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FINAL REPORT

LONGITUDINAL JOINT CONSTRUCTION FOR HOT MIX ASPHALT PAVEMENTS

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16 Abstract

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The objective of this research project was to conduct a literature review on longitudinal joint construction for hot-mix asphalt pavements. The review covered the issues related to the principles of hot-mix asphalt paving and compaction for longitudinal joint construction, longitudinal joint problems, and some longitudinal joint construction techniques and specifications from different studies. Specific recommendations have also been made for application in the State of Kansas.

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Final Report

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THE KANSAS DEPARTMENT OF TRANSPORTATION
TOPEKA, KANSAS

KANSAS STATE UNIVERSITY
MANHATTAN, KANSAS

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PREFACE

The Kansas Department of Transportation's (KDOT) Kansas Transportation Research and New-Developments (K-TRAN) Research Program funded this research project. It is an ongoing, cooperative and comprehensive research program addressing transportation needs of the state of Kansas utilizing academic and research resources from KDOT, Kansas State University and the University of Kansas. Transportation professionals in KDOT and the universities jointly develop the projects included in the research program.

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ABSTRACT

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Introduction

1.1 Introduction and Problem Statement

The longitudinal joint between asphalt mats is often the weakest part of a bituminous concrete pavement. Often these joints deteriorate fast under traffic as evidenced by the two-year old pavements on K-113 and US-24 near Manhattan in Figure 1. Because of the difficulty in compacting the unconfined edges, the joints usually exhibit lower densities than the remainder of the asphalt mat. Theoretically, a uniform gradient at the same density level as the rest of the pavement is desirable, as it is believed that the longitudinal cracks result primarily from the density gradient that is usually encountered across the joint. This density gradient can be attributed to low density at the unconfined edge when the first lane is paved and relatively high density at the confined edge when the adjacent lane is paved (1-3). Water infiltrates through the low-density area with high air voids and results in premature failures. Areas of high density also cause a stress concentration during thermal expansion and contraction and induce cracking.

1.2 Study Objectives

The objective of this research project was to conduct a literature review on longitudinal joint construction for hot-mix asphalt pavements. The following questions were addressed in the review:

- What is a longitudinal joint and how is it constructed?
- What are the causes of longitudinal joint deterioration and what are the possible solutions?
- What are the new techniques and specifications for longitudinal joint construction?

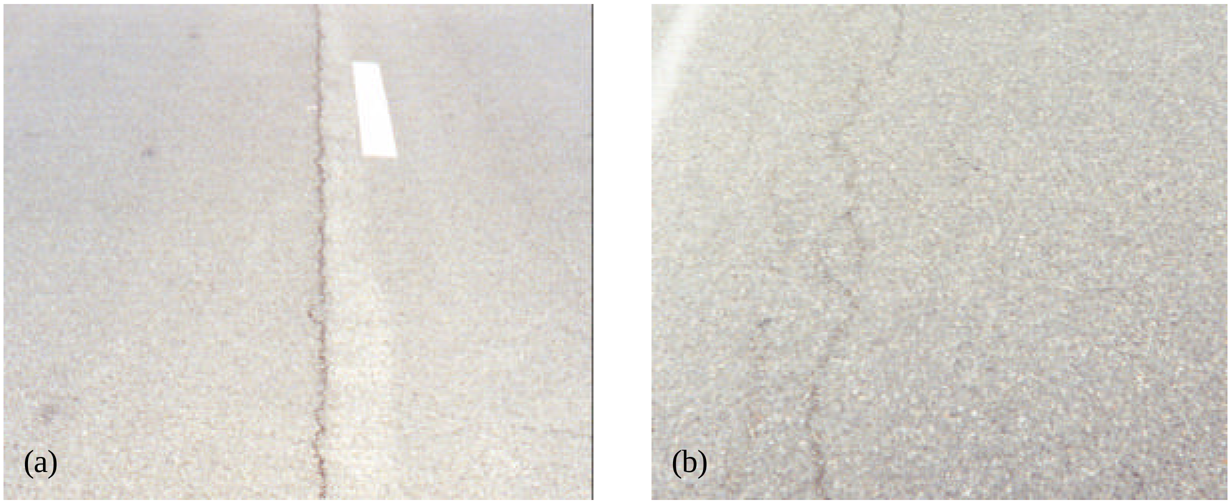


FIGURE 1: (a) Longitudinal Joint Cracking on North Bound K-113 Highway and (b) Longitudinal Joint Cracking on US-24 West in Manhattan, Kansas

1.3 Organization of the Report

This report is divided into four chapters. Chapter 1 is the introduction to the longitudinal joint problem. Chapter 2 describes the principles of compaction. Chapter 3 presents the longitudinal joint construction methods and related research. Chapter 4 presents the conclusions and recommendations.

Chapter 2

Principles of Compaction

2.1 Principles of Paving

Compaction is the process of compressing a given volume of hot-mix asphalt (HMA) to remove air and to achieve a desired density. The process is accomplished by pressing together the asphalt coated aggregate particles. Compaction is considered successful when the finished mat reaches optimum void content (less than 7%). The voids in an under compacted mix tend to be interconnected and permit the intrusion of air and water throughout the pavement. Air and water carry oxygen, which oxidizes the asphalt binder in the mix causing it to become brittle, and consequently, the pavement itself may fail.

The HMA mixture has an initial density of approximately 75 percent of laboratory design density (bulk density) when it is transferred to the paver. Once it is compacted under the roller, the density of the HMA is expected to reach about 96 percent of the laboratory density (4). The newly placed HMA mat behind the paver is compacted by the vibratory screed and rollers. The vibratory screed generally provides approximately 25 percent of the mat compaction (4). Both extrusion and vibration compact the mat under the screed. Rollers provide the final compaction. Two or more rollers operate in a defined pattern at a certain temperature behind the paver. The rolling pattern should be established as quickly as possible to allow the roller onto the mat before the HMA cools appreciably. Particle reorientation in the rolling process is better achieved when the asphalt film on the aggregate particle is less viscous (5). As this film cools and becomes more viscous, particles do not slide by one another easily, and the mat becomes more difficult to compact.

When compacting the mat, the assumptions are: i) All compaction is done in one direction, and ii) The base does not move and the sides of the mixture under compaction are confined (4). Since the mix is not confined at the outer edges as it is being compacted, it spreads out and becomes wider. Therefore, either the desired thickness or the desired density is not achieved. This problem is typically common when placing a 3.6 m (12 foot) wide mat. The mat becomes wider and thinner as the mix is being compacted. Thus, the desired density is not achieved at the outer edges.

2.2 Factors Influencing Compaction

Hot mix asphalt compactors utilize four principles of compaction, or combinations, to meet specified density requirements: (1) Static weight, (2) Kneading action, (3) Impact, and (4) Vibration. The following factors affect the compaction of hot-mix asphalt:

2.2.1 Material Properties

Aggregates: The compactive effort increases with increasing angularity, nominal maximum size and hardness of the aggregate (6).

Asphalt binder: Asphalt cement with higher viscosity needs greater compactive effort. Mixture with too little asphalt may also require an increase in compactive effort, whereas a mix with too much asphalt may shove under the rollers.

Initial mix temperature: A mix that is placed at a higher temperature will be easier to compact than will a mix with lower temperature. However, if the initial mix temperature is too high, the mix may be tender and difficult to compact until the mix temperature decreases and the viscosity of asphalt increases.

2.2.2 Environmental Variables

Layer thickness: As the thickness of the layer placed increases, the time available for compaction increases.

Air and base temperature: A higher air temperature allows more time for compaction. A moist base layer significantly increases the cooling rate of the new overlaying asphalt layer (6).

Mix laydown temperature: As the temperature of the hot-mix asphalt being placed increases, the time available for compaction increases.

Wind velocity: A thin layer of mix will cool more quickly in a strong wind. Wind may cause the surface to cool so rapidly that a crust will form. This effect is more pronounced for thin layers than thick layers.

Solar flux: A mix will cool more slowly on a sunny day compared to a cloudy one.

2.2.3 Equipment Factors

Frequency and Forward Speed of Roller: The higher the frequency the better the compaction. At high frequency the roller applies more uniform compaction. A minimum of 2000 vibrations/min is suggested to compact hot-mix asphalt (6).

Amplitude of Applied Force: Extreme forces are not desirable because they can crush the aggregates and force the mat to deform. Low amplitude forces may not result in sufficient compaction to obtain the desired density. This is true especially when the gradation is coarse and the temperature of the mat is cooling fast. The vibratory compactor should compact in static mode for thin layers with thickness below 75 mm (3 in.). Otherwise the compactor may bounce after few passes due to the variability in the stiffness of the underlying pavement courses (6).

