Project 04-05: Improved Performance of Longitudinal Joints on Asphalt Airfield

Airfield Asphalt Pavement Technology Program (AAPTP)

FINAL REPORT

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DISCLAIMER

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EXECUTIVE SUMMARY

The unsatisfactory performance of longitudinal joints is one of the biggest problems on asphalt concrete or hot mix asphalt (HMA) airfields. Several different approaches to constructing longitudinal joints have been used with varying degrees of success. Clear guidance is needed to identify the best longitudinal joint construction practices and to develop acceptance criteria.

The objective of this study is to develop technical guidance for the improved construction and performance of longitudinal joints on asphalt airfield pavements. This guidance shall consist of recommendations for FAA specification for asphalt longitudinal joints and a guidance document on the various longitudinal joint construction practices.

The research approach for this project included an extensive review of literature on construction of asphalt longitudinal joints; collecting and synthesizing information from experienced airfield engineers; critical evaluation of the existing FAA and DOD specifications; developing best practices of longitudinal joint construction; and preparing a draft implementation plan to promote improved longitudinal joint construction within asphalt airfield community.

An extensive review of literature is included in this report on the various topics related to longitudinal joints including the following:

- **Conventional longitudinal joint construction.** There are several steps in the construction of a good quality conventional joint based on experience. These include paving the first lane in a uniform, unwavering line; compacting the unsupported edge of the first lane (cold lane) properly; controlling the height of the uncompacted HMA in the hot lane; and proper overlapping during the paving operation. Raking or luting at the longitudinal joint can be eliminated if minimal overlapping is done. Any excessive overlapped material on the cold lane should be "bumped" with a lute onto the hot mat **just** across the joint. Obtaining adequate compaction at the joint is the final key in obtaining a durable longitudinal joint. Joints with high densities generally show better performance than those with relatively low densities.

- **Special longitudinal joint construction techniques**. Various special joint construction techniques such as notched wedge joint, rubberized asphalt tack coat (joint adhesive), cutting wheel, restrained edge device, joint maker, infrared joint heater and joint tape have been researched largely on highway pavements by the National Center for Asphalt Technology in Michigan, Wisconsin, Colorado and Pennsylvania and by other states such as Kentucky. Advantages and disadvantages of these techniques including their field performance have been described. Unfortunately, no comprehensive field research project on longitudinal joints has been undertaken on airfield pavements.

Several airfield engineers across the US were contacted to share their experience in longitudinal joint construction. Their detailed experiences have been reported in an appendix with a brief summary in the main report.

Both FAA and DOD specifications were reviewed in light of the literature review and inputs from airfield engineers. It has been recommended to make compaction level both at the joint and mat based on theoretical maximum density (TMD) rather than the bulk specific gravity of daily compacted Marshall specimen, which is more variable. The minimum permissible density values for the joint and mat and evaluation of acceptance should be based on Section 401-5.2 Acceptance Criteria of the FAA Engineering Brief 59A dated May 12, 2006, which states the following:

Evaluation for acceptance of each lot of in-place pavement for joint density and mat density shall be based on PWL. The contractor shall target production quality to achieve 90 PWL or higher.

The percentage of material within specification limits (PWL) shall be determined in accordance with procedures specified in Section 110 of the General Provisions. The acceptance limits shall be as follows:

Mat density, % of TMD	*92.8 minimum*
Joint density, % of TMD	*90.5 minimum*

It is preferable to produce hot longitudinal joints by operating two or more pavers in echelon at least in the central portions of runways and taxiways. This would minimize the number of longitudinal joints in the area, which is subjected to direct application of severe aircraft loadings.

If echelon paving is not possible then it is recommended to use the following best practices for constructing durable “cold” longitudinal joints. Because of the inadequate information on performance of different longitudinal joints in airfield pavements, the information available from highway pavements has been used to recommend these best construction practices. However, the feedback from the airfield engineers has been considered in formulating these recommendations. The report describes in detail the similarities and differences between longitudinal joints on highway pavements and airfield pavements in terms of asphalt mix types, pavement geometry, effect of climate on performance, effect of loading and kneading action of traffic, construction and maintenance. It was concluded that there are far more similarities between the two and the differences are minimal. Therefore, the good experiences from the highway pavements should be considered for airfield pavements as well.

The following four best practices of longitudinal joint construction are listed in decreasing order of preference.

1. Combination of Notched Wedge Joint, Rubberized Asphalt Tack Coat (joint adhesive), and Minimum Joint Density Requirements: Construct a notched wedge longitudinal joint. The unconfined edge of the first paved lane has a vertical notch at the edge generally ranging from ½ inch (13 mm) to 3/4 inch (19 mm) in height and then a wedge with 1:12 taper. The notched wedge joint can be formed by using a home made sloping steel plate attached to the inside corner of the paver screed extension. Commercial attachments are also available. The overlap layer of the adjacent paving lane is required to be placed and compacted within 24 hours. The vertical notch and taper are tack coated with rubberized asphalt binder (joint adhesive) prior to placing the overlap wedge of the adjacent lane. The thickness of the tack coat is about 1/8 inch (3 mm) on the slope of the HMA edge. The rubberized asphalt tack coat need not be applied on the entire taper. It is considered adequate to apply it on the vertical notch and the top 3-4 inches (76-102 mm) wide band of the taper. The heat from the HMA in the adjacent lane and the roller pressure causes the sealant to adhere strongly along the joint face resulting in a strong bond between the two lanes and providing a built-in sealer at the joint. After the rubberized asphalt tack coat is applied, the adjacent lane (hot lane) is placed. The end gate of the paver should extend over the top surface of the previously placed HMA by a distance of approximately ½ inch (13 mm). The most efficient joint compaction method is to roll the longitudinal joint from the hot side overlapping the cold lane by approximately 6 inches (150 mm).

2. Rubberized Asphalt Tack Coat (Joint Adhesive) and Minimum Joint Density Requirements: This practice is similar to that in Item 1 above except that no notched wedge joint is used. The first lane (cold lane) is paved as usual with the normal, unconfined edge slope. A rubberized asphalt tack coat (joint adhesive) is applied on the entire face of the unconfined edge of the cold lane using the procedure described in Item 1. The other paving operations are similar to Item 1.

3. Notched Wedge Joint and Minimum Joint Density Requirements: This practice is similar to that in Item 1 above except that a conventional tack coat material (which is used on the main line) is applied to the entire face of the notched wedge joint in lieu of rubberized asphalt material.

4. Cutting Wheel and Minimum Joint Density Requirements: The cutting wheel technique involves cutting 1½ - 2 inches (38-51 mm) of the unconfined, low-density edge of the first paved lane after compaction, while the mix is plastic. It is important to remove all low-density material at the edge of the first paved lane. Some contractors remove as much as a 6-inch (150-mm) strip to meet and exceed airfield joint density requirements. The cutting wheel can be mounted on an intermediate roller or a motor grader. This process obtains a reasonably vertical face at the edge, which is then tack coated before placing the abutting HMA. It is important to restrict the overlap to about ½ inch (13 mm) while placing the adjacent lane. It is very important to have a skilled cutting wheel operator, who must cut straight without wavering and a skilled paver operator, who must closely match the cut line with minimal overlap.

A standalone document on best practices of longitudinal joint construction was also prepared for practicing airfield engineers and is included in the report as an appendix.

CHAPTER 1. INTRODUCTION AND RESEARCH OBJECTIVE

Problem Statement and Research Objective

The unsatisfactory performance of longitudinal joints is one of the biggest problems on asphalt concrete or hot mix asphalt (HMA) airfields. Several different approaches to constructing longitudinal joints have been used with varying degrees of success. Clear guidance is needed to identify the best longitudinal joint, develop acceptance criteria and understand the benefits and limitations of asphalt longitudinal joints on airfields. This project will provide the Federal Aviation Administration (FAA) recommendations on specifications and documentation for improved asphalt longitudinal joint construction for airfields.

The objective of this study is to develop technical guidance for the improved construction and performance of longitudinal joints on asphalt airfield pavements. This guidance shall consist of recommendations for FAA specification for asphalt longitudinal joints and a guidance document on the various longitudinal joint construction practices. The recommendations and guidance must consider but not be limited to the following:

1. Existing types of longitudinal joint construction techniques and their respective performance
2. Applicability and comparison of highway longitudinal joint construction practices to airfield pavements
3. Preferred and acceptable alternative longitudinal joint construction practice
4. Echelon paving
5. Use of tack coats and/or other materials at longitudinal joints
6. Use of joint heaters

7. Permeability of the longitudinal joint
8. Acceptance specifications and pay factors

Scope of Study and Research Approach

Recommendations for improved performance of longitudinal joints were to be developed by addressing the following tasks:

Task 1 -- Review existing literature on longitudinal joints for asphalt concrete pavements.

Task 2 -- Assemble representative national airfields database of types, location and performance of longitudinal joints used on asphalt airfield pavements considering the different climates and airfield classifications in the US.

Task 3 -- Develop a comprehensive document on best practice of longitudinal joint construction. This includes pro and cons and must address the issues listed in the objectives.

Task 4 -- Evaluate existing FAA (150/5370-10B) and DOD (UFGS-02749) specifications and develop recommendations for FAA on improved longitudinal joints. This recommendation document shall include options and/or alternatives and comprehensive acceptance requirements.

Task 5 -- Develop draft implementation plan to promote improved longitudinal joint construction within the asphalt airfield community.

Task 6 -- Submit a draft report and make presentation to the technical panel.

Task 7 -- Finalize project report and recommendations considering the comments provided by the technical panel.

The research approach for this project included an extensive review of literature on construction of asphalt longitudinal joints; collecting and synthesizing information from experienced airfield engineers; critical evaluation of the existing FAA and DOD specifications; developing best practices of longitudinal joint construction; and preparing a draft implementation plan to promote improved longitudinal joint construction within asphalt airfield community. A standalone document on best practices of longitudinal joint construction was also prepared and included in an appendix.

CHAPTER 2. REVIEW OF LITERATURE

A longitudinal construction joint occurs when a lane of Hot Mix Asphalt (HMA) is constructed adjacent to previously placed HMA. Longitudinal joints are inevitable in both highway and airfield pavements, unless paving is done in the echelon formation (which is generally not the case).

A majority of the existing literature on longitudinal joints in asphalt concrete or hot mix asphalt pavements pertains to highway pavements rather than airfield pavements. The following are some differences between airfield and highway pavements in terms of longitudinal joints:

- Since airfield runways are very wide compared to most highway pavements, there can be numerous longitudinal construction joints on runways (Figure 1). Airfield runway longitudinal construction joint lengths easily exceed nine times the length of the runways thereby creating a huge maintenance problem (Figure 2) if they are not durable enough to resist traffic and environmental conditions (1). Therefore, longitudinal joints have a more significant effect on the performance and life of an airfield runway compared to highway pavement.
- Longitudinal joints in an airfield are subject to direct application of severe loads, especially in the central portions of runways and taxiways (2). Maximum aircraft weight is expected to exceed 550 tons when the Airbus 380 enters into service (3). Application of severe loads close to longitudinal joints can potentially induce cracking in the joints, which are the weakest part of the pavement.

Figure 1. Aerial view of airport runway showing longitudinal joints

Figure 2. Deteriorated long joints on airfield runway

- Airfield pavements are mostly characterized by low repetition of loading, need for supporting much heavier loads (compared to highway) and channelized traffic; which govern and in turn are affected by pavement (for example, runway and taxiway) width and type of aircrafts using them (4).
- Unlike in highways, airfield pavements do not have the beneficial effects of kneading effect from traffic. Therefore, in areas of relatively little traffic on airfield runways asphalt pavement can get oxidized at an accelerated rate (5).
- Usually the airfield pavements need to be constructed within relatively short periods of time, in many cases at nights, and hence workability is a primary concern.
- Damaged longitudinal joints are of very serious concern in airfield pavements. Loose materials from such areas can cause Foreign Object Damage (FOD) to aircrafts, leading to loss of life and equipment. Potential sharp edges along open longitudinal joints can also endanger aircraft (3).

In spite of the preceding differences between airfield and highway pavements it is believed that opening (cracking) of the longitudinal construction joint is more a thermal phenomenon (contraction/expansion) rather than a load-associated phenomenon. This is evident from the fact that the problem of longitudinal joints (both on airfield and highway pavements) is more severe in the northern tier states of the US with cold climate compared to the southern states with hot climate. This has been confirmed from experience with the military airfields (see Appendix A). Therefore, the experience gained on highways is generally applicable to airfield pavements and should be considered and used in the latter.

Although the airfield paving technology has been updated from time to time, one of the major causes of distress in airfield pavements has always been and remains as failures such as raveling and cracking at longitudinal joints (5).

Engineers, consultants and contractors have continuously tried to develop methods for constructing better performing longitudinal joints in pavements. Such methods include overlapping and luting operations; different types of rolling patterns for compacting the joint; and the use of special joint construction techniques and equipment, such as cutting wheel; restrained edge device; notched wedge joint; rubberized asphalt tack coat (joint adhesive); and joint heaters. At the same time, many agencies have started using specifications that are written specifically for construction of better joints such as density requirements at joints. Unfortunately, while the experience of failures along joints is remarkably similar, the experience with different joint construction techniques of different agencies is far from being uniform.

Therefore, there is a critical need for a guidance document for improving longitudinal joint construction in airfield pavements, which would provide both specification requirements as well as recommendations for selecting the best construction practice under a variety of conditions. The following review of existing literature on longitudinal joints for asphalt concrete pavements has been conducted and arranged in the following order:

- Introduction
- Conventional longitudinal joint construction
- Research on longitudinal joints by the National Center for Asphalt Technology (NCAT) and other agencies
- Special joint construction techniques
- New developments in paving equipment

- Permeability of joints
- Joint density specifications

INTRODUCTION

Quite often, one of the most obvious premature failures in HMA pavement takes place at the longitudinal construction joint, which also happens to be the weakest part of a multilane pavement structure. The premature deterioration of the longitudinal joint occurs in the form of cracking and/or raveling. The distresses are caused by relatively low density and surface irregularity at the joints. A density gradient also exists across a typical longitudinal joint. Such a density gradient is caused by the low density at the unconfined edge when the first lane (hereinafter called the cold lane) is paved and a relativity high density at the confined edge, when the adjacent lane (hereinafter called the hot lane) is paved. In addition, there is more rapid cooling of the HMA mix near the unconfined edge of the cold lane resulting in relatively low density. Therefore, it is not uncommon to encounter densities at the joint, which are significantly lower than those in the mat away from the joint (6, 7, 8, 9).

Burati and Elzoghbi (8) studied joint densities during 1984 construction of two FAA Eastern Region airports at Morristown Municipal Airport, New Jersey and Rochester-Monroe County Airport, New York. Joint core densities were significantly lower than mat core densities at both airports.

Field evaluation of 35 highway pavements in Texas (9) revealed that the density was always lower at the unconfined edge than in the middle of the lane and this was almost always statistically significant. This difference in density ranged from 2 to 12 lbs per cu ft (32 to 192 kg per cu m) but the average was about 6 to 7 lbs per cu ft (96 to 112 kg per cu m) or 4 to 5 percentage points. Similar experience has been documented on airfield runways (10).

Typically, a crack develops at the longitudinal joint in due course of time, sometimes as soon as one year in service (Figure 3). The crack becomes wider and more ragged every year. This phenomenon observed on both highway and airfield pavements is more prevalent and severe in areas with very cold climatic conditions, which also cause transverse shrinkage cracking in HMA pavements. Figures 4a, 4b, and 4c show an example of the progression in the severity of the crack at the longitudinal joint as documented in the research project conducted by the National Center for Asphalt Technology (NCAT).

It is also not uncommon for the HMA pavement to develop raveling on one side of the longitudinal joint as shown in Figures 5 and 6. In a majority of cases, raveling occurs on the side of the cold lane, which usually has lower density at the unconfined edge. Raveling can also occur on the side of the hot lane due to inadequate compaction, which may result from bridging action if the edge of the cold lane is higher than the hot lane due to excessive material.

Both cracking and raveling allow intrusion of water into the pavement system, which weakens the foundation of the pavement requiring extensive repairs (Figure 7). Sealing of the longitudinal crack and patching of raveled areas also entail undesirable maintenance cost. Longitudinal joints often look coarse in surface texture. This can happen primarily for two reasons: segregation and handwork. Because longitudinal joints occur at the edge of the paver screed and auger system and the HMA has been moved beyond the end of the auger there is a potential of HMA being segregated. Typically, HMA from the hot lane, which overlaps the cold lane, is luted back onto the hot side of the joint. This handwork usually results in a coarse surface texture.

Figure 3. Typically a crack develops at the longitudinal joint

(a) (b) (c)

Figure 4. Progression in the severity of longitudinal crack with time

Figure 5. Raveling along longitudinal joint

Figure 6. Raveling along longitudinal joint

Figure 7. Intrusion of water through open longitudinal joint into the pavement system weakens its foundation requiring repairs

Because of the preceding problems associated with longitudinal joints, many highway agencies have started to require reasonable durability of the joints as one of the parameters on warranty projects (11). Similar to the Federal Aviation Administration (FAA), many highway agencies have also begun to specify minimum compaction levels at the longitudinal joints. More and more agencies are getting interested in obtaining durable longitudinal joints in pavements (12).

The industry is successfully pursuing the concept of perpetual or long lasting HMA pavements, which should reasonably be maintenance free. Since the longitudinal joint is an integral part of the HMA pavement it is essential that it is as durable as the mainline pavement (13). Highly temperature-susceptible asphalt binders, which may induce low-temperature thermal cracking, are also not desirable because they do not provide adequate resistance to cracking at the longitudinal joint (14).

The National Center for Asphalt Technology (NCAT) has done extensive field research in evaluation of some 12 different longitudinal joint construction techniques during the 1992-

2002 period (15, 16, 17, 18, 19). A summary of findings on the relative performance of these different construction techniques is included in this literature review later.

CONVENTIONAL LONGITUDINAL JOINT CONSTRUCTION

Longitudinal joints can be broadly classified as follows (6, 20):

- **Hot Joints**

  Hot joints are produced when two or more pavers are operating in echelon (parallel) as shown in Figure 8. The pavers are spaced closely such that the lane placed first does not cool significantly before the second lane is placed adjacent to the first lane. When the longitudinal joint is compacted, the HMA on both sides of the joint is essentially within the specified compaction temperature range and, therefore, a hot joint is produced. Constructed properly, a hot longitudinal joint appears almost seamless and invisible and produces the highest density when compared to semi-hot and cold joints (6). On some Maryland highway projects it was determined that the average density of hot joints was about the same as the average density of the mat away from the joint (1). But in a majority of cases, echelon paving is not possible because of limited capacity of HMA production to feed more than one paver. However, attempt should be made to pave in echelon at least the central portions of runways and taxiways. This would minimize the number of longitudinal joints in the area, which is subjected to direct application of severe aircraft loadings (2).

- **Semi-Hot Joints**

  A semi-hot joint or a warm joint is produced when the paver is restricted to

Figure 8. Paving in echelon

proceed for a certain distance before moving back to place the adjacent lane. The HMA in the first lane generally cools down to a temperature of about 120F to 140F (49 to 60C) before the adjacent lane is placed. Semi-hot joint is by far the most commonly used joint type on HMA paving projects. Numerous highway studies and an airfield study (7) have demonstrated that the semi-hot joint densities are significantly lower than the mat interior densities.

- **Cold Joints**

A cold joint is produced when the first paved lane has cooled overnight or more before the adjacent lane is placed to match it. A cold joint will also be produced if paving of the first lane is carried too far ahead such that the HMA has cooled well below 120F (49C).

Construction of durable longitudinal joints is an art, which requires a team of skilled people with paving experience (21). The team primarily consists of the paving foreman, paver operator, raker, screed man, and roller operator. The team should follow good construction practices, which are presented in detail in Chapter 5 and Appendix B. Many of these construction practices have been reported by Schrocman (22) based on experience.

Paving and Compacting the First Lane

One of the important requirements in obtaining a durable joint is proper compaction of the unsupported edge of the first lane (cold lane). The unsupported edge typically has a slope of approximately 60 degrees. Obviously, the wedge formed by this slope at the edge does not receive as much compaction as the mainline away from the edge (22).

Breakdown compaction with a vibratory or static steel wheel roller can be done with the roller operating in three different locations in respect to the unsupported edge of the first lane.

First, rolling can begin with the edge of the roller drum away from the unsupported edge. However, this practice will cause the HMA to shove or move out due to shear loading on the mix at the edge of the steel drum. The extent of this transverse movement will depend upon the stiffness of the HMA mixture, and bond with the substrate, either through aggregate interlock or through tack coat. This movement will (a) typically cause a crack to be formed at the edge of the drum, and (b) create a depression at the unsupported edge so that it will be very difficult to match the joint when the adjacent lane is placed (22).

Second, rolling can begin with the edge of the steel drum right on the unsupported edge of the first lane. Although this practice will eliminate cracking at the edge of the roller drum, it would still shove and push out the mix underneath the drum. Therefore, it would not be possible to obtain adequate density at the unsupported edge (22).

Third, rolling can begin with the edge of the steel drum extending over the edge of the first lane by about 6 inches (150 mm). At this position, the edge of the drum does not exert any shear force in the HMA because it is out hanging in the air. Therefore, there is minimal transverse movement of the HMA and reasonable amount of density is obtained at the unsupported edge of the lane. Obviously, this third practice of compacting the unsupported edge will produce the best results and is, therefore, recommended (22).

Pneumatic tired rollers are typically used in the intermediate phase of HMA compaction. However, they are sometimes used for breakdown rolling. In that case, pneumatic tired rollers do not perform as well as steel wheel rollers in constructing longitudinal joints. During rolling, the outer tire tends to roll over the unsupported edge of the first paved lane, which complicates the make-up of the joint when the adjacent lane is placed and compacted (22).

Paving the Second Lane and Overlapping

Another key point in obtaining a good longitudinal joint is proper overlapping during the paving operation. The end gate of the paver should extend over the top surface of the previously placed HMA by a distance of approximately 1 to 1½ inches (25 to 38 mm). Attention to this detail will not only provide the requisite amount of HMA on top of the joint for proper compaction, it will require minimal or no raking and luting (22, 23).

If there is too much overlap, the excessive overlapped material on the cold lane may be “bumped” with a lute onto the hot mat **just** across the joint as shown in Figure 9. The bump should lie just above the natural slope or the wedge at the edge of the cold lane.

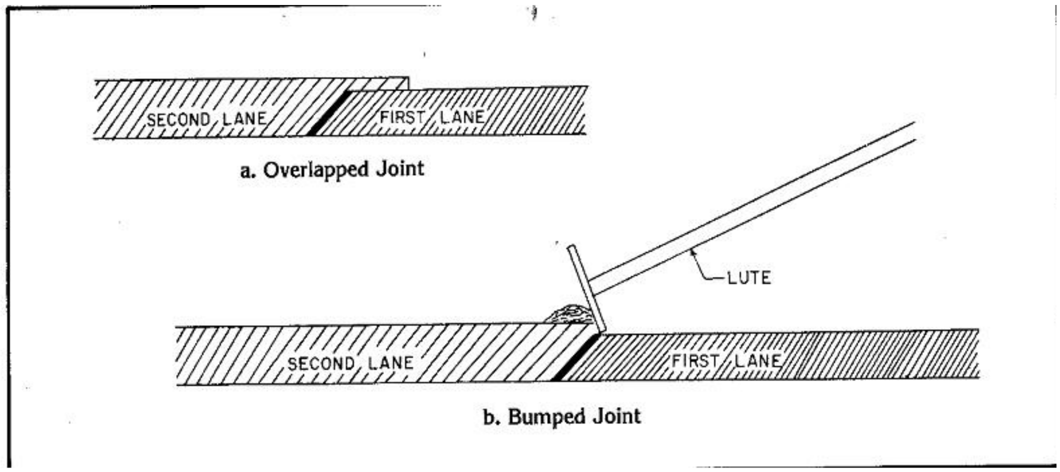

Figure 9. Excessive overlapped material on the cold lane needs to be "bumped" with a lute onto the hot mat just across the joint

Sometimes, there is a tendency to broadcast the raked material onto the HMA in the hot lane (Figure 10). This is not only undesirable for obtaining a good longitudinal joint, this practice affects the surface texture of the mat adversely.

