Best Practices for Longitudinal Joint Construction and Compaction

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16. Abstract

Joints are the weakest area of an asphalt pavement and longitudinal joint cracking occurs for a number of reasons that lead to low density, low indirect tensile strength, and high permeability at the joint. The purpose of this study was to evaluate the different joint construction techniques used in South Carolina and perform comprehensive testing and analysis to compare the effects of multiple variables on the quality and performance of the longitudinal joints.

Nine asphalt resurfacing projects were selected for sampling to make observations, conduct field testing, and cut cores from the joint and interior portion of the pavement for lab testing. The selected asphalt pavement projects consisted of three different surface type mixes (surface type A, B, and C), two longitudinal joint construction techniques (safety edge and butt joint), and one rolling pattern (hot overlap).

Like other research studies, the laboratory performance of longitudinal joint was significantly worse than interior portions of the mat with respect to density, permeability, and/or indirect tensile strength (ITS). The compacted asphalt pavement density shared a direct and indirect relationship with ITS and permeability, respectively. The safety edge did not significantly improve the quality or performance of longitudinal joint. Through statistical analysis, surface mix type and depth of the compacted asphalt pavement were found to influence the performance of the joint in laboratory testing. Field testing, on the other hand, generally did not yield significant differences between the pavement interior and joint edge with respect to in-situ density or infiltration.

The results of this study informed the development of a set of best practice guidelines for longitudinal joint construction along with recommendations for further assessment prior to developing new specifications for joint construction.

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Executive Summary

The primary objective of this study was to identify best practices for construction of longitudinal joints in asphalt pavements in South Carolina and subsequently create a best practices guide informed by the research and make recommendations for potential specification revisions. To accomplish this objective, several tasks were completed with outcomes that contributed to the overall goal.

A review of the relevant literature on the topic of longitudinal joint construction was completed to identify findings from previous studies and best practices employed by transportation agencies and paving contractors from around the world. The findings from the literature informed the field and laboratory evaluation in this study and provided the foundation for the best practice guidelines developed as part of this study.

Two surveys were conducted as part of this effort to gain an understanding of the state-of-the-practice with respect to longitudinal joint constructing in South Carolina and the United States. The first survey was administered to SCDOT personnel and South Carolina asphalt paving contractors. There were a total of 40 responses to this survey (35 from the SCDOT and 5 from South Carolina contractors). The national survey yielded 26 responses from transportation agencies across the US. The information gathered from these surveys provided an understanding of practices used for joint construction both in South Carolina and throughout the US. The survey also identified issues and recommendations related to joint construction.

A field and laboratory study was designed to measure the relative performance of longitudinal joints compared to the interior of the pavement. Nine asphalt resurfacing projects were included in this study. For each project, the research team conducted field testing to measure the following:

- Pavement surface temperature during paving and compaction
- Pavement density profile across the width of the pavement using a density gauge
- Pavement infiltration at the interior of the pavement and the joint

In addition, sets of cores were collected from the pavement interior and joint from multiple locations at each project. These cores were then evaluated in the lab to measure the density, permeability, and indirect tensile strength (ITS). The results of the field and laboratory testing were compare the joint performance to the interior pavement performance. The results of the lab testing had lower variability than the in-situ testing and generally indicated that the joints exhibited lower density, higher permeability, and lower strength than the cores from the interior of the pavement section. The in-situ evaluation exhibited similar trends, but the differences were generally not statistically significant due to the higher variability of the results.

This study observed construction of longitudinal joints in projects in South Carolina and compared the performance of the joint and interior portion of the hot lane. Based on the density, permeability, and indirect tensile strength (ITS) results from this research, conclusions related to the performance of longitudinal joints considering individual site, surface mix type, thickness, and nominal maximum aggregate size (NMAS) were made. In addition, the effectiveness of in-place density, lab and in-place infiltration, and ITS were evaluated based on the results.

Based on the results of this study, the following conclusion were made:

- Out of the nine asphalt surfacing construction projects evaluated in this study, eight projects showed significant differences between the interior portion of the pavement and the joint based on density, permeability, and/or ITS results.

- None of the projects exhibited a statistically different in place density (gauge density) when comparing the interior of the pavement to the edge of the joint. Only one of the projects exhibited statistically different in-situ infiltration rates between the pavement interior and joint edge.
- As the density of asphalt increased, the ITS increased linearly and as the density of asphalt decreased, the lab permeability increased exponentially.
- All the field testing results had higher variability than lab testing results, indicating the field testing may not be as reliable for checking the quality of the joint.
- The density gauges were more capable of accurately measuring the density of the interior portion the lane when using the cores as a baseline, but the accuracy decreased when measuring density of the joint. This is likely due to the fact that the joint density in the field was measured next to the joint, but the cores were taken on the joint.
- The safety edge joint technique without compaction on the wedge did not significantly improve the performance of the joint compared to the butt joint technique.
- Using the Surface type A or B mix and increasing the depth of asphalt pavement, statistically improved density of the joint.
- The survey indicated that more research needs to be conducted in South Carolina to determine the effectiveness of other joint construction techniques.

The results and conclusions informed as set of recommendations that addressed both implementation and future study. The implementation recommendations focused on a set of Longitudinal Joint Construction Best Practice Guidelines (Appendix C) that can serve as a resource for SCDOT and contractor personnel. These guidelines address: Planning and Design, Mix Design, Mix Delivery, Joint Preparation, Tack Application, Paver Operation, Roller Operation, Quality Control, and Training. In addition, although not recommended at this point in time, recommendations were made to further monitor longitudinal joint performance during construction before developing longitudinal joint specifications.

CHAPTER 1. Introduction

Plant mixed asphalt (hot mix asphalt [HMA] and warm mix asphalt [WMA]) are the most commonly used pavement materials in pavement construction for a number of reasons, including (McDaniel et al. 2012 and Transportation Research Board Committee 2001):

- They allow traffic to be opened quickly after construction
- They allow traffic flow in an adjacent lane during construction
- The cost of materials is more economical compared to concrete
- Easy maintenance
- They are recyclable
- They have good skid resistance
- They absorb heat, which helps melt snow
- They are more flexible and resistant to brittle cracking

Although asphalt roads provide many benefits, paving one lane at a time creates a problem because it requires a longitudinal joint between adjacent lanes. With most construction materials, a joint is often considered the weakest link and asphalt pavements are no different. The joint is cited as the most common location of premature failure, and even the most durable asphalt pavement is susceptible to longitudinal joint cracking. Therefore, it is important to research and identify ways to improve the durability of longitudinal joints to improve the performance and service life of asphalt pavements and reduce life-cycle costs. Because of the importance of longitudinal joints, highway agencies have been actively researching methods to improve the longevity of asphalt pavements by improving the quality of joints since at the least the 1960s (Buncher et al. 2012).

When fresh, hot asphalt is placed next to a substantially cooler, compacted pavement, the resulting joint and surrounding area will typically form a weak plane that is less dense and more permeable than the interior portions of the pavement mat. This creates issues because when the permeability is high, the chance of water and air infiltrating the pavement is greater, which can accelerate the deterioration near the joint due to moisture, freeze-thaw, and oxidation. The damage from water and air can cause cracking and raveling in the beginning and allow more water and air to penetrate, leading to even greater deterioration such as joint failures and potholes (Williams 2011). Longitudinal cracking is illustrated in the photos provided in Figure 1.1.

Longitudinal joint cracking issues continue to be seen due to the limited budgets and time to complete pavement construction on a deadline, thus potentially limiting focus on improving the quality of longitudinal joints. Therefore, it is important to pay particular attention to proper practices to construct quality, long-lasting joints to minimize the occurrence of premature joint failures. In response to these common failures, some state departments of transportation (DOTs) have conducted research and developed best practice guidelines specific to the conditions in their state (Buncher et al. 2012; McDaniel et al. 2012; Kandhal et al. 1997; Williams et al. 2013). These research studies have indicated that creating quality joints requires understanding of proper joint construction techniques, appropriate methods to measure the quality of joints after construction, and specifications for the quality of constructed joints.

(a) (b) (c)

Figure 1.1: Longitudinal joint cracking

Across the country and around the world, many longitudinal joint construction techniques have been studied with varying degrees of success and even contradictory results with the same techniques. This is due to the fact that joint quality is influenced by a number of factors such as the type of mix and condition of the site, and there is no “silver bullet” solution to joint construction. Some of the reported factors that affect the quality of joints include (Buncher et al. 2012):

- Lift thickness
- Nominal maximum aggregate size (NMAS) of the asphalt mix
- Mix type
- Lane configuration
- Traffic control requirements
- Project scheduling
- Roller patterns
- Special joint tools (e.g., notched wedge joint and cutting wheel)
- Joint adhesives
- Joint sealers

Problem Statement

In an asphalt pavement, joints are considered the weakest part of the pavement as they frequently fail quicker than the surrounding pavement areas, resulting in the need for costly repairs. In particular, longitudinal joints typically tend to exhibit performance problems before the rest of the pavement structure. Improving construction practices specific to the compaction of longitudinal joints in HMA pavements could extend the life and decrease the life-cycle cost of these pavements by preventing premature failure at longitudinal joints.

Study Objectives & Scope

The overarching goal of this study was to identify best practices for construction of longitudinal joints in asphalt pavements in South Carolina and subsequently create a best practices guide informed by the research and make recommendations for potential specification revisions. To accomplish this primary objective, the scope of this study included a series of tasks discussed in the individual chapters within this report.

Chapter 2. Conduct a literature review to compile basic and detailed information about longitudinal joint construction practices.

Chapter 3. Conduct a survey to ascertain the state-of-the-practice related to longitudinal joint construction.

Chapter 4. Perform comprehensive testing and analysis to compare the effects of multiple variables on the quality and performance of longitudinal joints.

Chapter 5. Develop a document of best practices for joint construction.

Chapter 6. Summarize conclusions and develop recommendations.

CHAPTER 2. Literature Review

Longitudinal joints are formed when pavement lanes are paved one lane at a time to minimize traffic disruptions by allowing traffic to flow on the adjacent lane. When a first lane is constructed, the fresh asphalt mix is placed resulting in an unconfined edge where there is no structural support to restrain new mix from sloughing laterally during compaction. On the other hand, the second lane will have a confined edge during compaction at the joint of two lanes where the first paved lane and the new second lane meet. Therefore, two uneven surfaces can form at the joint due to the confined and unconfined edges (McDaniel et al. 2012). Regarding temperature, the edge of the first paved lane will cool down to the ambient temperature while the edge of the second lane is paved, creating bonding issues due to temperature differences. The structural support and temperature differences of the two lanes generate problems such as lower density, higher permeability, higher segregation, and lower adhesion at the joint (Estakhri et al. 2011; Williams 2011). Zinke et al. noted that a lack of material at the interface of the two pavement lanes is also responsible for low density at the joint (2008). These factors and others will influence the durability of hot mix asphalt (HMA) pavements. Longitudinal joints are identified as the weakest part of HMA pavements, and more problems and failures are likely to occur at the longitudinal joint than the wheel paths, edges, and other parts.

Longitudinal joint cracking can occur at a weak joint resulting from high air void content or separations at the surface which can connect to other voids within asphalt layers to initiate deterioration at the joints by allowing air and water to infiltrate deeper into the pavement. Once water infiltrates asphalt layers, debonding can occur due to stripping and reduce the service life of a pavement. In the colder environments of northern regions, ingress of water can cause joint failures due to freezing and thawing cycles. When air enters the asphalt pavement, it can oxidize the asphalt binder which accelerates the aging process and lowers the bond strength. Longitudinal joint cracking issues have been the focus of many research efforts and many joint construction practices have shown to be successful in improving the performance. However, many states have identified various methods as best longitudinal joint practices based on field and lab performance. Therefore, more research is needed to evaluate the practices and conditions in each state.

In the typical pavement construction process, the first lane is allowed to cool after placing a fresh mix of asphalt and compacting with rollers. Then, the second lane is laid adjacent to this lane with the same fresh mix material. When hot asphalt meets the existing cooled pavement joint, a joint is formed between the two pavements—the weak link. When placing the new asphalt for the first lane, the density at the edge of the asphalt will typically be lower than the density of the central portions of the mat because the edge is unconfined during compaction. Estakhri et al. showed there is an area of low density at the edge of the first paved lane, which was confirmed in the literature that stated the same point (2011). In this report, the first lane is referred to as the “cold lane.” When placing the fresh asphalt on the second lane, the mix may not bond properly at the joint due to the temperature difference between hot fresh asphalt and cooled asphalt of the first lane. The second lane is referred to as the “hot lane” in this report.

Rolling Patterns

Compaction at longitudinal joints is accomplished using combinations of steel drum and pneumatic tire rollers and different rolling patterns are practiced to improve the quality of the joint. There are hot overlap, hot pinch and cold roll methods and each method specifies different roller settings positions for each pass. Each roller pattern can affect joint performance differently.

Hot Overlap

The hot overlap method is a pattern commonly used to compact a longitudinal joint. When using the hot overlap method, the breakdown roller should overlap the joint approximately 6 in (152 mm) onto the cold lane while the majority of the roller remains on the hot lane (Figure 2.1). The roller should also be in the vibratory mode during compaction. This is considered an efficient rolling method because the majority of roller travels on top of the hot lane. The hot overlap method helps minimize the vertical differential between lanes, and it is typically advised for achieving an adequate bond at the joints (Williams 2011; Kandhal 1997). One issue with the hot overlap method is that it may cause lateral movement of the mat (Buncher et al. 2012).

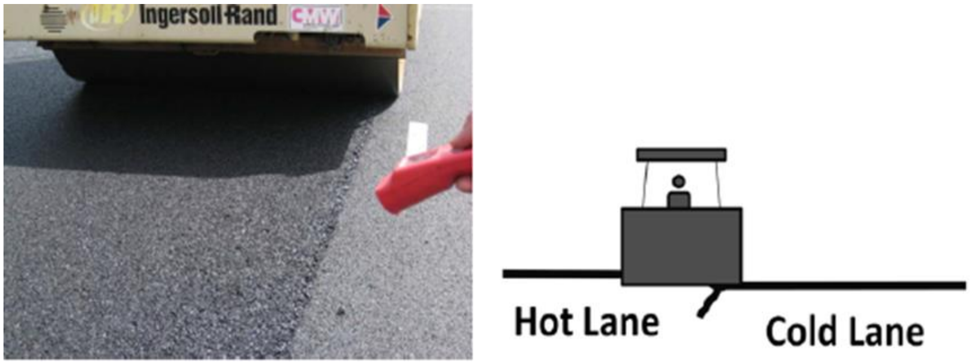


Figure 2.1: "Hot Overlap Rolling Pattern" on asphalt pavement. (Williams 2011).