Impact Spacing: The impact spacing is determined by dividing the frequency of vibration (vib/min) by the roller speed (m/min or feet/min). Impact spacing between 10 and 12 impacts/ft

(33 and 39 impacts/meter) is suggested to obtain a balance between roller productivity and layer smoothness.

Roller passes, zone, and pattern also affect the compaction achieved.

Chapter 3

Longitudinal Joint Construction

3.1 Traditional Joint Construction Methods

Regan (7) summarized the traditional joint construction techniques in use in a state-of-the art report and joint construction study for airfield pavements for the Federal Aviation Administration.

3.1.1 No Treatment

In this method, the paver places the hot mix in a lift with vertical edges on both sides. As the lift is rolled, mix particles along the unconfined edge slough off and roll down the face to form a natural angle of repose (7). No raking or luting is done. Figure 2 shows a schematic of this joint construction technique.

3.1.2 Bumping Unconfined Edges

This method is similar to the "No Treatment" method except luting is done to bump or manually shape the unconfined edge as the paver moves. The mat is then rolled. Figure 3 shows the schematic of this technique.

3.1.3 Wedge or Tapered Edges

This technique uses a paver attachment to build a stable edge slope on the unconfined edge of the mat, as shown in Figure 3. Slopes of 1:6 and 1:3 vertical to horizontal have been used. Arizona and Michigan DOTs have used 1:6 slopes while New Jersey and Kansas use 1:3. These slopes were selected for traffic safety reasons. Compaction along the sloping unconfined wedge is accomplished by a small roller pulled by the paver, as shown in figure 4 (7).

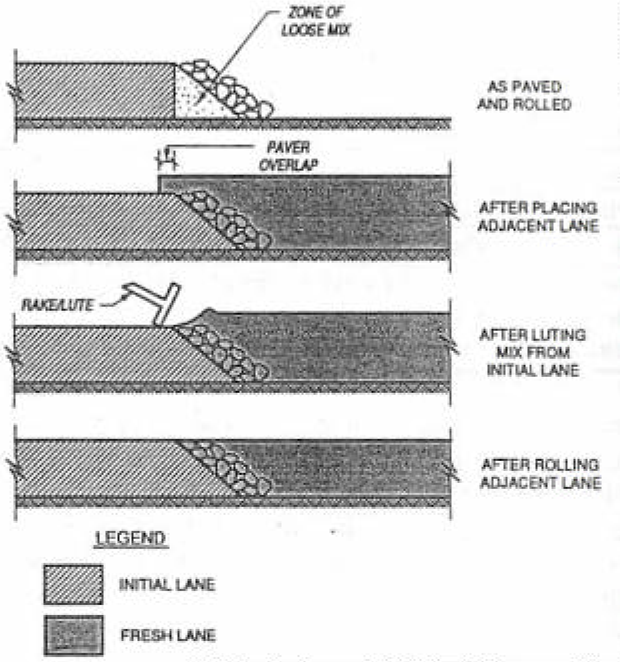


FIGURE 2: No Treatment Longitudinal Joint (7)

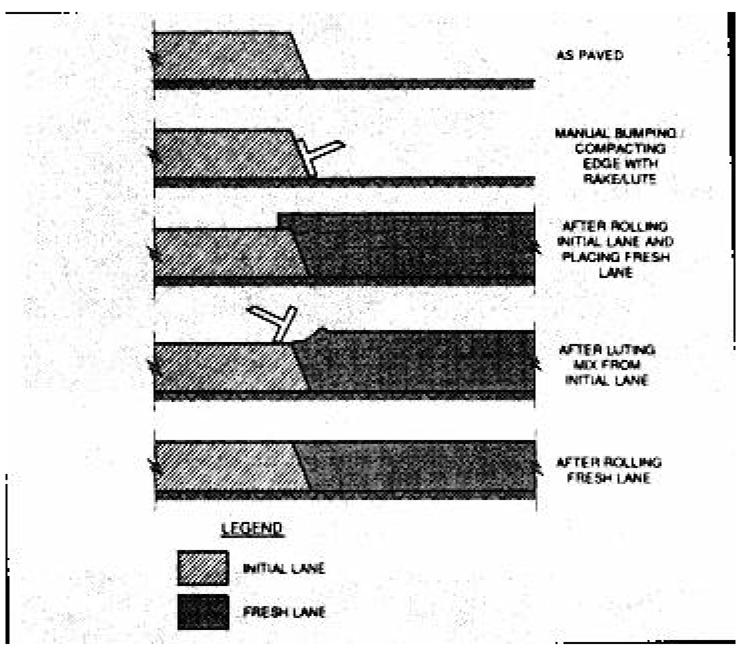


FIGURE 3: Bumping Unconfined Edge Technique (7)

FIGURE 4: Roller Compaction of the Michigan Wedge Joint (7)

3.1.4 Cutting Back the Joint

Sometimes lack of confinement of the mix during the compaction process results in low-density zones, as shown in Figure 5a. In order to remove the low-density portion of the mix, the longitudinal edge of the previously placed mix is cut back using a saw for a distance of 25 to 50 mm (1 to 2 in) (5). A tack coat is placed on the newly exposed vertical face of the longitudinal joint, illustrated in Figure 5b, before paving the adjacent lane. If the wedge is not cut back, proper joint density could be achieved through overlapping, raking, and compacting.

3.1.5 Overlapping the Joint

The amount of overlap between the new mat and the previously placed mat is important. The end gate on the paver should extend over the top surface of the adjacent mix a distance of not more than 25 to 37 mm (1 to 1 ½ inches) (5). This amount of overlap provides enough material on top of the joint to allow for proper compaction without having extra mix, which must be pushed back from the joint by a raker. The height of the new mix above the compacted mix should be 6 mm (1/4 in) for each 25 mm (1 in.) of compacted mix (5).

Roller manufacturer Ingersoll-Rand suggests that the roller should travel with most of the drum on the adjacent hot mat when compacting a longitudinal joint (8). Vibration should always be turned on when traveling on an uncompacted surface. With the roller in the vibratory mode, the operator should overlap the cold mat about 150 mm (6 in) to pinch the material into the joint. Ingersoll-Rand claims that this technique is the most efficient method for compacting longitudinal joints.

However, excessive overlap of the paver screed over previously placed mat is a major problem in longitudinal joint construction. Since this extra asphalt mix cannot be pushed into the compacted mat, the material is raked into the new mat. Minimal raking is necessary when the longitudinal edge of the first lane is vertical and the correct overlap is used.

3.1.6 Raking the Joint

Excessive raking of the longitudinal joint may cause long-term performance problems. The mix material that is pushed off the longitudinal joint and deposited on the new asphalt mat changes the surface texture of the mat from one side of the lane to the other, and the required density at the joint may become impossible to achieve. Raking of the longitudinal joint can be eliminated with proper overlapping of the new mix on the previously placed mat.