Figure 10. Bad practice of broadcasting the raked material onto the hot lane

Compacting the Longitudinal Joint

Obtaining adequate compaction at the joint is the final key in obtaining a durable longitudinal joint. Extensive field research by the National Center for Asphalt Technology (NCAT), discussed later, indicated that the joints with high densities generally showed better performance than those with relatively low densities (16, 17).

Three primary methods have been used for compacting longitudinal joints.

Rolling from the hot side: The most efficient joint compaction method, also indicated in the NCAT field research, is to roll the longitudinal joint from the hot side overlapping the cold lane by approximately 6 inches (150 mm) as shown in Figure 11. The steel wheel roller can be operated in vibratory or static mode, preferably the vibratory mode to obtain better compaction. This rolling pattern allows most of the weight of the roller to compact the HMA in the hot lane as well as at the joint. The HMA at the edge of the hot lane is constrained due to the presence of

Figure 11. Rolling from the hot side with a 6-inch overlap on cold lane

cold lane and is compacted promptly without any significant cooling, thus resulting in high density. This pattern is also effective if the pavement has different cross slopes at the longitudinal joint.

Akpinar and Romanoschi (24) obtained stress strain curves from the vertical force-displacement data, which were used to model the deformation of HMA under the roller in the finite element analysis. Their analyses showed optimum longitudinal joint construction technique was obtained when the roller operated from the hot side during the first pass.

Rolling from the hot side 6 inches (150 mm) away from the joint: In this method, the first pass of the steel wheel roller is made entirely in the hot lane with the edge of the drum approximately 6 inches (150 mm) away from the joint as shown in Figure 12. This method has some value if a tender mix is encountered or when the HMA lift thickness is greater than 4 inches (100 mm). The concept behind this method is that the HMA will be pushed and "crowded" towards the joint. On a subsequent pass the roller will compact the intervening narrow strip of HMA, expecting better compaction at the joint. However, if this method is employed in face of a tender mix problem, it is recommended to identify and remedy that problem so that conventional rolling from the hot side with about 6 inch (150 mm) overlap on the cold side can be used.

Rolling from cold side: A few years ago, it was a common practice to roll the longitudinal joint from the cold side, that is, the first pass of the steel wheel roller was made with most of the drum on the cold lane and overlapping the hot lane by about 6 inches (150 mm) as shown in Figure 13 (17, 25). It was believed that this rolling technique allowed the joint to be "pinched," thus obtaining high density at the joint. However, as also evidenced in the NCAT field research, this method generally is not as efficient as rolling from the hot side. Rolling from

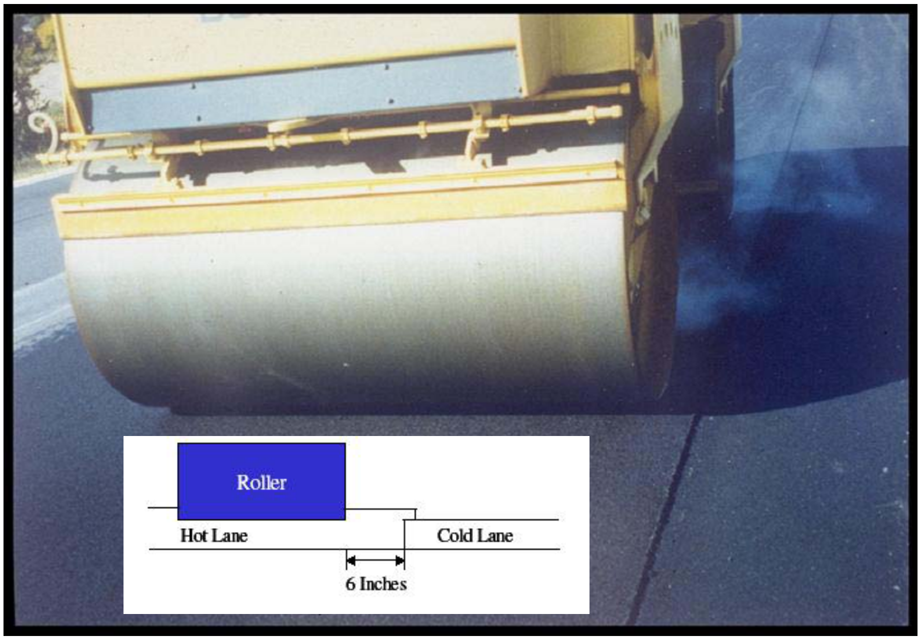

Figure 12. Rolling from the hot side 6 inches away from the joint

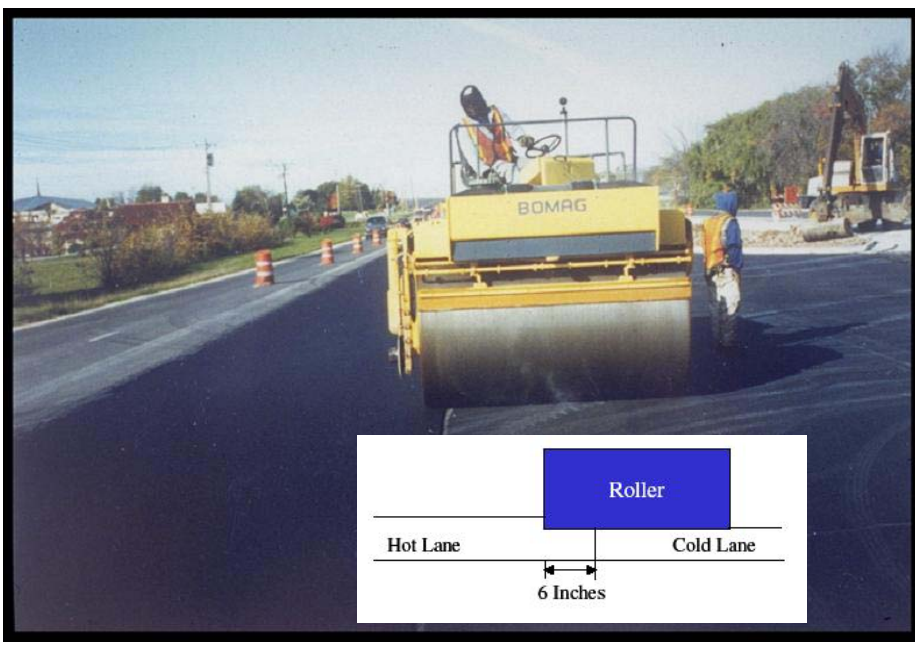

Figure 13. Rolling from the cold side with a 6-inch overlap on hot lane

the cold side has the following disadvantages:

- Most of the weight of the roller during the first pass is on the compacted cold lane and, therefore, the loose HMA in the hot lane does not get any significant compactive effort.
- Since the steel wheel roller can be operated only in static mode and not in vibratory mode during the first pass, there is less compactive effort imparted to the mix at the joint.
- During the so-called “pinching” of the joint in the first pass, the HMA in the hot lane is cooling off, thus reducing the potential for obtaining good density.
- If there are different cross slopes (such as at crown) at the longitudinal joint, this technique will cause a reduced effective contact between the roller drum and the mix in the hot lane adjacent to the joint during the first pass. This would result in low density at the joint on the hot side.
- The cold lane cannot be kept open safely to traffic on highways if rolling is done from the cold side (25).

Desirable Compaction Level at the Longitudinal Joint

Most specifications for longitudinal joint density require the density level at no more than 2 percent below the required mainline mat density. For example, if the required minimum mainline mat density were 92 percent of the theoretical maximum density (no more than 8 percent air voids), the required minimum density at the joint would be of 90 percent of the theoretical maximum density. By paying attention to construction details mentioned earlier, it is possible to obtain a joint density within 1.5 percent of the mainline density (22).

Usually, it is not possible to obtain an accurate density measurement right on the joint using a nuclear gauge, which is centered on top of the visible line between the cold and hot lanes. This is because the nuclear gauge cannot be placed flat across the joint without rocking (17). The compacted HMA on one side of the joint is usually higher than the other side causing uneven surface across the joint. Similarly, the nuclear gauge cannot be placed flat on a joint with a crown.

Therefore, the joint density is best measured by obtaining a 6 inch- (150 mm) diameter core centered on top of the visible line between the two lanes. It should be noted that the core would not consist of equal volumes of mix from the cold lane and the hot lane. Due to the presence of natural slope at the unconfined edge of the cold lane, most of the mix in the core will come from the cold lane. This is acceptable because the density of the cold side is of major concern.

Echelon Paving

As mentioned earlier, hot joints are produced when two or more pavers are operating in echelon (parallel) as shown in Figure 8. Usually the pavers are within 30 feet (9 meters) of each other. The amount of overlap is critical in obtaining a durable hot joint. The end gate of the trailing paver should not extend more than one inch (25 mm) onto the adjacent HMA placed by the leading paver. This will prevent the end gate of the screed of the trailing paver from dragging on the HMA already placed by the leading paver. Careful attention to this overlap will not require any raking either, which is difficult to do by standing on the uncompacted mat of the first lane (23).

Breakdown roller that is compacting the HMA behind the leading paver should be kept at least 6 inch (150 mm) away from the edge of the mat. After the trailing paver places HMA against the uncompacted edge of the first lane, the rollers that are working behind the trailing paver are used to compact the HMA on both sides of the joint. If the above procedures of proper overlap and compaction are followed, a virtually seamless pavement can be obtained (23).

Tack Coating Longitudinal Joints

According to some engineers, applying a tack coat on the face of the unconfined edge of the cold lane ensures a better bond (adhesion) and seal of abutting HMA lanes. The tack coat usually consists of asphalt cement; emulsion; or hot poured, rubberized asphalt sealer (also called joint adhesive). Application of tack coat is a standard practice in some countries, for example, United Kingdom, Japan, and South Africa. However, opinions vary in the United States. Some engineers believe application of thin tack coating material such as asphalt cement and emulsion in case of semi-hot joint is unnecessary since it may not contribute in improving the durability of the longitudinal joint (23). Recent NCAT field research, discussed later, has demonstrated that the use of hot-poured, rubberized asphalt sealer as a tack coat or joint adhesive (about 1/8 inch or 3 mm thick) on the face of the first paved lane produced the most durable longitudinal joints. Therefore, it appears that thick tack coats may be more effective than generally used thin coats of asphalt cement or emulsion.

Most engineers would agree that a tack coat must be applied to a face, which has been exposed to weathering and traffic for a period of time to ensure good bond between the abutting lanes.

NCAT RESEARCH ON LONGITUDINAL JOINT CONSTRUCTION TECHNIQUES

The National Center for Asphalt Technology (NCAT) initiated a national study of evaluating various longitudinal joint construction techniques in 1992 with the cooperation of the state departments of transportation and the HMA industry. This study (15, 16, 17, 18) involved evaluation of 12 different construction techniques used on four projects: (a) seven techniques on I-69 in Michigan (1992); eight techniques on State Route 190 in Wisconsin (1992); seven techniques on I-25 in Colorado (1994); and eight techniques on State Route 441 in Pennsylvania (1995). Table 1 shows the techniques used on each project. Each test section within a project was 500 feet (152 m) long. Different joint construction techniques also included three joint rolling techniques described earlier. Unless otherwise indicated, rolling of all other test sections was done from the hot side.

Table 1. Longitudinal Joint Construction Techniques used in Michigan, Wisconsin, Colorado and Pennsylvania

Construction/Rolling Technique		Project			
		MI	WI	CO	PA
1.	Rolling from hot side	X	X	X[a]	X
2.	Rolling from cold side	X	X	X[a]	X
3.	Rolling from hot side 152 mm (6 inch) away from joint	X	X	X[a]	X
4.	(1: 12) Tapered joint with 12.5 mm offset without tack coat	X	X[b]		
5.	(1: 12) Tapered joint with 12.5 mm offset with tack coat	X	X[b]		
6.	Edge restraining device		X		X
7.	Cutting wheel with tack coat	X	X	X[a]	X
8.	Cutting wheel without tack coat			X[a]	
9.	Joint maker	X	X		X
10.	Tapered (1: 3) joint with vertical 25 mm offset			X	
11.	Rubberized asphalt tack coat			X	X
12.	NJ Wedge (1: 3) and infrared heating				X

[a] Unconfined edge had a 1:3 taper
[b] Tapered (1:12) joint did not have any vertical offset

A detailed description of each joint construction technique is given in the next section. A brief description is given below so that the conclusions from this study can be understood:

Notched Wedge Joint

The notched wedge joint is formed by providing a vertical notch and a taper at the edge of the lane paved first (cold lane). A taper of 1:12 (vertical: horizontal) was used. The taper is then overlapped when the adjacent lane (hot lane) is placed.

Edge Restraining Device

The restrained edge compaction technique utilizes an edge-compacting device, which provides restraint at the edge of the first lane constructed. The restraining device consists of a hydraulically powered wheel, which rolls alongside the compactors drum simultaneously pinching the unconfined edge of the first lane towards the drum providing lateral resistance (23). This technique is believed to increase the density of the unconfined edge. The adjacent lane is then abutted against the initial lane edge.

Cutting Wheel

The cutting wheel technique involves cutting 1½-2 inches (38-51 mm) of the unconfined, low-density edge of the first lane after compaction, while the mix is still plastic. It is not uncommon to cut back as much as 6 inches (150 mm) on airfield pavements, which have stringent density requirements. A 10-inch (254-mm) diameter cutting wheel mounted on an intermediate roller is generally used for the purpose (23). The cutting wheel can also be mounted on a motor grader, which was the case in Michigan and Colorado. This process obtains a reasonably vertical face at the edge, which is then tack coated before the placement of the abutting HMA.

Joint Maker

This was an automated joint construction technique developed in the early 1990s. It consists of a device, which is attached to the side of the screed at the corner during construction. The device forces extra material at the joint through an extrusion process prior to the screed. It is claimed that proper use of the joint maker ensures high density and better interlocking of aggregates at the joint.

Tapered (1:3) Joint with Vertical One-Inch Offset

In this method used in Colorado, the unconfined edge of the 2-inch (51 mm) thick cold lane was constructed with a 1-inch (25 mm) vertical step (offset) at the top of the joint and a 1:3 (1 vertical: 3 horizontal) taper starting from the base of the vertical step.

Rubberized Asphalt Tack Coat (Joint Adhesive)

The unconfined edge of the first paved lane adjacent to the joint was not provided with any taper in this experimental section. On the following day, a rubberized asphalt tack coat (Crafco pavement joint adhesive Part Number 34524) was applied on the face of the unconfined edge before placing the adjacent lane. The thickness of the tack coat was about 1/8 inch (3 mm).

New Jersey Wedge (1:3)

In this technique used on the Pennsylvania project, a wedge joint consisting of a 1:3 (1 vertical: 3 horizontal) taper was formed during construction of the first lane by using a sloping steel plate attached to the inside corner of the paver screed extension (26). During the second pass of the paver an infrared heater was used to heat the edge of the previously placed layer to a surface temperature of about 200F (93C).

Construction details of all four projects have been published elsewhere (15, 16, 17, 18). A minimum of six sets of cores was obtained right on the joint in each test section to determine the average joint density resulting from different techniques. The performance of different joints was evaluated visually every year by a team of five evaluators up to six years in service. Periodical and final performance evaluation data for all four projects has been published during the 1994-2002 period (15, 16, 17, 18).

The following general conclusions were drawn from this extensive NCAT research project:

- Longitudinal joint constructed with rubberized asphalt tack coat (joint adhesive) gave the best performance with no significant cracking. The joint was hardly visible.
- The notched wedge joint with 1:12 taper has the best potential of obtaining a satisfactory longitudinal joint.
- Both cutting wheel and the edge restraining device have a good potential of obtaining a satisfactory joint. However, these techniques are operator dependent and, therefore, may not give consistent performance results. For example, the quality of joint with cutting wheel is dependent upon the skill of the operator in making a straight cut and the skill of the paver operator in matching the cut edge if it is not straight or it is wavering.
- Rolling of the longitudinal joint should be done from the hot side with 6-inch (150 mm) overlap of the roller drum on the cold lane. Rolling should preferably be done with a vibratory roller as soon as possible to obtain the highest possible density of the joint to ensure best performance.
- Joints with high densities generally showed better performance than those with relatively low densities. Therefore, the user agencies should specify minimum acceptable compaction levels to be achieved at the joint. It is recommended that the density at the joint be not more than two percent lower than the density specified in the lanes away from the joint. Densities right on the visible joint line need to be determined by taking cores. It is not possible to use

nuclear density gauge because of seating problem right on the joint.

Beside the NCAT study, another comprehensive longitudinal joint study (27) was undertaken by the Kentucky Transportation Center in 1999 to evaluate joint density produced by different techniques. The techniques included notched wedge joint, edge restraining device, joint maker, rubberized asphalt tack coat (joint adhesive), HMA joint tape, and infrared joint heating system. Some of the major conclusions and recommendations from this study include:

- Contractors are consistently achieving levels of density at or near the construction joint that are within three percent of the lane density. It is recommended that specifications be written that would require contractors to achieve that level of density at or near the construction joint.
- The infrared joint heating system achieved the highest joint density of all the methods; however, only one short project was included in this study. The restrained-edge method of joint construction achieved the second highest overall densities and statistically was significantly better than the conventional method of joint construction. The notched wedge only marginally improved densities overall, while the joint maker showed no improvement over conventional construction techniques.
- It appeared the notched-wedge joint method produced the lowest permeabilities at the joint.
- Preliminary performance data indicate that all projects are currently performing well with projects having joint adhesives performing as well as, or better than, projects without joint adhesives. It is recommended that more projects be constructed using joint adhesives.

Another comprehensive study (28) was undertaken by the Wisconsin Department of Transportation in 1993. The performance of eight joint construction techniques including cutting wheel and edge restraining device with emphasis on the notched wedge joint was evaluated for 10 years. Various techniques of compacting the notched wedge joint were evaluated. Performance evaluations were based on density results and an overall performance ranking based on amount of longitudinal joint cracking. The following conclusions were drawn and recommendations made:

- The NCAT study concluded that the cutting wheel joint and restrained edge joint sections performed best in their Wisconsin project, followed by the wedge joint (without notch). Upon the completion of this Wisconsin study, it has been found that the notched wedge joint performs better than the cutting wheel and restrained edge joint. The results show that the notched wedge joint in Wisconsin, when constructed with better equipment and by more experienced workers, performs as well as it does in Michigan.
- From the constructability standpoint, the notched wedge joint creates less debris and can be constructed more efficiently than the cutting wheel joint and the restrained edge joint. The wedge joint is also significantly safer for traffic, as the transition from the newly paved lane to the unpaved lane is tapered instead of a vertical step-off like the other joint methods produce. The results of this study have found that the tag-along roller and the steel wheel side roller compaction techniques both produce acceptable wedge joints. However, since it is often difficult for the paver operator to see the tag-along roller, the steel roller is preferred for compacting the wedge joint.
- Due to the success of the wedge joint in other states, the Wisconsin DOT developed a Special Provision Specification for Longitudinal [Wedge] Joints of Asphaltic Pavements in

1994 to be used at the option of the contractor. With increased experience and better equipment, the success of the wedge joint in Wisconsin has grown steadily and it is now constructed by many of the state's contractors.

- It is recommended to revise the specification to make notched wedge joint construction a requirement instead of an option. Any other longitudinal joint construction technique would not be permissible without the engineer's approval. This would help to ensure consistent quality in joint construction work.

Unfortunately, comprehensive research projects on longitudinal joint construction similar to NCAT, Kentucky and Wisconsin have not been conducted on airfield pavements. However, the valuable experience gained on highway pavements should be considered when constructing longitudinal joints on airfield pavements.

SPECIAL JOINT CONSTRUCTION TECHNIQUES

Special joint construction techniques such as rubberized asphalt tack coat (joint adhesive), notched wedge joint, cutting wheel, restrained edge device, and joint maker included in the NCAT research project are now described in detail in this section. Other techniques such as HMA joint tape and infrared heating system, which were evaluated in the Kentucky study (27), are also described.

As mentioned earlier, special joint construction techniques have been used if (a) the joint has to be warranted, (b) specifications require a minimum specified density at the joint, or (c) a built-in joint sealer needs to be provided.

Rubberized Asphalt Tack Coat (Joint Adhesive)

In this technique, the first lane (cold lane) is paved as usual with the normal unconfined edge slope. A rubberized asphalt tack coat (Crafco pavement joint adhesive Part Number 34524 was used in both NCAT and Kentucky studies) is applied on the face of the unconfined edge of the cold lane. The thickness of the tack coat (also called joint adhesive) is about 1/8 inch (3 mm) on the slope of the HMA edge.

The rubberized asphalt sealant material is supplied as a ready to use solid material in containers. It is melted in a jacketed double boiler type melting unit, which is equipped with both agitation and re-circulation systems. The melting unit must be capable of safely heating the sealant to 400F (204C). The sealant is best applied using a pressure feed wand. An applicator shoe attached to the end of the wand helps in spreading the sealant uniformly on the slope of the unconfined edge. Figures 14 and 15 show the application of rubberized asphalt tack coat on a paving project. Application excesses should not exceed more than 2 inches (51 mm) at the bottom of the joint or more than ½ inch (13 mm) at the top of the joint (29).

The sealant should preferably be applied within four hours of the time that the adjacent

Figure 14. Application of rubberized asphalt tack coat at joint ahead of paving

Figure 15. Application equipment for rubberized asphalt tack coat

HMA lane is placed. The heat from the HMA in the adjacent lane and the roller pressure causes the sealant to adhere strongly along the joint face resulting in a strong bond between the two lanes and providing a built-in sealer at the joint (29).

The joint adhesive has a consistency of a thick pancake mix. It hardens quickly and after a short period it feels slightly tacky to the touch. During placement of the second lane, the adhesive may sometimes stick to the tires of the haul trucks if pulling across the longitudinal joint area. Therefore some caution is needed during construction (30).

The rubberized asphalt tack coat or joint adhesive gave the most durable joint in the NCAT field study conducted in Colorado and Pennsylvania. This is despite the fact that the joint density in those test sections was not among the highest.

The Utah department of Transportation (UDOT) specified and used the rubberized asphalt tack coat or joint adhesive extensively between 1985 and 1993 (31). Over four million linear feet of cold longitudinal construction joint were tack coated with this material during this time period. Special provisions (32, 33) on Bituminous Joint Tack were used on numerous projects throughout the state. Although the Utah DOT continued the use of rubberized asphalt tack coat for eight years (1985 to 1993) with apparent success, its use started to decline in 1993 after the DOT shifted its emphasis from procedural requirements (using the special provisions) to density penalties introduced in 1992 (31).