Hot Pinch

The hot pinch method requires the roller to be on the hot lane with the edge approximately 6 in (152 mm) away from the joint (Figure 2.2) and requires the roller to be in vibratory mode during compaction. By placing the roller away from the joint, the roller pushes HMA laterally towards the joint. This method is the preferred choice for tender mixes or relatively thick lifts (Kandhal 1997). It has been reported that the hot pinch method has resulted in improved joint performance (Williams 2011; Williams et al. 2013). When the hot pinch method is used, the lateral movement of the material can form a hump after the first pass. The hump needs to be flattened to produce an even uniform surface and it is important to note that potential exists for cracks to develop along the pinch lines. After the hot pinch method, it is recommended to use a pneumatic tire roller instead of steel roller to compact joints because the kneading action of this type of roller can increase the density in low density areas that steel-wheel roller miss due to bridging effects (Williams 2011). Other research suggested using the hot overlap method when there are signs of cracking when using the hot pinch method (Buncher et al. 2012).

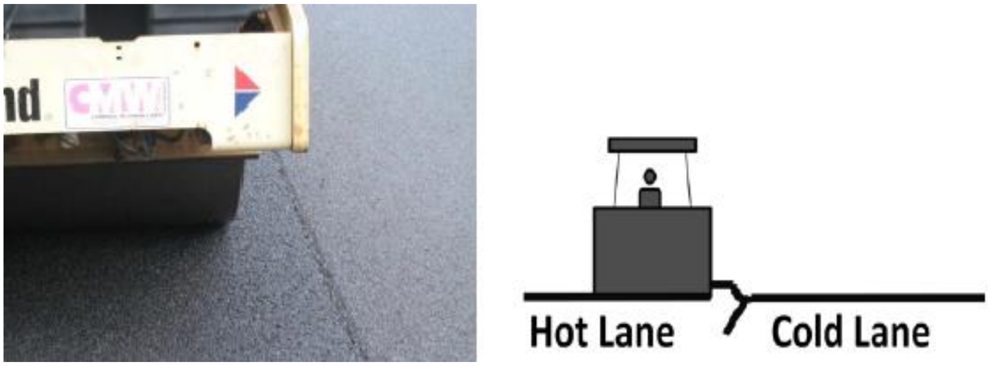


Figure 2.2: "Hot Pinch Rolling Pattern" on asphalt pavement. (Williams 2011).

Cold Roll

The cold roll method requires the majority of the roller contact surface to be on the cold lane instead of the hot lane and the roller overlaps the hot lane by 6 to 12 in (152 to 304 mm) (Figure 2.3). The roller is set in static mode during compaction to avoid the development of cracks in the cold lane. This method is known for eliminating vertical differential at the joint, but it is also considered to be inefficient because it requires compacting areas that are already compacted. The static mode is used for the cold roll to avoid damaging the cold lane and it is less efficient than the vibratory mode. Additionally, when the roller is compacting from a cold mat area, the remainder of the hot mat cools, making it more difficult to compact the remainder of the hot lane in successive passes. However, some studies have reported that the cold roll method could minimize potential development of cracks at longitudinal joints (Marquis 2001). When compacting the free edge of the cold lane, Williams et al. recommended not using a pneumatic tire roller because it can cause transverse movement and push the material away from the edge. Therefore, they recommended only to use steel-wheel rollers to compact even though the cold lane may show signs of cracks at the free edge (Williams et al. 2013).

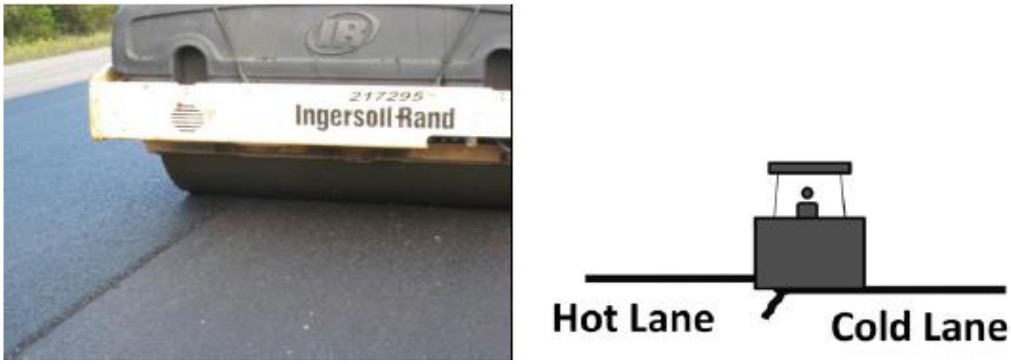


Figure 2.3: "Cold Roll Rolling Pattern" on asphalt pavement. (Williams 2011).

Longitudinal Joint Construction Technique

The quality of longitudinal joints can be improved by employing different longitudinal joint construction techniques. These include echelon paving, sequential mill and fill, wedge, edge restraint, joint maker, cutting wheel, infrared joint heater, and joint adhesive and sealant methods. Some of these techniques involve attaching special mechanical devices to a paver, a roller, or a small motorized vehicle. The other techniques involve increasing the number of heavy equipment on the job site, changing the order of pavement construction, or applying chemical products. Each construction technique has different effects on the performance of the joint and should be evaluated accordingly.

Echelon Paving

Echelon paving involves paving multiple lanes at the same time using at least two pavers. This method minimizes longitudinal joint issues by placing two or more adjacent lanes at the same temperature. The second paver remains close behind the first paver to ensure the temperature at the joint is hot. Case studies in Canada have shown excellent longitudinal joint quality using the echelon paving method that eliminated the need for joint maintenance (Uzarowski 2009). Although this method saves time compared to constructing one lane at a time, it is not considered a practical option in all cases because of the disruption of the traffic flow and it requires multiple pavers, rollers, and trucks, which may also increase the operation cost.

Sequential Mill and Fill

When typical mill and fill occurs, the pre-existing pavement is milled prior to placing a new surface and all lanes are typically milled together. With sequential mill and fill, only one lane milled at a time instead of milling both lanes. Then, the milled surface and confining edges are thoroughly cleaned before a paver places fresh asphalt mix in the milled pavement area followed by compaction. This method provides the confining edge of the cold lane(s) for the hot lane, which results in increased pavement density at the joint (Williams et al. 2013). This also eliminates common uneven surface issues at the longitudinal joint. Additionally, this method does not require any specific equipment like other methods described in the following sections.

Wedge Construction

When constructing longitudinal joints, a paver screed with a special plate or a kicker plate can be used to shape free edges of the cold lane, forming a shoe or boot shaped edge (Figure 2.4). Wedge construction can be done with and without a notch at the top of the edge. Mallick reported that without the notch, the aggregate in the overlapping wedge cannot withstand the loads of rollers and compaction could crush the aggregate without the extra space and the crushed aggregate could cause raveling problems along longitudinal joints (2007). To compact the wedge, a special side roller must be attached to the compactor and different degrees of graduated surfaces, such as 3:1, 6:1, and 12:1 slope, are formed. The shape of the edge helps reduce transverse movement during the joint compaction. When the face of the graduated surface meets the overlapping material from the hot lane, the heat also provides better aggregate interlock during the joint compaction. Buncher et al. reported that other agencies found that the notched wedge joints provide higher densities than vertical or butt joints and the same results were seen in Nener-Plante's research as well (2012; 2012).

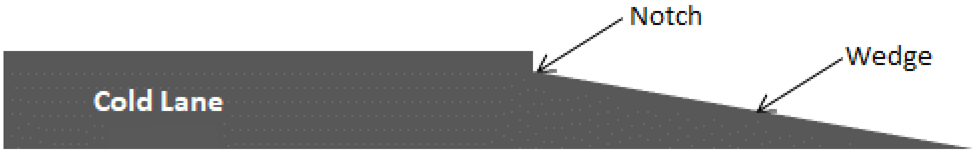


Figure 2.4: Schematic drawing of notched wedge joint construction

Edge Restraint

During the compaction of an asphalt pavement, a compaction drum with an additional fixture is used to provide confined edges or structural supports on the unconfined side of the mat (Figure 2.5). The difference between the wedge construction and the edge restraint methods is that with the edge restraint method, the pavement layer edges are more vertical than the wedge construction method. A hydraulically powered wheel attached to a roller will prevent horizontal movement of materials during the compaction and allow higher density measurements at the joint due to the specific compaction. This method relies on having an experienced operator and the results may be inconsistent (Williams 2012).

Figure 2.5: Edge restraint construction (Fleckstein et al. 2002)

Joint Maker

The joint maker allows the contractor to pre-compact the mix ahead of the screed by attaching a rounded-edge metal mass to the side of a paver screed. Also, a kick plate is attached to the end of paver screed to push extra asphalt mixture to the joint (Figure 2.6). This method provides an adequate amount of asphalt material at the joint to meet the appropriate thickness and density. It can also be added into the notched wedge joint technique.

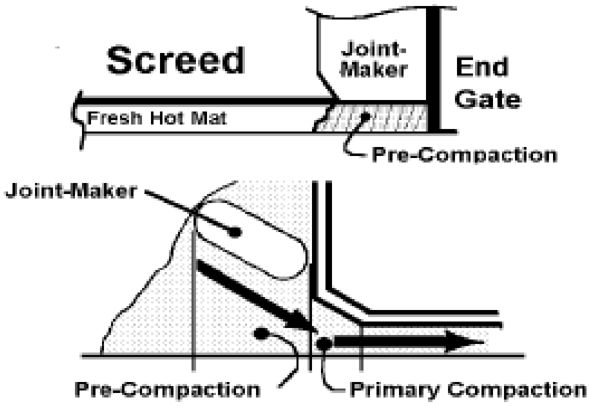


Figure 2.6: Joint maker construction (Fleckstein et al. 2002)

Cutting Wheel

The cutting wheel method involves cutting portions of the unconfined edge of the pavement with a 10 in (254 mm) diameter cutting wheel after placing a new lane. The cutting wheel is attached to an intermediate roller or other motorized equipment to cut and remove the low density materials at the edge of the cold lane (Figure 2.7). When the outer portion of the free edge is removed, the new, clean edges will have a higher density and provide better confining support to the adjacent pavement lane that will follow. This method's performance is dependent on the skills of the roller operator because it depends on how well the operator can cut straight lines.

Figure 2.7: Cutting wheel construction (Buncher et al. 2012)

Infrared Joint Heater

The joint heater is mainly used on the joint before paving the hot lane to preheat the cold edge thus reducing the temperature differential and improving the adhesion between the hot and cold lanes. The infrared joint heating method has been compared to the echelon method because those are the only two methods that minimize temperature differences between adjacent lanes. Increasing the temperature of the existing HMA material helps to improve bonding between hot and cold lanes, and reduce the viscosity, or increase the flowability (or compactability) of material. When bonding and compactability are improved, an increase in the joint density can be expected.

The infrared heater is operated using a propane heater and can be pulled behind a small motorized tractor on a trailer or mounted on a truck (Figure 2.8). If needed, another heater can be attached to a paver to meet the desired compaction temperature. It is essential to monitor the compaction temperature or moving speed because previous studies reported that scorching effects were seen on pavements due to exposure to high temperature. The infrared heater is known as the most effective construction method to mitigate longitudinal joint cracking by increasing the compaction of the joint. The use of a joint heater has been shown to decrease permeability, increase density, and increase the indirect tensile strength of the longitudinal joint (Huang and Shu 2010; Williams 2011; Williams et al. 2013).

The efficiency of the infrared heater may decrease when the thickness of the lift is increased, because infrared may not be able to penetrate to the bottom of the layer at the desired temperature without scorching the top layer. Daniel stated the infrared heating was capable of penetrating and heating up the mixture within 25 to 50 mm (1 to 2 in) of the joint up to around 60˚C (140˚F) during the initial compaction (2006). Since there have been mixed opinions and results in the past, more studies need to be conducted on the infrared joint heater method.

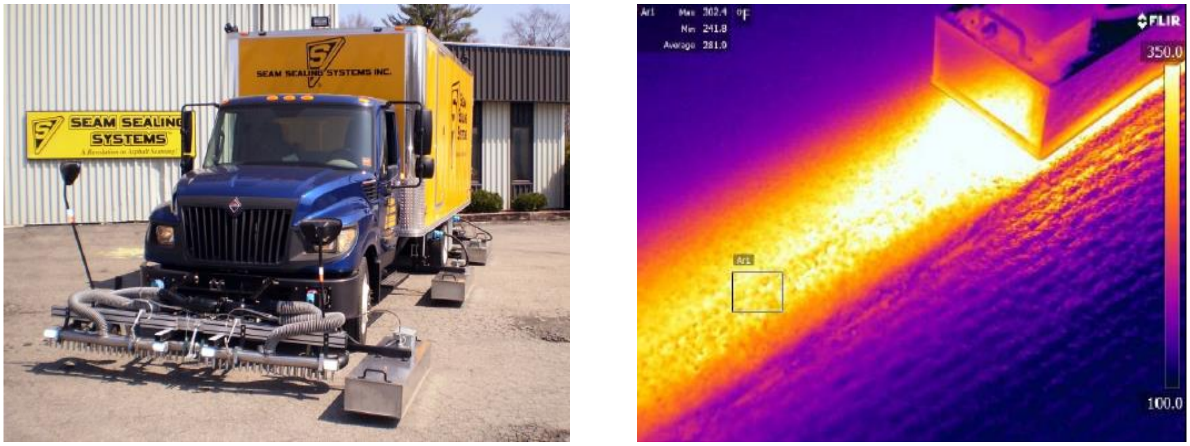


Figure 2.8: Infrared joint heater construction (Nener-Pante 2012)

Joint Adhesives and Sealants

Adhesives and sealants are used to prevent the ingress of water and air by bonding the joint or sealing the surfaces of layers to minimize the damage that can occur at longitudinal joints and to preserve high quality joints. The adhesives and sealants are supposed to reduce the permeability, but the majority of studies reported that there were no changes in permeability when using these products. Huang and Shu explained that sealers are not strong enough to withstand the falling head permeability test and emphasized that the absorption test is more appropriate to see the effectiveness of joint adhesives and sealants (2010). Commonly, adhesives are applied during and sealants are applied after joint construction. The adhesive is applied on the cold lane face of the joint before the hot lane is paved (Figure 2.9). The adhesive can also be applied to the joint after both sides of lanes are compacted, or it can be applied to the underlying layer before placing the overlay. When adhesives are placed beneath the overlay, the heat transferred from the HMA mixture is expected to cause the product to migrate upward through the joint, theoretically reducing interconnected voids (Williams, 2011). The sealants are applied only to the top of the joint after compaction.