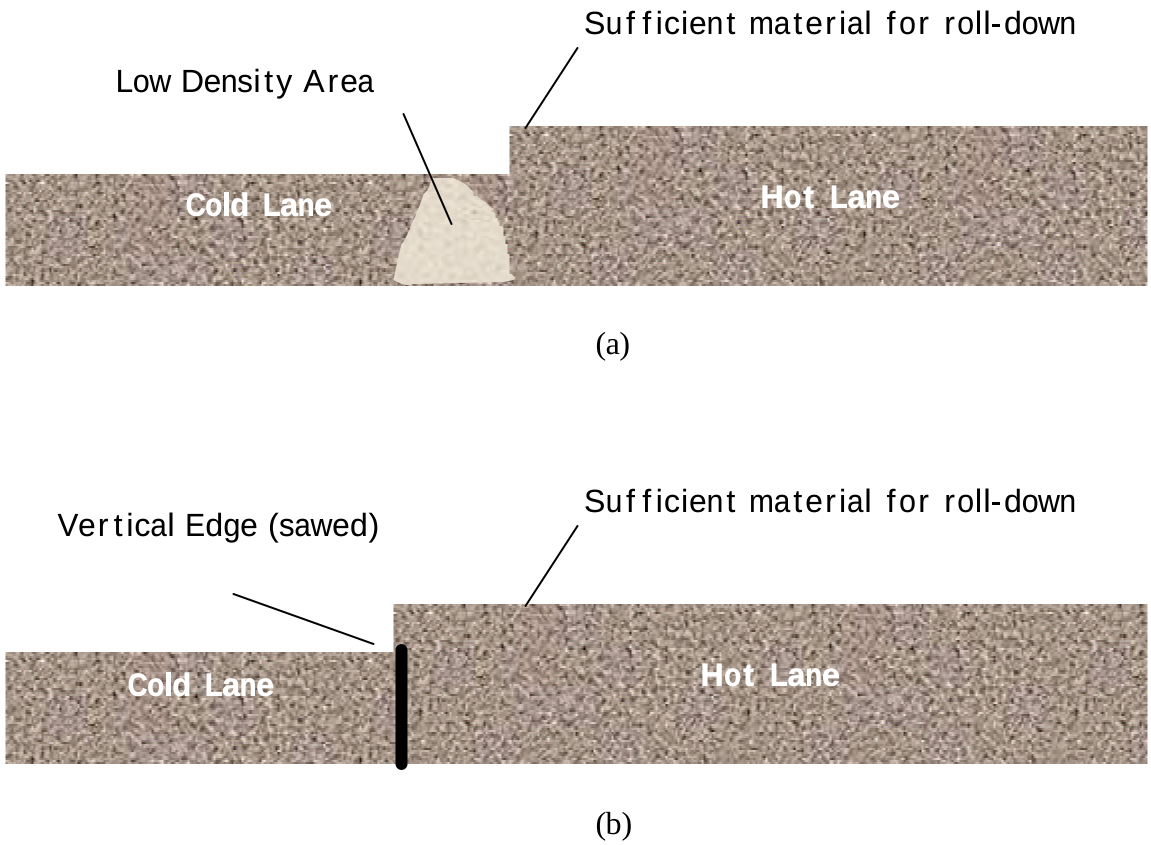


FIGURE 5: (a) Low Density Area, and (b) Vertical Edges on Longitudinal Joints

3.1.7 Compacting the Longitudinal Joint

The compaction equipment will not be able to compact the asphalt mixture along the joint properly if the level of the uncompacted mix is below the level of the compacted mix in the adjacent lane. In that case, part of the weight of the roller will be supported on the previously compacted mat, and the compaction equipment will bridge the mix in the joint, leaving it uncompacted. Use of an intermediate pneumatic tire roller instead of a steel wheel roller can minimize this problem. Thus, the level of the uncompacted mix at the longitudinal joint must be above the elevation of the compacted mix, by an amount equal to approximately 6 mm (1/4 in) for each 25 mm (1 in) of compacted pavement thickness.

3.2 Causes of Longitudinal Joint Cracking

As mentioned earlier, substantial difference in densities on either side of the longitudinal joint (density gradient across the joint) is the primary cause of longitudinal joint cracking (1-3). Cracks in the longitudinal joints allow the ingress of water into the pavement, leading to further disintegration. Low density occurs at the unconfined edge when the first lane is paved, and relatively high density occurs at the same edge when the adjacent lane is paved. This is primarily due to the fact that the edge of the cold lane is unconfined. The subsequent lane, however, has a confined edge and generally has higher density. Foster et al. (1) provide a detailed explanation, as follows: When the adjoining lane is paved, the edge of the first pass confines the new mix and prevents it from spreading. This results in higher density on the second pass at the center of the road. The unconfined edge of the first pass (in the center), however, is now at a lower elevation, and a minor depression may occur in the middle of the road. This area (from the first pass) also has not been sufficiently compacted and generally displays higher air voids. Therefore, the combination of the depressed area and a high void content allow water to accumulate in this area leading to further deterioration. The other causes of longitudinal cracks are:

The loss in temperature during rolling (3);

The height differential due to the poor construction (difficulty in compacting the unconfined edges) or differential settlements after cracking (3);

Residual stress occurring at the wheel path as the HMA mat density increases. When these residual stresses exceed the tensile strength of the HMA, cracking occurs (9); and

Temperature and environmental forces: Once the tensile stress under temperature changes or other environmental forces are higher than the existing tensile strength, the construction joint splits apart (10).

The challenges encountered in attempting to obtain uniform and high densities in longitudinal joint construction are listed with their corresponding solutions in Table 1.

TABLE 1: Challenges and Corresponding Solutions in Longitudinal Joint Construction (4)

CHALLENGES	SOLUTIONS
Proper taper on the first pass	Steer a straight line while laying the first pass. During the second pass, hold the overlap to the minimum required steering tolerance of 12.5 mm (1/2 inch).
Insufficient overlap for the second pass	Use an extendible screed with automated joint following device.
Low bond between the first and second passes	Obtain a vertical cold surface. Use a screed with an end gate that extends to the trailing edge of the screed. The end gate will confine the mat into a near-vertical edge.
Low density area at the joint	Use an infrared heater attached to the paver to soften the poorly-compacted mix at the edge of the first pass so mix from the second pass can roll into the softened area, increasing the density.
Insufficient material to allow for roll down to match final grade between the two passes	Use automatic controls to hold the preset amount of mix (sufficient material) needed for density at the joint. Extend end gate to the back of the screed.
Mix segregation at the outside edge of each pass	Adjust the auger speed and add confinement.

3.3 Types of Joints

3.3.1 Cold Joints

Cold joints occur where the first lane paved has cooled overnight or longer before the next lane is placed or where the first lane is carried so far ahead that the face has cooled to well below 49 °C (120 °F) (6). In this method a companion lane is placed against the first compacted lane. The base on which the companion lane is to be placed is cleaned with a broom, and the edge is tack coated. The paver screed is set to overlap the first mat by 25 to 50 mm (1 to 2 inches). The elevation of the screed above the surface of the first mat should be equal to the amount of roll-down expected during compaction of the new mat.

The coarse aggregate in the material overlapping the cold joint should be removed. The finer portion of the mixture left will be tightly pressed into the compacted lane as the joint is rolled.

3.3.2 Hot Joints

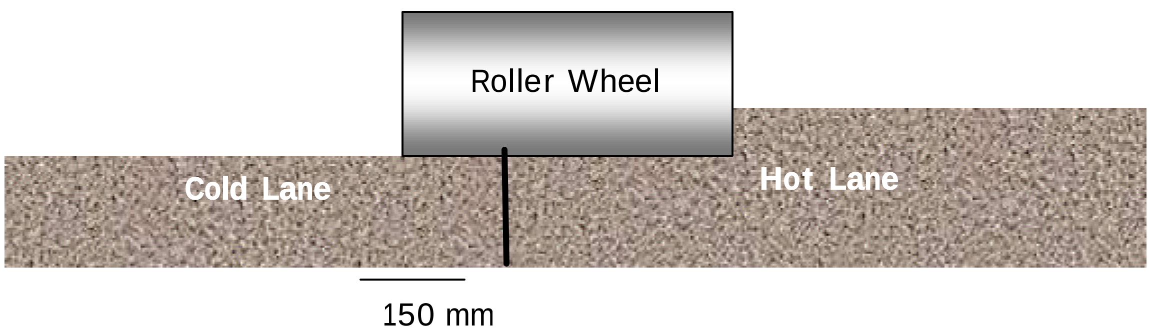
Hot joints are produced by two pavers operating *en echelon,* spaced closely enough so that the lane placed first does not cool significantly before the other lane is placed. There is no special treatment of the face of the joint placed first. The screed of the rear paver is set to overlap the mat of the front paver by 25 to 50 mm (1 to 2 inches) (6). Uniform density is obtained on both sides of the joints as the two mats are automatically matched in thickness. Both sides are compacted together and the hot mats form a good bond, reducing the potential for longitudinal joint cracking. Unless the roadway is closed to traffic, a disadvantage of this process is that traffic is blocked simultaneously in two lanes.

3.4 Conventional Longitudinal Joint Compaction Techniques

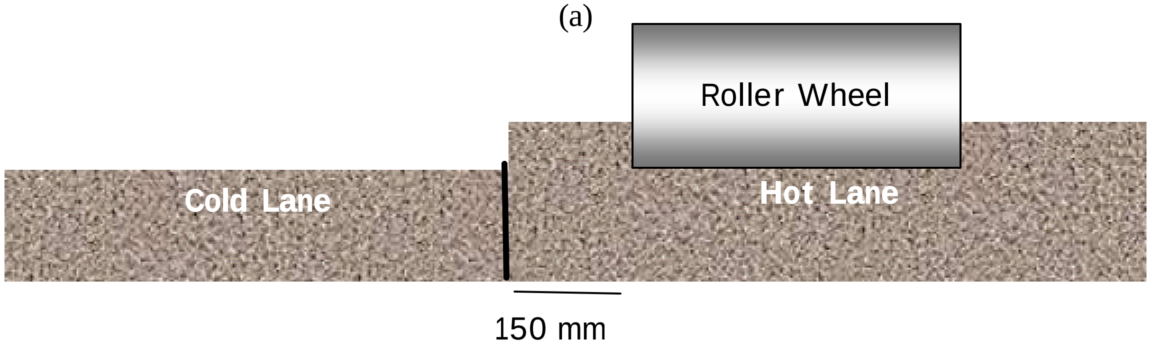
3.4.1 Rolling from the Hot Side

Running the roller on the hot mat while overlapping the joint by a distance of approximately 150 mm (6 in) over the cold mat is considered the most efficient way to compact the longitudinal joint, as shown in Figure 6a (1, 2, 3). Sometimes the first pass of the roller is completed with the edge of the machine about 150 mm (6 in) inside of the longitudinal joint, as shown in figure 6b (6).