The Massachusetts Department of Transportation and the Maine Turnpike have used this method successfully since 1989. The Massachusetts DOT specified asphalt-rubber tack material conforming to Federal Specification Number SS-S-1401 (34). The Maine Turnpike specified the use of asphalt-rubber tack material conforming to Federal Specification Number SS-S-1401 C (35). The rubberized asphalt tack coat material has also been accepted for use in other states such as New Jersey, Michigan, Indiana, and Ohio (on Turnpike) and has been used on some warranty projects.

One pound (0.45 kg) of the rubberized asphalt material covers about 8 running feet (2.4 m) of 1/8" thick x 2" wide (3x51 mm) joint tacking band. The installed cost is approximately $0.40/foot or about $2000/mile.

The rubberized asphalt tack coat has also been used successfully on a notched wedge joint (Figure 16), which is discussed next. This combination should result in a very durable longitudinal joint.

The New York Department of Transportation (36) constructed three field projects in 2004 using three different joint adhesives on notched wedge joint. Besides the joint adhesive from

Crafco, Inc. as discussed earlier two additional joint adhesives were used experimentally: Joint Adhesive from Deery Corp. and Joint Adhesive (called eXtruded Joint Bond) from Asphalt Materials, Inc. The application of all three products did not present any problem (such as pickup by roller) during paving. No long-term performance data is available for these three projects at the present time.

The Maine Department of Transportation (37) has evaluated two rubberized asphalt joint sealers and a high-float medium-setting (HFMS) emulsion to tack the longitudinal joint. After about five years in service, all three joint sealers have performed well. A permeameter manufactured by Worcester Polytechnic Institute was used on all three joint types. No water loss, a key gauge in permeability testing was recorded on any test section.

Figure 16. Close up of rubberized asphalt tack coat application on a notched wedge joint

Notched Wedge Joint

Experiments with wedge (or taper) longitudinal joints were begun by the New Jersey Department of Transportation (NJDOT) in 1982 and involved a modification of the Arizona procedure. Unlike Arizona, which had used 1:6 taper, the NJDOT adopted a 1:3 taper for its so-called New Jersey wedge joint (26). Infrared heating of the lower cold wedge is required when the overlapping upper wedge of the adjacent lane is placed and compacted. Typically, four ribbon burners in a stainless steel box are mounted to the paver. Mixed performance results have been obtained from the use of the New Jersey wedge joint. Primarily, two problems have been experienced. Since there is no vertical notch at the top of the edge, the aggregate in the mix in the overlapping wedge cannot be accommodated and gets crushed under rollers resulting in raveling in a narrow strip right along the longitudinal joint. This raveling phenomenon was also observed in the New Jersey wedge test section in Pennsylvania (18). Second, the use of infrared heating has generally been found to be inconsistent and mostly ineffective. Either the bottom wedge is not heated to the desired temperature or it is heated to excessive temperatures (especially when the paver slows down or stops) exposing the asphalt binder to detrimental oxidation.

The Michigan Department of Transportation started the use of a "notched" wedge joint in the late 1980s. The unconfined edge of the first paved lane has a vertical notch at the edge generally ranging from ½ inch (13 mm) to 3/4 inch (19 mm) in height depending upon the nominal maximum aggregate size (NMAS) of the HMA mixture. Generally, a vertical notch of about ½ inch (13 mm) height is considered adequate for most surface course mixtures. This height has given excellent results in NCAT and Wisconsin studies, and in Michigan. The height of the notch can be increased in case of binder and base course mixtures, which have a larger NMAS. Figure 17 shows a schematic of a notched wedge joint. At the bottom of the vertical notch, the wedge is provided a taper of 1:12 (vertical: horizontal). To avoid feathering the taper to zero height, which may cause dragging of the HMA, it is recommended to end the taper with a minimal height such as 3/8 inch (9.5 mm) to avoid dragging of the material.

Usually a loaded wheel, which is attached to the paver, is used to compact the taper (Figures 18 and 19). Typically, the roller weighs 100 to 200 lbs (45 to 91 kg) and is approximately 14 inches (356 mm) wide by 12 inches (305 mm) in diameter. The overlap layer

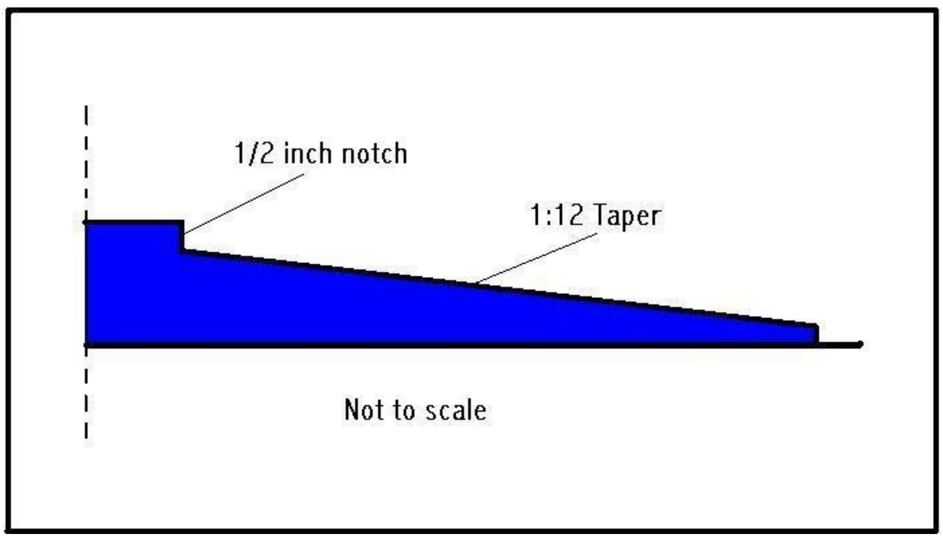

Figure 17. Schematic of notched wedge joint

of the adjacent paving lane is required to be placed and compacted within 24 hours unless delayed by inclement weather. The vertical notch and taper are tack coated with asphalt binder prior to placing the overlap wedge. Rubberized asphalt tack (joint adhesive) coat has also been used successfully on the notched wedge joint, as discussed earlier. This should combine the benefits of both joint construction techniques. The rubberized asphalt tack coat need not be applied on the entire taper. It is considered adequate to apply it on the vertical notch and the top 3-4 inches (76-102 mm) wide band of the taper.

Figure 18. Small roller attached to paver compacts the taper of notched wedge joint

Figure 19. View of finished notched wedge joint

The notched wedge joint can be formed by using a homemade sloping steel plate attached to the inside corner of the paver screed extension. However, commercial devices are now available which can be attached to the screed to form the notched wedge joint.

The notched wedge joint does not always work well for thinner HMA lifts. Ideally, it gives the best results with a minimum lift thickness of 1½ to 2 inches (37 to 51 mm). On the other hand, excessive thick lifts produce a long taper, which may not be desirable. The length of the taper is generally restricted to 12 inches (305 mm). Whereas the small roller attached to the paver is ideal for wearing courses, a pneumatic tired roller can be used for base and leveling courses (the vertical notch, for the most part, is lost) (38).

The Michigan DOT specification (39) requires that the top course taper shall overlap and slope in the opposite direction of the lower course taper.

The notched wedge joint has the following advantages:

- **Durability**. Experience in Michigan (40), Wisconsin (28), and results from NCAT longitudinal joint study (15, 16, 17) have shown that the notched wedge joint has very good potential of obtaining a durable longitudinal joint. This is probably due to the following factors.

1. According to the NCAT study and the Kentucky study (27) reasonably high densities were obtained at the notched wedge joint. First, the wedge portion of the joint in the first paved lane provides some lateral support (confinement) during compaction and a greater density is obtained at the edge. Second, the hot lane is laid over the notched wedge joint rather than forced up against it as in conventional joint construction. Third, the vertical notch in the first lane provides positive confinement, which aids in achieving high density for the

second lane at the joint.

The notched wedge joint was compared to conventional longitudinal joint construction techniques on projects in five states (Alabama, Colorado, Indiana, Maryland and Wisconsin) in another NCAT field study (41). The evaluation consisted of comparing the in-place density obtained through cores at five locations across the longitudinal joint of the HMA pavement (at the center line, 6 inches (150 mm), and 18 inches (450 mm) on either side of the center line). The results of the study indicated that the notched wedge joint could be used successfully to increase the in-place density at the longitudinal joint.

2. Because the 1:12 taper in the bottom wedge is relatively thin, the hot overlapping wedge heats it up effectively to achieve further compaction when the adjacent lane is compacted. Use of any other roller besides the paver mounted small roller is not warranted because it can be detrimental to the configuration of the joint, especially the vertical notch and thus will be counter-productive. In fact, the Wisconsin study (28) showed that the paver-mounted roller gave the highest density at the joint.

3. Typically, a longitudinal crack develops at a conventional joint. The long taper probably provides increased resistance at the interface of the two overlapping wedges for the crack to propagate along a longer path. In addition, the intrusion of water into the pavement system is also impeded because of the longer path. This was confirmed in the Kentucky study (27), which showed significantly reduced permeability at

the notched wedge joint.

- **Increased Safety.** The 1:12 tapered edge eliminates the steep drop-off thus providing increased safety to the motoring public on highways, who can traverse from one lane to another with a minimal amount of problem.
- **Increased Productivity.** The use of notched wedge joint allows continuous paving of a lane for an entire day without the typical specification requirement that all lanes be resurfaced to within one load of the same point-of-ending at the completion of each day’s paving operations (39). This eliminates the need for contractors to switch traffic and backup their paving equipment for paving the adjacent lane. The result is less down time and more paving time, which may increase production by 20 to 30 percent. In addition, the number of transverse construction joints is minimized resulting in a smoother ride.
- **Improved Alignment for Paving Adjacent Lane.** The presence of the vertical notch at the edge of the first paved lane facilitates better alignment for the placement of the matching adjacent lane.

According to experience from military airfields (see Appendix A) the wedge joint works better than other methods if it is done properly and it saves money by not having to cut back, clean and remove the cut asphalt mix.

Cutting Wheel

The cutting wheel technique involves cutting at least 1½ - 2 inches (38-51 mm) of the unconfined, low-density edge of the first paved lane after compaction, while the mix is plastic. As mentioned earlier, it is not uncommon to cut back as much as 6 inches (150 mm) of the unconfined edge on airfield pavements to meet FAA's stringent joint density requirements. The cutting wheel is usually 10 inches (254 mm) in diameter with the cutting angle about 10 degrees from the vertical towards the mat to be cut and about 45 degrees on the open side to push the trimmings away (Figure 20). The cutting wheel can be mounted on an intermediate roller or a motor grader (Figure 21). The HMA trimmings can be collected and recycled. A reasonably vertical face at the edge is obtained by this process (Figure 22), which is then tack coated before placing the abutting HMA. It is important to restrict the overlap to about ½ inch (13 mm) while placing the adjacent lane.

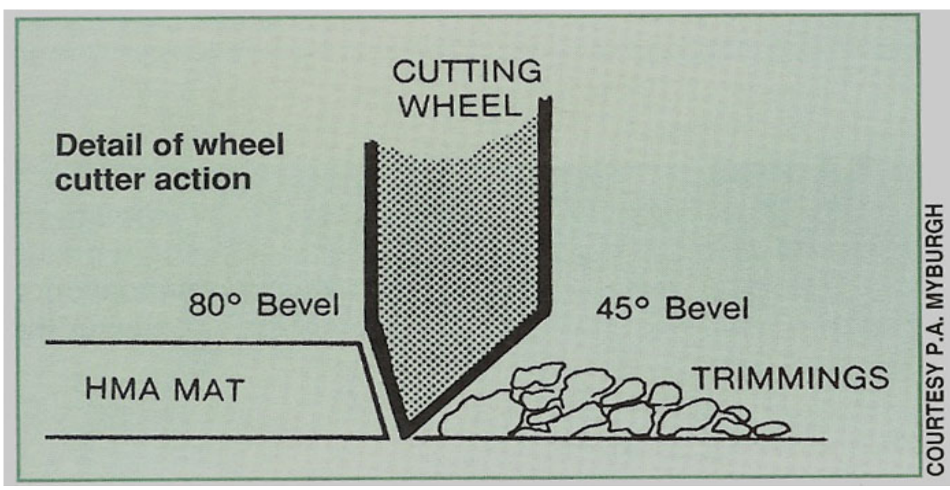

Figure 20. Schematic of cutting wheel

Figure 21. Cutting wheel mounted on a motor grader

Figure 22. View of the edge after the use of cutting wheel

The cutting wheel has largely been used in case of airport runways where the agency has a stringent requirement of obtaining a specified minimum density at the joint. For example, a 3-inch (75-mm) strip was removed with a cutting wheel by a contractor to meet and exceed joint density PWL (percent within limits) specifications in case of an important airport project in Florida (42).

It is important to remove all low-density material at the edge of the first paved lane. Removal of the 1:1 slope shoe only improved the short-term performance of the longitudinal joint but did not produce a durable joint in a Wisconsin study (43).

The use of cutting wheel technique does improve the density at the joint and according to the NCAT study (17, 18) has a good potential of obtaining a satisfactory longitudinal joint. However, this technique has the following disadvantages:

- Unnecessary extra costs are involved in paving operations and discarding the trimmings. It may be difficult to place asphalt mix at the bottom (corner) of the vertical cut face of the unconfined edge.
- The technique may not give consistent performance results (17, 18, 44) because of its dependency on the skill of the cutting wheel operator (who must cut straight without wavering) and the paver operator (who must closely match the cut line with minimal overlap).
- According to experience from military airfields (see Appendix A), the cutback method creates a smooth vertical face, which is more likely to crack.

The use of cutting wheel is highly prevalent in airfield construction because it is often required in the specifications.

Edge Restraining Device

The edge restraining (or edge compacting) device has been used in some parts of Germany and France. It consists of a hydraulically powered wheel, which rolls alongside the compactors drum simultaneously pinching the unconfined edge of the first lane towards the drum (Figure 23). The device keeps the HMA at the edge from pushing out as the roller compacts the HMA during the first pass (Figures 24, 25, and 26). This technique is believed to increase the density of the unconfined edge and, therefore, improves the overall density at the joint.

The edge-restraining wheel is approximately 3 inches (75 mm) wide and beveled up toward the roller at an approximate 45-degree angle. The roller with the edge restraining wheel attachment is operated in static mode while the device is being used. When the edge-restraining wheel is lowered, the edge of the steel wheel roller is approximately 6 inches (150 mm) away (30).

On Pennsylvania Project in NCAT study, two passes were made with this device lowered. Once completed the longitudinal joint face of the first lane (cold side) had an approximate 45 degree compacted slope. The original breakdown roller then finished the rest of the lane in vibratory mode including the six inches, which were not rolled when the edge-restraining wheel was lowered (30).

According to the NCAT study (17, 18) the edge-restraining device has a good potential of obtaining a satisfactory longitudinal joint. However, similar to the cutting wheel, this technique has the following disadvantages:

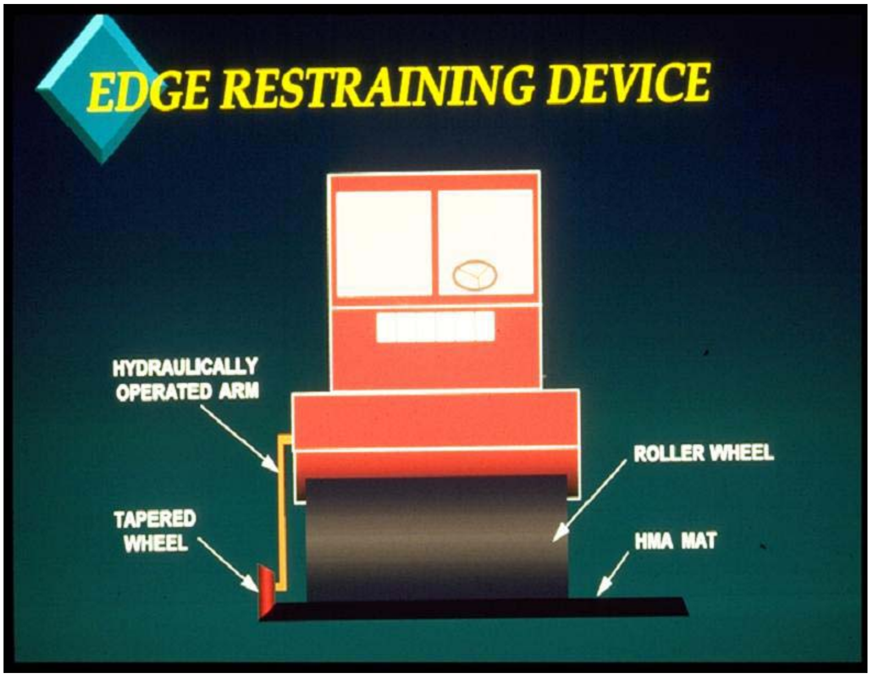

Figure 23. Schematic of edge restraining device

Figure 24. Edge restraining device being used

Figure 25. Close up of edge restraining device

Figure 26. View of the edge compacted with the edge restraining device

- Extra costs are involved in paving operations.
- This technique may not give consistent performance results because of its dependency on the skill of the roller operator who must steer so that the restraining device is consistently in contact with the unconfined edge.
- Varying mat thickness may present problems in using the restraining device effectively. If the mat thickness increases, the edge restraining wheel may not be sufficiently wide to confine the entire edge slope.

Joint Maker

Joint maker is an automated joint construction device, which was developed by TransTech Systems, Inc. of Latham, New York in the early 1990s. It is attached to the side of the screed at the corner during paving (Figures 27 and 28). The joint maker is claimed to force extra material at the joint through an extrusion process prior to screed with the objective of achieving some pre-compaction.

The primary component of the joint maker is the oval-shaped “compaction shoe” at the bottom (Figure 27). The level of the heel of the compaction shoe is kept slightly above the bottom of the screed; the height is based on the mat thickness. For example, a height of 3/4 inch (19 mm) is used for mat thickness of 1-2 inches (25-51 mm) according to the joint maker operating instructions. The height can be changed through a mat depth-adjusting bolt, which is on the vertical side of the device. The angle of attack of the compaction shoe also needs to be changed depending on the mat thickness. This adjustment provides for increasing or decreasing

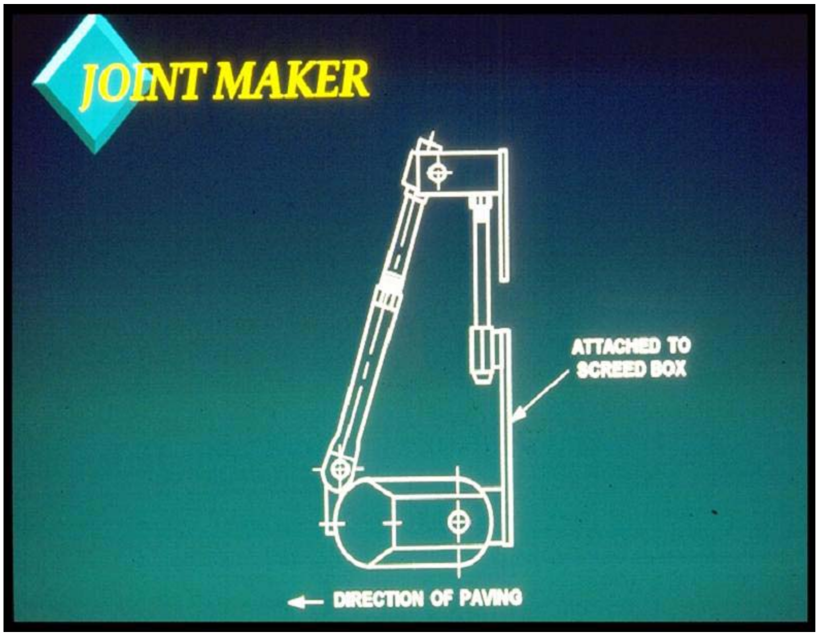

Figure 27. Schematic of joint maker

Figure 28. Joint maker attached to the side of the screed at corner

the density at the edge of the mat being paved. For example, a 20-degree angle is recommended for mat thickness of 1-2 inches (25-51 mm). The angle of attack is changed by the density adjustment arm, which is on the slanted part of the joint maker. Since the compaction shoe is about 4 inches (100 mm) wide, the joint maker is designed to increase density in a 4 inch-wide (100 mm-wide) strip at the edge.

The evaluation of two HMA construction projects in Albany Count Airport showed that generally there was no statistically significant difference between the joint maker technique and the conventional manual luted joint technique (1). The performance of longitudinal joint constructed with the joint maker in the NCAT field study was also less than expected (17, 18). The Kentucky study (27) also showed that joint density obtained with the joint maker was not adequate. It appears that the height of the "compaction shoe" in reference to the bottom of the screed and its angle of attack to obtain optimum density at the edge of the mat is mix specific in terms of mix's plasticity and stiffness. Field studies in Maine (44) have indicated that the joint maker had difficulty pre-compacting relatively coarser Superpave mixtures compared to Hveem designed Grade "C" fine mixtures. This means both height and angle of attack may have to be established based on trial and error at the beginning of each paving project, which can be rather tedious.

Infrared Joint Heating System

Infrared heating of the unconfined edge of the first paved lane has been used since the early 1980s in conjunction with the New Jersey wedge joint as mentioned earlier. The infrared heater was mounted on the paver to heat the New Jersey wedge when placing the adjacent lane. An independent infrared joint heating system has now been developed and used in field trials since 1999 (27, 45, 46). The objective of this system is to obtain a hot joint during conventional longitudinal joint construction.

The infrared joint heating system consists of two or three pre-heaters and one paver-mounted heater. The pre-heaters, which are connected in series, are towed with a small tractor over the joint approximately 100 feet (30 m) ahead of the paver (Figure 29). Propane cylinders are used to feed the infrared heaters. Both the pre-heaters and paver-mounted heaters are placed about 2-3 inches (51-76 mm) above the pavement surface and straddle the joint. The infrared heaters usually target a final surface temperature of 340F (171C) behind the paver-mounted heater. The target surface temperature can be achieved by changing the number of pre-heaters, the distance between pre-heaters and paver, and the height of the heaters above the pavement surface. All these variables need to be adjusted taking into account prevailing ambient conditions such as air temperature and wind velocity. The pre-heaters run continuously as long as the towing vehicle is operated at a speed high enough to prevent overheating the HMA at the joint. If the towing vehicle slows down too much, the pre-heater is designed to shut down automatically. The paver-mounted heater (Figure 30) has also been designed to shut down once the HMA at the joint exceeds a specified temperature.

Field trials of the infrared joint heating system have been conducted in New Hampshire (45, 46) and Kentucky (27) during 1999-2004 to evaluate the joint density results for hot joint construction using this system. Some improvements in the density of the joint have been reported. However, long-term performance data is not yet available. Recently, infrared joint heaters have been used on apron and taxiway of an airfield in New England and on runway of an airfield in Mason City, Iowa. Details are given in Appendix A.

The following observations have been reported in using this system (45, 46):

- Infrared heaters increase the temperature of the HMA at the joint but the desired

Figure 29. Infrared preheaters are towed with a small tractor ahead of the paver

Figure 30. Infrared heater mounted on the paver

- compaction temperature is only reached at the surface. This system needs to be developed further to improve the extent of heat penetration.
- Normally, traffic is maintained on the lane adjacent to the paving lane. Since the tractor and pre-heaters travel over the joints ahead of the pavers, there are safety concerns related to the proximity of the passing highway traffic to the equipment. Obviously, this is not of much concern on airfield pavements.
- Additional manpower is required in using the infrared joint heating equipment, which includes an operator for the pre-heater tow tractor, a person to monitor pavement temperatures, and an additional traffic control person.
- Permeameter testing on the binder and surface layers indicated that the control section centerline joint is more permeable, on average, than the infrared heated test section but not statistically significant.
- Field cracking survey conducted one year after the binder course showed that 93 percent of the control section joint had cracked while only 17 percent of the infrared heater test section was cracked. After one year, the joint in the surface course of the control section showed 36 percent cracking whereas the test section showed about 2 percent cracking. Annual monitoring has been planned to be continued. As per experience in other field research projects, performance rankings can change significantly from year to year.

