0.5 to 0.75-inch |
| Consultant 4 | 0.5-inch |
| Consultant 5 | 0.5 to 1.0-inch |
| Consultant 6 | 0.5-inch |
| Consultant 7 | 1.0 to 1.5-inches (mill or cut back, then overlap 0.5-inch) |
| Consultant 8 | 1.0 to 1.5-inches |
| Consultant 9 | 0.75 to 1.0-inch |
| Consultant 10 | 0.5 to 0.75-inch |

| | **Answer** |
|---|---|
| Contractor 1 | 2.0 to 6.0-inches |
| Contractor 2 | 1.0-inch |
| Contractor 3 | 0.5 to 0.75-inch |
| Contractor 4 | 1.0 to 2.0-inch |
| Contractor 5 | 1.0-inch |
| Contractor 6 | 1.0 to 1.5-inches |
| Contractor 7 | 0.0 (no overlap) |

**11) What do you do with the overlap? Push it back to the joint, nothing, other?**

| | **Answer** |
|---|---|
| Consultant 1 | Do nothing |
| Consultant 2 | Do nothing |
| Consultant 3 | Do nothing |
| Consultant 4 | Push it back |
| Consultant 5 | Do nothing |
| Consultant 6 | Do nothing |
| Consultant 7 | Do nothing |
| Consultant 8 | Push it back |
| Consultant 9 | Fine mix do nothing, coarse mix push it back |
| Consultant 10 | Do nothing |

| | **Answer** |
|---|---|
| Contractor 1 | Push it back |
| Contractor 2 | Push it back |
| Contractor 3 | Do nothing |
| Contractor 4 | Do nothing |
| Contractor 5 | Do nothing |
| Contractor 6 | Do nothing |
| Contractor 7 | Remove it with a flat bottom shovel |

**12) How do you roll the 2nd pass? Hot overlap onto cold, Cold overlap onto hot, Hot side staying back 6 +/- inches from joint, Roll from the outside to the joint, other.**

| | **Answer** |
|---|---|
| Consultant 1 | Hot side staying back 6-inches |
| Consultant 2 | Roll from outside to joint |
| Consultant 3 | Hot overlap onto cold |
| Consultant 4 | Hot side staying back 6-inches |
| Consultant 5 | Hot side staying back 6-inches |
| Consultant 6 | Hot side staying back 6-inches |
| Consultant 7 | Hot overlap onto cold |
| Consultant 8 | Cold overlap onto hot (static on ay up, vibratory on hot on way back) |
| Consultant 9 | Hot overlap onto cold |
| Consultant 10 | Hot side staying back 6-inches |

| | **Answer** |
|---|---|
| Contractor 1 | Cold overlap onto hot |
| Contractor 2 | Roll from outside to joint |
| Contractor 3 | Cold overlap onto hot |
| Contractor 4 | Hot overlap onto cold |
| Contractor 5 | Cold overlap onto hot |
| Contractor 6 | Hot side staying back 6-inches |
| Contractor 7 | Hot side staying back 6-inches |

**13) Do you monitor the longitudinal joint density?**

| | **Answer** |
|---|---|
| Consultant 1 | No |
| Consultant 2 | Yes, nuclear gauge correlated to cores |
| Consultant 3 | Yes, nuclear gauge average of each side |
| Consultant 4 | Yes, nuclear gauge |
| Consultant 5 | Yes, nuclear gauge, cores for acceptance |
| Consultant 6 | Yes, nuclear gauge |
| Consultant 7 | Yes, cores |
| Consultant 8 | Yes, nuclear gauge |
| Consultant 9 | Yes, nuclear gauge |
| Consultant 10 | Yes, nuclear gauge 6-inches off joint |

| | **Answer** |
|---|---|
| Contractor 1 | Yes, nuclear gauge within 1-foot of joint |
| Contractor 2 | Yes, nuclear gauge |
| Contractor 3 | Yes, nuclear gauge |
| Contractor 4 | Yes, nuclear gauge 3-inches off joint |
| Contractor 5 | Yes, nuclear gauge |
| Contractor 6 | Yes, nuclear gauge |
| Contractor 7 | Yes, nuclear gauge, cores for acceptance |

**14) Which type of spec offers the best chance for long term performance? Method spec or Minimum density**

| | **Answer** | |
|---|---|---|
| Consultant 1 | Method | |
| Consultant 2 | ---------- | |
| Consultant 3 | Minimum Density. | 90% |
| Consultant 4 | Minimum Density | ? |
| Consultant 5 | Minimum Density | Mat – 2% |
| Consultant 6 | Minimum Density | 90% |
| Consultant 7 | Minimum Density | 90.5 to 91.0% |
| Consultant 8 | Minimum Density | Mat – 3 lbs |
| Consultant 9 | Minimum Density | 91% |
| Consultant 10 | Minimum Density | Mat – 1% |

| | **Answer** | |
|---|---|---|
| Contractor 1 | Minimum Density | 90% |
| Contractor 2 | Minimum Density | 90% |
| Contractor 3 | Minimum Density | 90% |
| Contractor 4 | Method | |
| Contractor 5 | Minimum Density | Mat – 2% |
| Contractor 6 | -------- | |
| Contractor 7 | Minimum Density | 90% |

