

## Synthesis of Longitudinal Joint of Flexible Pavement

Mohd Rosli Mohd Hasan\*, David Porter, Zhanping You

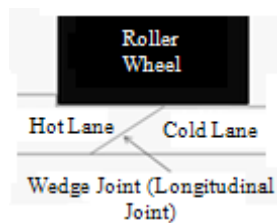
Department of Civil and Environmental Engineering, Michigan Technological University, 1400 Townsend Drive, Houghton, MI 49931-1295, USA

\*Corresponding author: mmohdhas@mtu.edu

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### Graphical abstract



### Abstract

This paper provides a wide range of information related to longitudinal joints of asphalt pavement, such as types of longitudinal joints, performance evaluations, factors of failure, and selection of the best practice in constructing longitudinal joints. Additionally, this synthesis provides an overview of construction methods which are typically used in constructing longitudinal joints, along with guides and approaches implemented by different road builders or authorities to attain a better longitudinal joint. It was found that difficulties during compaction of the asphalt pavement at the center line resulted in poor joint density. This has reduced the performance and durability of pavement that is associated with cracks and degradations due to moisture damage, such as raveling. Results from previous field studies and laboratory evaluations have been summarized to understand the factors of failure of the adjacent joint. The Michigan joint technique was found to be the best method in constructing longitudinal joints of HMA. The cutting wheel and the edge restraining device techniques are also recommended by the asphalt technologists however are dependent on the machine operator to obtain consistent results.

*Keywords:* HMA, joint, construction techniques, distresses, performance, density

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### 1.0 BACKGROUND

A Longitudinal joint is defined as a pavement centerline between the two adjacent lanes. Cracking frequently develops along the joint (Figure 1) when adjacent lanes are paved separately and mainly develop due to difficulty in achieving adequate density between the lanes. Additionally, cracking occurs due to severe environment conditions associated with repeated freeze-thaw cycles and continuous traffic loading, this results in the crack widening and lengthening causing eventual loss of asphalt [1]. One of the earliest published works on the topic of longitudinal joints appeared in 1964 [2]. The paper revealed that joints are often considered as the weakest section of a bituminous pavement. Under unfavorable conditions of exposure and construction, visible deteriorations may occur first at the joints. This has resulted in pavement distresses and accelerates the asphalt concrete's deterioration due to infiltration of moisture or water into the pavement system [3,4]. According to a Federal Highway Administration (FHWA) report, longitudinal joint cracks can be categorized into three severity levels, which are low, moderate and high [5], and known to be one of the sources of the pavement failure [6,7]. Figure 2 shows a picture of a moderate longitudinal joint crack opening filled with sand and exhibiting a raveling issue on the spotted area. A majority of the states in the US are facing the same problem regarding to longitudinal joint cracking. Different approaches in the construction procedures have been used in addressing this problem which typically varied between states depending on their specifications and climates [8].



**Figure 1** Longitudinal joint cracks



**Figure 2** Longitudinal joint crack opening filled by undesired materials

## 2.0 SCOPE

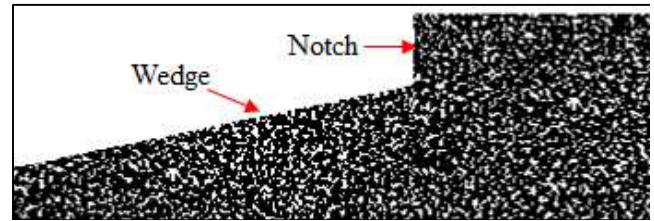
This synthesis aims to fulfill the following objectives:

- i. To provide information related to construction methods and specifications, as well as failures and distresses at the longitudinal joint.
- ii. To explore available studies on the performance of longitudinal joints and affecting factors.
- iii. To discover the best practices for better durability of longitudinal joints.