The principle behind this method of compaction is that better compaction is obtained when the mix is shoved toward the joint by the roller. No lateral movement will occur under the roller if the mix is stable.



(a)



(b)

FIGURE 6: (a) Rolling the joint from the hot side, and (b) rolling from the hot side 150 mm (6 inches) away from the joint.

3.4.2 Rolling from the Cold Side

In this old practice, initial rolling of the longitudinal joint starts from the cold side of the joint so that the cold mat supports most of the weight of the roller. In contrast to rolling from the hot side, the majority of the compactive effort is wasted. The mix on the hot side of the joint tends to cool down while the roller is operating on the cold side of the longitudinal joint. As a result, more compactive effort is needed to achieve the required density. It was thought that this method allowed the rollers to "pinch" the joint and obtain a higher degree of density. However, the lane placed first will have an unsupported edge that is always difficult to compact (6).

3.4.3 Echelon Paving

In this method of paving two pavers run next to each other. The longitudinal joint is constructed similar to the building of a joint against a cold layer. The amount of overlap between the first and second lanes is very important. The recommended maximum distance that the screed and end gate of the trailing paver should extend over the uncompacted mat behind the first paver should be 25 mm (1 inch) (5). No raking is necessary. The distance between the rollers and the free edge of the mat on the side of the second paver is required to be approximately 150 mm (6 inch). Once the second paver places the mix against the uncompacted edge of the mix from the first paver, the rollers compacting the second lane start to compact the mix on both sides of the joint.

3.5 New and Experimental Longitudinal Joint Construction Techniques

3.5.1 Introduction

The highway industry has attempted to find longitudinal joint construction techniques that can minimize or eliminate cracking at the joints. A variety of techniques have been successfully used to construct good longitudinal joints. In this section some new and experimental longitudinal construction joint techniques from different studies are presented.

3.5.2 Colorado, Michigan, Wisconsin, and Pennsylvania Techniques

A comprehensive study was conducted by the National Center for Asphalt Technology (NCAT) to evaluate effectiveness of twelve different longitudinal joint construction techniques from Michigan, Wisconsin, Colorado and Pennsylvania (2,3).

Three testing locations were chosen within a test section of about 30 m (100 feet) in length at 15 m (50 feet) intervals. At each location, cores samples were taken at the joint and in the hot lane to see the density variation around the longitudinal joint.

Additionally, nuclear density readings were obtained on each section to supplement the limited number of core samples. Thus, adequate sample sizes were obtained to draw statistically valid conclusions. The nuclear density readings were obtained at nine locations approximately 15 m (50 feet) apart within each test section. In Michigan project, nuclear density tests were performed at the joint and 305 mm (1 foot) from the joint on both the cold and hot sides at each location. In the Wisconsin project, readings were taken only at the joint and 305 mm (1 foot) from the joint on the cold side for each section.

Bulk specific gravity (ASTM D2726) of the sawed cores from the joint and the hot lane were determined in the laboratory. Theoretical maximum specific gravities (Rice specific gravity) were also determined and compared with the results obtained at the HMA plant. The means and standard deviations were calculated for these laboratory-measured density values. The longitudinal joint construction techniques were ranked based on the average density of five core samples. A regression analysis correlated the core densities and the corresponding nuclear density readings taken at the same location. The correlation made it possible to convert nuclear densities into corresponding core densities.

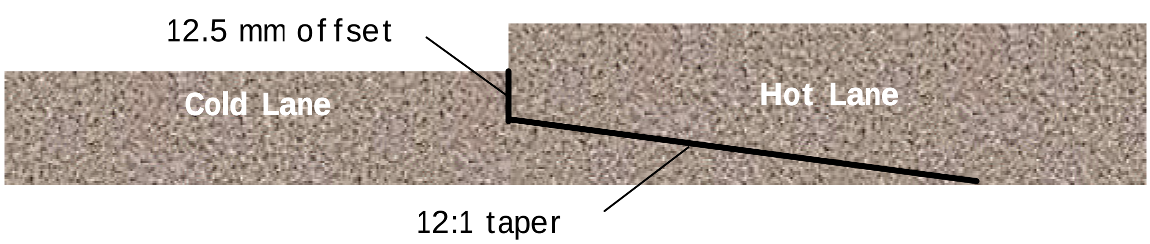
The performance of different longitudinal joints was evaluated after one to four years in service. Table 2 shows the techniques that showed the best performance in terms of densities obtained on four different projects.

Overall the Michigan joint technique, with the 12.5 mm vertical offset and 12:1 taper (Figure 7a), was judged to be the best. The cutting wheel and the edge restraining device techniques, shown in Figure 8, were thought to have good potential but were found to be too operator dependent. Thus, these techniques may not produce consistent results. Among three different joint rolling techniques used on all four projects, rolling the joint from the hot side generally showed the best performance, followed by rolling from the hot side at 150 mm (6 inch) away from the joint (Figure 7b) (2,3).

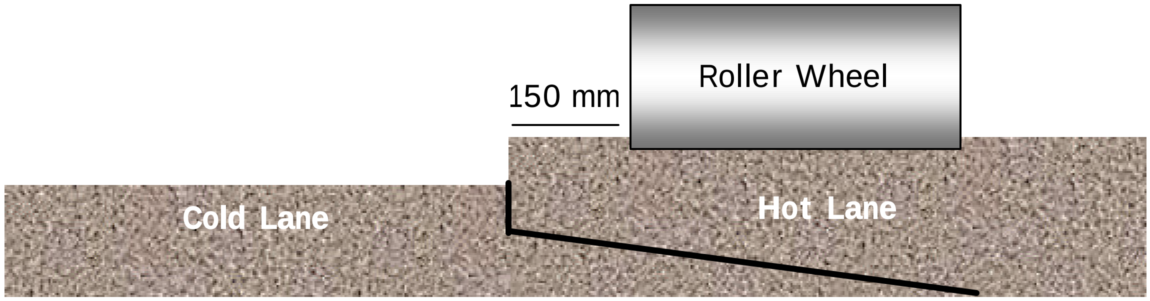
In the *Tapered (12:1) Joint with 12.5 mm Offset without Tack Coat* (Michigan wedge joint) technique, the joint between the adjacent lanes was constructed as two overlapping wedges (Figure 7a). The wedge joint was constructed by tapering the edge of the lane paved first. Later the taper was overlapped when the adjacent lane was paved. A 1:12 taper was formed by a steel plate attachment to the paver screed. After the first mat was placed and tapered to the required slope, the lane was compacted with the roller not extending more than 50 mm (2 inches) beyond the top of the unconfined edge (2,3). The tapered, unconfined face of the wedge was compacted with a small roller attached to the paver. The tapered face was not tack coated on this section. No adjacent lane was paved the next day.

TABLE 2: Longitudinal Joint Construction Techniques for Achieving High Densities

	Best-Performing Technique	Years in Service	Schematic
Michigan	12.5 mm vertical offset and 12:1 taper	3	Figure 7a
Wisconsin	Edge restraining device and the Michigan joint	4	Figures 8a and 7a
Colorado	Tapered joint (25 mm vertical offset and 3:1 taper), cutting wheel, and rubberized tack coat (joint adhesive)	2	Similar to 7a
Pennsylvania	Cutting wheel, rubberized tack coat (joint adhesive), and rolling from hot side	1	Figures 8b and 7b

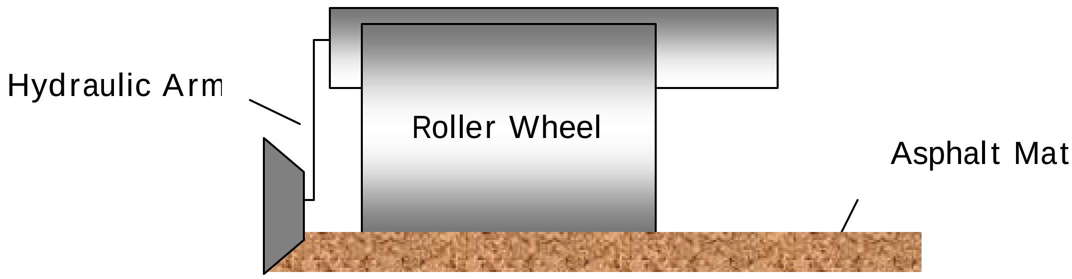


(a)

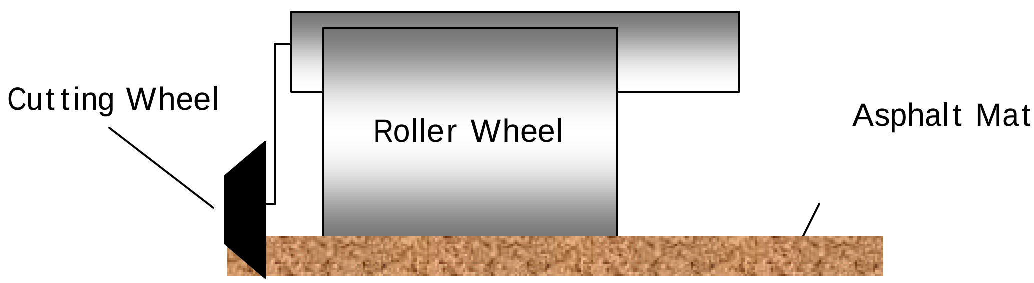


(b)

FIGURE 7: Schematic of Michigan joint showing (a) (12.5 mm offset and 12:1 taper, and (b) rolling from the hot side 150 mm away from joint.