HMA Joint Tape

HMA joint tape, which consists of polymerized asphalt, mineral filler and cellulose, has been used in Europe since the early 1980s. Asphalt Materials, Inc. introduced the European HMA joint tape in the U.S. in 1997 under the brand name of Tbond (47). The tape comes in 33 ft (10 meter) rolls with different cross-sectional sizes such as 1.6 inch (40 mm) wide by 0.4 inch

(10 mm) thick. After some experience, a three-person crew is generally adequate to install the joint tape onto the face of the cold lane. The tape is unrolled and attached to the vertical face with occasional tacks and/or hammering the tape onto the HMA (Figure 31). The paper backing from the side facing the fresh hot mix is then removed (48). When the tape is placed, it should stick above the pavement ¼ inch (6 mm) or so. When hot mix is placed in the adjacent lane and compacted, the heat and pressure melts the tape into the joint. The compaction process flattens the top ¼ inch (6 mm) of the tape sticking out above the surface forming a seam over the joint and creating a "T." It is recommended to install the joint tape just one or two truckloads ahead of the paver, if possible. Trucks should not be allowed to cross it because they pick it up.

The total cost of installing TBond tape in 1999 has been reported (48) to be about $0.80/ linear ft ($0.65 for the tape and $0.15 for the labor).

Figure 31. HMA joint tape being applied to a notched wedge joint

The HMA joint tape is more labor intensive compared to rubberized asphalt tack coat. Asphalt Materials, Inc. has recently developed a new extrudable tape, which is claimed to be less labor intensive. Similar to Crafco's rubberized asphalt tack coat (joint adhesive), it is melted in a Crafco double-jacketed boiler unit and extruded on site. This product was mentioned earlier under Rubberized Asphalt Tack Coat earlier.

NEW DEVELOPMENTS IN PAVING EQUIPMENT

Both conventional and special joint construction techniques discussed earlier require care to detail and consistency to ensure correct joint construction. Highway paver manufacturers, who are members of CIMA, formed a cooperative Longitudinal Joint Construction Committee in 1996. The objective of this committee was to explore improvements to existing paving equipment to ensure excellent joint construction through mechanical means (49). The following areas have been explored.

Paver Screed

If uniform density is to be assured throughout the width of the mat including its edges, the mix cannot be allowed to spread out. To prevent the spreading action of HMA at the edges, the screed of the pavers must be equipped with an end gate extending to the back of the screed. This arrangement will assure that the HMA is contained while initial compaction takes place during lay down by the paver. Field trials have shown this modification improves the edge considerably and should improve its density (49).

Extended end gates were common many years ago but they were discontinued due to the following reasons:

(a) To make the end gates easier to raise and lower for accessibility to HMA for handwork, and

(b) Complications resulting from the use of hydraulic strike-offs in front of the screed. Strike-offs are used to extend the width of the screed primarily for placing shoulders and turnouts.

The Committee has recommended that end gates extending to the trailing edge of the screed should be used on the centerline joint. If the paver is equipped with hydraulic strike-offs, they should only be used on the side away from the centerline.

Joint Compactors

A screed extension has been developed that would achieve compaction within 92 to 94 percent of laboratory density on the outside 12 inches (305 mm) of the screed area using a vibratory joint compactor. The compactor unit is attached to the screed and the bottom screed plate is isolated from the main screed extension. A hydraulic vibrator is mounted directly to the joint compactor’s screed plate (50). Preliminary tests have indicated that a vertical joint with compaction of 94 to 95 percent of laboratory density can be achieved with the proposed joint compactor.

PERMEABILITY OF JOINTS

Similar to density, permeability of the longitudinal joint is also a measure of quality, as a less permeable joint will not allow the intrusion of water and foreign matter that lead to some premature distresses. Studies (51, 52, 53, 54, 55) have shown a correlation between the field permeability and in-place density of HMA mixtures.

The use of permeability is needed in addition to the use of density because of three reasons. First, several studies have established the fact the permeability (of air and water) in

HMA is more directly related to durability, in terms of resistance against moisture related damage and premature oxidation and cracking (56, 57, 58). Secondly, it is difficult to obtain representative cores (for determination of density) from the “joint”, or to use a nuclear gage to determine the density at the “joint”. Lastly, the use of a permeameters would provide a “non-destructive” technique to get quick results, without the need for taking cores.

The potential exists for the use of a field permeameter as a tool to evaluate the quality of longitudinal joints. Developing test equipment and establishing a test procedure, testing frequency and acceptance criteria for using a field permeameter to evaluate the quality of longitudinal joints in HMA pavements will allow agencies to better estimate the overall pavement performance and more accurately plan maintenance and rehabilitation strategies, saving valuable resources and improving serviceability to the traveling public.

A literature review on the use of permeameter for longitudinal joints revealed only two references. Pretorius et al (59) have described the Marvil test for determination of quality of joint construction in airports. The Marvil test is essentially a flow test that is used in South Africa to determine the water permeability of asphalt and base course layers. The equipment consists of a circular weight and an acrylic tube with volume markings. A pressure head of 380 mm is used to measure flow of water through a 175 mm diameter circular area. Pretorius et al (59) have reported that untreated joints had permeabilities 10 times greater than the adjacent mat; permeabilities values of 30 l/h to 250 l/h have been cited. In the same paper, the authors mention a decreased permeability for joints with improved construction techniques (below 3l/h).

In a current study for the New England state departments of transportation, Mallick and Daniel (60) have developed a simple and effective joint permeameter (Figure 32) to evaluate the permeability of longitudinal joints, relative to the permeability of the adjacent mat. The permeameter consists of three standpipes, which can be used for measuring the flow of water through a joint and through the mat on either side of the joint. Results from testing on several projects show that this permeameter can be used successfully to determine permeability of joints.

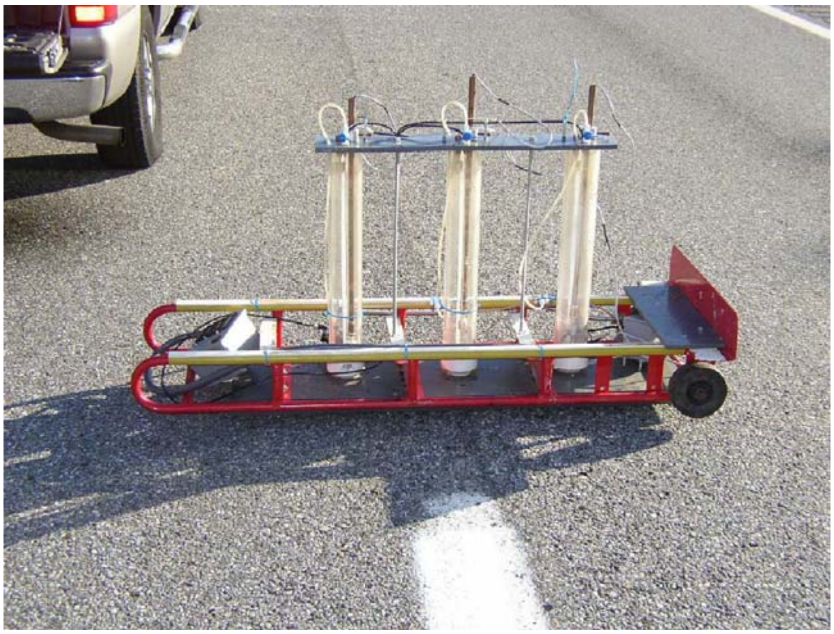

Figure 32. Permeability apparatus manufactured by WPI used in Maine

The testing performed in this study shows that joints have significantly higher permeability compared to adjacent mats, different types of joints have different permeabilities and that treatment of joints with sealers and using improved joint construction techniques such as joint heater can reduce the permeability significantly.

More research is needed to fine tune the permeameter, obtain extensive field permeability data on joints, and establish permeability criteria for ensuring durable longitudinal joints.

JOINT DENSITY SPECIFICATIONS

Burati and Elzoghbi (8) evaluated the 1984 construction of two FAA Eastern Region airports in Moristown, New Jersey and Rochester, New York. Rochester airport was constructed without pay adjustment provision in its specification for joint construction. The specifications for the Morristown airport included pay adjustments for joint density. Joint density variability was significantly higher than the adjacent mat density variability at Rochester but not at Morristown. Both projects were constructed with density differences between joint and mat areas of 6 to 7 lbs per cu ft (96 to 112 kg per cu m). The average density ratio (joint/mat) ranged from 95 to 96 percent.

The Burati-Elzoghby study was instrumental in the FAA's use of joint density in acceptance of asphalt airfield pavement construction. The P-401 Specification dated July 7, 1992 included basic acceptance criteria developed in their study.

According to a study in 1991 (61) increased emphasis on joint density through a proper HMA specification with financial incentives does produce improved test results. Joint density was specified at 96.5 percent minimum of Marshall laboratory density on several airfield HMA projects. On projects without any financial incentive 99.7 percent of the sampled joints did not meet the specification requirement. Conversely, on projects with reduced-pay specifications 66.2 percent of sampled joints did not meet the specification requirement. This indicated a significant overall improvement in joint density.

The 10-year (1992-2002) NCAT field study on longitudinal joints (17, 18) concluded the following pertaining to joint density as mentioned earlier:

Joints with high densities generally showed better performance than those with relatively low densities. Therefore, the user agencies should specify minimum acceptable compaction levels to be achieved at the joint. It is recommended that the density at the joint be not more than two percent lower than the density specified in the lanes away from the joint. Densities right on the visible joint line need to be determined by taking cores. It is not possible to use nuclear density gauge because of seating problem right on the joint.

Sebaaly et al (62) evaluated various joint geometrics and rolling techniques in Nevada during 2004 and 2005 with an objective to develop a joint density specification for HMA projects. Based on the statistical analysis of extensive field data they recommended that the Nevada DOT implement the following joint density specification:

The density at the joint should be a maximum of 2 percent less than the corresponding mat density and the density at the joint should be a minimum of 90 percent of the theoretical maximum density (TMD).

The above specification requirement is in accordance with NCAT study's recommendations. Sebaaly et al also concluded that all three joint geometrics studied by them: natural slope, cut edge with rubberized asphalt tack coat, and tapered (3:1) joint will meet the recommended joint density specification.

Kandhal (63) asked the state highway agencies in 2004 as to what steps they have taken in recent years for obtaining a durable longitudinal joint. The following response were received from some states:

Connecticut

The Connecticut DOT has used a joint density specification for the last 10 years and it includes a pay factor. The DOT requires that the density on the "hot" side of the joint be no less than 90 percent of the TMD compared to 92 percent for the mat away from the joint. New specifications released in 2001 (Form 816-2004) apply a weighted correction that puts emphasis on joint density as follows: Final Density Adjustment = 40 % (Mat Density) + 60 % (Joint Density).

Kansas

The Kansas DOT implemented new joint density criteria in October 2004. The criteria is: The interior mat density minus joint density (taken at 8 inches from the joint) should be equal to or less than 3.0 pounds per cubic foot (48 kg per cu m) or the joint density should be greater than or equal to 90 percent of the theoretical maximum density (TMD). If either condition is met, the joint density passes.

Kentucky

After extensive research Kentucky Transportation Cabinet implemented the following criteria for joint density in 2004. A minimum density value of 89.0 percent of the TMD is specified for roadway cores taken within 3.0 +/- 0.5 inches (76 +/- 13 mm) of the longitudinal joint. This specification is 3 percent less than the corresponding requirement for density cores obtained from the mat away from the longitudinal joint.

Missouri

The Missouri DOT allows a 2 percent lower density on the “cold” side (unconfined side) of the joint compared to the mat away from the joint. The “hot” side (confined side) must meet density requirement similar to the mat away from the longitudinal joint.

Ontario, Canada

The Ontario Ministry of Transportation has developed a lane-edge compaction specification based on cores taken at the confined and unconfined edges of each lane for contracts of at least 15,000 tonnes of hot mix. Sublots range from 500 to 1000 tonnes depending on the size of the contract. Price adjustments are based on percent within limits (PWL) criteria using lower limits, which range from 89 percent to 90 percent of the theoretical maximum density depending upon the mix type. The price adjustments are as follows:

• More than 95 percent PWL Bonus up to 1 percent

• 90 to 95 percent PWL Full pay

• Less than 90 percent PWL Price reduction

Obviously, the state highway agencies are concerned with the durability of longitudinal joints and more and more are seriously considering specifying a minimum level of density at or near the joint similar to what the FAA has done over many years.

The most recent Federal Aviation Administration's Advisory Circular (AC) 150/5370-10B Item P-401 Plant Mix Bituminous Pavements dated April 25, 2005 has the following joint density requirements (64).

Section 401.5b(2) on joint density specifies obtaining core centered on the joint and a minimum core diameter of 5 inches. This is in accord with the conclusions of the NCAT study.

The minimum levels of compaction expressed as a percentage of average bulk specific gravity of compacted laboratory specimens have been specified in Table 5 as follows:

Surface course (mat)	96.3%
Base course (mat)	95.5%
Joint	93.3%

A complete review of P-401 joint density specification and recommendations for revising it are given in Chapter 4.

The latest Unified Facilities Guide Specifications (65) dated April 2006 has the following joint density requirements. Unlike the FAA P-401 Specification, this specification specifies the minimum joint density based on the theoretical maximum density (TMD) rather than the density of the laboratory compacted Marshall specimen. Also, this specification requires a minimum average joint density of 92.5 percent based on the TMD to get 100 percent pay. A complete review of the Unified Facilities Guide Specification in terms of joint density is also given in Chapter 4.

The preceding literature review did not reveal any major airfield research project involving different longitudinal joint construction techniques. However, the experience gained on highway research projects should be considered for application on airfield pavements.

CHAPTER 3. EXPERIENCE OF AIRFIELD ENGINEERS

In order to develop best practices of longitudinal joint construction it was prudent to consider the experience of airfield engineers. Therefore, it was decided to collect and synthesize information on different types of longitudinal joints in airfields of different types, in different geographical locations in the US.

Methodology of Collecting and Synthesizing Information

Airports were selected from different FAA regions so as to cover all four Long Term Pavement Performance (LTPP) climatic regions – wet-no freeze, wet-freeze, dry-no freeze and dry-freeze. Both major airports and smaller general aviation airports were targeted in the selected FAA regions. Lists of FAA contacts in the regions and airfield engineers in the selected airports were prepared. Details are given in Appendix A. Contacts were made with the airfield engineers by phone, letters, and e-mails to gather information on longitudinal joint construction. Additional inputs were obtained from airfield consultants, military, contractors, material suppliers, and equipment manufacturers.

Summary of Information Gathered

Unfortunately, there is little information available from airports on different types of longitudinal joints as mentioned in the literature review (Chapter 2). Mostly, the prevalent construction practice is to cut back the cold or warm joint and tack coat the cut face with asphalt binder before placing the adjacent lane. This practice is either specified in the contract or contractors use it in order to meet agency's stringent requirements for density at the joint. Recently, some other techniques such as tapered wedge joint and infrared heating of joint have been attempted on some airfield pavements.

However, conversations and correspondence with some airfield engineers have brought out various other factors related to longitudinal joints. Such factors include: mix information, construction practices, joint density specifications, performance and maintenance of longitudinal joints. The following is a summary of the salient points concerning longitudinal joints, which were made by various airfield engineers. Their detailed inputs and interviews are contained in Appendix A.

1. Since the longitudinal joint is a weak point in an airfield pavement, a crack usually develops at the longitudinal joint due to shrinkage during cold weather. The incidence and extent of cracking problem is severe in cold climatic regions of the US compared to the hot climatic regions. Cracks are more likely to develop easily on a saw-cut vertical joint compared to a tapered or wedge joint. Figure 1 shows a crack, which appeared on a longitudinal joint on a runway in Mt. Home, AFB, Idaho. This joint was constructed in 2002 with the cutback procedure. This photograph was taken in 2007, five years later.

2. Typical distresses such as cracking and raveling in longitudinal joints happen in about four to five years after construction. Initially a crack occurs along the joint, which leads to secondary cracks. Generally, such cracks are sealed promptly by the maintenance crew before they become a problem. Hot poured rubberized

Figure 33. Low severity cracking in joints (Mt. Home AFB, Idaho)

asphalt is usually used for crack sealing. Raveled areas adjacent to joints are patched before they pose Foreign Object Damage (FOD).

3. There have been no additional concerns/problems with joints when polymer modified asphalt binders such as PG 76-22 were used in lieu of conventional binders.

4. Overdoing the luting operation can potentially cause segregation at or near longitudinal joint.

5. Paving in echelon may not always be practical since enough quantity of HMA may not be available to feed two pavers.

6. According to one agency, rolling from the cold side with a 12-inch (300-mm) overlap on the hot side provides a smoother transition between mats without any bump.

7. The skill and experience of screed operator, raker, and roller operator are probably the most vital component making a good longitudinal joint.

8. One agency requires the use of two pavers working in echelon in center sections of runways and taxiways. A material tranfer vehicle (MTV) is also required for large airport projects.

9. Performance related specifications especially those related to joint density have helped in improving the quality of joints. Possibility of penalty due to low density at joint has forced contractors to use techniques such as cut back of cold joints to improve joint density.

10. Some agencies have reduced the nominal maximum aggregate size from ¾ inch (19 mm) to ½ inch (12.5 mm) to minimize segregation at joint as well as in the mat away from the joint.

11. One agency has a requirement of using a 25-foot wide paver.

12. Some agencies do not require cutting back, application of tack coat, and checking of density for the bottom lift joints.

13. Some agencies require 4 samples per lot for testing joint density. Cores are centered directly over the joint.

14. One agency requires the same compaction (minimum 98 percent of the laboratory density) for joint and the mat away from the joint.

15. Contractors favor the tapered method, if done properly. It is also very economical compared to cutting back procedure. Figures 2 through 7 show a typical saw cutting procedure to remove the low density portion of the unconfined edge of the compacted lane and to obtain a clean vertical face. It is quite obvious that this process is labor intensive and expensive as compared to notched wedge or tapered joint. The experience with the performance of the cutting back procedure is quite similar on both highway and airfield pavements. Whereas this procedure is better than conventional procedure, cracking does takes place after a few years. Many asphalt technologists believe it is probably due to the smooth vertical face at the joint.

16. The use of tack coats, especially those with materials such as rubberized asphalt, which can enhance bond, have merit.

Figure 34. Sawing operations

Figure 35. Removing approximately 200 mm of unconfined edge

Figure 36. Removing cut edge

Figure 37. Power washing cut edge joint

Figure 38. Clean washed cut edge

Figure 39. Cleaning joint prior to tack application

17. Longitudinal joints constructed with infrared joint heating system, if done properly, generally produce high density at the joint. This technique has been tried on some airfield pavements.

18. According to a contractor's experience it is important to compact the longitudinal joint very promptly with a heavy breakdown roller; provide enough material at the joint; do minimal raking; and compact the joint properly and adequately.

19. The use of different techniques in constructing longitudinal joints on airfield pavements has resulted in different results in most cases. The effect of switching from one technique to another on the quality of the construction joints is complex and is dependent on many factors which include contractor's experience with a specific technique, available equipment, and climatic conditions.

CHAPTER 4. EVALUATION OF EXISTING FAA AND DOD SPECIFICATIONS AND RECOMMENDATIONS

The objective of this task is to conduct a critical review of the existing FAA (AC 150/5370-10B) Item P-401 Specifications dated 4/25/2005 and DOD (Unified Facilities Guide Specification 32 12 15 dated April 2006, which replaced UFGS-02749 of June 2005). Then, together with the results of the literature review (Chapter 2) and experience of airfield engineers (Chapter 3) practical recommendations were to be developed for improving the FAA Specifications, which would lead to the capability of constructing superior longitudinal joints, ability to consider multiple options to produce superior quality joints, and to ensure quality control and acceptance requirements for joint construction.

Review of FAA P-401 Specifications (AC 150/5370-10B) dated 4/25/2005

Review of the FAA P-401 Specifications for Plant Mix Bituminous Pavement in view of recent research and technology related to longitudinal joint construction is as follows.

Section 401-4.12 on placement of hot mix asphalt (HMA) specifies that any joint exposed for more than 4 hours or whose surface temperature has cooled to less than 160° F shall be cut back to expose a clean, sound surface and tack coated.

The preceding specification, therefore, allows the use of cutting wheel only. Research conducted by the National Center for Asphalt Technology (NCAT) has indicated that the cutting wheel has a good potential of obtaining a durable joint. However, its success is dependent upon the skill of the cutting wheel operator who must cut the pavement edge in an unwavering line and the skill of the paver operator who must match the cut line if it is wavering. This usually results in inconsistent performance of longitudinal joints made with a cutting wheel. Therefore, other better techniques of constructing longitudinal joints such as notched wedge joint and/or rubberized asphalt tack coat (joint adhesive) recommended in Chapter 5 must also be permitted to be used by the contractors along with the minimum joint density requirement.

Section 401.5b(2) on joint density specifies obtaining cores centered on the joint and a minimum core diameter of 5 inches. It is recommended to use a minimum core diameter of about 6 inches, which is quite common in the paving industry and has been used successfully in most longitudinal joint research studies. Both the Unified Facilities Guide Specifications 32 12 15 of April 2006 and the FAA Engineering Brief 59A of May 12, 2006 specify 6-inch diameter cores.

The minimum levels of compaction expressed as a percentage of average bulk specific gravity of compacted laboratory specimens have been specified in Table 5 of P-401 as follows:

Surface course (mat)	96.3%
Base course (mat)	95.5%
Joint	93.3%

First of all, it is recommended to make compaction level both at the joint and mat based on theoretical maximum density (TMD) rather than the bulk specific gravity of daily compacted Marshall specimen, which is more variable. Most state DOTs use TMD rather than bulk specific gravity of the compacted Marshall specimen. It is the air void content we are concerned with rather than the percent compaction. In other words, the durability of the joint is related to air voids content rather than the percent compaction. The Unified Facilities Guide Specification (UFGS) of April 2006 and the FAA Engineering Brief 59A of May 12, 2006 also specify mat and joint compaction based on TMD.

The minimum permissible density values for the joint and mat and evaluation of acceptance should also be based on Section 401-5.2 Acceptance Criteria of the FAA Engineering Brief 59A dated May 12, 2006 such as follows:

Evaluation for acceptance of each lot of in-place pavement for joint density and mat density shall be based on PWL. The contractor shall target production quality to achieve 90 PWL or higher.

The percentage of material within specification limits (PWL) shall be determined in accordance with procedures specified in Section 110 of the General Provisions. The acceptance limits shall be as follows:

Mat density, % of TMD	92.8 minimum
Joint density, % of TMD	90.5 minimum

The above minimum density criteria for mat and joint density are also in general accord with the recommendations by NCAT based on several field experiments, and are expected to provide good quality longitudinal joints for airfield pavements. These density criteria for the joint must be specified regardless of any joint construction method employed to ensure reasonable durability of the joint.