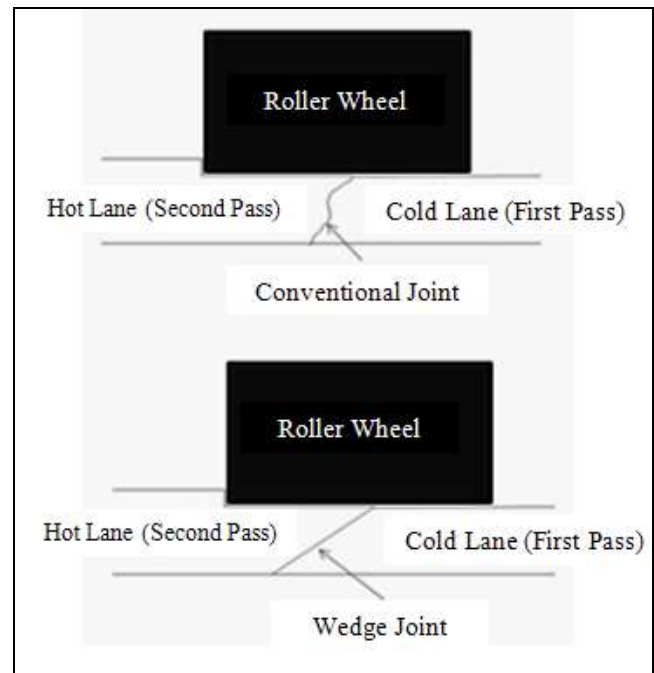
## 3.0 CONSTRUCTION METHODS AND SPECIFICATION

The construction techniques of longitudinal joints can be categorized into three different types; hot, semi-hot and cold joints. The hot joint is constructed with pavers operating considerably close together at the same time so that the temperature of the first laid lane has not significantly reduced before the second lane is placed [9,10]. Meanwhile, in the construction of semi-hot and cold joints, the adjacent lanes are paved when the first lane has cooled down to temperature approximately 120-140°C and below 120°C, respectively. There are a few methods that have been used in the construction of semi-hot and cold joints, such as a bumped joint (joint overlap the first lane 50.8 to 101.6mm (2 to 4 inches)), wedge joint (consists of two overlapping wedges) and a notched wedge joint as shown in Figure 3 [3]. Formerly, the Arizona Department of Transportation (ADOT) was credited as being one of the first agencies that implemented the longitudinal wedge joint, while the New Jersey Department of Transportation (NJDOT) placed a steeper wedge to reduce the potential of raveling (3:1 versus 6:1) [2,11]. The NJDOT also initiated an infrared heating process to the

cold joint in the construction procedure. Application of the wedge joint for construction of longitudinal joint can be used to improve the density of the joint throughout the pavement layer [4,11-14]. Figure 4 shows the comparison between the conventional joint and the wedge joint construction techniques.



**Figure 3** Notched wedge joint



**Figure 4** Conventional and wedge joints construction techniques [4]

The National Center for Asphalt Technology (NCAT) conducted evaluations on different longitudinal joint construction methods in four different states in the US between 1992 and 1995, involving Michigan, Wisconsin, Colorado and Pennsylvania [15]. The descriptions of the construction methods are summarized based on a report written by Kandhal and Mallick [15] as shown in Table 1.