(a)



(b)

FIGURE 8: (a) The edge restraining device, shown here as a tapered wheel, densifies the edge as the roller passes and prevents mixing from moving laterally during compaction; and (b) The cutting wheel trims the unconfined edge of the cold material.

In the *Tapered Joint (12:1) with 12.5 mm Offset with Tack Coat* method, an emulsion tack coat was applied on the unconfined, tapered face of the cold lane before the overlapping wedge was placed and compacted. This technique was similar to the Michigan technique described earlier except for the tack coat. The tack coat is generally applied to prevent the ingress of water and to obtain good adhesion between the lanes.

In the *Rolling from the Hot Side 150 mm from the Joint* method, the compaction started with the edge of the roller at approximately 150 mm (6 inch) from the joint on the hot side (Figure 7b). The lateral pushing of the material toward the joint during the first pass of the roller was believed to produce a high density at the joint. This method is suggested for a tender mix or thick lifts since they are more easily pushed toward the joint (2, 3).

In the *Edge Restraining Device* method, an edge compacting device connected to the roller restrains the edge of the first lane, as shown in Figure 8a. A tapered wheel rolls alongside the compactor and pinches the uncompacted edge towards the drum. In this way, lateral resistance with higher densities is obtained. This technique was used in the Pennsylvania and Wisconsin projects.

In the *Cutting Wheel* method, cutting wheels are used to cut vertically and remove approximately 50 mm (2 inches) of material along the unconfined edge before paving the adjacent paving lane, as shown in Figure 8b. The objective is to remove low-density areas of mix along the joint. The operation is performed while the mix is still warm. Later a thin uniform coat of bituminous material is sprayed on the surface on which the hot mix is placed. The second lane should be placed while the first lane is still hot. Another way to obtain vertical edges is to use end gates to prevent reductions in density due to spreading of the mat during first pass. This technique was used in the Michigan, Wisconsin, Colorado, and Pennsylvania projects.

3.5.3. Colorado Experimental Sections

The following seven types of longitudinal joint construction techniques were used on the Colorado project (2):

In the *3:1 Taper Rolled from Hot Side* method, the major portion of the roller weight traveled on the hot side. First, the unconfined edge of the first paved lane was constructed with a 3:1 taper at the joint (Figure 9a). Behind the screed a steel plate was dragged to obtain the taper. Later the taper was tacked with diluted slow-setting emulsified asphalt with a 1:1 combination of emulsion and water. After 24 hours, asphalt mixture on the hot side was placed using a conventional overlapping technique. The end gate of the paver extended approximately 25 mm to 37 mm (1 to 1 ½ in) over the top surface of the previously placed material. The difference in height between the uncompacted material and the previously placed material was approximately 6 mm for each 25 mm (¼ in for each 1 in) of compacted material placed. No luting was done. The compaction of the joint was started from the hot side, overlapping the cold side about 150 mm (6 in).

The *3:1 Taper Rolled from Cold Side* method was basically the same as the first method except that the major part of the roller was on the cold side of the joint (Figure 9 b). The desired compaction was difficult to obtain with this method because the hot side started to cool down while the roller was operated on the cold side and the roller timing became critical.

The *3:1 Taper Rolled from Hot Side 150 mm from Joint* method is similar to the first method except that the compaction was started with the edge of the roller 150 mm (6 inches) from the joint on the hot side (Figure 9c). It was assumed that high density was obtained at the joint due to lateral pushing of the material toward the joint after the first pass of the roller. This method was suggested for tender mixes and thick lifts in hot-mix asphalt paving.

In the *Taper Removed and Tack Coated* method, the cold side unconfined edge was constructed with a 3:1 taper (Figure 9d). After 24 hours the full width of the taper was removed with a cutting wheel attached to a motor grader. After applying a tack coat on the vertical face of the cut, the hot side material was placed. Lay down and compaction were done as in the first method.

The *Taper Removed but no Tack Coat* procedure was the same as the previous method except that no tack coat was applied to the vertical face before placement of the adjacent hot lane (Figure 9e).

In the *Tacked 3:1 Taper with 25 mm Vertical Offset* method, the unconfined edge of the cold side of the pavement was constructed with a 25 mm (1 in) vertical offset at the top of the joint (Figure 9f). The rest of the joint was constructed with a 3:1 taper. The vertical face was not tacked; instead the taper face was tacked, before placement of adjacent hot material and subsequent rolling from the hot side.

In the *Rubberized Asphalt Tack Coat* method no taper was used to the unconfined edge of the first paved lane adjacent to the joint. After 24 hours a rubberized asphalt tack coat was applied on the face of the unconfined edge and then the adjacent lane was placed. The tack coat was approximately 3 mm thick. No luting was done. The compaction of the joint was started from the hot side, overlapping the cold side about 150 mm (6 in). From the samples it was observed that the cold mat was approximately 3 to 5 mm lower than the hot lane overlap after compaction.

Observations on the Colorado project led to the following conclusions: The *Tacked 3:1 Taper with 25 mm Vertical Offset* method (Figure 9f) was the best longitudinal joint construction technique; and rolling from the hot side at 150 mm (6 inch) from the joint was the best rolling technique; see Figure 9c.

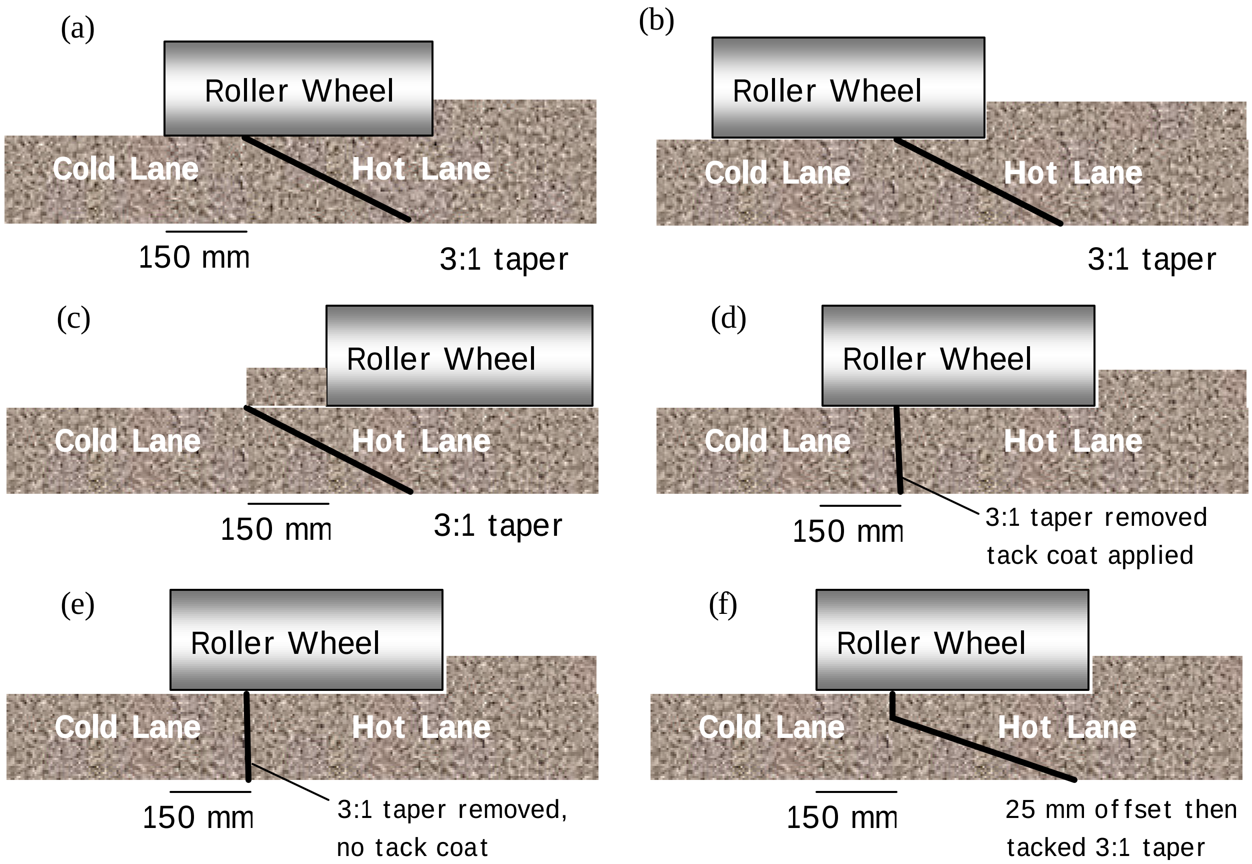


FIGURE 9: Colorado joint construction and rolling techniques.