Figure 2.9: Joint adhesive and sealant construction (Williams 2011)

Specifications

Many states have specifications on mat density requirements for HMA layers, but many do not have any specifications or guidelines for constructing longitudinal joints. Highway agencies have been conducting research on longitudinal joint construction since the 1960s and have found multiple longitudinal joint construction methods and compaction patterns that improve joint performance. However, there have not been any significant improvements on longitudinal joints and most states do not have specifications or guidelines for the joint construction or quality. Figure 2.10 identifies 16 states that have set specifications on longitudinal joints according to McDaniel et al. (2012), Wang et al. (2016), and Williams (2011) and Table 2.1 lists the state requirements for the constructed joints. Buncher et al. reported that 17 states had a minimum density requirement at the joint and 35 states had some sort of longitudinal joint specification (2012). The minimum density requirement ranged from 89% to 92% of theoretical maximum density according to surveys.

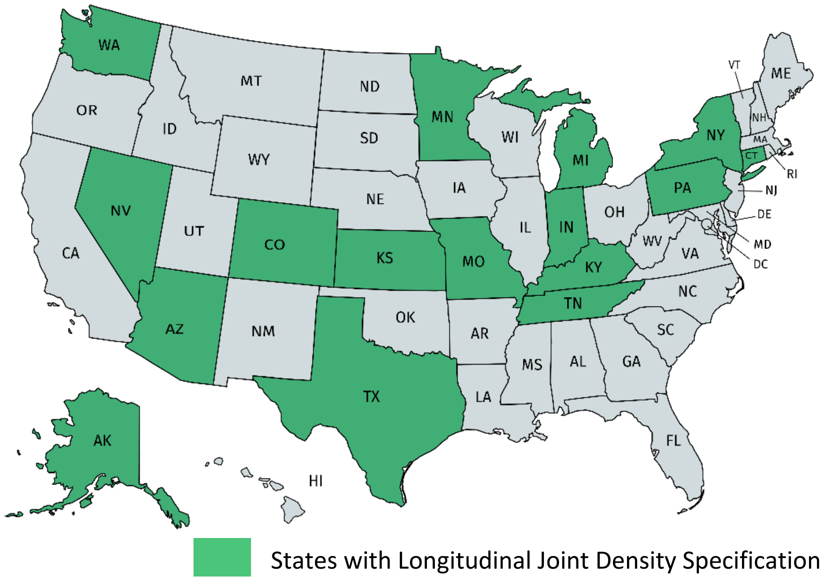


Figure 2.10: States with specifications for longitudinal joint density in 2011-2012 (McDaniel et al. 2012; Williams 2011)

Table 2.1: States with specifications on longitudinal joint density (McDaniel et al. 2012; Wang et al. 2016; Williams 2011)

JOINT DENSITY REQUIREMENT		
State	***Percent***	***Requirement***
AK	> 91	of theoretical maximum specific gravity (2011; 2016)
AZ	-	same density requirements as mainline paving (2016)
CO	≥ 92	of theoretical maximum specific gravity (2011), tolerance 4% variation (2016)
CT	90-97	of theoretical void free density (2011)
IN	> 91	of theoretical maximum specific gravity (2012)
KS	≥ 90	of theoretical maximum specific gravity, or interior density minus joint density less than equal to 3 lb/ft^3 (2015)
KY	87-97	of theoretical maximum specific gravity (2016)
MD	-	method specification for longitudinal joints (2012)
MN	-	same density requirements as mainline paving (2011)
MI	≥ 89	of theoretical maximum specific gravity (2012; 2016)
MO	> 98	of the interior density (2011)
NV	≥ 90	of theoretical maximum specific gravity (2016)
NY	90-97	of theoretical maximum specific gravity (2016)
	90	of theoretical maximum specific gravity (2011)
PA	90	of theoretical maximum specific gravity (2012)
TN	89	of theoretical maximum specific gravity (2011)
TX	> 90	of theoretical maximum specific gravity (2011) and no more than 3% less than mat density (2012; 2016)
WA	> 90	of theoretical maximum specific gravity (2012)
FAA	93.3	of theoretical maximum specific gravity (2011)

Offset Requirement

When constructing asphalt pavement, a joint is formed and the joints of each asphalt layer are stacked and typically offset 6 in (152 mm) as shown in Figure 2.11. The offset is supposed to prevent continuous water intrusion by disconnecting direct paths of two joints between surfaces and underlying courses. Out of 50 states, 24 states have offset requirements between 2 and 12 in (50-300 mm) for longitudinal joints of successive layers. Some states even require the surface joint to be offset from the lane lines by 6 to 12 in (150-300 mm) separately and yet other states require the joint at the surface to be located on the lane line (McDaniel 2012; Williams 2011). The states with an offset requirement are shown in Figure 2.12.

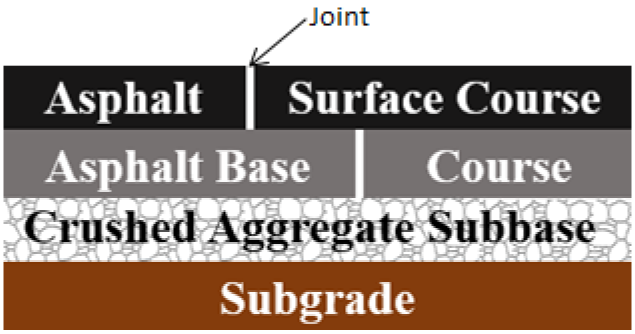


Figure 2.11: Longitudinal joints offset

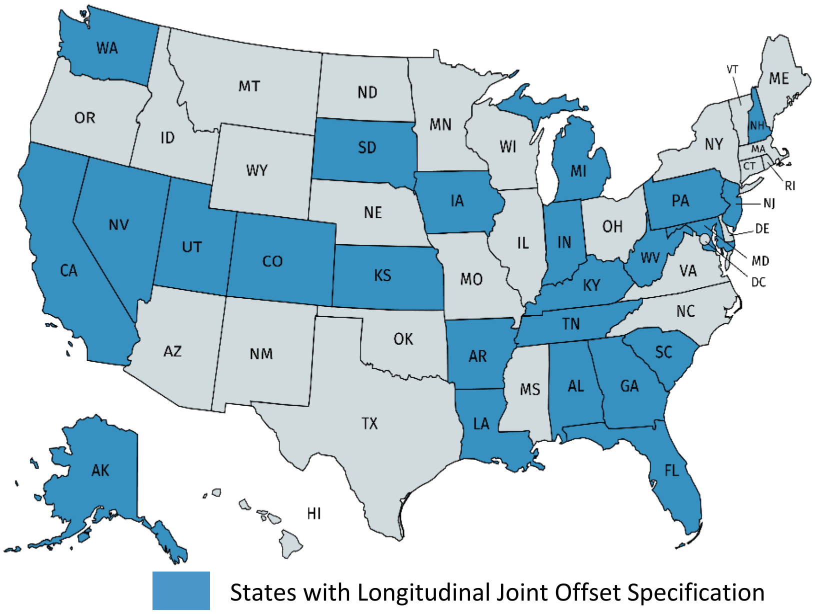


Figure 2.12: States with offset specifications for longitudinal joints in 2011-2012 (McDaniel et al. 2012; Williams 2011)

Compaction Requirement

In terms of compaction, nine states specifically mentioned the first roll must be done on longitudinal joints to maximize joint compaction. Additionally, some states specified compaction methods depending on certain conditions (McDaniel 2012; Williams 2011). The states with compaction requirements are shown in Figure 2.13.

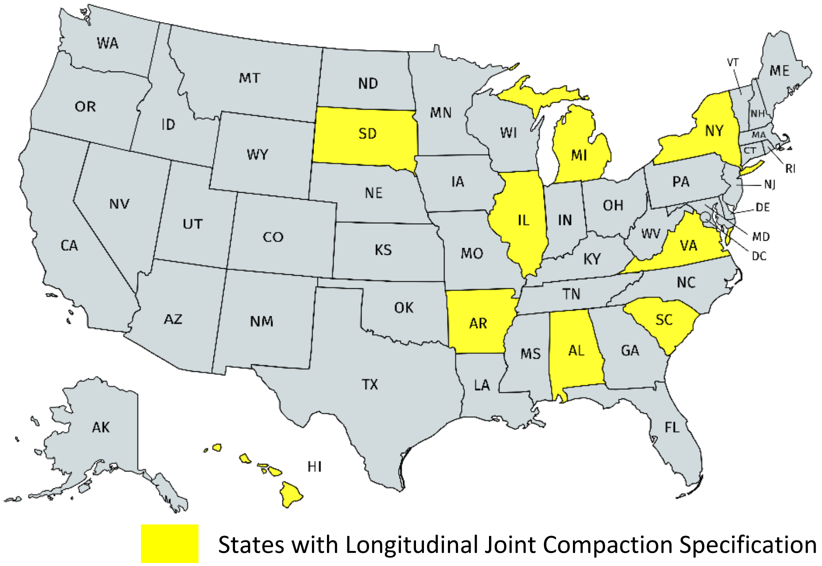


Figure 2.13: States with compaction specifications for longitudinal joints in 2011-2012 (McDaniel et al. 2012; Williams 2011)

Tack Coat Requirement

The tack coat is bituminous liquid asphalt that promotes bonding among particles and layers, 16 states specify that tack coat must be applied on the face of the longitudinal joint or on the surface of the joint (McDaniel 2012; Williams 2011). The states with a tack coat requirement are shown in Figure 2.13.

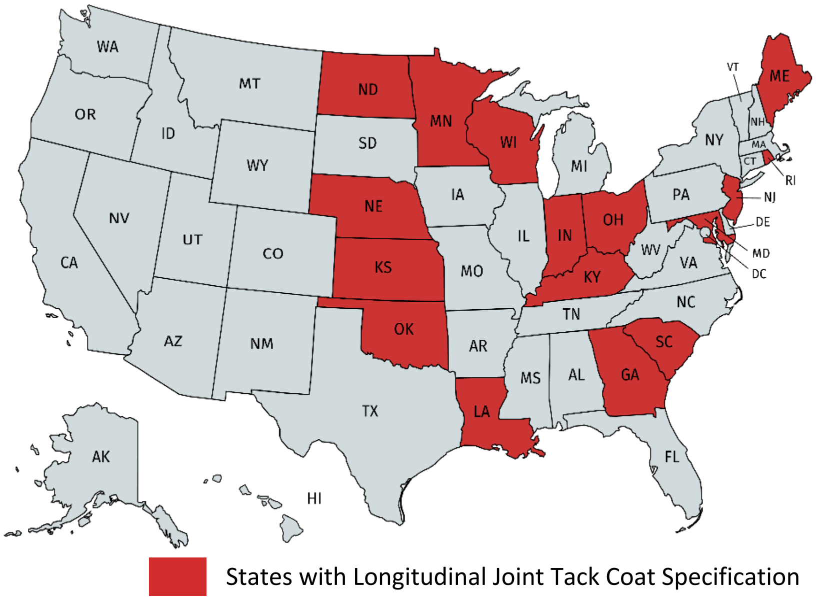


Figure 2.14: States with tack coat specifications for longitudinal joints in 2011-2012 (McDaniel et al. 2012; Williams 2011)

Mix Design

Asphalt mix is typically composed of aggregate, binder, and sometimes other additives and changes in the properties or quantity of each component can influence the quality and performance of a longitudinal joint. Cooley et al. stated that the nominal maximum aggregate size (NMAS) can influence the permeability of a pavement and confirmed that asphalt mixtures with large NMAS require a dense and thick lift for the asphalt pavement to become impermeable (2002). In accordance with Cooley et al., Buncher et al. recommended that the thickness of the asphalt pavement layer should be at least four times the NMAS of coarse aggregates and three times the NMAS of fine aggregates (2012). Moreover, based on the survey results and literature reviews, Buncher et al. (2012) and Mallick et al. (1999) suggest using the smallest NMAS mix which will minimize a rutting issue because the smaller NMAS mix is less permeable than the large NMAS mix. To make the surface less permeable, it is recommended to use a finer gradation and add more binder to the mix to lower the air voids in the mix.

Other States and Organizations Findings

Michigan, Wisconsin, Colorado, and Pennsylvania (Kandhal et al. 1997)

Performance of longitudinal joints constructed using different methods were observed across Michigan, Wisconsin, Colorado, and Pennsylvania after a couple years of service and researchers reported that the notched wedge joint technique having a 12.5 mm vertical offset with a 12:1 taper had the best performance based on visual inspections and density measurements. The cutting wheel and the edge restraining methods had high density measurement, but the report did not recommend these two methods because they rely on the skills of the operator. The report stated that the hot overlap method is the best rolling technique and hot pinch method as the second optimal option. The construction and rolling techniques conducted included hot overlap, hot pinch, cold roll, 12:1 wedge, edge restraining, cutting wheel, joint maker, 3:1 wedge, 3:1 wedge with infrared heating, and rubberized asphalt tack coat.

Tennessee (Huang et al. 2010)

Research by Huang et al. focused on comparing and evaluating the effectiveness of different joint adhesives (Crafco, Pavon, polymer emulsion, and basic emulsion) and joint sealers (Joint Bound and Replay), and the effectiveness of an infrared joint heater itself. In categories of adhesives and joint sealers, the polymer emulsion and basic emulsion resulted in the lowest air voids and permeability and revealed that only the polymer emulsion had an increase in indirect tensile strength (ITS) of the longitudinal joint. Among all construction practices evaluated in this research, the infrared heated longitudinal joint performed the best in terms of air voids, permeability, and ITS.

Arkansas (Williams 2011)

Arkansas highways constructed using different longitudinal joint techniques revealed the joint heater, notched wedge, and joint sealer methods were most successful, and the joint heater method recorded the highest density measurements. On the other hand, the pavements with joint adhesive and the tack coat measured the lowest density measurements. When the permeability, absorption, and infiltration levels of joints were compared with the density, results showed that denser asphalt pavements had lower permeability, absorption, and infiltration levels while lower density asphalt pavements had opposite results. The joint stabilizer was the most effective in water related testing followed by the joint heater and notched wedge methods. For the rolling methods, authors recommended the use of the hot pinch and cold roll methods.

Maine (Nener-Plante 2012)

Nener-Plante conducted a field study in Maine to evaluate vertical edge joints, notch wedge joints, and notch wedge with infrared heated joints and reported most of the joint density was above 90% of the maximum specific gravity, which is uncommon, for all three joint construction methods.