**Table 1** Description of the longitudinal joint construction techniques

Methods	Description
Rolling from hot side	Compaction performed from the hot side with a major portion of the roller wheel is on the hot side with overlap of 152mm (6 inches) on the cold lane.
Rolling from cold side	Rolling performed in the static mode with a major portion of the roller wheel on the cold side with about 152mm (6 inches) of the roller wheel on the hot side of the longitudinal joint.
Rolling from hot side 6 inch away from joint	Rolling carried out with the edge of the roller approximately 152mm (6 inches) from the joint on the hot side. This technique is recommended by the asphalt paving technologists for tender mixes or thick lifts to achieve desired density at the joint.
Tapered (12:1) joint with 12.5 mm offset without tack coat	Also known as Michigan wedge joint technique, the joint was constructed as two overlapping wedges by lowering the edge of the lane paved first and the lowered section is then overlapped when the second lane is placed. A taper with 1:12 (vertical/horizontal) was used to construct this joint.
Tapered joint (12:1) with 12.5 mm offset with tack coat	Construction method is similar to the above technique except a tack coat layer was applied on the tapered face before the second wedge was placed and compacted. The tack coat is applied to avoid the infiltration of water and to maintain tight bonding between the lanes.
Edge restraining device	The edge-compacting device is used in this technique while placing the first lane to increase the density of the edge. Compaction performed by rolling from the hot side after layering the adjacent lane.
Cutting wheel with tack coat	This technique involves cutting 38-51 mm (1½-2 inches) of the unconfined edge of the first lane after compaction, while the mix is still plastic. Generally, a cutting wheel with the diameter 254 mm (10 inch) attached to an intermediate roller is employed. A tack coat is then applied.
Cutting wheel without tack coat	Construction method is similar to the above technique except that no tack coat was applied to the vertical face of first lane edge before placement of the second lane.
Joint maker	This device mounted to the side of the screed at the corner during construction to forces extra material at the joint through an extrusion process prior to the screed. A kicker plate is also attached to lute back the overlapped HMA mix without the help of a lute man and compaction was performed from the hot side.
Tapered (3:1) joint with vertical 25 mm offset	The unsupported edge of the first lane constructs with a 25 mm vertical step (offset) at the top of the joint. The rest of the joint was formed with a 3:1 taper and tack coat was applied before placement of the second lane. The vertical step was formed using angle iron under the drag device used to form the 3:1 taper, and then the pavement was compacted from the hot side.
Rubberized asphalt tack coat	A rubberized asphalt tack coat was applied on the face of the unconfined edge before placing the second lane. The thickness of the tack coat was about 3 mm and the rolling was performed from the hot side.
New Jersey wedge (3:1)	A sloping steel plate attached to the inside corner of the paver screed extension was used to form wedge joint. An infrared heater is used in the placement of second lane to heat the edge of the first placed layer to a surface temperature about 90°C and the second lane was overlapped by 50.8 – 76.2mm (2 to 3 inches) on the first lane. The overlapped material is lute back 76.2-101.6mm (3 to 4 inches) from the edge of the cold mat and finally the pavement is compacted from the hot side.

According to Morgan [1], the application of adhesive material on the centerline could delay the formation of cracks. However, if cracking did develop, it potentially limits the crack depth, as well as delays the damage caused by the traffic and freeze-thaw cycles. The Colorado Department of Transportation (CDOT) has evaluated the efficiency of adhesive material by implementing it in the six different construction techniques. This study also was aimed to investigate the issue associated with pavement densities along the longitudinal joint. The results were presented for each year during the assessment period, whereas after the first year the results indicate that there was a slight raveling that had been spotted with no cracking appearing on the pavement surface. In the following year, the rank was determined based on an average rating, which was given by five evaluators. The joint was ranked third in the overall performance with 4% of the centerline cracked and slightly raveled.

Moreover, in an effort to reduce the longitudinal joint failure, Illinois Department of Transportation (IDOT) has initiated a series of assessments to determine the applicability of sealant to improve the durability of longitudinal joints. Two products had been selected in the study, which were J-Band® and QuickSeam®. These sealant materials were implemented at four trial projects in Illinois. The performances of field and laboratory specimens were evaluated through a series of permeability tests to ensure the applicability of sealant in reducing the permeability of the HMA along the longitudinal joint zone. The sealants were applied to the longitudinal joint area before paving the surface layer of HMA. In this technique, the effects of heating and vibratory compacting had drawn the sealant material up and into the surface layer. Furthermore, it was also stated that the desired migration of the sealant material is approximately three-fourths the thickness of the