3.5.4 Trans Tech Pre-compaction Equipment

TransTech, Inc of Schenectady, New York markets joint makers and an edge follower, as shown in Figure 10 (11). The Joint Maker attaches to the paver screed extensions on both sides and forces the hot mix into the joint area, pre-compacting a 100 mm-wide (4 in) section on both sides of the asphalt paver as the mat is laid. The first pass forms a straight vertical edge and the second pass closes the joint with interlocked aggregates. The Wedge Joint Maker forms a high density tapered wedge edge. An adjustable notch setting helps the wedge to keep its shape and not flatten out during the compaction process. Kicker plates, attached on the end gate skis, move extra hot-mix asphalt off the cold mat and then position it over the hot joint. The advantage of this method is that the automation eliminates the need for continuous hand luting. The edge follower automatically positions the screed extension to ensure consistent alignment to the cold mat edge during longitudinal joint closing. The edge follower consists of a sensor box, a control box and a mounting bracket. The sensor box is raised or lowered to place the bottom of the box 12.5 mm (.5 in) above the cold mat edge to be followed. Mat overlap can be varied with lateral adjustment handles. The TransTech pre-compaction technique has been successfully used in Pennsylvania, Connecticut, and Illinois (12), and has resulted in high-density longitudinal joints.

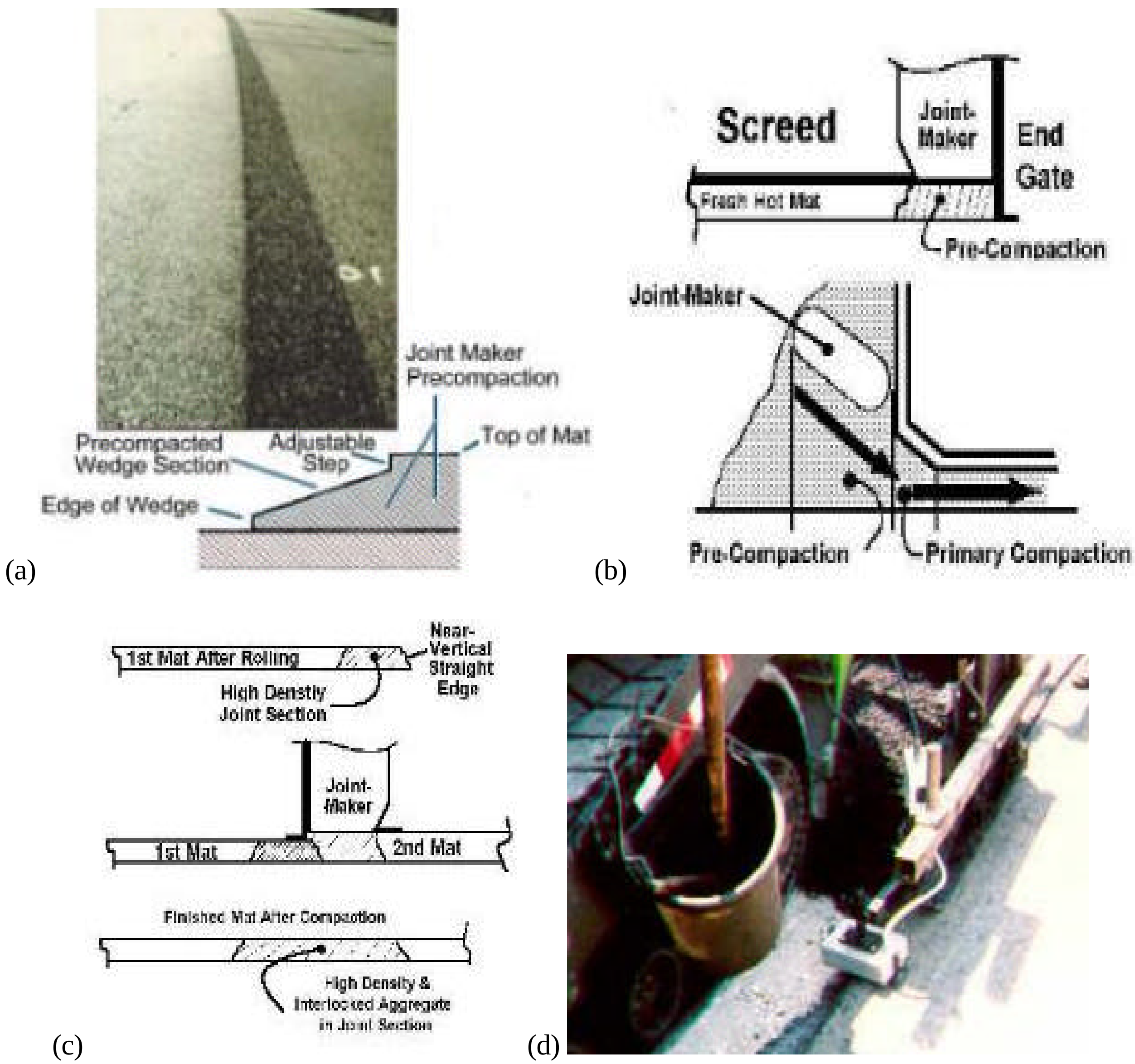


FIGURE 10: Transtech joint construction equipment and techniques. (a) TransTech Wedge Joint Maker, (b) TransTech Vertical Joint Maker, (c) Schematic of Joint Making Operation, and (d) TransTech Edge Follower

3.6 Missouri Department of Transportation and the U.S. Army Corps of Engineers Specifications for Longitudinal Joints

3.6.1 Missouri Department of Transportation (MODOT)

MODOT specifies that adjustable plates be attached to both sides of the paver. The outside plate is adjusted at 45 degrees with the surface of the roadbed and slightly compacts the mat. The inside plate is normal to the roadbed and is used for placing the material for the longitudinal joint. The cold mixture edge is required to be set up to a vertical edge by slight compaction with the back of a rake if it slumps. A well-bonded and sealed joint is obtained by maximum compaction. If necessary, a light coating of bituminous material can be applied to the exposed edge before paving the hot-mix asphalt. Irregularities on the cold mat edge must be removed before paving the second lane.

The density at the longitudinal joint is specified to be not less than 2% below the specified density on traveled way pavement within 150 mm (6 inches) of a longitudinal joint. This joint includes the pavement on the traveled-way side of the older joint. The pay adjustments for the joint density applies to the full width of the traveled way and is in addition to any other pay adjustments

3.6.2 The U.S. Army Corps of Engineers

The following guide specifications related to the longitudinal joints are based on the Unified Facilities Guide Specifications (UFGS) of the Department of Defense. The hot mix asphalt (HMA) for airfields is covered by UFGS-02749 of March 2002 (13):

3.6.2.1 Placing

The longitudinal joint in one course shall offset the longitudinal joint in the course immediately below by at least 300 mm (1 ft). However, the joint in the surface course shall be at the centerline of the pavement.

3.6.2.2 Longitudinal Joints

Longitudinal joints that are irregular, damaged, uncompacted, cold (less than 80 °C or 175 °F at the time of placing the adjacent lane), or otherwise defective, shall be cut back a minimum of 50 mm (2 inches) from the edge with a cutting wheel to expose a clean, sound vertical surface for the full depth of the course. All cutback material shall be removed from the project. All contact surfaces shall be given a light tack coat of asphalt material prior to placing any fresh mixture against the joint. The contractor will be allowed to use an alternate method if it can be demonstrated that density, smoothness, and texture requirements can be met.

3.6.2.3 Mat and Joint Densities

For determining in-place density, one random core (100 or 150 mm diameter) will be taken from the mat (interior of the lane) of each sublot, and one random core will be taken from the joint (immediately over joint) of each sublot. A standard lot will be equal to 2,000 metric tons, and will consist of four equal sublots. After air drying per ASTM D 2726 for laboratory-prepared, thoroughly dry specimens, cores obtained from the mat and from the joints will be used for in-place density determination.