Among the three construction practices, the vertical edge had the lowest density recordings. The notch wedge joints exhibited some improvements in density compared to the vertical edge joints, but the density difference between the vertical edge and heated notch wedge joints was not significant.

Canada (Uzarowski et al. 2009)

Uzarowski et al. evaluated echelon paving with and without a material transfer vehicle (MTV) and the joint heating method in parts of Canada. The three cases showed successful results in field density by raising the joint temperature. Additionally, the authors conducted a study of improving the quality of longitudinal joints using a warm mix asphalt (WMA), but concluded more studies needed to be conducted to evaluate the effectiveness of WMA.

Canada-Ontario (Marks 2006)

Four longitudinal joint techniques (butt joint, joint heater, joint maker, and combination of joint heater and joint maker) were evaluated and the joint quality was compared using density. From this study, no single method was found to be superior and all joint densities were excellent throughout the project.

Kentucky (Fleckstein et al. 2002)

Research in Kentucky reported improvements in density not only at the joint but also across the mat when the notched wedge method was used. The author explained the wedge was restraining the edge of the mat and decreasing the lateral movement of the mat concurrently. The notched wedge joints also produced the lowest permeability of all joint construction methods. The notched wedge was recommended to be used only on lifts of 1.5 in or thicker. For the restrained edge method, improvements in density and permeability at the joints were seen compared to the control sections. One problem with using the restrained edge method was creating a longitudinal ridge in the mat when the wheel was compacting at the edge of the pavement. The infrared joint heater was the most successful in increasing density and moderately decreasing the permeability, but authors emphasized the importance of the need for a better attachment that does not impede the speed of the paving train. The study also evaluated joints constructed using Crafco and Tbond joint adhesives in the field, and both reduced the permeability of joints. The restrained edge method had the highest average normalized density, and the notched wedge had the second highest density at joints. Among all the joint construction methods, the joint maker did not statistically improve density at any area and was not recommended for longitudinal joints.

Virginia (Appea et al. 2010)

The Virginia Department of Transportation and Virginia Asphalt Association cooperated to develop a communication and training program focused on proper joint compaction instead of developing a longitudinal joint density specification and/or requiring specific construction techniques. Improvements in joint density were observed continually in the surface mix with 12.5 mm and 9.5 mm nominal aggregate size after the adherence of the joint memorandum. The improving trends were confirmed through statistical analysis.

Mississippi (Johnson 2000)

The research division of the Mississippi Department of Transportation evaluated the effectiveness of a joint maker and pre-compaction screed in achieving higher and more uniform density across the HMA pavement mat and the longitudinal edges. The research included a field study and found increases in density measurements up to 2% along joints and across the mat. However, the author pointed that out the control sections provided a more uniform density and lower standard deviation when compared to the joint maker and pre-compaction screed sections.

FAA Federal Aviation (Kandhal et al. 2007)

Longitudinal joint cracking is not only seen on highways, but also in asphalt airfields. A study sponsored by the FAA determined that using a combination of notched wedge joint and rubberized asphalt tack coat was the most preferred choice if echelon paving is not practical. The second and third most preferred joint construction methods were rubberized asphalt tack coat and notched wedge joint, respectively. The study made recommendations on asphalt airfield longitudinal joints based only on literature reviews, surveys, and recommendations from airport engineers and consultants.

Connecticut (Zinke et al. 2008)

The Connecticut Department of Transportation and the Federal Highway Administration investigated the performance of notched wedge joint compared with a traditional butt joint at various random locations in Connecticut. From this research, Zinke et al. identified there were lower average density readings recorded 6 in (150 mm) on the cold side of the joint compared to those 6 in (150 mm) on the hot side of joint. To address the issue, the notched wedge joint method was used to reach a higher average density, compared to butt joint construction 6 in (150 mm) on the cold side of the joint and at the joint. The authors reported the use of the notched wedge joint did not impede the paving process.

Wisconsin (Toepel et al. 2003)

In previous studies conducted at the National Center for Asphalt Technology (NCAT), wedge construction was not favorable due to inferior performance in Wisconsin, but it performed better than conventional methods in Michigan. It was noted that the Wisconsin wedge did not have the ½ in vertical notch like the Michigan wedge and the face of Wisconsin wedge was not compacted. Therefore, further study was conducted to investigate the effectiveness of wedge construction with different compaction in Wisconsin. NCAT evaluated eight joint construction techniques, including butt joint, wedge joint with truck tire rolling, wedge joint without rolling, wedge joint with steel side roller, wedge joint with rubber side roller, edge joint with tag-along roller, cutting wheel, and edge constraint methods. Among these construction techniques, the wedge joint with steel side roller and the wedge joint with the tag-along roller performed best with respect to density at the joint.

Nevada (Sebaaly et al. 2008)

A study was completed in Nevada to obtain knowledge and aid in the development of a longitudinal joint specification. The study consisted of five construction practices and two rolling patterns. The five joint construction methods included, natural slope, edge restraining, cutting wheel with and without a rubberized tack coat, and 3:1 tapered wedge. The rolling patterns studied included, hot overlap and hot pinch methods. When the performance of rolling methods was compared, they were statistically similar. Out of the five joint construction methods, edge restraining, cutting wheel with tack coat, and 3:1 tapered wedge were recommended.

Indiana (McDaniel et al. 2012)

For the Indiana Department of Transportation, McDaniel listed advantages, disadvantages, and comments on past performance and quality of longitudinal joint construction methods in Table 2.2.

Table 2.2: Joint construction technique advantages and disadvantages (McDaniel et al. 2012).

Joint Treatment	**Advantages**	**Disadvantages**	**Likelihood of Success & Acceptance; Recommendation**
Full Width, Echelon or Tandem Paving	Avoids cold joint Good performance	Only tandem can be done under traffic Traffic control/safety issues with tandem Echelon and tandem require two pavers and two crews, which increases cost Need high capacity plant	Work well when feasible, but rarely feasible mainly because of traffic Implement when possible, but will not be routine
Various Rolling Patterns (number and type of rollers, number and location of passes, timing of passes)	Can change easily when conditions change (temperature, mix behavior, etc.) Usually does not require additional equipment or manpower	Since there is not one rolling pattern that works in all cases, experience or some tested property is needed to determine what works best in a given situation	Changing rolling patterns is easy Little to no impact on cost Maintain the lack of restrictions for certain mixes
Butt Joint	Common and familiar Can work well when properly constructed	Edge drop off requires pulling up adjacent lane (productivity impacts) Water can penetrate roadway easily if joint separates, especially if joints in underlying layers are not offset	Could work well with attention to detail but experience shows that attention is sometimes lacking Continue to require joint adhesive and fog seal

Table 2.2: (cont'd) Joint construction technique advantages and disadvantages (McDaniel et al. 2012)

Joint Treatment	**Advantages**	**Disadvantages**	**Likelihood of Success & Acceptance; Recommendation**
Tapered or Notched Wedge Joint	Avoid issue with edge drop off Can perform well if properly constructed Similar to safety edge, which is becoming more familiar and may provide confinement at the edge of lane	Requires compaction of the wedge Notch and taper dimensions need to be appropriate for NMAS and layer thickness	Can be effective Not attractive to contractors if there is a requirement to pull up adjacent lane Consider requiring compaction (preferably with vibratory plate attached to paver) for wedge
Edge Restraining or Pre-compaction Devices	Can increase density near joint	Requires skillful operator	Mixed performance at best Not worth promoting
Cutting Wheel	Removes low density material	''Wastes'' new mix Requires equipment and manpower to cut and to remove debris Requires skillful operator	Mixed performance at best Not worth promoting
Sequential Mill and Fill	Removes low density material from unsupported edge at center of lane Does not require new/more equipment	May require milling sub to stay on job longer or return later ''Wastes'' new mix Milling action might damage adjacent mix in place	Expert opinions are mixed Maintain contractor option Evaluate existing sequential mill and fill projects to decide whether to encourage or restrict in future

Table 2.2: (cont'd) Joint construction technique advantages and disadvantages (McDaniel et al. 2012)

Joint Treatment	**Advantages**	**Disadvantages**	**Likelihood of Success & Acceptance; Recommendation**
Infrared Joint Heater	Avoids cold joint Increases adhesion at interface Works well in some places	Requires extra equipment and fuel Lengthens paving train Interfere with delivery trucks and paving crew Safety issues Can scorch mix	Mixed performance Not worth pursuing
Joint Adhesives	Improve adhesion at the interface No negative impacts on performance Insurance against poor performance	Increase costs Require equipment and manpower Have not always demonstrated improvement in performance (permeability)	Cost increases are expected to be low when used routinely; increased performance can easily offset increase in costs Continue to require Monitor performance to support future decisions
Joint Sealer	Reduce permeability around the joint No additional equipment required No negative impacts on performance Insurance against poor performance	Increase costs Have not always demonstrated improvement in performance (permeability) Must be applied before pavement markings and after coring	Cost increases are expected to be low when used routinely; increased performance can easily offset increase in costs Continue to require Monitor performance to support future decisions

CHAPTER 3. Survey of Longitudinal Joint Practices

Survey of Practices in South Carolina

A survey was distributed to SCDOT and contractor personnel across South Carolina to gain an understanding of longitudinal joint construction practices currently used throughout the state. The study was used to elicit opinions about some other practices and to inform longitudinal joint construction guidelines. The survey was administered using Survey Monkey and was sent to construction engineers, maintenance engineers, asphalt managers, material engineers, and asphalt material managers from all seven districts within the SCDOT (Figure 3.1). Additionally, the survey was sent to the contractor members of the South Carolina Asphalt Pavement Association (SCAPA) and included quality control managers, asphalt plant managers, and asphalt operation managers from multiple construction companies. The survey consisted of 17 questions that are presented in Appendix A.

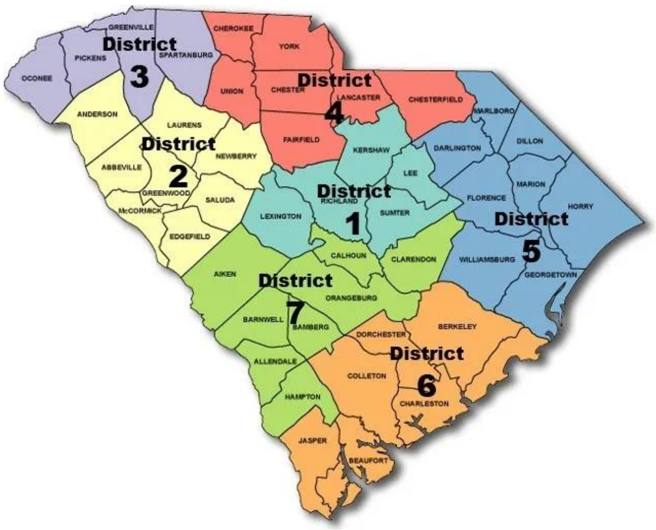


Figure 3.1: Map of the SCDOT engineering district boundaries.

Survey Results and Analysis

The survey responses included five responses from contractors and 35 responses from SCDOT personnel from different districts of South Carolina. Two of the 40 participants had at least three years of experience but less than five years. Ten of the 40 participants have been involved with asphalt pavement construction for at least five years but less than 10 years and other 28 participants had experience with asphalt pavement construction for 10 years or more (Figure 3.2). The general occupation classification of the participants is summarized in Figure 3.3. The majority of respondents were construction engineers from SCDOT.

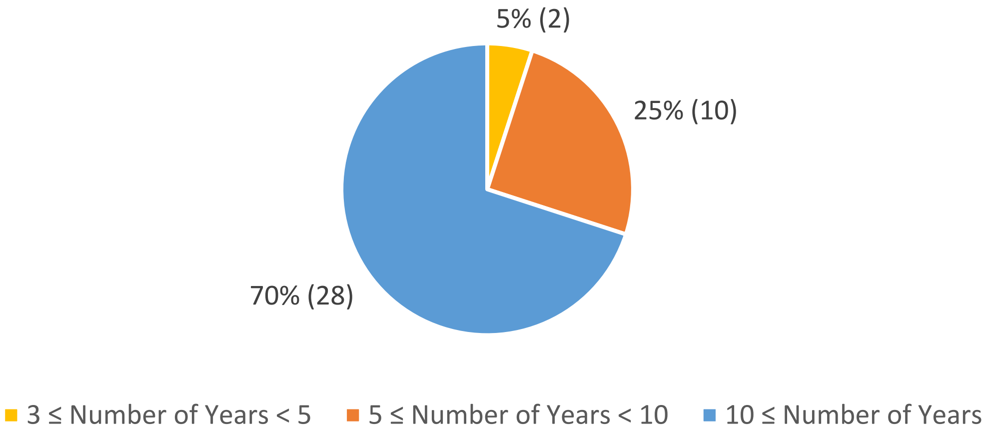


Figure 3.2: Number of years of experience (contractors and SCDOT personnel)

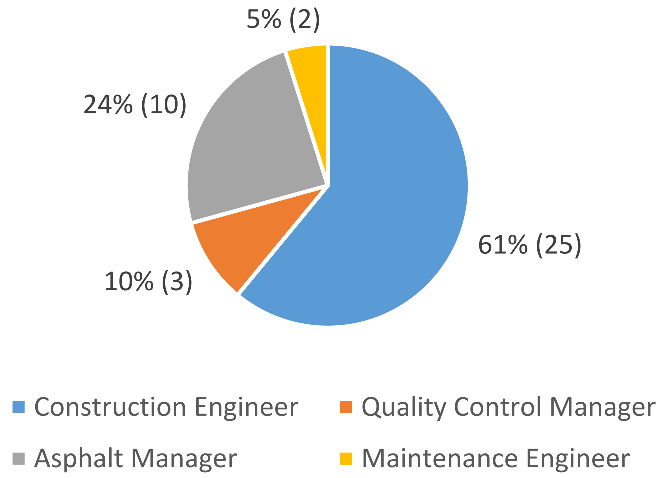


Figure 3.3: Occupation of the survey participants (contractors and SCDOT personnel)

Across South Carolina, different rolling patterns are used to construct longitudinal joints to meet South Carolina specifications on density and smoothness of the pavement mat. (SCDOT does not have a joint density specification.) To understand the common practices of joint compaction that are practiced in South Carolina, the survey asked what rolling methods are practiced or observed for the first pass (Figure 3.4), second pass (Figure 3.5), and third pass (Figure 3.6). Based on the survey responses, the hot overlap and the hot pinch methods are most commonly used for the first pass, but the use of the hot pinch method gradually decreases for the second and third pass. In contrast to the hot pinch method, the use of the cold roll method was the lowest for the first pass, but a gradual increase in the use for the second and third pass was observed. Based on the observations of the experienced personnel, most participants responded that the hot pinch was the best rolling method to compact longitudinal joints based on visual, density, or permeability observations as shown in Figure 3.7.