surface layer [16]. Winkelman [16] further mentioned that the J-Band® material is supplied to the construction site using a tanker truck. At the jobsite, the material was preheated and transferred to a smaller tank, where it was further heated to the required temperature and pumped using the application tool. The sealant material was placed with various thicknesses across the band width, which was 45.72cm (18 inches). In addition, the total thickness was also varied based on the thickness of the HMA surface overlay. Thicker pavement overlays needed extra sealant material prior paving to consider the migration of a desired amount of sealant material. The QuickSeam® material was manufactured in prefabricated rolls and transported to the field. During the construction, the first pass of the material was placed nine inches wide and adjacent to the longitudinal joint of the HMA. This sealant layer was covered up by the first pass of the HMA surface layer. The second sealant pass was also placed nine inches wide, where a portion of the material rests on the vertical face of the first pass of the HMA surface overlay. From the study the results indicated that both of sealant materials were very sticky and easily stuck to the tires of the passing automobiles. However, the effects of sealant in reducing the permeability and connectivity of air voids in the longitudinal joint were not consistent.

#### ■4.0 FAILURE AND PAVEMENT DISTRESSES AT LONGITUDINAL JOINT

Foster et al. [3] provided a detailed explanation on the crack formations on the longitudinal joint. The authors mentioned that during the placement and rolling of the adjoining lane, the edge of the first lane prevents the new mix from dispersing. This has resulted in a lower density, minor depression and higher air void

distributions at the center line of the road, which permits water to accumulate in the area and cause further deterioration [3,4]. Additionally, Akpınar and Hossain [8] had mentioned other factors that have contributed to the joint cracks, which were due to loss in temperature during compaction process, difference in pavement thickness due to poor construction technique (associated with difficulties during pavement compaction), and difference in settlements after cracks were formed [17]. Besides that, the joint cracking also can occur when the traffic load has exceeded the tensile strength of the asphalt pavement which initiates the cracks formation on the HMA joint [18]. The significant changes of temperature and environmental forces also should not be neglected: the joint can be split apart when the tensile stress caused by the temperature changes or other environmental forces are higher than the structural strength capacity of the pavement [19]. In general, the factors that can influence the compaction of HMA are material properties, environmental variables, and equipment [8].

The typical premature deterioration of longitudinal joint occurs in the form of cracking or raveling [4, 20, 21]. These conditions occur in areas with a very cold climate condition that also results in transverse shrinkage cracking of the asphalt pavement. In general, raveling is typically generated on the side of the cold lane, which commonly has lower density at the unconfined edge. However, the raveling or particle loss also can occur in a lane with inadequate compaction [20, 21]. The damaged longitudinal joints are also a very serious concern in airfield pavements. The loose materials from the pavement surface, especially the pavement joints, might cause Foreign Object Damage (FOD) to aircrafts, leading to loss of equipment and life. Meanwhile, potential sharp edges along the cracks' opening are also dangerous to the aircraft activities [22]. It is believed that cracking that splits the longitudinal joints is often caused by thermal related phenomenon instead of load associated impacts. The phenomenon that is related to thermal cracking occurs more severely in the northern tier of states in the US since they experience a colder climate than southern states [23].

Mallick et al. [24] mentioned that cracking and raveling permit intrusion of water into the pavement layer system. This intrusion weakens the foundations of the pavement and results in the need for extensive repairs. The crack openings also lead to other related distresses, such as oxidation and joint separations [9, 25]. The author also relates the longitudinal joint issues to the vertical difference, which may be associated to poor workmanship during construction or settlement after the longitudinal cracking appears. Once moisture, or water, is able to penetrate the longitudinal crack and is stored at these locations the potential of moisture related distresses will be aggravated [9]. In some cases, cracks were developed along the longitudinal joint within one year of service [25]. Overall, the deterioration of longitudinal joints can occur due to construction methods, environmental impacts, as well as load and pavement structural related factors.