The average in-place mat and joint densities are expressed as a percentage of the average theoretical maximum density (TMD) for the lot. The average TMD for each lot will be determined as the average TMD of the two random samples per lot. The average in-place mat density and joint density for a lot are determined and compared with Table 3 to calculate a single pay factor per lot based on in-place density, as described below. First, a pay factor for both mat density and joint density are determined from Table 3. The area associated with the joint is then determined and will be considered to be 3 m (10 feet) wide times the length of completed longitudinal construction joint in the lot. This area will not exceed the total lot size. The length of joint to be considered will be that length where a new lane has been placed against an adjacent lane of hot-mix asphalt pavement, either an adjacent freshly paved lane or one paved at any time previously. The area associated with the joint is expressed as a percentage of the total lot area. A weighted pay factor for the joint is determined based on this percentage. The pay factor for mat density and the weighted pay factor for joint density are compared and the lowest selected. This selected pay factor is the pay factor based on density for the lot. An example of these calculations is shown below:

Let us assume the following test results for field density made on the lot:

(1) Average mat density = 93.2 percent (of laboratory TMD).

(2) Average joint density = 91.5 percent (of laboratory TMD).

(3) Total area of lot = 30,000 square feet.

(4) Length of completed longitudinal construction joint = 2,000 feet.

Step 1: Determine pay factor based on mat density and on joint density, using Table 3:

Mat density of 93.2 percent = 98.3 pay factor.

Joint density of 91.5 percent = 97.3 pay factor.

Step 2: Determine ratio of joint area (length of longitudinal joint x 10 ft) to mat area (total paved area in the lot). Multiply the length of completed longitudinal construction joint by the specified 10 ft. width and divide by the mat area (total paved area in the lot).

(2000 ft. x 10 ft.)/30,000 sq.ft. = 0.6667 =ratio of joint area to mat area.

Step 3: Weighted pay factor (wpf) for joint is determined as indicated below:

wpf = joint pay factor + (100 - joint pay factor) (1 - ratio)

wpf = 97.3 + (100 - 97.3) (1 – 0.6667) = 98.2%

Step 4: Compare weighted pay factor for joint density to pay factor for mat density and select the smaller:

Pay factor for mat density: 98.3%.

Weighted pay factor for joint density: 98.2%

Select the smaller of the two values as pay factor based on density: 98.2%.

When the TMD on both sides of a longitudinal joint is different, the average of these two TMD will be used as the TMD needed to calculate the percent joint density. All density results for a lot will be completed and reported within 24 hours after the construction of that lot.

TABLE 3: Pay Factor Based on In-Place Density

Average Mat Density (4 cores)	Pay Factor (%)	Average Joint Density (4 cores)
94.0 – 96.0	100.0	Above 92.5
93.9	100.0	92.4
93.8 or 96.1	99.9	92.3
93.7	99.8	92.2
93.6 or 96.2	99.6	92.1
93.5	99.4	92.0
93.4 or 96.3	99.1	91.9
93.3	98.7	91.8
93.2 or 96.4	98.3	91.7
93.1	97.8	91.6
93.0 or 96.5	97.3	91.5
92.9	96.3	91.4
92.8 or 96.6	94.1	91.3
92.7	92.2	91.2
92.6 or 96.7	90.3	91.1
92.5	87.9	91.0
92.4 or 96.8	85.7	90.9
92.3	83.3	90.8
92.2 or 96.9	80.6	90.7
92.1	78.0	90.6
92.0 or 97.0	75.0	90.5
Below 92.0, above 97.0	0.0 (reject)	Below 90.5

3.7 Colorado DOT Longitudinal Joint Construction Survey

The Colorado Department of Transportation (CODOT) conducted a survey of the performance, specification, and research on the longitudinal joint construction in asphalt paving in 2000. Four specific questions were asked:

- Is longitudinal joint performance a problem?
- Are there any specifications for longitudinal joint construction?
- If answered "yes" in (ii), is this a density and/or configuration specification?
- Is there any research study in progress?

Twelve out of 22 states (55%) reported longitudinal joint performance problems in their states. Thirteen out of 17 states responding (76%) do have some kind of specifications to cover longitudinal joint construction. The majority (75%) has configuration-type specifications and the rest have density specifications. At least one state was reviewing its current specifications to move toward density specification. Six states reported to have some type of research study going on in this area.

3.8 KDOT Longitudinal Density Evaluation Specifications

Starting with projects let October 2002, KDOT has added a longitudinal joint density evaluation procedure to all bituminous pavements as subsection 603.03(e)(2) in Special Provision 90M-6917, following the specifications of the Texas Department of Transportation (14). The traveled way joint density would be evaluated by taking two or three readings in the transverse direction one paver width wide. The traveled way joint density, either one or two locations, is subtracted from the interior density and the difference in density compared to the allowable limits. The acceptable criterion for the joint density is:

Interior Density - Joint Density < 50 kg/m^3

3.8.1 Selection of Joint Density Evaluation Locations

A lot for joint density evaluation would be defined as the distance paved with each mix designation per day. The number of sublots would be defined from Table 4. Each sublot would have approximately the same length. One longitudinal location would be randomly selected within each sublot.

TABLE 4: Determination of Number of Sublots per Day

Distance Paved		Number of Sublots
Metric	English	
0 m - 150 m	0' - 500'	0
151 m - 300 m	501' - 1000'	1
301 m - 600 m	1001' - 2000'	2
601 m - 900 m	2001' - 3000'	3
901 m - 1200 m	3001' - 4000'	4
1201 m and greater	4001' and greater	5

At each sublot longitudinal test location, the nuclear density would be determined on the traveled way at two or three transverse locations (See Figures 11 and 12). Sublot joint density evaluation will be completed before compaction is completed in the third sublot, and likewise, the second sublot evaluated before fourth sublot compaction completed, and third sublot evaluated before fifth sublot completed. Two or three (Figure 12) locations would be tested as follows:

1. The random longitudinal location would be selected as described earlier.
2. The "joint density" would be determined with the source rod of the gauge 0.2 m (8 inches) off the mat edge that will become a longitudinal joint. The source rod would be positioned so it is closest to the laydown machine (point the gauge towards the roller).

3. A transverse location between 0.6 m (2 ft) for each edge of the mat would be selected. The "interior density" would be determined at this location. The source rod would be positioned so that it is closest to the laydown machine (point the gauge towards the roller).

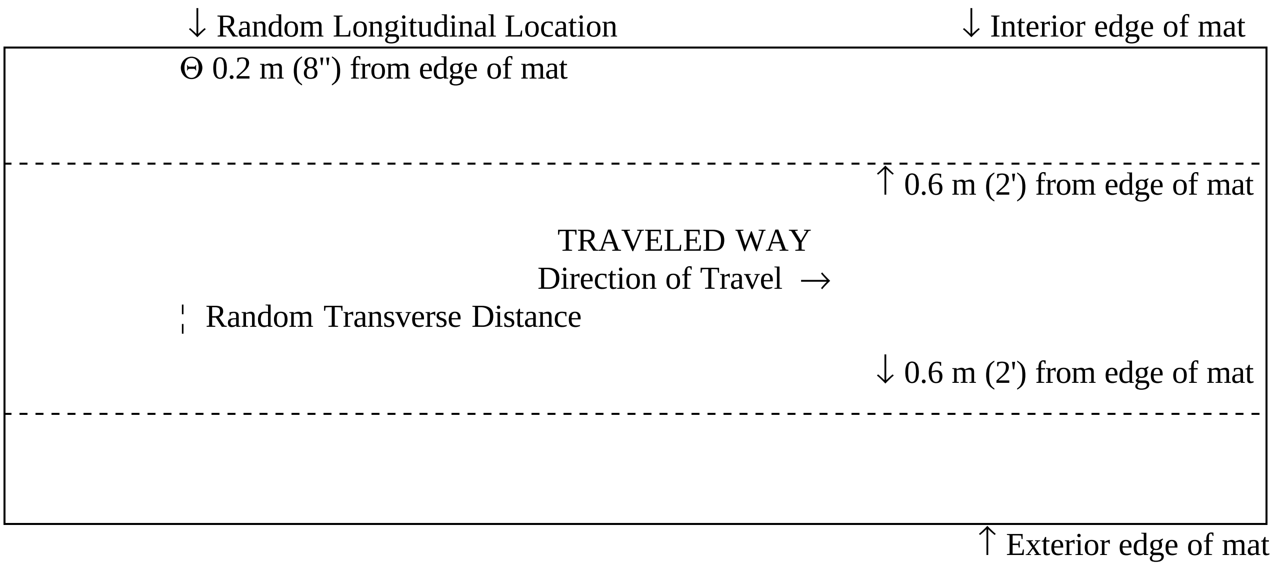


FIGURE 11: Joint density test locations for two tests. Traveled way without hot mix shoulders or shoulders placed at the same time as the traveled way. Each lane placed would be tested. Figure not to scale.