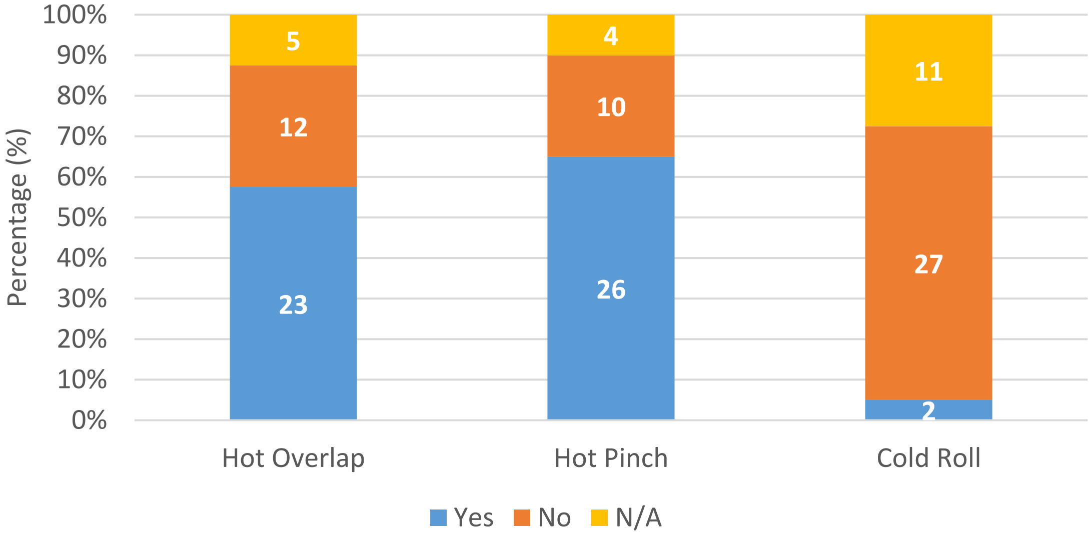


Figure 3.4: Survey of first pass compaction observed

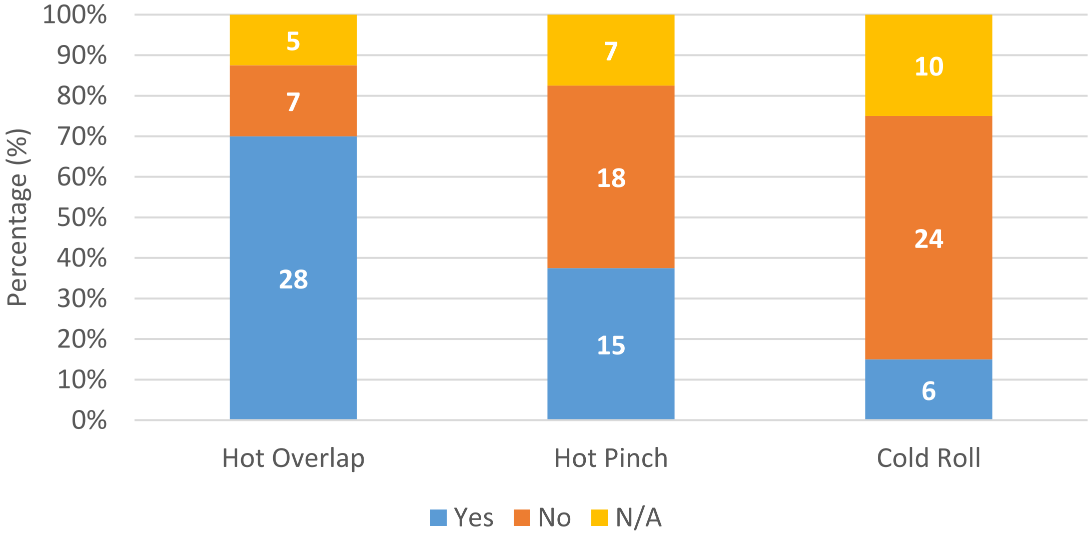


Figure 3.5: Survey of second pass compaction observed

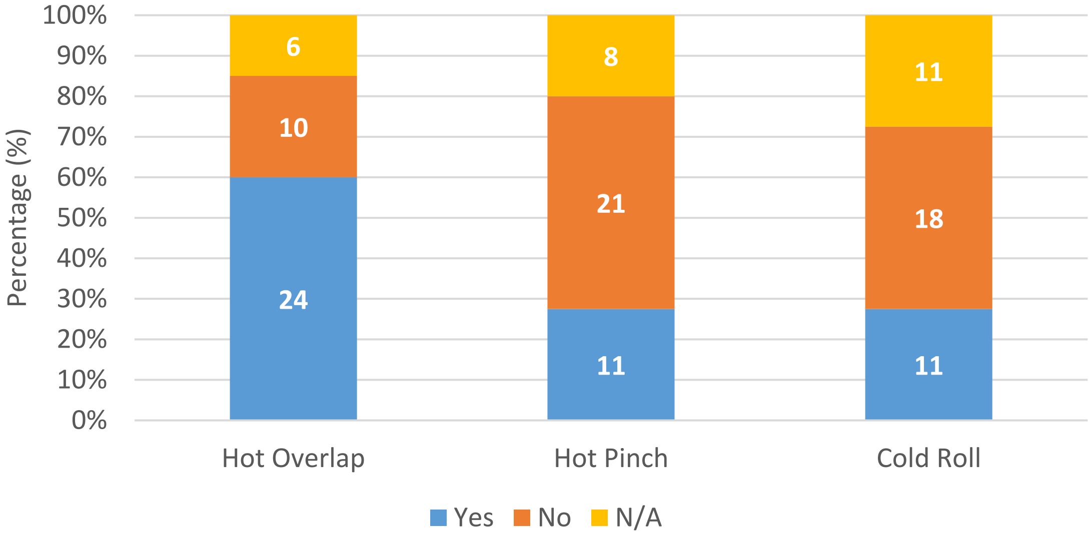


Figure 3.6: Survey of third pass compaction observed

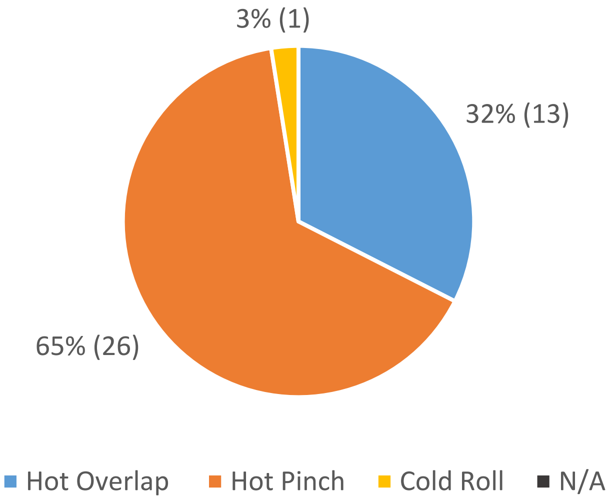


Figure 3.7: Survey of opinions about the best longitudinal joint rolling method

When survey takers were asked if there were any obstacles to using the specific joint compaction method that they consider to be the best, two of the contractors replied that traffic is an issue and explained that the narrow road becomes dangerous for their employees. One respondent also mentioned that it is difficult to perform the hot pinch method for night work because of roller operator's limited visibility. The other contractors responded that lane configuration presented a challenge (1 response) as well as crew management (1 response).

Five SCDOT personnel responded that the traffic of the location and the spacing concerning the safety of employees discouraged using a specific construction practice. Two SCDOT respondents noted there is difficulty in managing roller operators to follow the instructions. Two SCDOT personnel responded that there were no obstructions to performing the best construction method. Other responses included mix type (1 response), contractor buy-in (1 response), and historic preservation areas (1 response). The rest of the responses were either not related to the question or the respondents skipped the question.

A question regarding methods employed to maintain straight joint lines during asphalt pavement construction was also included and the responses are summarized in Figure 3.8. The majority stated paint or chalk marking and string lines are used to keep the joint straight.

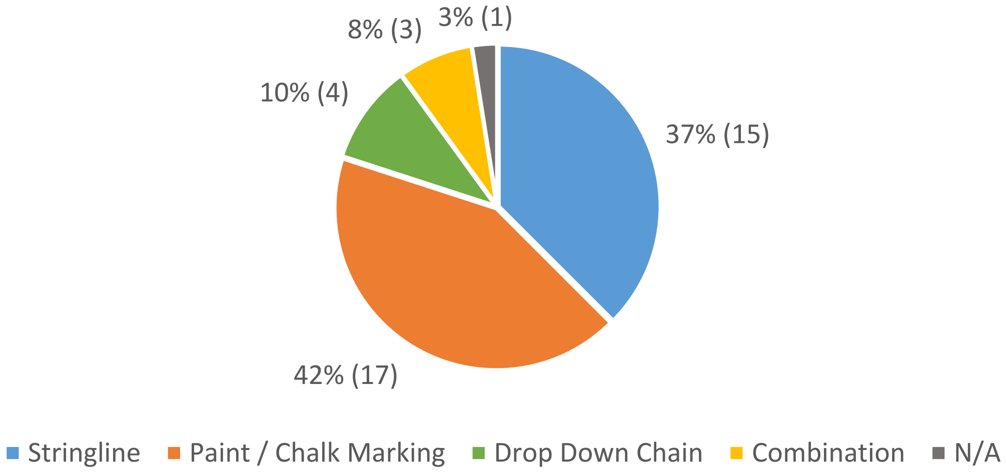


Figure 3.8: Survey of methods for maintaining straight joint lines

During the construction of asphalt pavements, the thickness and the width of the pavement mat can be adjusted based on the existing conditions of the site. When matching the edge of existing lane with the fresh asphalt mix, some of the excessive mix will become loose near the joint before compaction. The survey takers were asked what observations were made when addressing excess overlap material, and the responses are presented in Figure 3.9. Most participants stated raking or luting is done to push the excess materials back to the joint and four people responded that nothing is done. One person selected “other” option and stated that the excess material was placed back on the mat.

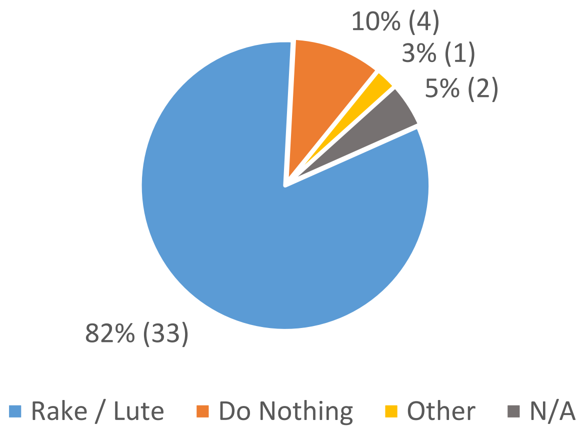


Figure 3.9: Survey of handling excess overlap material

The quality of longitudinal joints can be improved by performing different longitudinal joint construction techniques and the survey takers’ preference of all known techniques is presented in Figure 3.10. The butt joint was the most preferred technique and the joint heater is a technique that is never preferred.

The participants were asked if there were reasons why some of the construction practices are most preferred. Two contractors responded that best joint performance was the reason and one contractor indicated cost and ease of construction.

The most common SCDOT responses were familiarity, experience, and ease of use (9 responses). Six responses from SCDOT revealed that the preferred techniques were due to best joint performance, practical, and effective results. Moreover, three added that a certain technique is limited due to the traffic control and two mentioned increase in cost and contractors do not favor special equipment needed to pave. One responded that there are mixed opinions or proof that other methods are better than the traditional method. One participant answered that the preferred option depended on South Carolina specifications. Only one respondent mentioned some of the practices cause a variation of temperature across a mat.

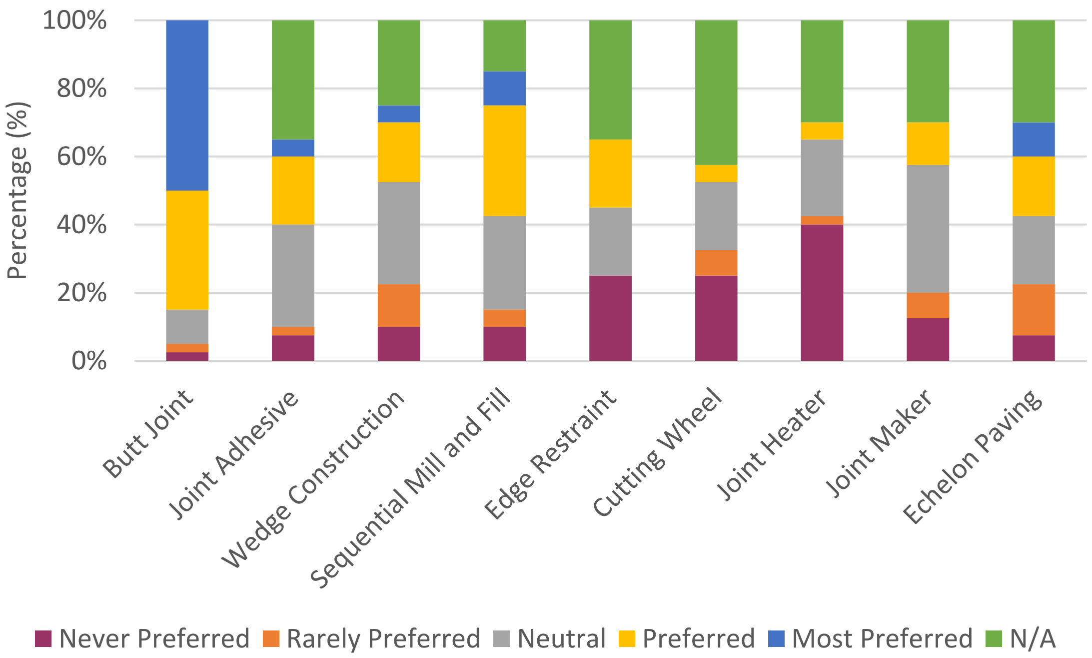


Figure 3.10: Preference rating of joint construction techniques

When the respondents were asked why certain construction practices perform better than other practices, one contractor answered that more overlapping is performed on wedge and another responded that joint adhesive increases bonding between the existing lane and the new lane. Because South Carolina does not experience freezing temperatures often, one contractor concluded that the butt joint technique performs well.