**15) Does a 9.5mm mix have a better chance for good performance than a 12.5mm?**

| | **Answer** |
|---|---|
| Consultant 1 | Yes |
| Consultant 2 | Yes |
| Consultant 3 | Does not matter as long as 4 x NMAS |
| Consultant 4 | No |
| Consultant 5 | Yes |
| Consultant 6 | Does not matter as long as 4 x NMAS |
| Consultant 7 | Does not matter as long as 4 x NMAS |
| Consultant 8 | No. lift thickness most important |
| Consultant 9 | Yes |
| Consultant 10 | Yes |

**Answer**

| | |
|---|---|
| Contractor 1 | Yes |
| Contractor 2 | No |
| Contractor 3 | Yes |
| Contractor 4 | Yes |
| Contractor 5 | ------- |
| Contractor 6 | Yes |
| Contractor 7 | Yes |

**16) Does a 9.5mm mix with a design asphalt content of 6.2% asphalt have a better chance for good performance than that same mix at 5.7% asphalt?**

| | **Answer** |
|---|---|
| Consultant 1 | Yes |
| Consultant 2 | Yes |
| Consultant 3 | Yes |
| Consultant 4 | No |
| Consultant 5 | Yes |
| Consultant 6 | Yes |
| Consultant 7 | Maybe, too many other factors |
| Consultant 8 | No, good mix design more important than just asphalt content |
| Consultant 9 | Yes |
| Consultant 10 | ------- |

| | **Answer** |
|---|---|
| Contractor 1 | Yes |
| Contractor 2 | No |
| Contractor 3 | Yes |
| Contractor 4 | Yes |
| Contractor 5 | ------ |
| Contractor 6 | Yes |
| Contractor 7 | Yes |

**17) Can I do anything in late season paving to improve the longitudinal joint?**

| | **Answer** |
|---|---|
| Consultant 1 | Overband the joint, good construction practices |
| Consultant 2 | Keep auger tight to end gate, adjust paving speed to assure constant flow of fresh material |
| Consultant 3 | Stay close to paver with rollers |
| Consultant 4 | Short distance between paver and rollers |
| Consultant 5 | Use a joint heater in the northern tier of the U.S. |
| Consultant 6 | Use a "warm mix additive" |
| Consultant 7 | No |
| Consultant 8 | Temperature critical, keep rollers close |
| Consultant 9 | Switch to finer mix, maybe add some asphalt, maybe joint heater |
| Consultant 10 | Echelon paving |

**Answer**

| | |
|---|---|
| Contractor 1 | Make sure joint is clean, tack is cured |
| Contractor 2 | Run warm mix |
| Contractor 3 | Best practices, slow paver down, additional roller(s) |
| Contractor 4 | Rollers tight to the paver, may need additional roller(s) |
| Contractor 5 | Increase temperature within allowable range |
| Contractor 6 | Maintain temperature, keep rollers tight to paver |
| Contractor 7 | Adjust paver speed to allow rollers to stay close to paver |

**18) Have you ever been required to seal the surface of a longitudinal joint as part of the contract? If yes what was the material? What was the width of the overband?**

| | **Answer** |
|---|---|
| Consultant 1 | Yes, PG-grade or emulsion, 6-inches |
| Consultant 2 | No |
| Consultant 3 | No |
| Consultant 4 | Yes, --------, 3 to 4-inches (question its value) |
| Consultant 5 | No |
| Consultant 6 | ------- |
| Consultant 7 | No, (wasted effort) |
| Consultant 8 | ------- |
| Consultant 9 | No |
| Consultant 10 | ------- |

| | **Answer** |
|---|---|
| Contractor 1 | Yes, emulsion, 12-inches (fractured aggregate not the norm) |
| Contractor 2 | No |
| Contractor 3 | No |
| Contractor 4 | No |
| Contractor 5 | No |
| Contractor 6 | Yes, PG-grade, ------- |
| Contractor 7 | No |

**19) Tips that can make a difference.**

| | |
|---|---|
| Consultant 1 | Must plan for the joint in the construction process |
| Consultant 2 | Tack full width of the mat, never starve the joint, minimize water on the drum |
| Consultant 3 | Make sure auger is within 12-inches of end gate |
| Consultant 4 | Use mechanical joint matcher rather than sonic (temp effects sonic |
| Consultant 5 | Paving crew makes the difference! End plate down, |
| Consultant 6 | Vibratory screed on! End gate down |
| Consultant 7 | Vibratory screed on! Difference behind paver 78% vs 70% |
| Consultant 8 | Vibratory screed on! Auger material all the way to end gate |
| Consultant 9 | Periodically get someone from outside to audit paving crew. It eliminates bad habits they may have gotten in to |
| Consultant 10 | Training, training, training. Set goals and standards; insist paving crew maintain standards |

| | |
|---|---|
| Contractor 1 | Seasoned paving crew, make sure every pass is straight, set end gate properly |
| Contractor 2 | Clean face of joint, tack w/emulsion, sufficient material at the joint, auger extension within 12-inches of end gate, we always use a rubber tire roller |
| Contractor 3 | "Cleanliness is next to Godliness. On occasion we have vacuumed wedge joint." Echelon paving when possible. |
| Contractor 4 | "Be careful when making roller arc at beginning and end of pass not to roll open the joint." |
| Contractor 5 | ---------- |
| Contractor 6 | "Best joint must sacrifice ride and sometimes yield, control material overlap and depth, automatics On and a good screed operator" |
| Contractor 7 | "Consistent mix temperature. Sufficient rollers to stay close to paver |