Review of Unified Facilities Guide Specification UFGS 32 12 15 dated April 2006

Review of the Unified Facilities Guide Specification UFGS 32 12 15 (which replaced UFGS-02749), the military specification for airfields, is as follows.

Unlike the FAA Specification P-401, this specification specifies the minimum joint density based on the theoretical maximum density (TMD) rather than based on the density of the laboratory compacted Marshall specimen. As discussed earlier, the use of TMD is preferable because it directly gives the air voids at the joint. Also, this specification requires a minimum *average* joint density of 92.5 percent based on the TMD. That is, no more than 7.5 percent *average* air voids at the joint. Most state DOT specifications do not allow air voids at the joint exceeding 10 percent. Therefore, the UFGS is more stringent and, if met, should produce a durable longitudinal joint compared to most state DOT specifications.

Unlike the FAA Specification, the UFGS does not use PWL but uses Table 8 to calculate pay factors from both mat and joint *average* density values. These two pay factors are then integrated based on total area of the lot and length of the longitudinal construction joint.

The UFGS requires that joints, which are irregular, damaged, uncompacted or cold, should be cut back with a cutting wheel. Unlike FAA, the UFGS does allow the paving contactor to use an alternate method of joint construction if it can be demonstrated that density, smoothness, and texture can be met.

The UFGS allows obtaining 4 or 6" diameter cores right on the joint, whereas the P-401 requires the core diameter to be 5" minimum. Since a core with a diameter of 4" may be rather too small to represent the joint, at least 6"-diameter cores should be obtained to minimize variability of density measurements.

Specific Recommendations for Revising FAA (AC 150/5370-10B) P-401 Specification dated 4/25/2005

Based on the preceding detailed review of the current FAA and Unified Facilities Guide Specification (UFGS), the following specific recommendations are made for revising the existing FAA P-401 Specification.

General

Specify to use echelon paving at least for the central portion of runways and taxiways. This would minimize the number of longitudinal joints in the area, which is subjected to direct application of severe aircraft loadings.

Section 401-4.12 Joints

The current specification requires cutting back the edge of the first paved lane if it has been left exposed for more than 4 hours or whose surface temperature has cooled to less than 160 F. No other longitudinal joint construction technique is permitted for such so-called "cold" joints. Field research experiments (Chapter 2) have shown that three other cold joint construction techniques (such as notched wedge joint, rubberized asphalt tack coat, and their combination) have given more durable joints compared to the cutting wheel procedure required in the current FAA Specification. These three alternate longitudinal joint construction techniques are listed below in order of decreasing preference. These techniques must be considered by the FAA based on the extent of airfield traffic, aircraft gross weights (such as those given in Table A of the FAA specification), or climatic conditions at the airfield. Better longitudinal joint construction techniques are desirable for airfields with heavier traffic, airfields used by higher aircraft weights and airfields located in colder climate (the incidence of longitudinal joint opening is higher in cold climate compared to hot climate due to increased shrinkage).

1. Combination of notched wedge joint and rubberized asphalt tack coat (joint adhesive)
2. Rubberized asphalt tack coat (joint adhesive)
3. Notched wedge joint
4. Cutting wheel

Detailed description of the above four "cold" longitudinal joint construction techniques are given in Chapter 2 and Appendix B, which should be included as annexure to FAA P-401 Specification for the guidance of paving contractors. The minimum joint density requirements as given later must be met regardless of any technique selected by the contractor.

Section 401-5.1b(2) Joint Density

Specify the minimum core diameter for joint density to be 6 inches.

Section 401-5.1b(3) Sampling

Specify the minimum core diameter for joint density cores to be 6 inches.

Section 401-5.1b(4) Testing

Revise to indicate that the percent compaction (density) of core samples should be determined by dividing the bulk specific gravity by the average theoretical maximum density (TMD) obtained by ASTM D2041 rather than laboratory density.

Section 401-5.2 ACCEPTANCE CRITERIA

Revise this section so that it conforms to Section 401-5.2 of the FAA Engineering Brief 59A of May 12, 2006 as far as the requirements for joint density and mat density are concerned.

This means Table 5 of P-401 should be revised to reflect the following changes in the lower limits (L) of two items:

Item	**From**	**To**
Surface Course Mat Density	96.3% of Lab Density	92.8% of TMD
Joint Density	93.3% of Lab Density	90.5% of TMD

CHAPTER 5. BEST PRACTICES OF LONGITUDINAL JOINT CONSTRUCTION

INTRODUCTION

The best practices for constructing longitudinal joints in airfield pavements recommended in this chapter are based on the material presented in Chapters 2, 3, and 4.

As mentioned in Chapter 2, a significant amount of research has been conducted on joint construction techniques in highway pavements rather than airfield pavements. The results from many of those research projects have been implemented by many state departments of transportation in their regular construction. It is expected that these good practices will be considered and largely adopted by the airfield pavement community as well – and there are instances where some of the practices have been experimented on airfield pavements. However, before the results of the highway pavement research are considered for airfield pavements it is prudent to examine the similarities and differences between highway and airfield pavements in terms of their asphalt longitudinal joints. The following discussion examines the similarities and differences between these pavements from various aspects.

SIMILARITIES AND DIFFERENCES BETWEEN LONGITUDINAL JOINTS ON HIGHWAYS AND AIRFIELD PAVEMENTS

Asphalt Mix Type

Usually, higher the asphalt mix stiffness, the greater is the potential for the mix to develop cracking at the longitudinal joint. A high-stability, stiff dense-graded HMA is used both on airfield pavements and heavy-traffic highway pavements. Therefore, the mix type used on both pavements is quite similar in stiffness.

Pavement Geometry

Runways and taxiways are much wider compared to most highway pavements and therefore have many more longitudinal joints. Airfield runway longitudinal joint length can easily exceed nine times the length of the runway. This means if there is an inherent problem in the joint construction technique, it gets repeated many times over on runways and taxiways. However, some multi-lane highways near metropolitan areas do have many longitudinal joints similar to taxiways if not runways.

Effect of Climate on Performance of Longitudinal Joints

The normal development of a crack at the longitudinal joint after some time in service is more of a thermal phenomenon than anything else regardless of whether it is a highway or an airfield pavement. When the pavement cools in cold weather it shrinks and tensile stresses are induced in the pavement, which in turn cause the longitudinal joint (the weakest vertical plane in the pavement) to crack. That is why it has been observed that cracking at longitudinal joint both on highway and airfield pavements is more severe in the northern tier states of the US with cold climate as compared to the southern states with hotter climate.

Effect of Loading and Kneading Action of Traffic

Airport runways have landing areas where the pavement is subjected to severe impact loads. Highway pavements do not have such areas. The effect of impact loading, if any, on the performance of the longitudinal joints in the landing areas of the airfield runways has not been reported and needs to be studied. The aircraft traffic on wide runways and taxiways is usually channelized in the center compared to multi-lane highway pavements where every lane gets automobile or truck traffic although the intensity may be different. Traffic imparts a beneficial kneading action to a longitudinal joint whenever it goes across it. The kneading action usually helps in healing of the hairline crack, which initially develops on a longitudinal joint. There is hardly any kneading action by aircrafts on the longitudinal joints of runways and taxiways because the traffic is channelized and hardly goes across the joint (except where the joints are directly in the wheel path). This situation is similar to a longitudinal joint on a two-lane highway where the traffic hardly goes across the centerline. On a multilane highway some kneading action takes place when the traffic changes lanes.

Construction

Usually there are time constraints when paving airfield pavements so that no interruption is caused to air traffic. Such time constraints are also encountered on very busy highways especially in and around metropolitan areas, where paving has to be done during nighttime only.

In case of airfield paving large staging area is usually available for construction to accommodate all necessary equipments such as pavers, rollers, and trucks carrying the hot mix. Paving in echelon using multiple pavers is also easy in case of airfields. In case of highways, traffic has to be maintained in adjacent lanes and therefore large staging areas are not usually available and paving in echelon may not always be possible for lack of room.

Since there is no traffic during construction in case of airfield paving, shorter pulls (turning around the paver to lay the adjacent lane) are relatively easier to obtain a reasonably hot joint compared to highway paving where traffic has to be switched to different lane after every pull.

Maintenance

Once cracks and/or raveling develop at the longitudinal joint, maintenance of these joints (such as sealing and skin patching) is very difficult on runways and taxiways because of their excessive lengths compared to highway pavements. Moreover, such repairs have to be done proactively and promptly on airfield pavements so as to avoid the potential formation of foreign object damage (FOD), which is not of concern in case of highways. That is why, the FAA has taken the lead in the past and paid special attention to construction of quality longitudinal joints on airfield pavements.

From the preceding discussion of highway versus airfield pavements in terms of longitudinal joints, it appears there are far more similarities between the two and the differences are minimal. Therefore, the good experiences from the highway pavements must be evaluated and considered in light of the requirements of the airfield pavements and the adoptable practices from the highway pavements should be implemented by the airfield community as much as possible.

RECOMMENDED BEST PRACTICES FOR CONSTRUCTING DURABLE LONGITUDINAL JOINTS ON AIRFIELD PAVEMENTS

Because of inadequate information on performance of different longitudinal joint construction techniques on airfield pavements, the information available on highway pavements has been used to recommend the following best practices. Information given in Chapters 2, 3, and 4 has been utilized to make these recommendations for airfield pavements.

It is preferable to produce hot longitudinal joints by operating two or more pavers in echelon (Figure 8). But in a majority of cases, echelon paving is not possible especially with limited capacity of HMA production to feed more than one paver. However, attempt should be made to pave in echelon at least the central portions of runways and taxiways. This would minimize the number of longitudinal joints in the area, which is subjected to direct application of severe aircraft loadings**.**

If echelon paving is not possible then it is recommended to use the following best practices for constructing durable longitudinal joints. These practices are listed in decreasing order of preference.

1. Combination of Notched Wedge Joint, Rubberized Asphalt Tack Coat (Joint Adhesive), and Minimum Joint Density Requirements

Construct a notched wedge longitudinal joint. The unconfined edge of the first paved lane will have a vertical notch at the edge generally ranging from ½ inch (13 mm) to 3/4 inch (19 mm) in height depending upon the nominal maximum aggregate size (NMAS) of the HMA mixture. Generally, a vertical notch of about ½ inch (13 mm) height is considered adequate for most surface course mixtures. This height has given excellent results in NCAT and Wisconsin studies, and in Michigan. The height of the notch can be increased in case of binder and base course mixtures, which have a larger NMAS. Figure 17 shows a schematic of a notched wedge joint. At the bottom of the vertical notch, the wedge is provided a taper of 1:12 (vertical: horizontal). To avoid feathering the taper to zero height, which may cause dragging of the HMA, it is recommended to end the taper with a minimal height such as 3/8 inch (9.5 mm) to avoid dragging of the material.

Usually a loaded wheel, which is attached to the paver, is used to compact the taper (Figures 18 and 19). Typically, the roller weighs 100 to 200 lbs (45 to 91 kg) and is approximately 14 inches (356 mm) wide by 12 inches (305 mm) in diameter. There is no need to compact the taper with a conventional steel or pneumatic tired roller because it will simply destroy the vertical notch.

The overlap layer of the adjacent paving lane is required to be placed and compacted within 24 hours unless delayed by inclement weather. The vertical notch and taper are tack coated with rubberized asphalt binder (joint adhesive) prior to placing the overlap wedge as described later. The notched wedge joint can be formed by using a homemade sloping steel plate attached to the inside corner of the paver screed extension. However, commercial devices are now available which can be attached to the screed to form the notched wedge joint.

The notched wedge joint does not always work well for thinner HMA lifts. Ideally, it gives the best results with a minimum lift thickness of 1½ to 2 inches (37 to 51 mm). On the other hand, excessive thick lifts produce a long taper, which may not be desirable. In those cases, the length of the taper is generally restricted to 12 inches (305 mm). The top course taper shall overlap and slope in the opposite direction of the lower course taper.

The use of notched wedge joint allows continuous paving of a lane for an entire day without the typical specification requirement that all lanes be resurfaced to within one load of the same point-of-ending at the completion of each day’s paving operations. This eliminates the need for contractors to backup their paving equipment for paving the adjacent lane. The result is less down time and more paving time, which may increase production by 20 to 30 percent. In addition, the number of transverse construction joints is minimized resulting in a smoother ride.

One of the most important requirements in obtaining a good longitudinal joint is that the paver operator should place the first lane in a uniform, unwavering line. Attention to this detail will simplify the placement of the adjacent lane with a uniform overlap.

After the first lane (cold lane) is paved with a notched wedge and compacted, a rubberized asphalt tack coat (Crafco pavement joint adhesive Part Number 34524 or equivalent) is applied on the face of the unconfined edge of the cold lane. The thickness of the tack coat is about 1/8 inch (3 mm) on the slope of the HMA edge. The rubberized asphalt tack coat (joint adhesive) need not be applied on the entire taper. It is considered adequate to apply it on the vertical notch and the top 3-4 inches (76-102 mm) wide band of the taper.

The rubberized asphalt material is supplied as a ready to use solid material in containers. It is melted in a jacketed double boiler type melting unit, which is equipped with both agitation and re-circulation systems. The melting unit must be capable of safely heating the joint adhesive to 400 F (204 C). The adhesive is best applied using a pressure feed wand. An applicator shoe attached to the end of the wand helps in spreading it uniformly on the slope of the unconfined edge. Figures 14 and 15 show the application of rubberized asphalt tack coat (joint adhesive) on a paving project. Application excesses should not exceed more than ½ inch (13 mm) at the top of the joint.

The joint adhesive should preferably be applied within four hours of the time that the adjacent HMA lane is placed. The heat from the HMA in the adjacent lane and the roller pressure causes the material to adhere strongly along the joint face resulting in a strong bond between the two lanes and providing a built-in sealer at the joint.

The adhesive has a consistency of a thick pancake mix. It hardens quickly and after a short period it feels slightly tacky to the touch. During placement of the second lane, the adhesive may sometimes stick to the tires of the haul trucks if pulling across the longitudinal joint area. Therefore some caution is needed during construction.

After the rubberized asphalt tack coat (joint adhesive) is applied, the adjacent lane (hot lane) is placed. It is important to control the height of the uncompacted HMA in the hot lane. The height of the uncompacted HMA should be about 1¼ inch (32 mm) for each one inch (25 mm) of the compacted lift thickness in the cold lane. For example, if the compacted HMA in the cold lane is two inches (51 mm) thick, the height of the uncompacted HMA in the hot lane should be 2½ inches (64 mm), which is ½ inch (13 mm) above the level of the compacted mat.

Another key point in obtaining a good longitudinal joint is proper overlapping during the paving operation. The end gate of the paver should extend over the top surface of the previously placed HMA by a distance of approximately 1 to 1½ inches (25 to 38 mm). Attention to this detail will not only provide the requisite amount of HMA on top of the joint for proper compaction, it will require minimal or no raking and luting. If the overlap is consistent and within this suggested range, it will be better to avoid raking or luting altogether.

Obtaining adequate compaction at the joint is the final key in obtaining a durable longitudinal joint. The most efficient joint compaction method is to roll the longitudinal joint from the hot side overlapping the cold lane by approximately 6 inches (150 mm) as shown in Figure 11. The steel wheel roller can be operated in vibratory or static mode, preferably the vibratory mode to obtain better compaction. This rolling pattern allows most of the weight of the roller to compact the HMA in the hot lane as well as at the joint. The HMA at the edge of the hot lane is constrained due to the presence of cold lane and is compacted promptly without any significant cooling, thus resulting in high density. This pattern is also effective if the pavement has different cross slopes at the longitudinal joint.

Compact the joint promptly so that the minimum acceptable joint density is 90.5 percent of the theoretical maximum density (TMD), that is, no more than 9.5 percent in-place air voids at the joint. The minimum acceptable mat density (away from the joint) shall be 92.8 percent of the

TMD, that is, no more than 7.2 percent in-place air voids in the mat. Evaluation for acceptance of each lot of in-place pavement for joint density and mat density shall be based on PWL. The contractor shall target production quality to achieve 90 PWL or higher. The preceding acceptance criteria are based on Section 401-5.2 of the FAA Engineering Brief 59A dated May 12, 2006.

Usually, it is not possible to obtain an accurate density measurement right on the joint using a nuclear gauge, which is centered on top of the visible line between the cold and hot lanes. This is because the nuclear gauge cannot be placed flat across the joint without rocking. The compacted HMA on one side of the joint is usually higher than the other side causing uneven surface across the joint. Similarly, the nuclear gauge cannot be placed flat on a joint with a crown.

Therefore, the joint density is best measured by obtaining a 6 inch- (150 mm-) diameter core centered on top of the visible line between the two lanes. It should be noted that the core would not consist of equal volumes of mix from the cold lane and the hot lane. Due to the presence of taper or natural slope at the unconfined edge of the cold lane, most of the mix in the core will come from the cold lane. This is acceptable because the density of the cold side is of major concern.

2. Rubberized Asphalt Tack Coat (Joint Adhesive) and Minimum Joint Density Requirements

This practice is similar to that in Item 1 above except that no notched wedge joint is used. The first lane (cold lane) is paved as usual with the normal, unconfined edge slope. A rubberized asphalt tack coat (joint adhesive) is applied on the entire face of the unconfined edge of the cold lane using the procedure described in Item 1.

Best practices for paving and compacting the first lane, paving the second lane and overlapping, raking and luting, and compacting the longitudinal joint should be followed as given in Item 1.

The minimum joint density and mat density requirements should also be same as Item 1.

3. Notched Wedge Joint and Minimum Joint Density Requirements

This practice is similar to that in Item 1 above except that a conventional tack coat material (which is used on the main line) is applied to the entire face of the notched wedge joint in lieu of rubberized asphalt material.

Best practices for paving and compacting the first lane, paving the second lane and overlapping, raking and luting, and compacting the longitudinal joint should be followed as given in Item 1.

The minimum joint density and mat density requirements should also be same as Item 1.

4. Cutting Wheel and Minimum Joint Density Requirements

The cutting wheel technique involves cutting 1½ - 2 inches (38-51 mm) of the unconfined, low-density edge of the first paved lane after compaction, while the mix is plastic. It is important to remove all low-density material at the edge of the first paved lane. Some airfield contractors remove as much as 6-inch (150-mm) strip to meet and exceed joint density requirements. The cutting wheel is usually 10 inches (254 mm) in diameter with the cutting angle about 10 degrees from the vertical towards the mat to be cut and about 45 degrees on the open side to push the trimmings away (Figure 20). The cutting wheel can be mounted on an intermediate roller or a motor grader (Figure 21). The HMA trimmings can be collected and recycled. A reasonably vertical face at the edge is obtained by this process (Figure 22), which is then tack coated before placing the abutting HMA. It is important to restrict the overlap to about ½ inch (13 mm) while placing the adjacent lane.

It is very important to have a skilled cutting wheel operator, who must cut straight without wavering and a skilled paver operator, who must closely match the cut line with minimal overlap.

Best practices for paving and compacting the first lane, paving the second lane and overlapping, raking and luting, and compacting the longitudinal joint should be followed as given in Item 1.

The minimum joint density and mat density requirements should also be same as Item 1.

The preceding four best practices have been recommended based on the long-term performance of various longitudinal joint construction techniques in field research projects (largely highway projects), the feedback from airfield engineers, and practical considerations. Other longitudinal joint construction techniques such as Infrared joint heating and HMA joint tape may be developed further in the near future and may be added to the list of best practices. However, at this time sufficient long-term field performance data are not available to make such recommendations.

CHAPTER 6. DRAFT IMPLEMENTATION PLAN TO PROMOTE IMPROVED LONGITUDINAL JOINT CONSTRUCTION WITHIN AIRFIELD COMMUNITY

The objective of this task is to prepare an action plan for disseminating the best practice information on construction of longitudinal joints in airfields and to promote the use of the information.

Aviation administrators and engineers sometimes face problems such as unsatisfactory durability of longitudinal construction joints, for which information already exists, either in documented form or as undocumented experience of practitioners. Such information may be fragmented and scattered. Therefore, full knowledge of what has been learnt about a problem is needed to solve a problem. This AAPTP Project 04-05 report provides a compendium of the best knowledge available on constructing longitudinal joints that has been found to be most successful in enhancing their performance and durability.

Removing the unconsolidated edge via cutting has primarily been used in airfield construction for constructing "cold" longitudinal joints for a number of years. Many of the innovative longitudinal joint construction techniques that have been used successfully in highway pavement construction are also generally applicable in airfield pavement construction and should be considered. In the area of longitudinal joints, we must not allow costly research findings go unused and valuable experience overlooked. Therefore, there is a need to consider implementing whatever successful techniques have been developed through research. For accomplishing this objective, an effective implementation plan needs to be developed and executed by the FAA as soon as possible.

The proposed implementation plan includes the following six specific steps.

1. Refinement of the existing FAA specification

2. A set of best practices materials in a coherent fashion in html and pdf format that can be posted on AAPTP and/or FAA websites.

3. Mailing of best practices materials to the ten FAA regional offices

4. Seminars on best practices at each of the ten FAA regional offices

5. Presentations at various airfield conferences

6. Development of field performance database

1. Refinement of the existing FAA specification

The most significant and effective way to improve longitudinal joint construction practices will be through refinement of the existing FAA specification. Chapter 4 gives specific recommendations for the refinement of the existing FAA specification for construction of longitudinal joints. Obviously, the refinement needs to be carried out in accordance with existing rules and procedures of the FAA. It is recommended that the FAA Central Office call a special meeting of FAA regional engineers, airfield contractors and consultants, and academia (such as National Center for Asphalt Technology) to review and finalize the revisions to the FAA specifications proposed in Chapter 4 to improve the performance and durability of longitudinal joints in airfield construction.

2. Best practices documents in html and pdf format

The best practices, stand alone document given in Appendix B should be made available in html and pdf format such that this document can be placed in appropriate location in FAA/AAPTP website for convenient viewing and/or download.

3. Best practices documents for mailing

The best practices, stand alone document given in Appendix B should also be made available in paper format for mailing to all FAA regions, contractors and consultants.

4. Seminars on best practices documents

One-day seminars should be conducted at all FAA regional offices to make the airfield engineers familiar with the revised FAA specifications and the new innovative methods of longitudinal joint construction.

5. Presentations at various airfield conferences

Technical papers based on this AAPTP project report should be presented at national and international airfield conferences such as the following:

(a) Annual FAA National Airfield Conferences

(b) Annual Airfield Conferences held at Penn State

(c) ASCE Airfield and Highway Pavement Specialty Conferences

(d) FAA Regional Airfield Conferences such as Northwest Mountain Region Airport Conference

(e) FAA Worldwide Airport Technology Transfer Conferences

(f) Annual Swift Airfield Conference held in Canada

The above action will disseminate the information on longitudinal joints to the airfield community at large.

6. Development of Field Performance Database

It is recommended to use all four longitudinal joint construction techniques (given as best practices in Chapter 5 and Appendix B) simultaneously on several airfields located in different climatological zones of the US. Since airfield runways have several longitudinal joints it is easy to use all four techniques on the same runway. This will give the airfield community performance database for these techniques similar to the database obtained in highway applications. All FAA regions should be encouraged to use these four techniques simultaneously and monitor and report their long-term performance in airfields.

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APPENDIX A

INFORMATION GATHERED FROM AIRFIELD ENGINEERS

The objective of this task was to collect and synthesize information on different types of longitudinal joints in airfields of different types, in different geographical locations in the US. This task has been achieved as follows.