In response to the better performance question by SCDOT personnel, two explained echelon paving works the best because asphalt is being pulled on both lanes while the mix is still hot enough to connect two lanes into one. Two more personnel explained joint adhesive performs better than others because it assists with cohesion at the joint by increasing the bonding strength. With sequential mill and fill, one respondent explained that the hard-compacted edge to compact against improves the compaction of the new asphalt and allows better packing. Any technique with a confined edge will not produce loose material at the joint (1 response) compared to the unconfined edge. Another respondent added that mill and fill does not require hand work and emphasized that hand work worsens the performance of the joint. For notched wedge joint construction, one mentioned that it allows better compaction on the edge. All of the survey takers' performance rating of the specific construction methods based on visual, permeability or density observation are presented in Figure 3.11.

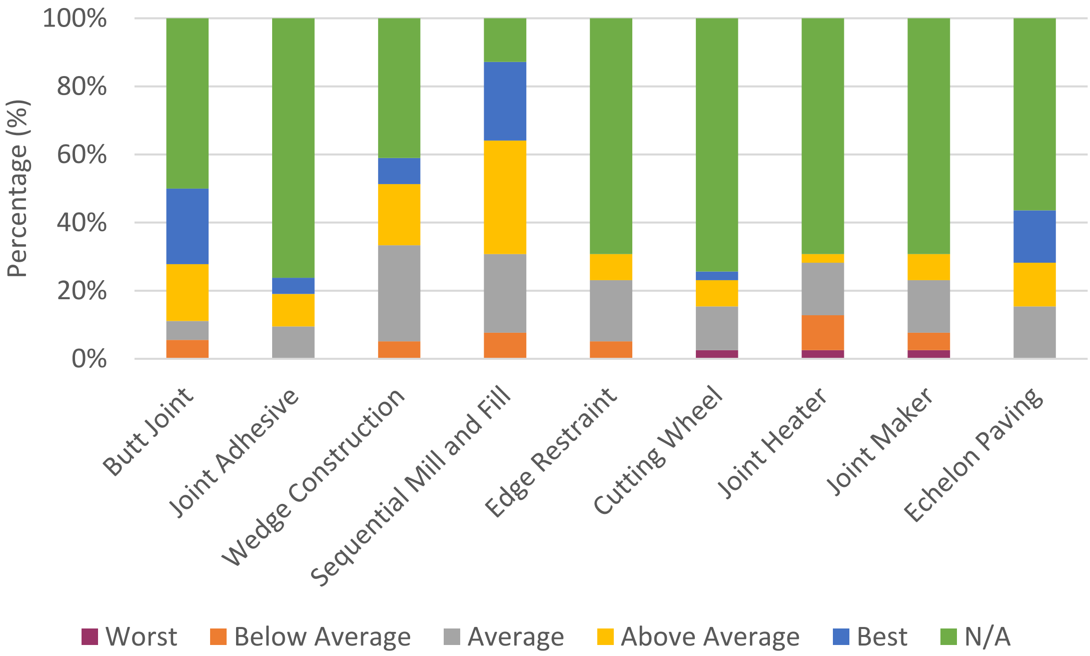


Figure 3.11: Performance rating of the joint construction technique

There are many factors that influence the quality of longitudinal joints in asphalt pavements and survey participants were asked about their opinions about the most important factors. Contractors answered tacking the joint (2 responses), compacting at hot temperature (2 responses), matching of the joint properly (2 responses), ensuring the joint is clean (1 response), and minimizing luting movement (1 response). The SCDOT personnel responses to the important factors that influence the quality of joints included:

- Proper compaction efforts at the joint (13 responses)
- Straight joint alignment (9 responses)
- Proper temperature and timing (7 responses)
- Clean and leveled joint (6 responses)
- Lute movement (6 responses)
- Adequate material at the joint (6 responses)
- Proper application of tack coat at edge (6 responses)
- Offsetting joints among layers (2 responses)
- Application of adhesive (1 response)
- Prep work prior to paving (1 response)
- Attention to detail (1 response)
- Grade (1 response)
- Depth (1 response)

Recommendations

As part of the survey, the participants were asked to provide any recommendations on improving the quality of future longitudinal joints in asphalt pavements. From the contractor responses, one suggested that a best practice guide be developed as a referral instead of developing a specification and another noted that managing the paving crews to follow the best practices of compacting and matching. From the SCDOT responses, eight participants suggested there should be specific contract requirement or specification on longitudinal joint construction. Some of the suggested specification requirements included the use of rubber tire for compaction, guarantee overlap of material over the joint, use of a physical string line, restriction on poor joint techniques, and increase in inspection emphasis. Six SCDOT personnel reemphasized clean, straight joints with proper tack coat and luting of the joint. Four survey takers replied training and recertification for roller operators should be necessary because paving crews are becoming less experienced. Two SCDOT respondents noted that the mill and fill method should be used instead of overlaying the edge. Since South Carolina does not have enough experience with using other joint construction techniques, two respondents recommended conducting more studies on the effectiveness of other methods and evaluating the quality of construction. One person emphasized the use of joint adhesive and utilization of more wedge markers because they are the easiest option to implement in the future. Other individual recommendations included taking additional time to prepare the joints, planning operations ahead of time, compacting the edges, and using the cold rolling technique.

Survey of Practices Across the United States

A survey was distributed to transportation departments across the US and Canada to gain an understanding of longitudinal joint construction practices currently used in other states and provinces. The study was used to elicit their opinions about some other practices and to create longitudinal joint construction guidelines. The survey was administered using Survey Monkey and was distributed to an AASHTO listserv by the SCDOT. The survey consisted of 18 questions that are presented in Appendix B.

Survey Results and Analysis

There were a total of 26 responses from US state transportation agencies. The respondents were generally experienced professionals as 21 had more than 10 years of experience with asphalt pavement construction (Figure 3.12). Only three of the respondents had less than five years of experience.

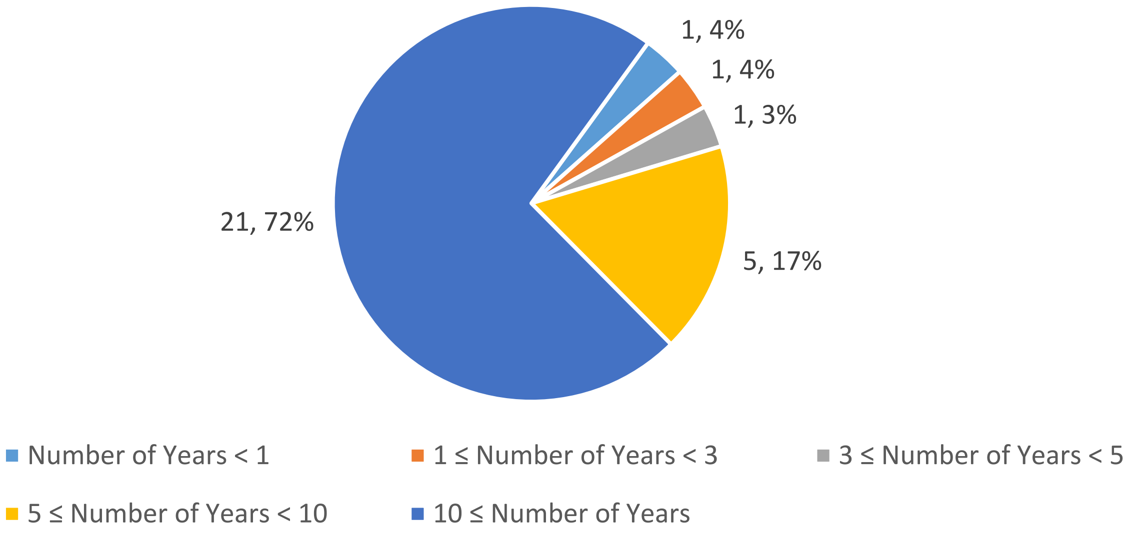


Figure 3.12: Number of years of experience

Across the US, different rolling patterns are used to construct longitudinal joints to meet specifications on density and smoothness of the pavement mat. To understand the common practices of joint compaction that are practiced, the survey asked what rolling methods are practiced or observed for the first pass (Figure 3.13), second pass (Figure 3.14), and third pass (Figure 3.15). Based on the survey responses, the hot overlap and the hot pinch methods are most commonly used for the first pass, but the use of the hot pinch method decreases for the second and third pass. The use of the cold roll method was the lowest for all passes. These results are similar to those from the survey of SCDOT personnel and contractors.

Based on the observations of the experienced personnel, most participants responded that the hot pinch was the best rolling method to compact longitudinal joints based on visual, density, or permeability observations as shown in Figure 3.16.

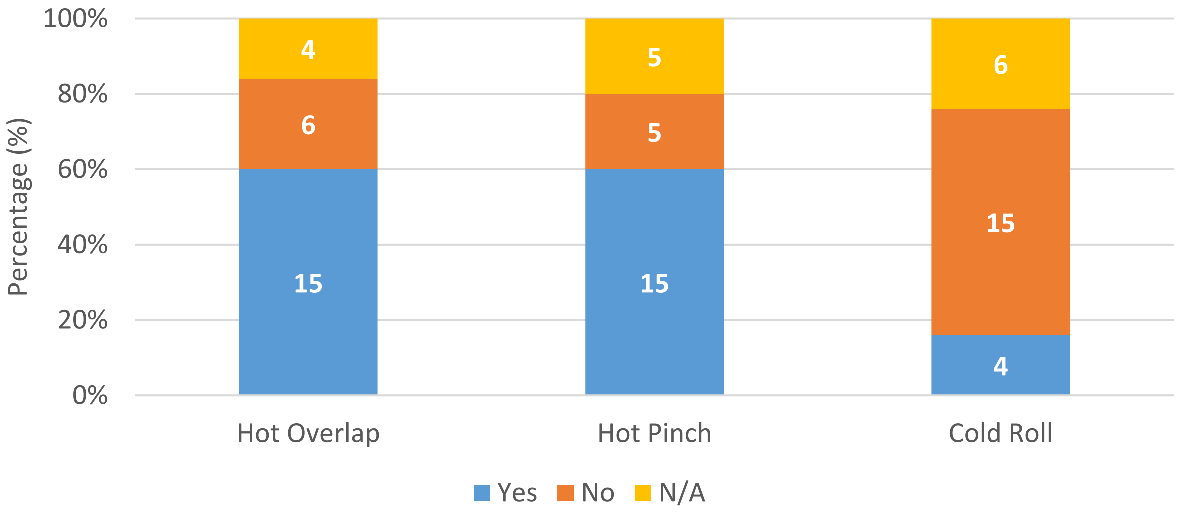


Figure 3.13: Survey of first pass compaction observed

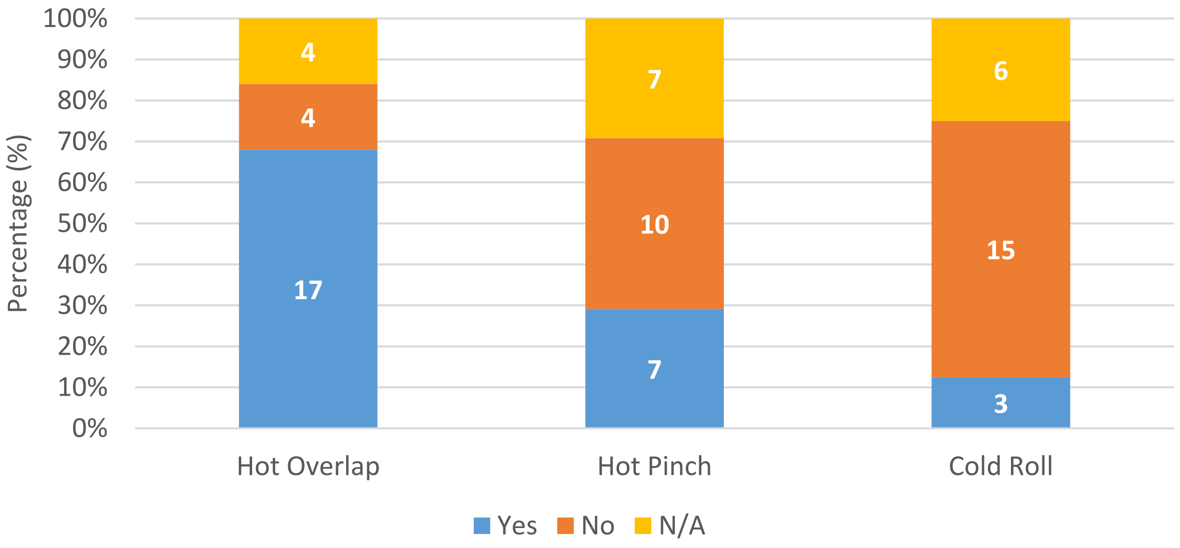


Figure 3.14: Survey of second pass compaction observed

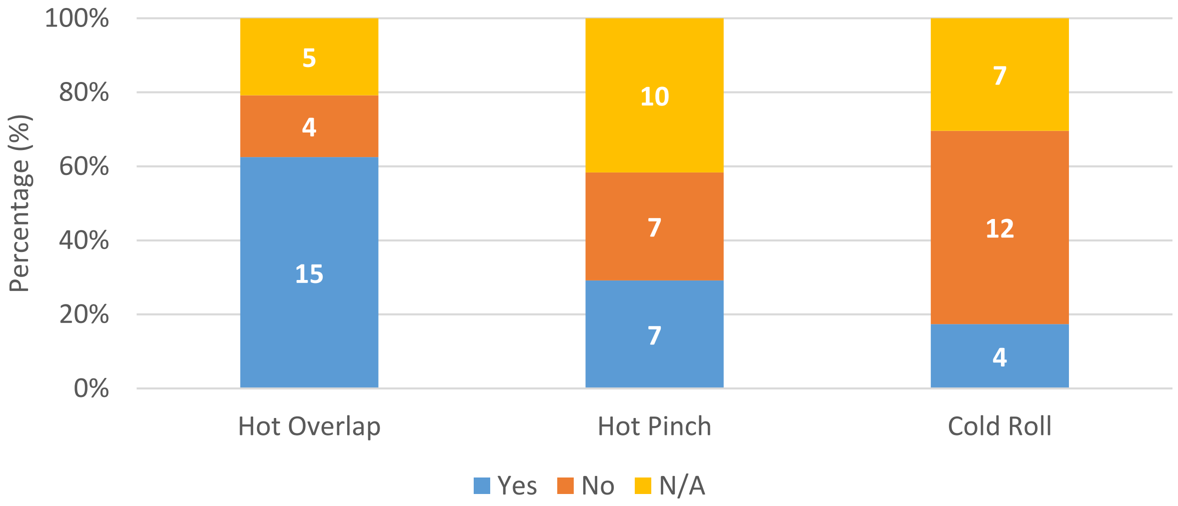


Figure 3.15: Survey of third pass compaction observed

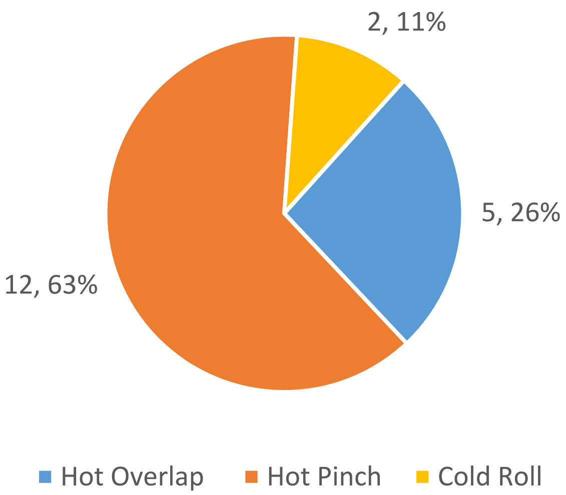


Figure 3.16: Survey of best rolling method

Survey takers were asked if there were any obstacles to using the specific joint compaction method that they consider to be the best. The responses focused on the following obstacles:

- Workers exposed to traffic when properly bumping the joint (2 responses).
- Convincing the contractors to use a certain method without specifying it (2 responses).