## 5.0 EVALUATION ON LONGITUDINAL JOINT AND AFFECTING FACTORS

Foster et al. [3] has evaluated different types of longitudinal joint construction techniques, which have been divided into hot, semi-hot, and cold joints together with several types of construction methods in Maryland and North Carolina. From the results, the difference of pavement density across the joint in cold-joint

construction and in certain types of semi-hot joint construction was found. The detected areas with low density were in the unconfined edge of the first lane [4], whereas practically all of the special joint construction procedures, such as bumping and pinching, are concerned with attempts to get a high density at the joint in the lane placed subsequently [3].

Baker et al. [11] carried out an investigation in New Jersey to quantify the efficiency of the wedge joints by measuring the density gradient across the joint. Nuclear density measurements were observed on three projects where wedge joints and conventional butt joints were used. It was concluded that the wedge joint construction method was a better, more uniform density than the conventional butt joint technique. By using this method, it was found that the wedge joint technique improved the density along the joint area, eliminated the vertical shear plane in the conventional joint, as well as resulted in a higher resistance to cracking under the effects of traffic and weathering. The nonnuclear density gauge also can be used to measure the density of longitudinal joint in asphalt pavement, where the discussion on both gauges were clearly mentioned by Troxler and Dep to assist the user in selecting the proper gauge for specific job [26]. From the previous studies, both methods are applicable for the evaluation of density near longitudinal joint in asphalt pavements [10, 13].

A study on factors affecting the uniformity and level of compaction of HMA has been conducted by Masad et al. [27]. In the first phase, the study involved evaluation of the samples prepared on the field and laboratory via X-ray Computed Tomography (X-ray CT). Moreover, the effects of different levels of compaction on the performance of asphalt mixtures was studied using a fracture mechanics approach and a Discrete Element Model (DEM) in the second phase of their report. Subsequently, to evaluate the distribution of asphalt pavements air voids using X-ray CT scan, core specimens were extracted from the field test section. From the results, it was found that the air voids distribution correlated well with the compaction efforts across the mat of the pavement surface. The compaction effort was defined as a function of the number of compactor passes and the relative location of each pass across the mat. The number of passes of different types of compactors was plotted along with the width of the test section. The result represents the average percent of air voids of at least two cores taken longitudinally at a given distance from the pavement section edge. From the results, the air voids at the center of the pavement mat was higher compared to both edges.

Masad et al. [27] found that the air void distribution is more uniform for specimens prepared using a modified asphalt binder compared to specimens prepared with a neat binder. In addition, the distribution and homogeneity of air voids is significantly correlated to the effects of the compaction pattern and the type of compactor used. Furthermore, a Compaction Index (CI) was developed to quantify the compaction effort at any point in the pavements. The CI was defined as a function of the number of passes at a designated point with respect to the compaction roller width. The correlation between percentage of air voids and CI was found to be very useful in determining the resulting compaction pattern (number of passes and location of these passes). The compaction pattern can be adjusted to achieve a uniform CI distribution across the pavement section, which corresponds to uniform air void distribution as depicted in Figure 5. Besides that, the CI can also be used to determine the sensitivity of a mixture to the compaction effort [28].

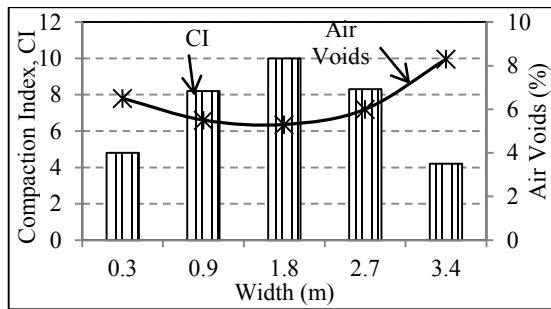


Figure 5 The correlation between compaction index and percentage of air voids

Referring to the study conducted by Masad et al. [28]. The percentage of air voids change at different rates as more compaction effort is applied (increase in CI). The results indicate that this mixture can be easily compacted using a relatively small compaction effort. Continuous increase in compaction effort (increase in CI) did not help in decreasing the percent air voids. Based on the X-ray CT scan result, the main difference in percent air voids was in the top 10 mm where the cores near the longitudinal joint have a higher percent air voids.