Selection of airports from different FAA regions

There are nine FAA regions and the national headquarters in Washington, DC. Specific FAA regions were selected so as to cover all four Long Term Pavement Performance (LTPP) climatic regions – wet-no freeze, wet-freeze, dry-no freeze and dry-freeze. An overlay of these four climatic zones over the FAA region map shows the regions that satisfy the four climatic regions. These regions are given in Table 1.

Table 1. FAA Regions selected for Task 2

FAA Region	Climatic Zone
Southern Region (Atlanta) parts of southwest (Ft. Worth and Oklahoma City and parts of Northwest Mountain (Seattle),)	Wet-No Freeze
Eastern (New York), New England (Boston) and parts of Great Lakes (Chicago)	Wet-Freeze
Parts of Southwest and Western Pacific (Los Angeles)	Dry-No Freeze
Parts of Northwest Mountain, Great Lakes and Central (Kansas City)	Dry-Freeze

Both major airports and smaller general aviation airports were selected in the regions given in Table 1. The list of selected airports is given in Table 2.

Table 2. Selected airports

	Primary LTPP Climate Zones For Large Airports			
FAA Region	**Wet-No Freeze**	**Wet-Freeze**	**Dry-No Freeze**	**Dry-Freeze**
New England (NE)		Boston, MA-BOS Providence, RI-PVD		
Eastern (E)		New York, NY-JFK Baltimore, MD-BWI		
Great Lakes (GL)		Chicago, IL-ORD Fort Wayne-Allen County–FWA-IN Dayton International, OH-DAY		
Southern (S)	Charlotte, NC-CLT Miami, FL-MIA			
Southwest (SW)	Houston, TX-HOU		El Paso, TX-ELP	
Central (C)		Des Moines, IA-DSM Kansas City, MO–MCI		Omaha, NE-OMA
Northwest Mountain (NWM)	Seattle, WA-SEA Portland, OR-PDX			Salt Lake City, UT – SLC, Spokane, WA - GEG
Western Pacific (WP)			Long Beach, CA-LGB San Diego, CA–SAN Burbank-Glendale Pasadena, CA-BUR	
Alaska (AK)		Anchorage, AK-ANC		

Contacts for collecting data

The information and experience on longitudinal joints was sought from FAA regions, specific airport engineers and consultants. Table 3 gives the list of FAA contacts in different regions. Table 4 gives the list of engineers, which have been contacted in many airports. Contacts with the personnel given in Tables 3 and 4 were made by phone, letters, and e-mails to gather information on longitudinal joints. Additional inputs were obtained from airfield consultants, military, contractors, and equipment manufacturers.

Table 3. List of FAA contacts in different regions

Region	Contact
Alaska	Pat Oien, 907-271-5445, Pat.Oien@faa.gov
Central	Doug Johnson, 816-329-2616, Doug.Johnson@faa.gov
Eastern	Guillermo Felix, 718-553-3345, Guillermo.Felix@faa.gov
Great Lakes	Richard Pur, 847-294-7527, Richard.Pur@faa.gov
New England	Victor Lung, 781-238-7625, victor.lung@faa.gov
Northwest Mountain	Jack Scott, 425-227-2622, Jack.Scott@faa.gov
Southern	Roger Hall, 404-305-6713, Roger.Hall@faa.gov
Southwest	Ron Hess, 817-222-5622, Ron.Hess@faa.gov
Western Pacific	Ruben Cabalbag, 310-725-3630, Ruben.Cabalbag@faa.gov

Table 4. List of engineers contacted in different airports

Airport	FAA Region	LTPP Zone	Contact (s)
Anchorage International Airport (ANC)	Alaska	Wet-Freeze	Andrea Morton, 907-266-2731, andrea_morton@dot.state.ak.us , Cynthia Ferguson, Cynthia_ferguson@dot.state.ak.us
Port Authority of New York & New Jersey (PANYNJ) Airports New York (JFK), LaGuardia (LGA), Newark (EWR)	Eastern	Wet-Freeze	Scott Murrell, 973-792-4327, smurrell@panynj.gov
Boston (BOS)	New England	Wet-Freeze	Bob Pelland, 617-568-5971, bpelland@massport.com
Omaha (OMA)	Central	Dry-Freeze	Dave Roth (402) 661-8014, dave.roth@eppleyairfield.com, Dan Owens (Consultant), dan.owens@lra_inc.com
Dayton International (DAY)	Great Lakes	Wet-Freeze	Youssef A. Elzein, 937-264-3584, yelzein@flydayton.com
Fort Wayne-Allen County Airport (FWA)	Great Lakes	Wet-Freeze	Sheryl Kelly, 260-747-4146, Kelly@fwairport.com
Baltimore/Washington Int. Airport (BWI)	Eastern	Wet-Freeze	Alex Ollerman, 410-859-7122, follerman1@bwiairport.com
Miami International (MIA)	Southern	Wet No-Freeze	Nancy Pantoja, 305-876-7928, npantoja@miami-airport.com
Portland International Airport (PDX), call	Northwest Mountain	Wet-No Freeze	Julie Thiessen, 503-944-7379 Julie.Thiessen@portofportland.com
Houston Hobby (HOU)	Southwest	Wet-No Freeze	Bill Gaw 281-233-1932, bill.gaw@cityofhouston.net
TF Green Airport (PVD)	New England	Wet-Freeze	Ahmed Shihadeh, 401-737-4000, ext. 275, ashihadeh@pvdairports.com
Salt Lake City International (SLC)	North West Mountain	Dry-Freeze	Mike Widdison, 801-575-2027, mike.widdison@slcgov.com

Information gathered

Unfortunately, there is little information available from airports on different types of longitudinal joints as mentioned in the literature review (Chapter 2). Mostly, the prevalent construction practice is to cut back the cold or warm joint and tack coat the cut face with asphalt binder before placing the adjacent lane. This practice is either specified in the contract or contractors use it in order to meet agency’s stringent requirements for density at the joint. Recently, some other techniques such as tapered wedge joint and infrared heating of joint have been attempted on airfield pavements.

However, conversations and correspondence with some airport engineers have brought out various other factors related to longitudinal joints. Such factors include: mix information, construction practices, joint density specifications, performance and maintenance of longitudinal joints. The following are summaries of input from some airport engineers.

1. Conversation with Mr. Scott Murrell, Chief Civil Engineer Port Authority of New York & New Jersey (PANYNJ)

JFK is a hub airport, with 175,000 annual departures (Dominant aircrafts: B 767 – 26%, 747, 777 and MD 11 – 15 %). LGA is a hub airport, with 200,000 annual departures (Dominant aircraft – B 737 – 40%) EWR is a hub airport with 259,000 annual departures (Dominant aircraft: B 737 – 50%, 747, 777, MD 11 – 6%)

The typical lift thickness is 3 inch for surface courses, with ½ inch Nominal Maximum Aggregate Size (NMAS) aggregates. The thickness has been recently reduced from 3-1/2 inch to 2 - 3 inch to enhance smoothness. For HMA, a 4 % in-place voids is required (as compared to the FAA recommended 3.5 %). The mixes are designed according to 75 blow Marshall procedure. The cost of mix (PG 76-22) is $65 per ton.

All of the Hot Mix Asphalt (HMA) used at PANYNJ airports is made up of polymer modified asphalt binder. Most of the asphalt is PG 76-22 grade, with about 10 % being PG 82-22. PG 82-22 is used in mixes in about 500 feet at the end of the runways where there is no concrete. The use of polymer modified asphalt (in significant amounts) started in the mid nineties. There have been no additional concerns/problems with joints with the modified mixes. PANYNJ had previously used Trinidad Lake Asphalt (TLA) and have had experience in maintaining high temperatures with modified asphalts for proper construction. A concern and the use of higher compaction effort had actually been experienced when the aggregate gradation was made coarser than what it was before.

Most of the jobs are for rehabilitation, overlays or mill and fill. Paving is done edge to edge, and longitudinal joints remain “warm” during paving – the occurrence of cold joints is eliminated. At the same time, PANYNJ requires the use of two pavers working in echelon in runways as well as in taxiway center sections. The use of 18-20 feet paving widths is common. Contractors follow the Asphalt Handbook, 2000 edition closely for paving operations. Material Transfer Vehicles (MTV) are required on runway jobs as well as in taxiways unless the job is one short parallel stretches. Paving at JFK is from midnight to mid noon, all night at LGA and, in day time (September) in EWR. In paving, the amount of raking is minimized.

The performance related specifications of PANYNJ, specifically those related to joint density, have helped in improving the quality of joints. There are examples (such as paving of 4R-22L runway) where the possibility of penalty due to low density at joint have forced contractors to using techniques, such as cut back of cold joints, to improve joint density.

The typical distress in longitudinal joints happens in about four to five years after construction. This distress occurs as initial crack along the joint, which leads to secondary cracks and ultimately loss of materials – although the loss is not as severe as raveling. Such cracks are identified by operations crews and taken care off immediately. Sometimes segregation is seen in the mix on the mat or along the joint, but recent penalty specification on joint densities has minimized their occurrence. There is some concern about water getting inside the pavement through cracks at longitudinal joints, but there has been no occurrence of stripping/moisture damage in the pavement.

Maintenance activity related to joints consists of sealing with hot poured rubberized asphalt.

For experimenting with new construction techniques, there is a plan for using Joint Adhesive (from Crafco) in one of PANYNJ’s road projects.

2. Conversation with Mr. Bob Pelland, Project Manager, Massport

Logan International Airport (BOS) is a large hub airport. Emplanement in 2004 was 12.7 million, making it the number 18 in the country. The number of operations in 2004 was 400,000.

The typical structure consists of HMA over crushed aggregate base over gravel subbsase for pavements constructed since the mid-1970’s. Prior to that time, HMA was placed over penetrated macadam over dry bound macadam over gravel subbase.

Currently used typical lifts are 2.5 inch to 3 inch, with P401 specified HMA, with lime additive. The mix consists of 18 % RAP, 4 % latex, and 1 % hydrated lime. The aggregates are mostly igneous trap rock or diorite. The asphalt is a PG 64-28 grade binder.

Regarding segregation the approach has been not to overdo with the lute. Also, Massport is going to ½ inch nominal maximum aggregate size from ¾ inch, to reduce segregation. This segregation shows up not only at joints but in other areas of the mat as well.

For joints in Logan, the paving is done edge to edge, with the shoulders done later with butt joints. As a rule, Massport does not allow ending up with cold joints.

The typical distress conditions are cracks opening up and raveling within 4-5 years of construction. The common repair technique is “overband” type of crack seal. The crack is filled with the sealing material with a wand and then a 1-ton roller is used to compact it. This material is more sticky and durable compared to the previously used rubbery and foamy material with routing. The amount of sealing is a significant part of the annual budget.

There has been no safety concerns regarding cracks or raveling at the joints. Generally aviation and engineering department inspection crews catch these cracks and raveling prior to becoming a problem. However, micro cracks do exist and some water does get inside through these cracks and in combination of subsurface water may cause subsurface damage, such as stripping.

3. Conversation with Mr. Dan Owens (Consultant) and Mr. David Roth, Omaha Airport.

Prior to 1999, standard mix and methods were used for paving longitudinal joints. There was serious concern regarding distress, such as raveling adjacent to the joints – these problems were the first to occur in a paving job. It was perceived that adequate density was not being achieved at the joints. Cracks at joints and moisture damage due to freeze thaw were issues, and the main complaints were from operational stand point - Foreign Object Damage (FOD); complaints were also about the high cost of patching from maintenance point of view.

The latest asphalt project was a resurfacing of the main runway in 1999.

In this job, the standard P401 mix was modified to make the gradation less coarse to aid compaction, the asphalt binder was recommended as a PG 70-28, to resist grooving, and the longitudinal joint construction technique was modified to accommodate a cut back of 6 inch before paving the adjacent lane. A pay item was included for the cut. Although hot joint (having pavers in echelon) was an option, it is not a practical option since the mix amounts are not enough to keep two pavers busy. A requirement for having 25 feet paver width was enforced. Density tests were conducted on joints as well as mat.

In future projects, the specification on the joints used on the 1999 project are kept, but the 25 feet paver width has been changed to 18 feet, to avoid segregation in the typical 21/2 inch layer, along the auger box location.

4. Information from Ms. Cynthia Ferguson, Anchorage International Airport (ANC)

General and Mix Information

The mix designs for pavements have varied from project to project. Structural sections of pavements at ANC generally consist of 8 to 10 inches of asphalt treated base (Type I or II) using PG 52-28 binder. The asphalt treated base is topped with 5 inches of Type III or V, using PG 64-28 binder (current design). Past projects have used 3 inches of Type II (with PG 52-28 binder) topped with 2 inches of Type III (with PG 58-28 binder). Blast area pavements are generally 3 inches of Type II using PG 52-28 binder.

Construction Information

There are different approaches to asphalt joint construction. Old Aviation specifications used to require a special “joint maker” that consisted of a steel shoe mounted on the screed end plate. Instead of having a vertical joint, the joint maker built a taper into the bottom half of the joint. It looked good on paper, but was impossible to construct. The biggest problem was with the edge of the mat displacing (not compacting) and cooling, resulting in a poor joint.

The skill and experience of the screed operator, raker, and roller operator are probably the most vital component making a good joint.

Contractors usually stack the joint using a rake, as this typically provides the best chance of success in achieving joint density. The preferred method of compaction is to “pinch” the stacked joint by rolling from the cold mat, and over-hanging onto the hot mat approx 1 ft. This rolling technique provides a smoother transition between mats, and has shown good results in achieving joint density requirements. Rolling a stacked joint from the hot side almost always creates a bump, which probably does not make for a long lasting joint. Snowplows can catch the bump if it is big enough. A screed operator that is not watching the joint can overhang the joint, giving the raker more material than needed. In this case the raker will either over-stack the joint making a bump, or will rake the excess (marbles) onto the hot mat, which can result in a segregated or open graded mat. Low density and open graded surfaces associated with the segregated areas can result in spalling, cracking, and ultimately mat/joint failure.

An alternative to stacking the joint is to hot lap the joint. This method works well only if the adjacent mat is hot enough to compact. Old DOT specifications gave the Engineer the option of allowing hot lapping. Hot lapping involves compacting the mat, leaving the outer edge of the mat uncompacted (approximately 1 to 2 ft). When the contractor ties onto the hot mat, the screed operator just overhangs the uncompacted outer edge. To construct a good hot lap joint, the adjacent joint was required by spec to be over 150° F. Experience has shown that an acceptable hot lap joint can usually be constructed at temperatures around 120° F without cutting but the incoming mix must be hot. Once the mat has cooled below 120° F the hot lap joint will not perform. It is important to keep the screed hot when using this method, because the asphalt binders act like a lubricant when hot. If the temperature of the incoming mix is not hot enough to keep the screed end plate hot, the mix will gum up on the plate and drag, leaving a segregated joint behind. This is more of a problem with polymer-modified asphalts, which need to be hotter to stay lubricated. Contractors like to use solvent to clean the gum off the end plate, and sometimes spray their screed down with solvent if their screed heaters aren't working or the mix is too cool. Solvent will definitely reduce the life of a joint. Hot lapping works well if the panels are short, mix is hot, and it's not raining.

Infrared joint repairs have also been tried to fix failed joints at ANC in the past. Advantage: Densities increased by 3-6% after treatment. Disadvantage: Binder burns out of mix, reducing the life of the treated area.

Specifications and Cost

- Bottom lift joints
  - Do not require density testing.
  - Do not require cutting back
  - Require Tack Coat

- Top lift joints
  - Require density testing. If the average joint density of a lot is less than 91%, the contractor is assessed a $5.00 per foot penalty, and required to apply an approved asphalt sealant. If the average joint density of a lot is greater than 91%, a $1.00 per foot bonus is paid.
  - Require cutting back. The specification is 2 inches for every 1-inch of thickness. Cutting back the outer edge of the mat provides for the best chance of achieving density requirements. This is because the outer edge of the mat is not confined, and compactive effort will only shove the material instead of compact it. This specification has not always been followed at ANC. Cutting the mat with a pizza wheel is not effective until the mat temperature is in the 90s. When the cut is attempted at too high a temperature, the mat tears. If the mat is too cool, the pizza wheel will not cut clear through the mat. If the mat is cold, saw cutting will achieve effective results. Removing the cut material should be done as quickly as possible, while it is still warm. If it cools, tack coat will make it very difficult to pull the material away from the joint. Experience has shown that some equipment works well for pulling the material away from the joint, while other equipment chews the joint up.

  - Require joint adhesive

  - All joints require a minimum overlap of 12 inches for longitudinal joints, and 10 ft for transverse joints.

5. Information from Mr. Mike Widdison, Salt Lake City International Airport (SLC)

Mr. Widdison furnished the following five tables containing information.

Table 5. General and Mix Information

Airport	Climate	Region	Type	Air Traffic	Location	Materials, mix, lift thickness	General comment
Salt Lake City International Airport (SLC)	Dry-Freeze	North West Mountain	Hub	2.1M	Salt Lake City, Utah	4 inch overlay, PG 70-28, FAA P-401	Runway overlay

Table 6. Construction information

Airport	Joint Type	Equip-ment	Time of constructio n	Manual Operations	Contractor Experience	Sequence	Conditions
SLC	Longitudinal	Cut back joints	Day operations	Minor	Very experience d	Lane by Lane	Warm to Hot

Note: Manual operations refer to raking/luting; Conditions refer to those during construction

Table 7. Construction Information

Airport	Joint Type	Any construction related distress such as segregation	Visibility during construction	Joints tacked?	Experience of raker/luter
SLC	Longitudinal w/cut back + tack	No distress caused by construction activities	good	yes	good

Table 8. Specifications and Cost

Airport	Joint Type	Specific joint related specification	Joint density specification?	Specific testing for joints?	Cost of mix
SLC	longitudinal	P-401	Cored directly over joint	Density test on cores taken directly over the joint	

Table 9. Maintenance and Performance

Airport	Joint Type	Distress	Time of first distress	Maintenance	Safety concer n	Complaint from Air traffic	Permeability/ Moisture related problems?
SLC	longitu dinal	Noted minor closing of the grooves at the touch down zones	2 yrs	Minor crack seal with hot pour sealant	none	none	none

The following is a summary of conversation with Mr. Widdison on March 24, 2006.

In the most recent overlay job density tests were conducted on the joint rather than by the side of the joints. Specification also calls for saw cut of cold joint if the delay between lane paving exceeds 4 hours. Mixes conform to FAA P401 specification.

The cut back was performed by a “cookie” cutter on joints. The cut was 2” – 3” back of the joint. The joints were tacked prior to the placement of the next lane.

Joint density -4 samples per lot – cores were centered on the joint. All joints met the specification requirements.

6. Information from Dan Feger, Burbank-Glendale Pasadena, California, CA-BUR

“Attached is a copy of our current P401 specification, which is modified somewhat from the standard FAA P401 specification. We believe our specification is more stringent than the standard, but we think it is actually more buildable, more cost effective, and gives longer-term performance than the standard specification.

In our modified specification, we specifically require that the contractor overlap adjacent pulls by 2-3 inches. This means the tamper bar and conveying screw actually ride slightly over the freshly laid adjacent pull, and in doing so provide additional compaction to the joint. This process routinely permits us to get the same compaction (in our case minimum 98%) in the main paving lane as well as in the joint. If you look at our joints ten years after they are laid, there is almost no perceptible "joint droop".

Our specification requires the same compaction in the joints as well as the field, and is a pass-fail type specification. Unlike PWL, there is no factored payment for percentage within limits. If the material is not at 98% compaction, it is removed and replaced, or left in place with no payment. Our contractors have no problem whatsoever in getting the joint and field densities at 98%. We think the standard specification, which permits 93% compaction in the joints, is grossly inadequate.

Our specification is intended to assure compliance with those factors that the contractor and plant can control--i.e. gradation, binder content, compaction and straightness. Other factors, such as flow, stability, and VMA, while desirable characteristics that must be included in the design mix process, cannot be directly controlled by the batch plant or the contractor, and conformance with specified limits for these performance criteria reflect more on the quality of the design mix procedure, and less on the paving procedure.

As an aside, the most significant factor, in our opinion, in deterioration of our P401 pavement is directly related to the grooving. We found, somewhat by accident, that grooving that is spaced at 2" apart instead of 1.5" apart, has a markedly better longevity.

In 1979, both of our intersecting runways were rebuilt, and one runway had 2" groove spacing, the other had 1.5" spacing. The 2" spacing lasted well beyond the 1.5" spacing, with the primary mode of failure being spalling between grooves, leaving holes that are about 1.5" in diameter. Because the current advisory circulars require 1.5" groove spacing, that is what we now use, but we think it would be better to revise the advisory circular accordingly. We typically get about 10 years of life out of our pavement before the grooves deteriorate and the groove spalling becomes objectionable.

Also, we had tried the use of Trinidad Lake Asphalt for a keel replacement in the early 90's on one of our runways. We do not think that the performance of this material extended the life of the pavement beyond the conventional asphalt material, and the extra cost of the material probably was not worth it, again because the mode of failure was grooving induced, not oxidation induced."

Attachment
BOB HOPE AIRPORT RUNWAY RECONSTRUCTION PROJECT
BID SCHEDULE E0622
DMJM HARRIS P – 401 1
February 21, 2006
6000 1290 rev 0
ITEM P401
PLANT MIX BITUMINOUS PAVEMENTS

The following is an extract from this specification.

“At longitudinal joints, alignment of the paver must be maintained so that the paver screed uniformly overlaps the edge of the previously placed mat by two to three inches. This is to insure that an adequate amount of unsegregated mix is placed in the critical longitudinal joint area prior to compaction. Paver extensions will not be permitted for this overlap unless approved by the Engineer and the paving equipment provides vibratory plate compaction of the extended material, i.e. Blaw Knox rubber tired paver. Before rolling longitudinal joints any excess coarse aggregate resulting from overlapping the previously placed mat must be carefully trimmed away, picked up and wasted or scattered over an unpaved lane if approved by the Engineer. Raking or scattering any excess material into the unrolled mat will not be allowed.

Longitudinal joints which are irregular, damaged, or otherwise defective shall be cut back to expose a clean, sound surface for the full depth of the course. In cold joints (transverse and longitudinal) where the temperature of the mix in the adjacent lane has dropped below the minimum temperature (260oF) specified for breakdown rolling, the joint shall always be cut back to a vertical surface. All contact surfaces shall be given a tack coat of bituminous material prior to placing any fresh mixture against the joint. While the surface is being compacted and finished, the Contractor shall carefully trim the outside edges of the pavement to the proper alignment. Edges so formed shall be beveled, while they are still hot, with the back of a rake or a smoothing iron and thoroughly compacted by tampers or by other satisfactory methods.

(3) **Joint Density.** The lot size shall be the total length of longitudinal joints constructed by a lot of material as defined in paragraph
401.5.1a. The lot shall be divided into four equal sublots.
c. **Joint Density.** Acceptance of each lot of in place pavement for joint
density shall be based on the average field density being equal or greater
than 98 percent of the average density of the laboratory prepared specimens, and where no individual determination deviates more than 1.8 percent from the average field density.

7. Summary of conversation with Mr. Youssef A. Elzein, P.E. – Senior Engineer, Dayton International Airport (DAY), Ohio

DAY has two asphalt and one concrete runway. Recently the concrete runway was overlaid with asphalt. DAY is a Category 2 commercial airport (medium hub size); there is a GAA portion on the side, which uses the same runways and taxiways. The overlay consisted of 4-inch mill and overlay; the joint in the centerline opened up within three years. The joint on this project on the 18-36 runway was done according to standard FAA specification that is, butt joint. Being concerned with the joint opening up DAY conducted a pavement structural evaluation/management study through Eckrose and Green/ARA. There was no concern about the structural condition. There has been no complaint from air traffic. Take off ends are paved with concrete. The Consultant did take pictures of joints and other areas of the pavement during the study.