- Issues when the mat temperature cools too much before compaction is complete (2 responses).

Of the 16 respondents to the question, seven indicated that there were no obstacles to using the preferred method.

A question regarding methods employed to maintain straight joint lines during asphalt pavement construction was also included and the responses are summarized in Figure 3.17. The majority stated paint or chalk marking and string lines, or a combination of these are most frequently used to keep the joint straight.

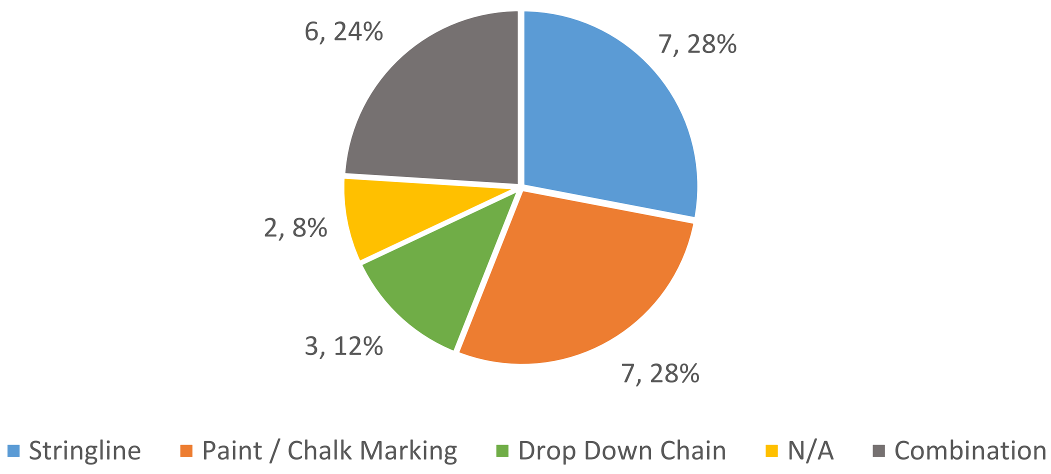


Figure 3.17: Survey of methods for maintaining straight joint lines

During the construction of asphalt pavements, the thickness and the width of the pavement mat can be adjusted based on the existing conditions of the site. When matching the edge of existing lane with the fresh asphalt mix, some of the excessive mix will become loose near the joint before compaction. The survey takers were asked what observations were made when addressing excess overlap material, and the responses are presented in Figure 3.18. Most participants stated that the most common practice was to do nothing, but also noted that there should not be excess material if proper practices are followed. When action is taken, the majority indicated that raking or luting is done to push the excess materials back to the joint. The two respondents who selected “Other” indicated that there should not be excess material.

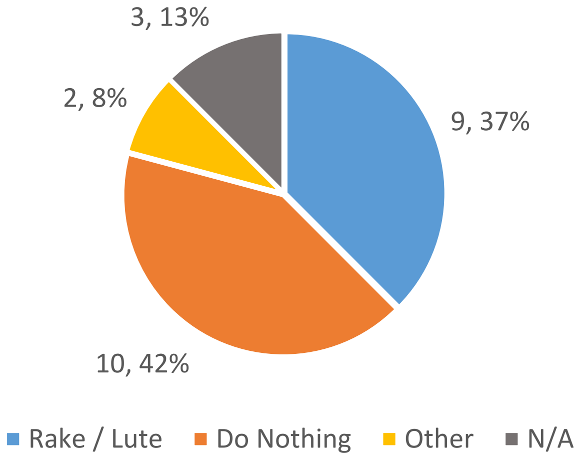


Figure 3.18: Survey of handling excess overlap material

The quality of longitudinal joints can be improved by using different longitudinal joint construction techniques and the survey takers' preference of all known techniques is presented in Figure 3.19. The most preferred practices were echelon paving, wedge construction, use of joint adhesive, sequential mill and fill, and butt joint, in order.

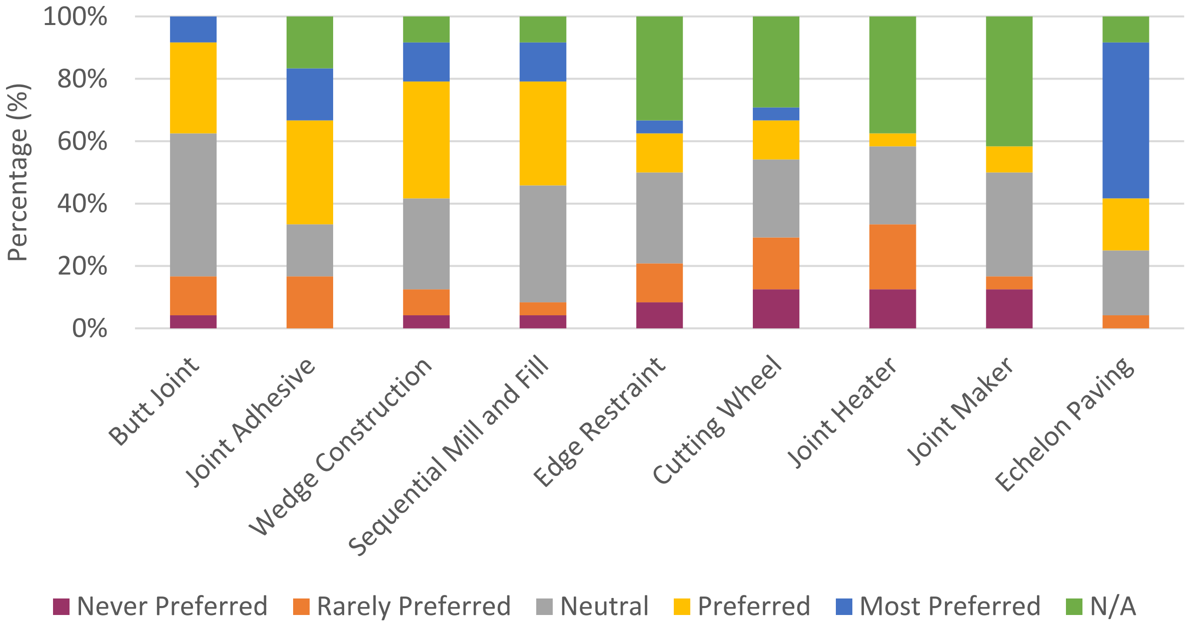


Figure 3.19: Preference rating of joint construction techniques

The participants were asked if there were reasons why some of the construction practices are most preferred. Most respondents indicated that producing the best joint performance was the reason and some noted constructability, safety, and cost.

The survey also asked respondents to rate the performance of different techniques based on visual observation, permeability, or density and the results are summarized in Figure 3.20. Additionally, the survey asked respondents to describe why some methods performed better than others. The results somewhat align with the preferences summarized in Figure 3.19. Echelon paving received the highest performance rating because it essentially eliminated the presence of the longitudinal joint (at least visually), resulting in consistent density across the entire width of the mat. Joint adhesives received the second highest rating and some combined joint adhesive with joint sealant, while noting that joint sealant was preferred as it helps reduce permeability. The high performance of sequential mill and fill was attributed to the dense vertical edges that provide restraint during compaction of the fresh mat.

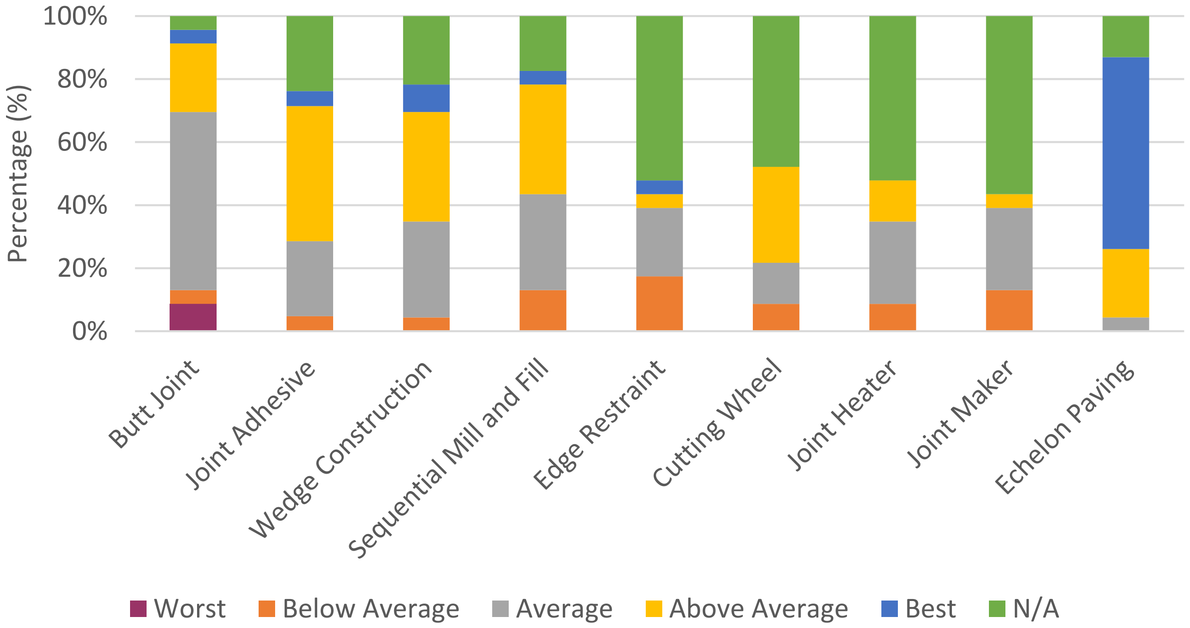


Figure 3.20: Performance rating of the joint construction technique

There are many factors that influence the quality of longitudinal joints in asphalt pavements and survey participants were asked about their opinions about the most important factors. The opinions about the important factors that influence the quality of joints included:

- Proper compaction efforts at the joint (12 responses)
- Adequate material at the joint (7 responses)
- Proper application of tack coat at edge (5 responses)
- Straight joint alignment (4 responses)
- Attention to detail (3 response)
- Proper temperature and timing (2 responses)
- QC testing (2 response)
- Non-segregated edge (1 response)
- Education (1 response)
- Perfecting and being consistent with a method (1 response)
- Smaller NMAS (1 response)

Recommendations

Finally, respondents were asked to provide their recommendations for constructing high quality longitudinal joints. A summary of recommendations includes:

- Implement a joint density or permeability specification (7 responses).
- Use echelon paving when possible (5 responses).
- Ensure the joints are straight and properly aligned (2 responses).
- Properly tack the vertical face of the joint (2 responses).
- Specify a specific joint construction method (2 responses).
- Ensure sufficient material is present at the joint (2 responses).
- Apply a joint sealant (18 inches wide) directly beneath the surface layer longitudinal joint (1 response).
- Apply a fog seal over the longitudinal joint (1 response).
- Improve the training and education of personnel (1 response).

CHAPTER 4. Experimental Methods for Field and Laboratory Evaluation of Longitudinal Joint Performance

The goal of this portion of the research was to evaluate the relative quality of longitudinal joints compared to interior portions of pavements in South Carolina. The comparison was made by performing field and lab measurements of density, permeability, and indirect tensile strength (ITS) at the longitudinal joint and adjacent lanes (hot and cold lanes) immediately after construction. The test plan sequence for this phase of the study is illustrated in Figure 4.1.

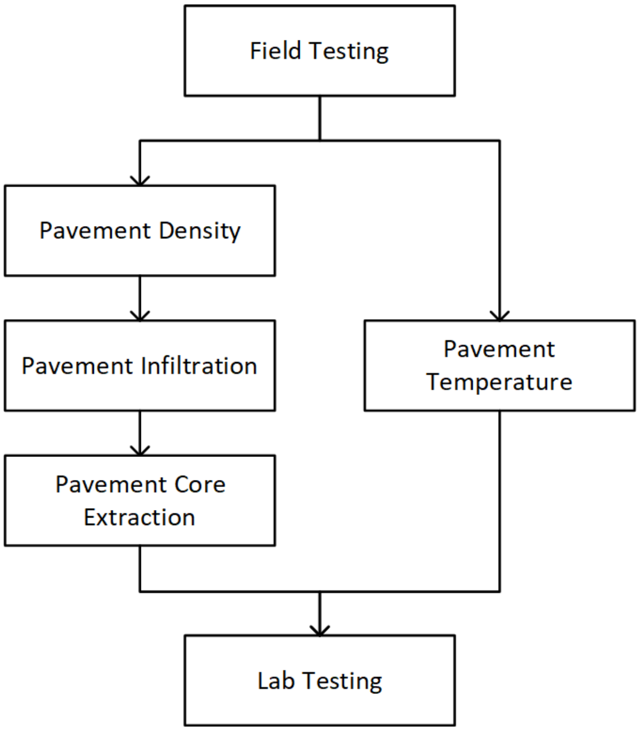


Figure 4.1: Field test plan sequence and procedures

Field Testing

During pavement construction, several qualitative observations and quantitative measurements were made related to longitudinal joint construction (Table 4.1).