Winkelman [16] performed a study to evaluate the performance of longitudinal joints constructed with joint sealant using a field permeability test. A three tier graduated cylinder permeameter was used. To provide a good seal with the pavement the tests were carried out by fitting a neoprene gasket on the pavement surface with a silicon seal between the pavement and the gasket, then a 9.07 kg (20 pound) weight was placed over the cylinder to avoid leakage of water during testing between cylinder and the gasket. The tests were performed at selected locations along the experimental and control section of each project. However, it was found that applications of sealant materials did not significantly reduce the permeability of the asphalt pavement.

According to the studies performed at the National Center for Asphalt Technology (NCAT) [15], the average joint density was used to classify the different techniques based on the Fisher’s Protected Least Significant Difference (LSD) procedure [17]. Tables 2 through 5 show the ranking level of the joint’s construction methods used in Michigan, Wisconsin, Colorado and Pennsylvania throughout these investigations. Based on the results, it indicates that different projects experienced different results with levels of the ranking system (A to D). Based on the overall ranking, 12:1 tapered joint with 12.5mm offset was the best method in constructing desirable performance of longitudinal joint since vertical offset is considered most essential to its performance. On the other hand, both cutting wheel and the edge restraining device have a good potential of obtaining a desirable joint performance. However, these techniques were highly depended on the operators’ skill to achieve a consistent result [15].

Table 2 Ranking of joint density in Michigan [15]

Techniques	Ranking			
	A	B	C	D
12:1 tapered joint with 12.5mm offset without tack coat	X			
12:1 tapered joint with 12.5mm offset with tack	X			
Cutting wheel with tack coat	X	X		
Joint maker				X
Rolling from hot side		X		
Rolling from cold side			X	X
Rolling from hot side 152mm (6inch) away from			X	

Table 3 Ranking of joint density in Wisconsin [15]

Techniques	Ranking			
	A	B	C	D
12:1 tapered joint with 12.5mm offset without tack coat		X	X	
12:1 tapered joint with 12.5mm offset with tack		X		
Edge restraining device	X			
Cutting wheel with tack coat	X			
Cutting wheel without tack coat	X			
Joint maker			X	
Rolling from hot side		X	X	
Rolling from cold side			X	
Rolling from hot side 152mm (6inch) away from		X	X	

Table 4 Ranking of joint density in Colorado [15]

Techniques	Ranking			
	A	B	C	D
Cutting wheel with tack coat		X		
Cutting wheel without tack coat		X	X	
Tapered (3:1) joint with vertical 25mm offset	X			
Rolling from hot side			X	
Rolling from cold side		X	X	
Rolling from hot side 152mm (6inch) away from		X	X	

Table 5 Ranking of joint density in Pennsylvania [15]

Techniques	Ranking			
	A	B	C	D
Edge restraining device	X			
Cutting wheel with tack coat	X	X		
Cutting wheel without tack coat	X	X		
Joint maker	X	X		
Rubberized asphalt tack coat			X	
New Jersey wedge (3:1) and infrared heating				X
Rolling from hot side		X		
Rolling from cold side	X	X		
Rolling from hot side 152mm (6inch) away from		X		

## 6.0 BEST PRACTICE FOR BETTER LONGITUDINAL JOINT

Prowell [29] in the presentation, “Practices and Specifications for Longitudinal Joint – A National Perspective” at Great Iowa Asphalt Conference specified some techniques which are considered among the best performing methods in constructing longitudinal joints, such as: a longitudinal joint with rubberized joint, notched wedge joint with 1:12 taper, cutting wheel and edge resistance device, as well as rolling from hot side with 6 inches overlap. Subsequently, Kandhal and Mallick [15] in their study specified that the Michigan joint technique (12.5 mm vertical offset and 12:1 taper) was found to be the best possible method of obtaining a satisfactory longitudinal joint. The cutting wheel and the edge restraining device techniques also have good potential but typically depend on the experience of the operator to obtain consistent results. Among the three different joint compaction methods, compaction from hot side gave the best result followed by rolling from hot side with 152 mm away from the joint. The author also mentioned that the pavement technologists and state department of transportations should specify a minimum level of compaction to be achieved at

the longitudinal joint. Meanwhile, the paver manufacturers should consider modifying the paver design to adopt the Michigan joint technique in road construction, especially to achieve high density along the unconfined wedge in the lane paved first.