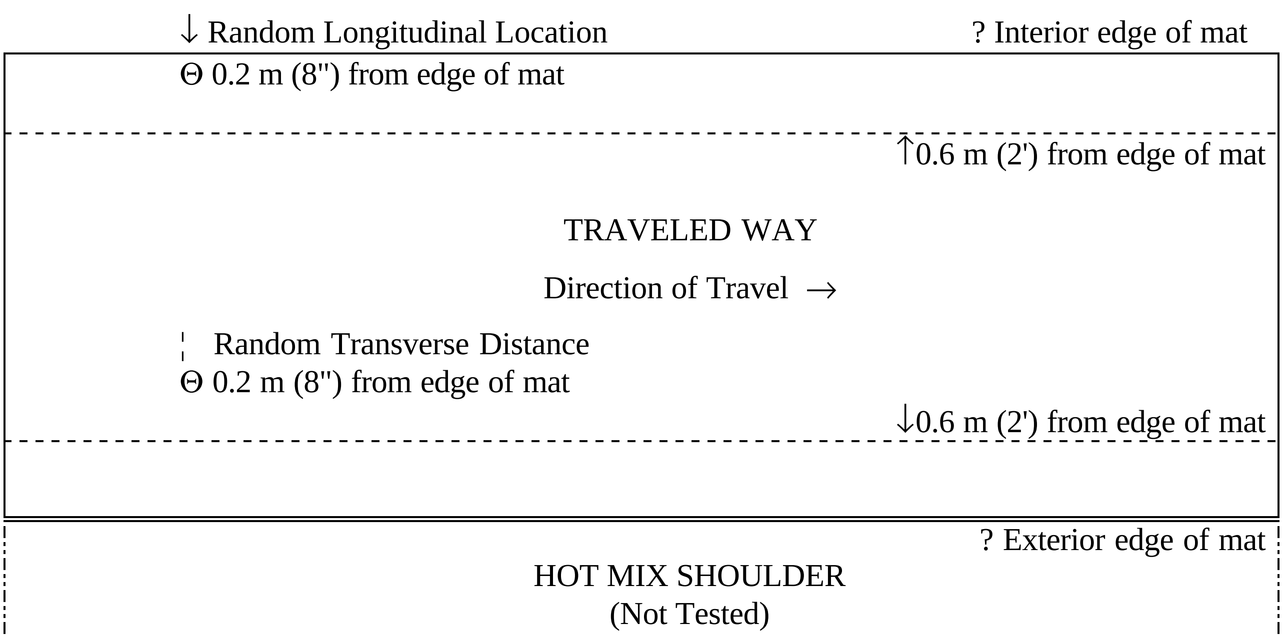


FIGURE 12: Joint density test locations for three tests. Traveled way with hot mix shoulder or shoulders not placed at the same time as the traveled way. Each lane placed would be tested. Figure not to scale.

3.8.2 Nuclear Gage Readings

Three one-minute readings would be taken in the backscatter mode and averaged. If one of the readings varies by more than 15 kg/m3 (1 lb/ft3), then it would be discarded and replaced with an additional reading. It is not necessary for the gauge to be calibrated to the mix.

3.8.3 Profile Evaluation

The contractor field representative will provide the Engineer results of the joint density evaluation as they are completed. Whenever the Engineer makes independent joint density verifications, the contractor will be supplied joint density evaluation results as they are completed. Whenever one of the evaluations fails the acceptable criteria established in 90M-6917 or latest update Special Provisions, the contractor will make changes to the mix, plant or roadway operations. Production of the hot mix is to cease whenever two consecutive checks by the contractor or by the Engineer fail. The contractor will make changes to the mix or process before production is restarted. The contractor may produce enough mix to place approximately 600 m (2000 ft) of pavement one paver width wide. Two joint density evaluations will be taken within this 600 m (2000 ft) of production. If both joint density evaluations meet acceptable criteria, the contractor may resume normal production. If one or both of the joint density evaluations fail, the contractor will make changes before production is restarted. The contractor may then produce enough mix for an additional 600 m (2000 ft) of pavement and this production will be evaluated as was the previous 600 m (2000 ft) of production. This procedure of placing and evaluating 600 m (2000 ft) sections will be continued until both joint density evaluations pass. Once the evaluation passes, normal production and joint density evaluations will resume.

The "drop in density" would be calculated by subtracting the "joint density" from the "interior density". The “drop in density” will be compared to the specification limits. It is to be noted that whenever three tests are taken at one transverse location, each joint density evaluation must pass the specified limits to be considered a passing location.

Chapter 4

Conclusions and Recommendations

4.1 Conclusions

Based on this literature review, the following conclusions can be drawn:

1. Longitudinal joints in asphalt pavements with high densities generally show better performance than those with relatively low densities.
2. Longitudinal joint performance is not satisfactory in most of the states. The joint construction practices and specifications vary widely from state to state. A majority of the states have configuration-type specifications.
3. The compactors have significant effects during compaction of longitudinal joints. The ability to change the characteristics of the vibration on the vibratory compactors rapidly enough to satisfy changing job conditions is important. However, there is still a need for defining the rolling pattern.

4.2 Recommendations

The following recommendations can be made based on this study:

4.2.1 Construction

1. Specify joint locations for the asphalt pavements to minimize direct load application.
2. Compaction of the longitudinal joint should involve rolling from the hot side of the layer with the roller wheels overlapping approximately 300 mm (6 inches) on the cold mat.
3. The Michigan or Colorado wedge joints with 12.5 to 25 mm (1/2 in. to 1 in.) vertical offset can be constructed and observed experimentally.

4. Finally, the finished joint shall have the same full depth density, texture, and smoothness as specified for other sections of pavement.

4.2.2 Density Pay Adjustments

The density at the joint should not be less than 2 percent below the specified density of the traveled way pavement within 150 mm (6 in) of a longitudinal joint. This joint includes the pavement on the traveled way side of the shoulder joint. The pay adjustments for the joint density should apply to the full width of the traveled way payment and should be in addition to any other pay adjustments.

4.2.3 Future Studies

1. The review of literature did not clearly indicate what portion of the roller should stay on the hot mat during compaction. This important issue should be researched.
2. A correlation between the pay factors and the differences in densities between the joint and the mat should be developed.
3. The length of the overlap is not well understood. In the literature, it seems to vary from 25 to 50 mm (1 to 2 inches), sometimes even 75 mm (3 inches). There is a need to define the overlap length of the hot mat over the cold mat.
4. The specified minimum compaction levels to be achieved at the longitudinal joint also need to be researched.

References

1. Foster, C.R., Hudson, S.B., and Nelson, R.S. Constructing Longitudinal Joints in Hot Mix Asphalt Pavements. HRB Research Record 51, Highway Research Board, Washington D.C., 1964, pp. 124-136.

2. Kandhal, P.S., and Mallick, R.B. Study of Longitudinal Joint Construction Techniques in Hot-Mix Asphalt Pavements. In Transportation Research Record 1543, Transportation Research Board, Washington D.C., 1996, pp. 106-112.

3. Kandhal, P.S. and Rao, S.S. Evaluation of Longitudinal Joint Construction Techniques for Asphalt Pavements. NCAT Report No. 94-1, National Center for Asphalt Technology (NCAT), Auburn University, 1994.

4. NAPA. Longitudinal Joints: Problems and Solutions. Quality Improvement Series 121, National Asphalt Pavement Association, Lanham, Maryland, 1997.

5. The Asphalt Institute. Principles of Construction of Hot Mix Asphalt Pavements. Manual Series No. 22 (MS-22), January 1983.

6. Hot Mix Asphalt Paving Handbook. The US Army Corps of Engineers, July 1991.

7. Regan, G. L. A State-of-the Art Study and Survey of Flexible Pavement Construction Jointing Techniques. Report No: DOT/FAA/AR-95/57, Federal Aviation Administration, Office of Aviation Research, Washington, DC, June 1996.

8. Asphalt Compaction Handbook. Ingersoll Rand, World Wide Web Literature, July 2000.

9. Roberts, F.L., Kandhal, P.S., Brown, E.R., Lee, D. Y. and Kennedy, T.W. Hot Mix Asphalt Materials Mixture Design and Construction. Second edition, NAPA Education Foundation, Lanham, Maryland, 1996.

10. Livneh, M. Site and Laboratory Testing in Order to Determine the Bonding Method in Construction Joints of Asphalt Strips. Proceedings, AAPT, Vol. 57, 1988.

11. TransTech Systems. Precompacted Tapered Wedge Joints. World Wide Web Literature, Schenectady, New York.

12. Illinois Department of Transportation. District Four Longitudinal Joint Experiment. Interim Report, Peoria, IL, May 1997.

13. United State Army Corps of Engineers. Hot-Mix Asphalt (HMA) for Airfields. Unified Facilities Guide Specifications Section No. 02749, March 2002.

14. Personal Communication with Rodney G. Maag, P.E., Field Engineer of KDOT, February 2003.