8. Summary of conversation with Jim Shealy, LPA associates, Columbia, South Carolina

Cutting back the pavement edge of the first lane by 4 to 6 inches is probably the best thing and works well to get high joint density. We do lose some asphalt mix. But if FAA specifies it, there is no problem.

McGhee Tyson , Knoxville, TN did a runway project by cutting back with a pizza cutter mounted on a loader or motor grader. They tacked the joint before placing the adjacent lane. Their joint density was above the first joint density specification, which came out at that time. The joint performed really well.

9. Experience from the New England Region (Skip Parker, Engineer, Stantec)

When the FAA started to require the testing of longitudinal joints for density the accepted construction method for a base course cold joint was to just match the existing lane and on a surface course the method was to saw cut a vertical face and tack the cold lane face. The hot lane was adjusted in depth for compaction and the joint overlap was usually 1 ½ to 2 inches as a standard for both base and surface courses. The overlapped material was manually bumped up at the top of the joint by a rake man on the cold lane and the rolling took place from the cold lane on to the hot lane just spanning the joint by 2 to 3 inches "pinching the joint", the next pass in reverse was set over to approximately 6 inches and run about 100 feet back on to the hot lane and breakdown rolling continued from that point on working across the mat. This system made for very smooth joints when properly done, however, the saw cut surface joints would open up with in just a few years and the process of saw cutting the joints took hours often delaying paving operation. The general paving method for runway or taxiway grade control was to set a "string line" for grade reference at the centerline and to run the first pass on automatic control thus setting the ride and grade. This method works fine for grade control, but produces two cold joints if the pulls are long say 2000 feet and production/ delivery rates to the paver are slow, say less than 300 tons per hour. A very good day of paving on airfields during the early to mid 1980's was 1200 tons in a 12-hour period and 1600 tons was the exceptional day. In an effort to minimize cold joints paving plans were developed with the contractors to shorten the pulls thus having at least warm joints to work with. The compaction of the mat was the issue not the longitudinal joints, the requirements were 98% of the Marshall tests back then or take out the mix. The average for longitudinal joints before showing signs of opening beyond a hairline crack was about 5 to 7 years depending on the mix gradation and airfield usage or lack of.

FAA Criteria in recent times

The paving industry as a whole has changed for the better; plant and paving equipment technology has improved the quality of the HMA produced and placed at airports throughout the US. The requirement for longitudinal joint densities meeting 93.3% of the average Marshall value is lower then other government agencies and in most cases can be obtained with a little extra attention to quality control by the contractor. The older versions of the specifications required the contractor to cease production, determine the cause, and fix the problem. It is the contractor's responsibility to determine the cause and to adjust methods to obtain the required results; however, there is no set time to cease nor what to do following poor joint densities obtained after the second or third rounds. Just recently a penalty clause was put in the specification to reduce payment by 5% for joints with a PWL less than 71%. Through the years several methods have been tried and a few stand out as having merit by adding 1% to 1.5% on average to the densities at the joint.

Methods used and field results over the years

First the paving operations at airports are quite different from highway paving operations in several ways. The paving crew does not have to deal with traffic in adjacent lanes, the use of a string line for reference grades to start the paving is usually required, the trucks can be stacked and waiting for the paver with out causing congestion of the site and the paving is of multi-lane widths up to or over 150 feet for runways and 35 to over 75 feet on taxiways. These conditions allow the use of labor force and equipment to freely use the entire area during the paving operations.

The use of a paving plan to adjust timing of the projected quantities for the day's production is the first consideration in providing quality longitudinal joints. The pulls should be limited in length to gauge the set back time so that a hot joint is made not a cold joint. This is very important on the first string line pass. This is not in the specifications, however, it is a practical approach that contractors generally **do not like** due to reduced production. They would rather pull three long passes in excess of 3000 feet leaving one longitudinal joint overnight, usually on centerline, than pulling six passes at 1500 feet with five hot to warm joints. Also, the FAA requires to stagger the transverse joints by ten feet in each adjacent lane, this requires saw-cutting of both types of joints prior to starting the next day's work. This has been changed in the field by some resident engineers, they require the paving to stop at a predetermined point and saw cut the full width of the pavement on a known grade usually removing five to ten feet of material. This allows for a controlled start on grade and only one transverse joint across the runway or taxiway, this method has had good success in the past and should be considered.

The unconfined edge of the first lane is where any improvement in density of the mat within six inches of the actual edge will help obtain higher densities on the joint. A simple but labor intensive field adjustment to the face of the edge prior to knock down rolling can make a measurable difference in the joint densities average. Compaction of the face of the edge by pushing the bottom of the edge then tamping the face with a lute to compact the loose material has merit. The hot edge material is compacted and the loose material and/ or large aggregate that falls from the edge is removed leaving a neat face prior to rolling. All mixes are different and sometimes following the knockdown rolling the edges give a little and a second tamp helps. This method has gained on average 1 to 1.5 percent density at the longitudinal joint on numerous projects.

Tack coating the edge should be a given requirement for all longitudinal joints with the exception of true hot to hot joints. Tack should be applied uniformly from a pressure system and prior to set back of the paver and trucks, this allows for setting and evaporation of water when emulsion is used. The use of hot-applied cutback asphalts should be considered for joint tacking.

The use of joint heaters ahead of the paver on airport projects to reheat cold joints to about 250 degrees F should be considered as a normal practice. The newer infrared joint heating systems can be run ahead of the pavers, and do not interfere with trucks or traffic. The temperature control systems of these units can bring the joint and surrounding material up to temperature with out burning the asphalt like the older systems. These systems as well as the paver mounted units have been used in New England with good results and have been able to improve the density of joints up to 2 percent to reach acceptable limits.

In 2006, in New England while paving a apron and entrance taxiway during the last week in October into the second week of November with air temperatures in the high thirties to low fifties maximum and with overcast conditions, the contractor requested using and the consultant approved the use of a joint heater for both base and surface courses on this portion of the project and tack to be used prior to heating. The taxiway was approximately 200 ft X 60 ft tying into an apron approximately 650 ft X 400 ft total size with areas left unpaved for future hangars. The lane width pulls were approximately 12.5 ft. wide and the lift thickness was 2 inches for base and top. The joint heater was a pull behind a pick-up truck automated system, which monitored temperature and the contractor's QC also used a hand held temperature gauge. A few different joint construction methods were tried. Based on three cores, the density at the longitudinal joint averaged 97.3 percent compared to that of the mat, which averaged 99.2 percent of the lab density.

It was agreed that extra cores would be cut and no penalties accessed should the experiment result in low density at the joints. The first method used was the manual compaction of the edge prior to knock down rolling, followed by tack and then the heater. This method added a little less then 1 percent density to the joint with two cores taken. The second method was to eliminate the tack coat and just bump compact the edge and heat. The results were very close to the average being slightly less then 0.5 percent lower than the average. There was a failure of the joint heater automatic starting device so two passes were made with out heating. One lane was not touched, just tacked and rolled, this joint showed the lowest of the job with two cores just above 94 percent. The bump compacted joint tested out on average of two cores at 96.3 percent.

On military jobs over the years the use of paver mounted joint heaters and thick coats of tack were the only way the contractors could obtain consistent densities on warm joints. In some cases the consultant have actually had contractor's saw cut one foot square sections of mix from the joint in order to obtain a larger sample area for testing and had improvements in densities of 1 percent over 4-inch diameter cores taken within the same area. The saw cutting, removal of material, and tacking cold joints left overnight was the only acceptable method allowed by some agencies. In many cases inspection of projects after one year of construction has revealed that at saw-cut cold joints, which have opened up well past hairline, the adjacent cold joints done during the same day were still tight. On the military jobs I have been on, longer lane pulls have been economically rewarding.

10. Experience from the Military (Cliff Sander)

Both echelon paving joints and cutback joints with emulsion tack were used in 2002 in the runway longitudinal construction joints in Mt Home AFB, ID. A recent visit (in 2007) has revealed low severity longitudinal cracking in both types of joints (Figure 1).

11. Experience from the Military (John Hamann)

Both cut back and tapered joints were used in a longitudinal joint construction in a New Mexico air force base in 2002. The different steps are shown in Figures 2 through 14. Inspection in 2007

Figure 1. Low severity cracking in joints (Mt. Home AFB, Idaho)

Figure 2. Sawing operations

Figure 3. Removing approximately 200 mm of unconfined edge

Figure 4. Removing cut edge

Figure 5. Power washing cut edge joint

Figure 6. Clean washed cut edge

Figure 7. Cleaning joint prior to tack application

Figure 8. Heavy breakdown roller immediately behind paver rolling joint

Figure 9. Minimum raking

Figure 10. Quality control process during paving operation

Figure 11. Compaction rolling pattern

Figure 12. Rolling joint behind paver

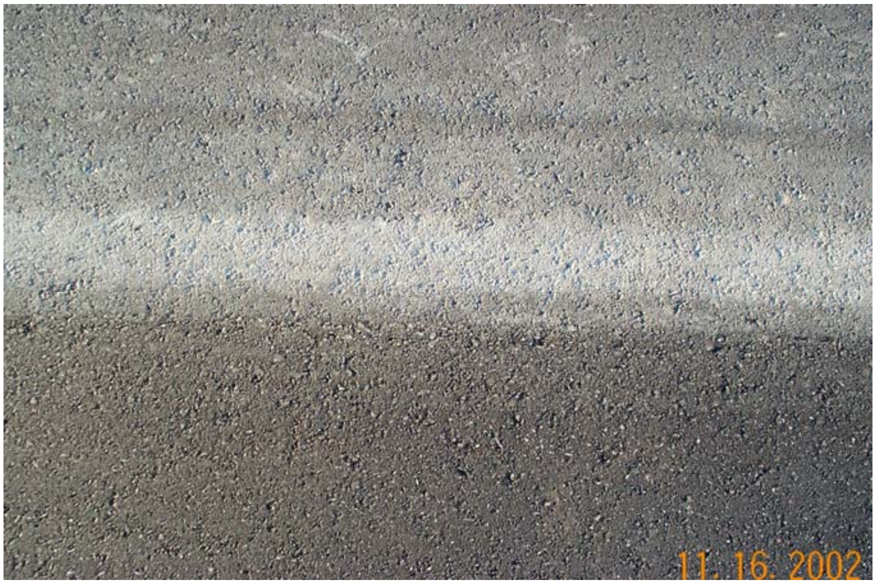

Figure 13. Properly compacted longitudinal joint

Figure 14. Improper joint with not enough material

showed that both joints are holding up well. It appears the tapered method works best if it's done properly, and it saves money by not having to cut back, clean, and remove the asphalt. Also, since the cut back method creates a smooth vertical face, it's more likely to crack.

There is also evidence that joints, which have been constructed by simple overlapping are also working well. In a 1996 runway reconstruction project in New Mexico, the longitudinal joints were not cut back, nor were they compacted as required. The paver simply overlapped the cold mat by a few inches, and the overlap was luted back over the joint. The roller then compacted the overlapped material directly down into the joint. The runway has a current (2007) PCI of 94, and there are no longitudinal cracks anywhere on it. It is believed that while the northern latitudes have colder temperatures which lead to more shrinkage cracking, in the southwest, there is more favorable climate which probably results in longer pavement life.

12. Experience of equipment manufacturer/contractor (Ray-Tech Infrared Corp)

Information was obtained in August 2006 from Ray-Tech Infrared Corp (Tom Allen). It describes the use of joint heating system for the paving of a runway in Mason City, Iowa (Figure 15). The infrared joint heating system was used for both the binder and surface courses. The layers were 50-100 mm thick and each paving lane was 1.5 km long and 3.6 m wide. The average paving speed was 12 m per minute. The joint was a standard vertical joint. The target density was 96 percent.

Intact cores could be obtained from the joints for testing. Test results from the cores indicated that the joint density specifications were either met or exceeded (Table 10).

Table 10. Core Test Data

DATE	LOT	CD1	CD2	CD3	CD4	Average Density	Std Dev	RD
7/21/2006	**Joint 1**	**95.89**	**93.87**	**93.70**	**96.26**	**94.93**	**1.333**	**93.3**
7/21/2006	**Joint 2**	**94.18**	**94.30**	**96.36**	**96.40**	**95.31**	**1.237**	**93.3**
7/22/2006	**Joint 1**	**94.77**	**94.85**	**94.48**	**97.82**	**95.48**	**1.568**	**93.3**
7/22/2006	**Joint 2**	**95.67**	**96.20**	**95.05**	**96.78**	**95.93**	**0.739**	**93.3**
7/24/2006	**Joint 1**	**93.91**	**97.88**	**94.81**	**97.02**	**95.91**	**1.855**	**93.3**
7/24/2006	**Joint 2**	**95.37**	**96.24**	**94.75**	**94.42**	**95.20**	**0.800**	**93.3**
7/25/2006	**Joint 1**	**96.41**	**97.12**	**95.63**	**97.91**	**96.77**	**0.975**	**93.3**
7/26/2006	**Joint 1**	**94.98**	**94.16**	**97.45**	**96.79**	**95.85**	**1.534**	**93.3**
7/26/2006	**Joint 2**	**97.93**	**97.39**	**94.95**	**95.99**	**96.57**	**1.352**	**93.3**
7/27/2006	**Joint 1**	**95.97**	**94.90**	**94.32**	**93.91**	**94.78**	**0.894**	**93.3**
7/27/2006	**Joint 2**	**94.82**	**95.15**	**95.07**	**94.57**	**94.90**	**0.262**	**93.3**
7/27/2006	**Joint 3**	**94.66**	**96.10**	**97.47**	**NA**	**96.08**	**1.405**	**93.3**
7/28/2006	**Joint 1**	**95.60**	**95.03**	**94.37**	**94.37**	**94.84**	**0.593**	**93.3**
7/28/2006	**Joint 2**	**98.05**	**94.46**	**95.57**	**95.04**	**95.78**	**1.580**	**93.3**
7/31/2006	**Joint 1**	**94.98**	**97.50**	**96.22**	**96.88**	**96.40**	**1.078**	**93.3**

Note: CD1; core density 1; Std Dev: standard deviation; RD: Required density

Figure 15. Use of Joint-Heating System

13. Information from New York DOT airport engineer (Lorrin Bird)

Part of the problem with longitudinal joints might be related to the decreased strength of the bond between paving lanes, due to two similar materials being joined at different temperatures. When pavement shrinks due to age or low temperature, the edge joint is much weaker than the middle of the paving lane, which suggests that cracking at the joint due to shrinkage may be a problem even if edge compaction issues were solved. The reduced cracking that was noted to result from the combination of a filler and a designed space between lanes allows the pavement to shrink and expand "freely", yet still appeared to retain the free edges with their potential compaction problems. Cracking problems due to compaction issues at the joint is acknowledged to be a major part of the issue, but bond strength between paving lanes may also be important.

SUMMARY

The following salient points concerning longitudinal joints were made by various airport engineers based on the preceding interviews or inputs.

20. Since the longitudinal joint is a weak point in an airfield pavement, crack usually develops at the longitudinal joint due to shrinkage during cold weather. The incidence and extent of cracking problem is severe in cold climatic regions of the US compared to the hot climatic regions. Cracks are more likely to develop easily on a saw-cut vertical joint compared to a tapered or wedge joint. Figure 1 shows crack, which appeared on a longitudinal on a runway in Mt. Home, AFB, Idaho. This joint was constructed in 2002 with the cutback procedure. This photograph was taken in 2007, five years later.

21. Typical distresses such as cracking and raveling in longitudinal joints happen in about four to five years after construction. Initially a crack occurs along the joint, which leads to secondary cracks. Generally, such cracks are sealed promptly by the maintenance crew before they become a problem. Hot poured rubberized asphalt is usually used for crack sealing. Raveled areas adjacent to joints are patched before they pose Foreign Object Damage (FOD).

22. There have been no additional concerns/problems with joints when polymer modified asphalt binders such as PG 76-22 were used in lieu of conventional binders.

23. Overdoing the luting operation can potentially cause segregation at or near longitudinal

joint.

24. Paving in echelon may not always be practical since enough quantity of HMA may not be available to feed two pavers.

25. According to one agency, rolling from the cold side with a 12-inch (300-mm) overlap on the hot side provides a smoother transition between mats without any bump.

26. The skill and experience of screed operator, raker, and roller operator are probably the most vital component making a good longitudinal joint.

27. One agency requires the use of two pavers working in echelon in center sections of runways and taxiways. A material tranfer vehicle (MTV) is also required for large airport projects.

28. Performance related specifications especially those related to joint density have helped in improving the quality of joints. Possibility of penalty due to low density at joint has forced contractors to use techniques such as cut back of cold joints to improve joint density.

29. Some agencies have reduced the nominal maximum aggregate size from ¾ inch (19 mm) to ½ inch (12.5 mm) to minimize segregation at joint as well as in the mat away from the joint.

30. One agency has a requirement of using a 25-feet wide paver.

31. Some agencies do not require cutting back, application of tack coat, and checking of density for the bottom lift joints.

32. Some agencies require 4 samples per lot for testing joint density. Cores are centered directly over the joint.

33. One agency requires the same compaction (minimum 98 percent of the laboratory density) for joint and the mat away from the joint.

34. Contractors favor the tapered method, if done properly. It is also very economical compared to cutting back procedure. Figures 2 through 7 show a typical saw cutting procedure to remove the low density portion of the unconfined edge of the compacted lane and to obtain a clean vertical face. It is quite obvious that this process is labor intensive and expensive as compared to notched wedge or tapered joint. The experience with the performance of the cutting back procedure is quite similar on both highway and airfield pavements. Whereas this procedure is better than conventional procedure, cracking does takes place after a few years. Many asphalt technologists believe it is probably due to the clean vertical face at the joint.

35. The use of tack coats, especially those with materials such as rubberized asphalt, which can enhance bond, have merit.

36. Longitudinal joints constructed with infrared joint heating system, if done properly, generally produce high density at the joint. This technique has been tried on airfield pavements.

37. According to a contractor's experience it is important to compact the longitudinal joint very promptly with a heavy breakdown roller; provide enough material at the joint; do minimal raking; and compact the joint properly and adequately. Figures 8 through 14 show the sequence of these desired operations.

38. The use of different techniques in constructing longitudinal joints on airfield pavements has resulted in different results in most cases. The effect of switching from one technique to another on the quality of the construction joints is complex and is dependent on many factors which include contractor's experience with a specific technique, available equipment, and climatic conditions.

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APPENDIX B

BEST PRACTICES OF LONGITUDINAL JOINT CONSTRUCTION

A longitudinal construction joint occurs when a lane of Hot Mix Asphalt (HMA) is constructed adjacent to previously placed HMA. Longitudinal joints are inevitable in both highway and airfield pavements, unless paving is done in the echelon formation, which is not always possible due to limited capacity of HMA production to feed more than one paver.

Various types of longitudinal joint construction techniques have been used in asphalt concrete or hot mix asphalt pavements for highway pavements. However, opening (cracking) of the longitudinal construction joint is more a thermal phenomenon (contraction/expansion) rather than a load-associated phenomenon. Therefore, the experience on highways should be considered for airfield pavements as well.

Since airfield runways are very wide compared to most highway pavements, there can be numerous longitudinal construction joints on runways (Figure 1). Airfield runway longitudinal construction joint lengths easily exceed nine times the length of the runways thereby creating a huge maintenance problem (Figure 2) if they are not durable enough to resist traffic and environmental conditions. Therefore, longitudinal joints have a significant effect on the performance and life of an airfield runway.

Damaged longitudinal joints are of very serious concern in airfield pavements. Loose materials from such areas can cause Foreign Object Damage (FOD) to aircrafts, leading to loss of life and equipment. Potential sharp edges along open longitudinal joints can also endanger aircraft. In addition, such joints (in airfield as well as highway pavements) can lead to ingress of moisture and undesirable materials and lead to premature failures in subsurface and ultimately

Figure 1. Aerial view of airport runway showing longitudinal joints

Figure 2. Deteriorated long joints on airfield runway

entire pavement, leading to a cycle of costly and time consuming repairs.

For the above reasons, engineers, consultants and contractors have continuously tried to develop methods for constructing better performing longitudinal joints in pavements. Such methods include overlapping and luting operations; different types of rolling patterns for compacting the joint; and the use of special joint construction techniques and equipment, such as cutting wheel; restrained edge device; notched wedge joint; and joint heaters. At the same time, many agencies have started using specifications that are written specifically for construction of better joints such as density requirements at joints.

There was need for developing a stand alone, comprehensive document on best practice(s) of longitudinal joint construction for airfield pavements. This document has been developed for practicing airfield engineers to fulfill that need. It is based on literature review, experience of airfield engineers, and evaluation of FAA specifications as reported in the final report of AAPTP Project 04-05, “Improved Performance of Longitudinal Joints on Asphalt Airfield”.

The best practices for constructing a conventional longitudinal joint shall be presented first followed by the recommended best practices for special longitudinal joint construction techniques to obtain durable joints.

CONVENTIONAL LONGITUDINAL JOINT CONSTRUCTION – BEST PRACTICES

Longitudinal joints can be broadly classified as follows:

- **Hot Joints**

  Hot joints are produced when two or more pavers are operating in echelon (parallel) as shown in Figure 3. The pavers are spaced closely such that the lane placed first does not cool significantly before the second lane is placed adjacent to the first lane. When the longitudinal joint is compacted, the HMA on both sides of the joint is essentially

Figure 3. Paving in echelon

within the specified compaction temperature range and, therefore, a hot joint is produced. Constructed properly, a hot longitudinal joint appears almost seamless and invisible and produces the highest density when compared to semi-hot and cold joints. As mentioned earlier, in a majority of cases, echelon paving is not possible due to limited capacity of HMA production to feed more than one paver. However, attempt should be made to pave in echelon at least the central portions of runways and taxiways. This would minimize the number of longitudinal joints in the area, which is subjected to direct application of severe aircraft loadings.

- **Semi-Hot Joints**

A semi-hot joint or a warm joint is produced when the paver is restricted to proceed for a certain distance before moving back to place the adjacent lane. The HMA in the first lane generally cools down to a temperature of about 120 to 140F (49 to 60C) before the adjacent lane is placed. Semi-hot joint is by far the most commonly used joint type on HMA paving projects. Numerous studies have demonstrated that the semi-hot joint densities are significantly lower than the mat interior densities.

- **Cold Joints**

A cold joint is produced when the first paved lane has cooled overnight or more before the adjacent lane is placed to match it. A cold joint will also be produced if paving of the first lane is carried too far ahead such that the HMA has cooled well below 120 F (49 C).

Construction of durable longitudinal joints is an art, which requires a team of skilled people with paving experience. The team primarily consists of the paving foreman, paver operator, raker or screed man, and roller operator. The team should follow good construction practices, which are presented here.

Paving and Compacting the First Lane

One of the most important requirements in obtaining a good longitudinal joint is that the paver operator should place the first lane in a uniform, unwavering line. Attention to this detail will simplify the placement of the adjacent lane with a uniform overlap.

Another important requirement in obtaining a durable joint is proper compaction of the unsupported edge of the first lane (cold lane). The unsupported edge typically has a slope of approximately 60 degrees. Obviously, the wedge formed by this slope at the edge does not receive as much compaction as the mainline away from the edge.