Benson and Scherocman [7] revealed that if the longitudinal joint is properly constructed, it was generally not necessary to apply a tack coat to the unconfined edge of the first lane, it can be done by cutting the unconfined edge of the first lane before the second lane is placed adjacent to it, and using two pavers running in echelon. Furthermore, the authors highlighted that construction of the centerline between adjacent lanes could be performed based on the steps below:

- i. The outer side of the first lane edge should be compacted by using the drum of a steel wheel roller, approximately 150 mm over the top of the unconfined edge.
- ii. The overlap of the second lane placed over the top of first lane should be limited to a distance of 25 to 40 mm.
- iii. The mix placed when laying the second lane should not be moved with a rake but should remain where it was placed by the edger plate mounted on the paver screed.
- iv. The asphalt mixture placed at the longitudinal joint should be rolled from the hot side of the joint (second lane) with the outside tire on the rubber tire roller directly over the joint or the drum of a steel wheel roller extending 150 mm over the top of the joint.

Practically, workmanship is one of the main issues that affects the durability of the longitudinal joint. Proper construction techniques generally result in a long life of the longitudinal joint without severe pavement distresses [7]. Besides, NAPA in their publication [30] had outlined the problems and corresponding solutions in longitudinal joint construction as summarized in Figure 6.

## 7.0 CONCLUSION

Based on the collected information, several conclusions can be made on the factors affecting the performance of longitudinal joints as follows:

- i. The failure can be seen as cracks or raveling form on the pavement center line which allows for the ingress of water into the pavement, besides the effects of traffic and/or freeze/thaw cycles leading to further disintegration and eventual loss of binder from the pavement surface.
- ii. The longitudinal joint between two lanes often deteriorates faster than other pavement sections.
- iii. Other factors contributed to joint cracking were: loss in temperature during the construction process, the

difference of pavement thickness due to poor construction, difficulties during compaction, differential settlements after cracking, and significant changes of temperature and environmental forces.

Additionally, conclusions can be made from the methods of placement and construction below:

- i. Application of wedge joint at the center line eliminated the density gradient, which resulted in a uniform density compared to the conventional butt joint technique and was more durable under the effects of traffic and weathering.
- ii. Use of adhesive material along the longitudinal joint could potentially delay formation of cracks. Even if cracking did develop, it potentially limits the crack depth, hence delaying damage.
- iii. Higher amounts of sealant material are required in a thicker pavement layer to acquire the desired amount of sealant material migration.
- iv. The Michigan joint technique is found to be the best method in constructing longitudinal joints of HMA. The cutting wheel and the edge restraining device techniques are also recommended by the asphalt technologists, however depend on the machine operator to obtain consistent results.
- v. Compaction from the hot side generally results in the desirable performance followed by rolling from hot side with 152 mm away from the joint.

To improve the durability and performance of longitudinal joints, several guidelines can be considered based on the previous evaluation:

- i. A constant density gradient is required throughout the pavement surfacing layer, where samples with lower percentages of air voids performed better.
- ii. Different compaction pattern and types of compactors used considerably affect the distribution of air voids in the pavement.
- iii. Applications of sealant materials did not significantly reduce the permeability of asphalt pavement.
- iv. The density of the joint is significantly lower than at the mat center, and confined edges had better densities than unconfined edges. However, the density near the confined edge was lower than the mat center.
- v. The air void distribution is more uniform for specimens prepared using a modified binder compared with specimens prepared with an unmodified binder.