Breakdown compaction with a vibratory or static steel wheel roller can be done with the roller operating in three different locations in respect to the unsupported edge of the first lane.

First, rolling can begin with the edge of the roller drum away from the unsupported edge. However, this practice will cause the HMA to shove or move out due to shear loading on the mix at the edge of the steel drum. The extent of this transverse movement will depend upon the stiffness of the HMA mixture. This movement will (a) typically cause a crack to be formed at the edge of the drum, and (b) create a depression at the unsupported edge so that it will be very difficult to match the joint when the adjacent lane is placed.

Second, rolling can begin with the edge of the steel drum right on the unsupported edge of the first lane. Although this practice will eliminate cracking at the edge of the roller drum, it would still shove and push out the mix underneath the drum. Therefore, it would not be possible to obtain adequate density at the unsupported edge.

Third, rolling can begin with the edge of the steel drum extending over the edge of the first lane by about 6 inches (150 mm). At this position, the edge of the drum does not exert any shear force in the HMA because it is out hanging in the air. Therefore, there is minimal transverse movement of the HMA and reasonable amount of density is obtained at the unsupported edge of the lane. Obviously, this third practice of compacting the unsupported edge will produce the best results and is, therefore, recommended.

Pneumatic tired rollers are typically used in the intermediate phase of HMA compaction. However, they are sometimes used for breakdown rolling. In that case, pneumatic tired rollers do not perform as well as steel wheel rollers in constructing longitudinal joints. During rolling, the outer tire tends to roll over the unsupported edge of the first paved lane, which complicates the make-up of the joint when the adjacent lane is placed and compacted.

Paving the Second Lane and Overlapping

It is important to control the height of the uncompacted HMA in the hot lane. The height of the uncompacted HMA should be about 1¼ inch (32 mm) for each one inch (25 mm) of the compacted lift thickness in the cold lane. For example, if the compacted HMA in the cold lane is two inches (51 mm) thick, the height of the uncompacted HMA in the hot lane should be 2½ inches (64 mm), which is ½ inch (13 mm) above the level of the compacted mat.

Another key point in obtaining a good longitudinal joint is proper overlapping during the paving operation. The end gate of the paver should extend over the top surface of the previously placed HMA by a distance of approximately 1 to 1½ inches (25 to 38 mm). Attention to this detail will not only provide the requisite amount of HMA on top of the joint for proper compaction, it will require minimal or no raking and luting. If the overlap is consistent and within this suggested range, it will be better to avoid raking or luting altogether.

Sometimes, an existing HMA is milled in one lane and a new HMA lift is placed as an inlay. In this case, the edge of the old, compacted HMA is almost vertical due to milling operation unlike the slope or wedge typically formed by the edger plate on the paver screed. In such cases, the amount of overlap should be no more than about ½ in (13 mm) to obtain a good longitudinal joint.

Raking and Luting

Raking or luting at the longitudinal joint can be eliminated if the minimal overlapping as recommended previously is followed. An excessive overlap will require removal of extra material from the cold lane onto the hot lane otherwise the aggregate in the mix remaining on the compacted lane will get crushed resulting in raveling. When that happens, the excessive overlapped material on the cold lane may be “bumped” with a lute onto the hot mat **just** across the joint as shown in Figure 4. The bump should lie just above the natural slope or the wedge at the edge of the cold lane. Since the HMA on the slope is usually not adequately compacted, there is a good potential that the roller can crowd and compact the bump into the joint.

Quite often, the person doing the raking sets the rake down on the compacted mix of cold

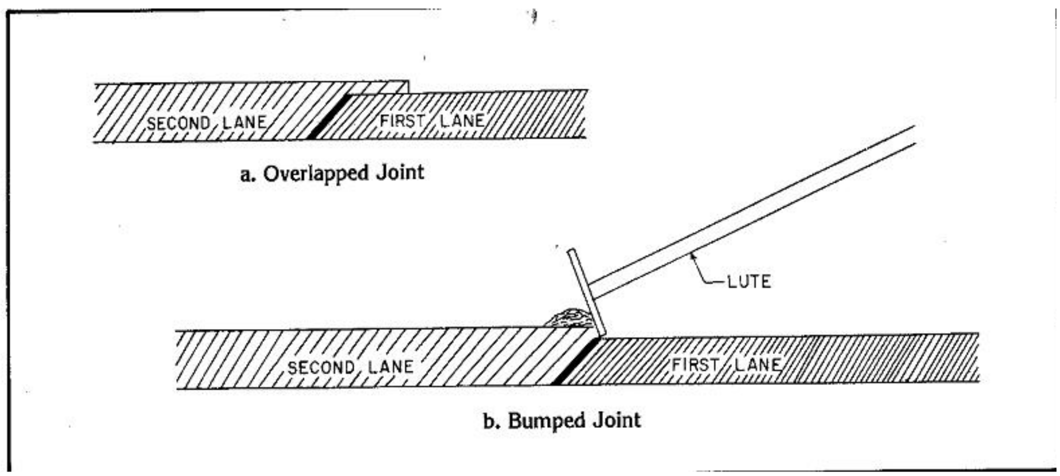

Figure 4. Excessive overlapped material on the cold lane needs to be "bumped" with a lute onto the hot mat just across the joint

lane and pushes the overlapped material farther across the joint on top of the uncompacted HMA in the hot lane. Due to this improper raking, the mix essentially remains at the same elevation on both sides of the joint and too high on the hot lane a short distance away from the joint. The problem is that the mix on the cold side of the joint is compacted and the mix on the hot side of the joint is uncompacted. Unless the loose HMA on the hot side is high–about ¼ inch (6 mm) higher for each one inch (25 mm) of compacted thickness–it is not possible for the roller to compact this mix adequately resulting in very low density. Moreover, the higher elevation of the loose HMA on the hot lane a short distance away also causes roller drum to bridge on the mat on the hot side of the joint, further contributing to low density. This undesirable construction practice creates two problems. First, the HMA adjacent to the joint toward the hot lane starts to ravel under traffic due to inadequate compaction (high air voids), which also allows intrusion of water into the pavement. Second, the HMA surface adjacent to the joint toward the hot lane is depressed and, therefore, ponding of rainwater will occur, which will deteriorate the joint.

Sometimes, there is a tendency to broadcast the raked material onto the HMA in the hot lane (Figure 5). This is not only undesirable for obtaining a good longitudinal joint, this practice affects the surface texture of the mat adversely.

Compacting the Longitudinal Joint

Obtaining adequate compaction at the joint is the final key in obtaining a durable longitudinal joint. Extensive field research by the National Center for Asphalt Technology (NCAT) has indicated that the joints with high densities generally showed better performance than those with relatively low densities.

The most efficient joint compaction method, also indicated in the NCAT field research, is

Figure 5. Bad practice of broadcasting the raked material onto the hot lane

Figure 6. Rolling from the hot side with a 6-inch overlap on cold lane

to roll the longitudinal joint from the hot side overlapping the cold lane by approximately 6 inches (150 mm) as shown in Figure 6. The steel wheel roller can be operated in vibratory or static mode, preferably the vibratory mode to obtain better compaction. This rolling pattern allows most of the weight of the roller to compact the HMA in the hot lane as well as at the joint. The HMA at the edge of the hot lane is constrained due to the presence of cold lane and is compacted promptly without any significant cooling, thus resulting in high density. This pattern is also effective if the pavement has different cross slopes at the longitudinal joint.

Desirable Compaction Level at the Longitudinal Joint

Compact the joint promptly so that the minimum acceptable joint density is 90.5 percent of the theoretical maximum density (TMD), that is, no more than 9.5 percent in-place air voids at the joint. The minimum acceptable mat density (away from the joint) shall be 92.8 percent of the

TMD, that is, no more than 7.2 percent in-place air voids in the mat. Evaluation for acceptance of each lot of in-place pavement for joint density and mat density shall be based on PWL. The contractor shall target production quality to achieve 90 PWL or higher. The preceding acceptance criteria are based on Section 401-5.2 of the FAA Engineering Brief 59A dated May 12, 2006.

Usually, it is not possible to obtain an accurate density measurement right on the joint using a nuclear gauge, which is centered on top of the visible line between the cold and hot lanes. This is because the nuclear gauge cannot be placed flat across the joint without rocking. The compacted HMA on one side of the joint is usually higher than the other side causing uneven surface across the joint. Similarly, the nuclear gauge cannot be placed flat on a joint with a crown.

Therefore, the joint density is best measured by obtaining a 6 inch- (150 mm) diameter core centered on top of the visible line between the two lanes. It should be noted that the core would not consist of equal volumes of mix from the cold lane and the hot lane. Due to the presence of natural slope at the unconfined edge of the cold lane, most of the mix in the core will come from the cold lane. This is all right because the density of the cold side is of major concern.

Echelon Paving

As mentioned earlier, hot joints are produced when two or more pavers are operating in echelon (parallel) as shown in Figure 3. Usually the pavers are within 30 feet (9 meters) of each other. The amount of overlap is critical in obtaining a durable hot joint. The end gate of the trailing paver should not extend more than one inch (25 mm) onto the adjacent HMA placed by the leading paver. This will prevent the end gate of the screed of the trailing paver from dragging on the HMA already placed by the leading paver. Careful attention to this overlap will not require any raking either, which is difficult to do by standing on the uncompacted mat of the first lane.

Breakdown roller that is compacting the HMA behind the leading paver should be kept at least 6 inches (150 mm) away from the edge of the mat. After the trailing paver places HMA against the uncompacted edge of the first lane, the rollers that are working behind the trailing paver are used to compact the HMA on both sides of the joint. If the above procedures of proper overlap and compaction are followed, a virtually seamless pavement can be obtained.

Tack Coating Longitudinal Joints

According to some engineers, applying a tack coat on the face of the unconfined edge of the cold lane ensures a better bond (adhesion) and seal of abutting HMA lanes. The tack coat usually consists of asphalt cement; emulsion; or hot poured, rubberized asphalt sealer (also called joint adhesive). Recent NCAT field research has demonstrated that the use of hot-poured, rubberized asphalt sealer as a tack coat (about 1/8 inch or 3 mm thick) (joint adhesive) on the face of the first paved lane produced the most durable longitudinal joints. Therefore, it appears that thick tack coats may be more effective than generally used thin coats of asphalt cement or emulsion.

Most engineers would agree that a tack coat must be applied to a face, which has been exposed to weathering and traffic for a period of time to ensure good bond between the abutting lanes.

RECOMMENDED BEST PRACTICES FOR CONSTRUCTING DURABLE LONGITUDINAL JOINTS ON AIRFIELD PAVEMENTS

Because of inadequate information on performance of different longitudinal joint construction techniques on airfield pavements, the information available on highway pavements has been used to recommend the following best practices.

It is preferable to produce hot longitudinal joints by operating two or more pavers in echelon (Figure 3). But in a majority of cases, echelon paving is not possible especially with limited capacity of HMA production to feed more than one paver. However, attempt should be made to pave in echelon at least the central portions of runways and taxiways. This would minimize the number of longitudinal joints in the area, which is subjected to direct application of severe aircraft loadings**.**

If echelon paving is not possible then it is recommended to use the following best practices for constructing durable longitudinal joints. These practices are listed in decreasing order of preference.

5. Combination of Notched Wedge Joint, Rubberized Asphalt Tack Coat (Joint Adhesive), and Minimum Joint Density Requirements

Construct a notched wedge longitudinal joint. The unconfined edge of the first paved lane has a vertical notch at the edge generally ranging from ½ inch (13 mm) to 3/4 inch (19 mm) in height depending upon the nominal maximum aggregate size (NMAS) of the HMA mixture. Generally, a vertical notch of about ½ inch (13 mm) height is considered adequate for most surface course mixtures. This height has given excellent results in NCAT and Wisconsin studies, and in Michigan. The height of the notch can be increased in case of binder and base course mixtures, which have a larger NMAS. Figure 7 shows a schematic of a notched wedge joint. At the bottom of the vertical notch, the wedge is provided a taper of 1:12 (vertical: horizontal). To avoid

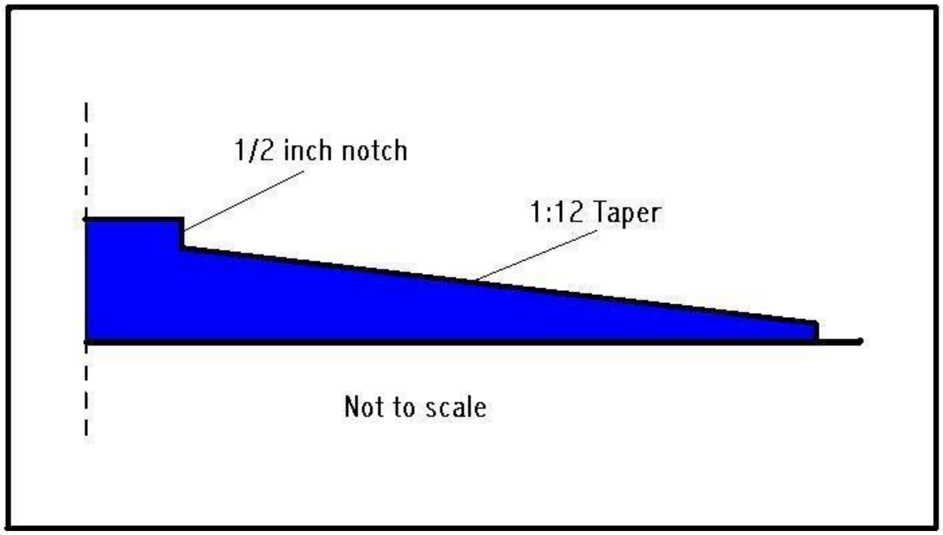

Figure 7. Schematic of notched wedge joint

feathering the taper to zero height, which may cause dragging of the HMA, it is recommended to end the taper with a minimal height such as 3/8 inch (9.5 mm) to avoid dragging of the material.

Usually a loaded wheel, which is attached to the paver, is used to compact the taper (Figures 8 and 9). Typically, the roller weighs 100 to 200 lbs (45 to 91 kg) and is approximately 14 inches (356 mm) wide by 12 inches (305 mm) in diameter. There is no need to compact the taper with a conventional steel or pneumatic tired roller because it will simply destroy the vertical notch.

The overlap layer of the adjacent paving lane is required to be placed and compacted within 24 hours unless delayed by inclement weather. The vertical notch and taper are tack coated with rubberized asphalt binder prior to placing the overlap wedge as described later. The notched wedge joint can be formed by using a homemade sloping steel plate attached to the inside corner of the paver screed extension. However, commercial devices are now available which can be attached to the screed to form the notched wedge joint.

The notched wedge joint does not always work well for thinner HMA lifts. Ideally, it gives the best results with a minimum lift thickness of 1½ to 2 inches (37 to 51 mm). On the other hand, excessive thick lifts produce a long taper, which may not be desirable. In those cases, the length of the taper is generally restricted to 12 inches (305 mm). The top course taper shall overlap and slope in the opposite direction of the lower course taper.

The use of notched wedge joint allows continuous paving of a lane for an entire day without the typical specification requirement that all lanes be resurfaced to within one load of the same point-of-ending at the completion of each day's paving operations. This eliminates the need for contractors to backup their paving equipment for paving the adjacent lane. The result is less

Figure 8. Small roller attached to paver compacts the taper of notched wedge joint

Figure 9. View of finished notched wedge joint

down time and more paving time, which may increase production by 20 to 30 percent. In addition, the number of transverse construction joints is minimized resulting in a smoother ride.

One of the most important requirements in obtaining a good longitudinal joint is that the paver operator should place the first lane in a uniform, unwavering line. Attention to this detail will simplify the placement of the adjacent lane with a uniform overlap.

After the first lane (cold lane) is paved with a notched wedge and compacted, a rubberized asphalt tack coat (Crafco pavement joint adhesive Part Number 34524 or equivalent) is applied on the face of the unconfined edge of the cold lane. The thickness of the tack coat is about 1/8 inch (3 mm) on the slope of the HMA edge. The rubberized asphalt tack coat need not be applied on the entire taper. It is considered adequate to apply it on the vertical notch and the top 3-4 inches (76-102 mm) wide band of the taper.

The rubberized asphalt sealant material is supplied as a ready to use solid material in containers. It is melted in a jacketed double boiler type melting unit, which is equipped with both agitation and re-circulation systems. The melting unit must be capable of safely heating the sealant to 400 F (204 C). The sealant is best applied using a pressure feed wand. An applicator shoe attached to the end of the wand helps in spreading the sealant uniformly on the slope of the unconfined edge. Figures 10 and 11 show the application of rubberized asphalt tack coat on a paving project. Application excesses should not exceed more than ½ inch (13 mm) at the top of the joint.

The sealant should preferably be applied within four hours of the time that the adjacent HMA lane is placed. The heat from the HMA in the adjacent lane and the roller pressure causes the sealant to adhere strongly along the joint face resulting in a strong bond between the two

Figure 10. Application of rubberized asphalt tack coat at joint ahead of paving

Figure 11. Application equipment for rubberized asphalt tack coat (joint adhesive)

lanes and providing a built-in sealer at the joint.

The adhesive has a consistency of a thick pancake mix. It hardens quickly and after a short period it feels slightly tacky to the touch. During placement of the second lane, the adhesive may sometimes stick to the tires of the haul trucks if pulling across the longitudinal joint area. Therefore some caution is needed during construction.

After the rubberized asphalt tack coat is applied, the adjacent lane (hot lane) is placed. It is important to control the height of the uncompacted HMA in the hot lane. The height of the uncompacted HMA should be about 1¼ inch (32 mm) for each one inch (25 mm) of the compacted lift thickness in the cold lane. For example, if the compacted HMA in the cold lane is two inches (51 mm) thick, the height of the uncompacted HMA in the hot lane should be 2½ inches (64 mm), which is ½ inch (13 mm) above the level of the compacted mat.

Another key point in obtaining a good longitudinal joint is proper overlapping during the paving operation. The end gate of the paver should extend over the top surface of the previously placed HMA by a distance of approximately 1 to 1½ inches (25 to 38 mm). Attention to this detail will not only provide the requisite amount of HMA on top of the joint for proper compaction, it will require minimal or no raking and luting. If the overlap is consistent and within this suggested range, it will be better to avoid raking or luting altogether.

Obtaining adequate compaction at the joint is the final key in obtaining a durable longitudinal joint. The most efficient joint compaction method is to roll the longitudinal joint from the hot side overlapping the cold lane by approximately 6 inches (150 mm) as shown in Figure 6. The steel wheel roller can be operated in vibratory or static mode, preferably the vibratory mode to obtain better compaction. This rolling pattern allows most of the weight of the roller to compact the HMA in the hot lane as well as at the joint. The HMA at the edge of the hot lane is constrained due to the presence of cold lane and is compacted promptly without any significant cooling, thus resulting in high density. This pattern is also effective if the pavement has different cross slopes at the longitudinal joint.

Compact the joint promptly so that the minimum acceptable joint density is 90.5 percent of the theoretical maximum density (TMD), that is, no more than 9.5 percent in-place air voids at the joint. The minimum acceptable mat density (away from the joint) shall be 92.8 percent of the TMD, that is, no more than 7.2 percent in-place air voids in the mat. Evaluation for acceptance of each lot of in-place pavement for joint density and mat density shall be based on PWL. The contractor shall target production quality to achieve 90 PWL or higher. The preceding acceptance criteria are based on Section 401-5.2 of the FAA Engineering Brief 59A dated May 12, 2006.

The joint density should be measured by obtaining a 6 inch- (150 mm-) diameter core centered on top of the visible line between the two lanes.

6. Rubberized Asphalt Tack Coat (Joint Adhesive) and Minimum Joint Density Requirements

This practice is similar to that in Item 1 above except that no notched wedge joint is used. The first lane (cold lane) is paved as usual with the normal, unconfined edge slope. A rubberized asphalt tack coat is applied on the entire face of the unconfined edge of the cold lane using the procedure described in Item 1.

Best practices for paving and compacting the first lane, paving the second lane and overlapping, raking and luting, and compacting the longitudinal joint should be followed as given in Item 1.

The minimum joint density and mat density requirements should also be same as Item 1.

7. Notched Wedge Joint and Minimum Joint Density Requirements

This practice is similar to that in Item 1 above except that a conventional tack coat material (which is used on the main line) is applied to the entire face of the notched wedge joint in lieu of rubberized asphalt material.

Best practices for paving and compacting the first lane, paving the second lane and overlapping, raking and luting, and compacting the longitudinal joint should be followed as given in Item 1.

The minimum joint density and mat density requirements should also be same as Item 1.

8. Cutting Wheel and Minimum Joint Density Requirements

The cutting wheel technique involves cutting at least 1½ - 2 inches (38-51 mm) of the unconfined, low-density edge of the first paved lane after compaction, while the mix is plastic. On airfield pavements, strips as wide as 6 inches (150 mm) have been cut to meet or exceed the FAA density requirements at the joint. The cutting wheel is usually 10 inches (254 mm) in diameter with the cutting angle about 10 degrees from the vertical towards the mat to be cut and about 45 degrees on the open side to push the trimmings away (Figure 12). The cutting wheel can be mounted on an intermediate roller or a motor grader (Figure 13). The HMA trimmings can be collected and recycled. A reasonably vertical face at the edge is obtained by this process

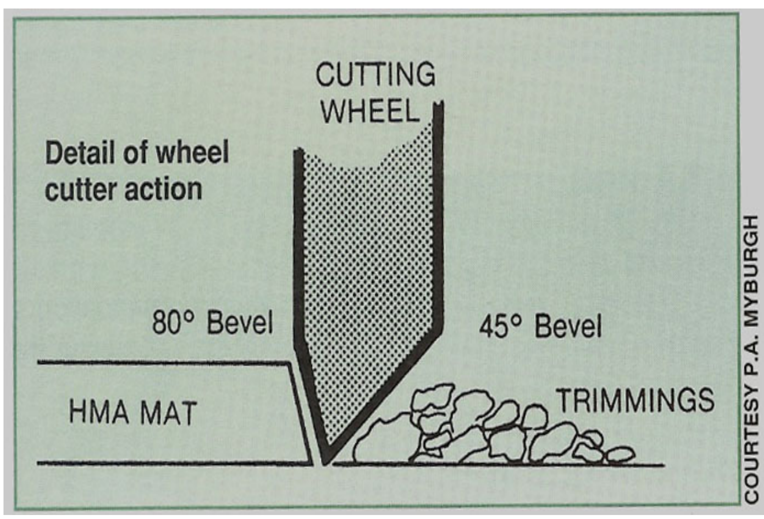

Figure 12. Schematic of cutting wheel

Figure 13. Cutting wheel mounted on a motor grader

Figure 14. View of the edge after the use of cutting wheel

(Figure 14), which is then tack coated before placing the abutting HMA. It is important to restrict the overlap to about ½ inch (13 mm) while placing the adjacent lane.

It is very important to have a skilled cutting wheel operator, who must cut straight without wavering and a skilled paver operator, who must closely match the cut line with minimal overlap.

Best practices for paving and compacting the first lane, paving the second lane and overlapping, raking and luting, and compacting the longitudinal joint should be followed as given in Item 1. The minimum joint density and mat density requirements should also be same as Item 1.

The preceding four best practices have been recommended based on the long-term performance of various longitudinal joint construction techniques in field research projects (largely highway projects), the feedback from airfield engineers, and practical considerations. Other longitudinal joint construction techniques such as infrared joint heating and HMA joint tape may be developed further in the near future and may be added to the list of best practices. However, at this time sufficient long-term field performance data are not available to make such recommendations.