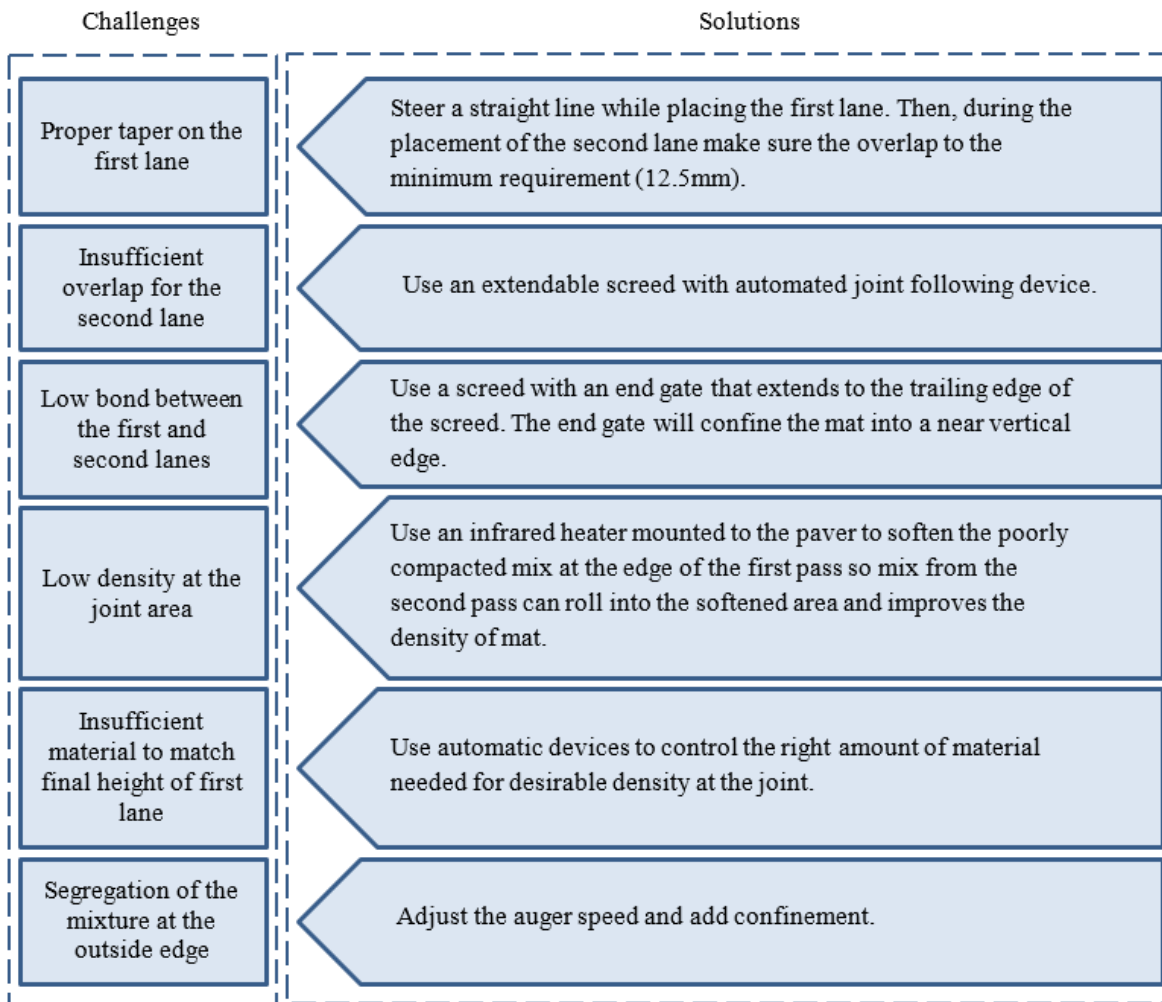


Figure 6 Problems and solutions in the construction of longitudinal joint [30]

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