Table 4.1: Field testing procedure summary

Field Testing	**Method**	**Frequency / Timing**	**Reason**
Joint Temperature	Use an infrared thermometer to measure the hot and cold lanes after paver has passed and measure the hot lane again just before the first roller pass	100 ft intervals	Determine the change in temperature just prior to compaction
In-Place Pavement Density	Use a PQI density gauge to measure density across the width of pavement	10 readings across the lane width	Compare field density at the joint to the remainder of pavement
In-Place Pavement Infiltration	Use a field permeameter at core locations to determine field infiltration	Each core location	Compare field infiltration at the joint and the hot lane
Pavement Coring	Determine the thickness of surface course and use a coring rig to cut cores	2 or 3 cores per station (at least 1 at joint and 1 in the central part of the mat)	Take cores back to laboratory for lab testing

Joint Temperature

The temperature of the pavement was measured on the hot and cold lanes as soon as asphalt was placed. The temperature of the hot lane was recorded again right before the first roller pass. For these measurements, a laser infrared thermometer, which has an accuracy of plus or minus 1 degree Celsius, was pointed approximately 2 ft off the ground and 1 ft away from the joint for the hot and cold lanes (Figure 4.2). The distance between each measuring point was set at 100 ft intervals and the distance was measured using a measuring wheel. Depending on the speed or delay of a roller on a construction site, the distance of the next measuring point was extended to 200 or 300 ft. At least four temperature measurements were taken depending on the speed of a paver. For the SC 8 project, temperature was measured after the first roller pass due to safety reasons.

Figure 4.2: Measuring joint temperature

In-Place Pavement Density

The in-place density of the pavement was measured following the finish roller passes. The density readings were recorded using a density gauge and measurements were taken across the width of a pavement as shown in Figure 4.3 and Figure 4.4 to obtain the transverse density profiles. The in-place density reading was recorded on the hot and cold lanes and near the joint if traffic or a quality control manager allowed. A Troxler nuclear density gauge was only used for the first US 25 project visit and a non-nuclear density gauge, Pavement Quality Indicator (PQI) 380, was used for the rest of the projects.

A nuclear density gauge contains radioactive material and it determines field density by detecting amount of gamma radiation passing through the asphalt pavement (Troxler 2009). A PQI 380 uses impedance spectroscopy to measure the electrical response of asphalt and calculate density. The PQI 380 is primarily used for newly-laid asphalt pavement with thickness ranging from 0.75 in to 6 in (TransTech 2016). Because the surface at a joint is typically uneven, the closest density gauge reading to the joint was centered at 1 ft away from the joint. The location of the first station tested was determined by the quality control manager’s coring location based on SC-T-101 (SCDOT 2013). Additional measurements were taken 100 ft and 200 ft from the first station, in the direction of paving.

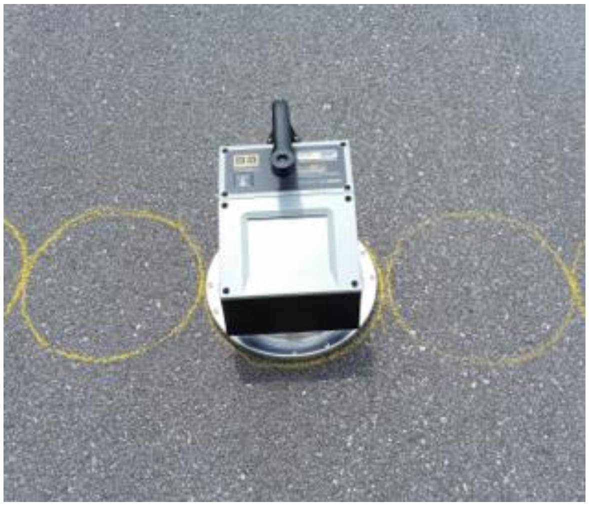


Figure 4.3: In-place, non-nuclear density gauge

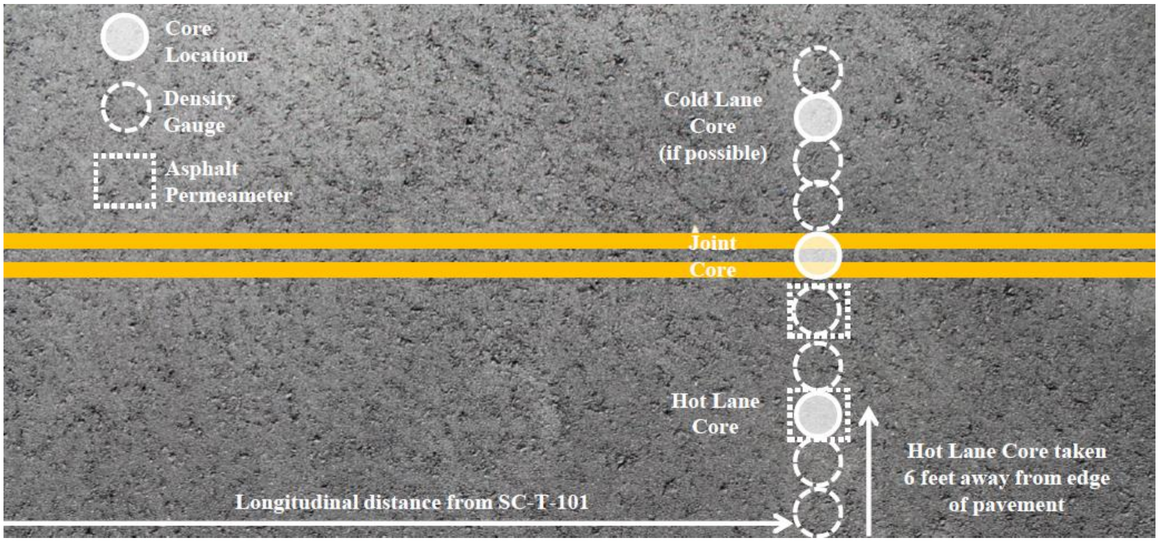


Figure 4.4: Testing plan on a constructed pavement

In-Place Pavement Infiltration

Pavement infiltration, the final field test, was conducted before coring samples from the pavement. The in-place infiltration was tested at the coring locations using the NCAT Asphalt Field Permeameter (shown in Figure 4.5) in accordance with the operating manual. The in-place infiltration test for joint sections was centered 1 ft away from the joint on the hot lane due to an uneven surface at the joint that resulted in water leaking through the seal between the permeameter and pavement surface. The Gilson NCAT field permeameter operating manual specified applying gentle, uniform foot pressure without twisting it to force the sealant into the asphalt mat (2013). In this study, water continued to leak without twisting to force the sealant into the asphalt mat, therefore, the permeameter was twisted slightly as it was sealed to the pavement. Additionally, the upper tier, which was included in the permeameter kit, was not utilized due to the water leaking through seal between the upper tier and bottom tier of permeameter. When calculating the field infiltration at the core locations, the permeability equation was not used due to the limited information on the thickness of the pavement. Instead, the infiltration rate was calculated using Equation 4.1.

$$Inf = \frac{a(h_1 - h_2)}{At} \tag{4.1}$$

Where: *Inf* = infiltration; *a* = inside cross-sectional area of the graduated cylinder; *t* = elapsed time between h_1 and h_2; and h_1 = initial head, h_2 = final head

Figure 4.5: In-place pavement infiltration

Pavement Coring

Pavement cores were taken at each test station at the longitudinal joint and center portion of the lane as illustrated in Figure 4.6. If there was a multiple lane closure, a core from the adjacent cold lane was also taken without disrupting traffic. To mitigate biased results, the longitudinal location of the first testing and coring location coincided with the random location of the contractor's acceptance cores as determined as per SC-T-101. The transverse location for the hot lane core was the center of the lane (i.e., 6 ft from the edge of the lane). Additional test stations (density, permeability, and coring) were located 100 ft and 200 ft downstream from the first location. If the quality control manager was not required to cut cores, then the first station was determined at 500 ft from the starting point of paving that day. The size of the field cores was 150 mm (6 in.) in diameter and thickness of cores varied from pavement to pavement. The cores were packed in a cooler of ice and transported to Clemson University. The bottom of each core was trimmed using a masonry saw with a diamond tipped blade to remove the tack coat and other adhered material (Figure 4.7). The trimmed cores were placed in an automatic core drying unit (Figure 4.8) to dry and prepare for lab testing.

Figure 4.6: Cutting a pavement core

Figure 4.7: Trimming a bottom part of pavement core

Figure 4.8: Core drying unit

Laboratory Tests

The pavement cores from the joint and the interior of two adjacent lanes were used to compare the relative quality and performance of longitudinal joints. The comparison was made by comparing the density, permeability, and indirect tensile strength (ITS) of pavement cores obtained at each test station. The comparison among different paving projects was also made to analyze any influence of different construction and compaction methods on the longitudinal joint quality. The procedures included in Figure 4.9 were used to evaluate the quality of the longitudinal joints.

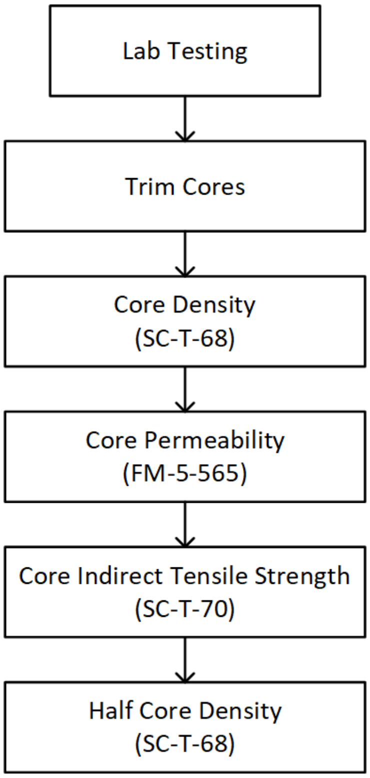


Figure 4.9: Laboratory test plan sequence and procedures

Density

After drying with the automatic core dryer, the bulk specific gravity (G_{mb}) and density of each core was measured in accordance with SC-T-68. After conducting indirect tensile strength tests, the density of each half core was also measured using the same procedure to compare density of the hot and cold lanes at the joint. The G_{mb} of the cores was calculated using Equation 4.2:

$$G_{mb} = \frac{A}{B - C} \quad (4.2)$$

where: G_{mb} = bulk specific gravity; A = mass of dry core in air; B = mass of core in saturated surface dry (SSD) condition; C = mass of core under water.

Permeability

A falling head permeameter (Figure 4.10) was used to measure the permeability of each core in the lab according to the FM 5-565 procedure outlined by the Florida DOT (2004). This procedure calls for the permeability to be determined by recording time required for 500 mL of water to flow through the specimen under a specific head. This study deviated from the FM 5-565 procedure, in that if the time exceed 30 minutes to complete the test in the first trial, the change in the head after 5 minutes was measured in the second trial. The coefficient of permeability, *k*, is based on Darcy's law and was calculated using Equation 4.3:

$$k = \frac{aL}{At}\ln\left(\frac{h_1}{h_2}\right) * t_c \tag{4.3}$$

where: k = coefficient of permeability; a = inside cross-sectional area of the graduated cylinder; L = average thickness of the core; A = diametral area of the core; t = elapsed time between h_1 and h_2; h_1 = initial head; h_2 = final head; and t_c = temperature correction for viscosity of water.

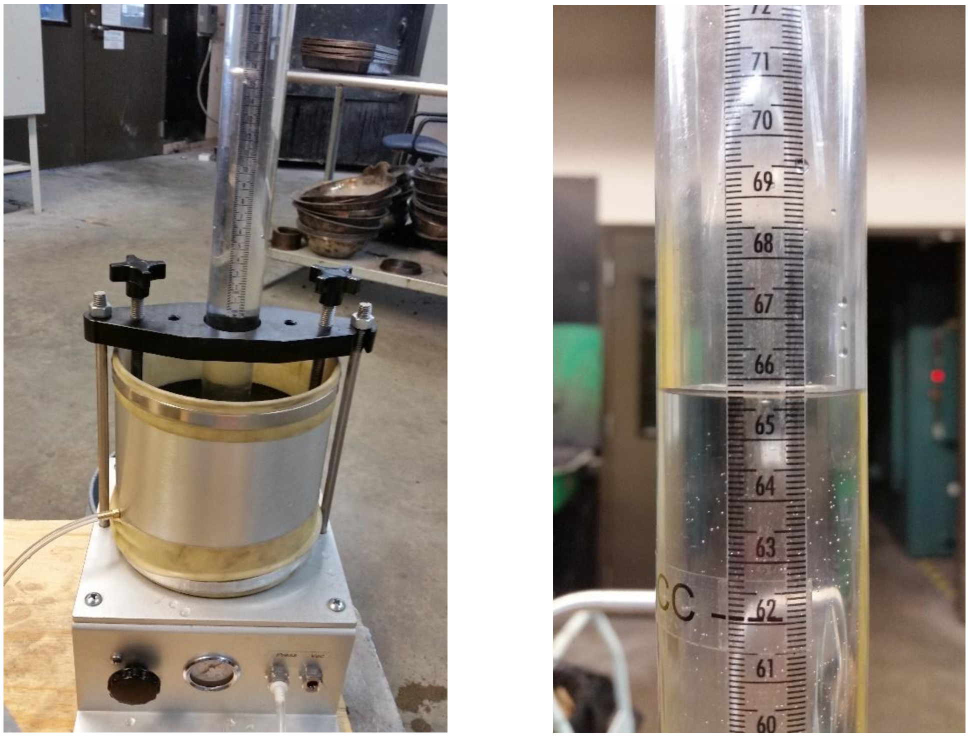


Figure 4.10: Falling head permeameter

Indirect Tensile Strength

The indirect tensile strength (ITS) of cores taken from the field was measured following SC-T-70 to determine the strength of each core. The ITS information can also be used as an indicator of adhesion between cold and hot lanes for joint cores (Huang et al. 2010). When testing a core (joint or interior), the specimen was positioned in the test fixture so the direction of traffic was oriented vertically across its diameter (i.e., in the direction of loading). This ensured that when the joint cores were tested, the joint was aligned with the load to apply tensile forces directly to the joint (Figure 4.11). The ITS was calculated using Equation 4.4:

$$ITS = \frac{2\,(L)}{\pi(H)(D)} \tag{4.4}$$

where: *L* = maximum load applied; *H* = height of the core; *D* = diameter of the core.

Figure 4.11: Indirect tensile strength test

After splitting the joint cores during the ITS testing, the density of the cold side and hot side of the broken cores were measured again per SC-T-68.

Project Locations

All of the data for this research was from nine asphalt construction projects from the 2017 paving season completed in South Carolina DOT Districts 1, 2, and 3 at the locations indicated in Figure 4.12. The projects evaluated in this study included three different surface type mixes (surface type A, B, and C), two longitudinal joint construction techniques, and one rolling pattern (hot overlap).

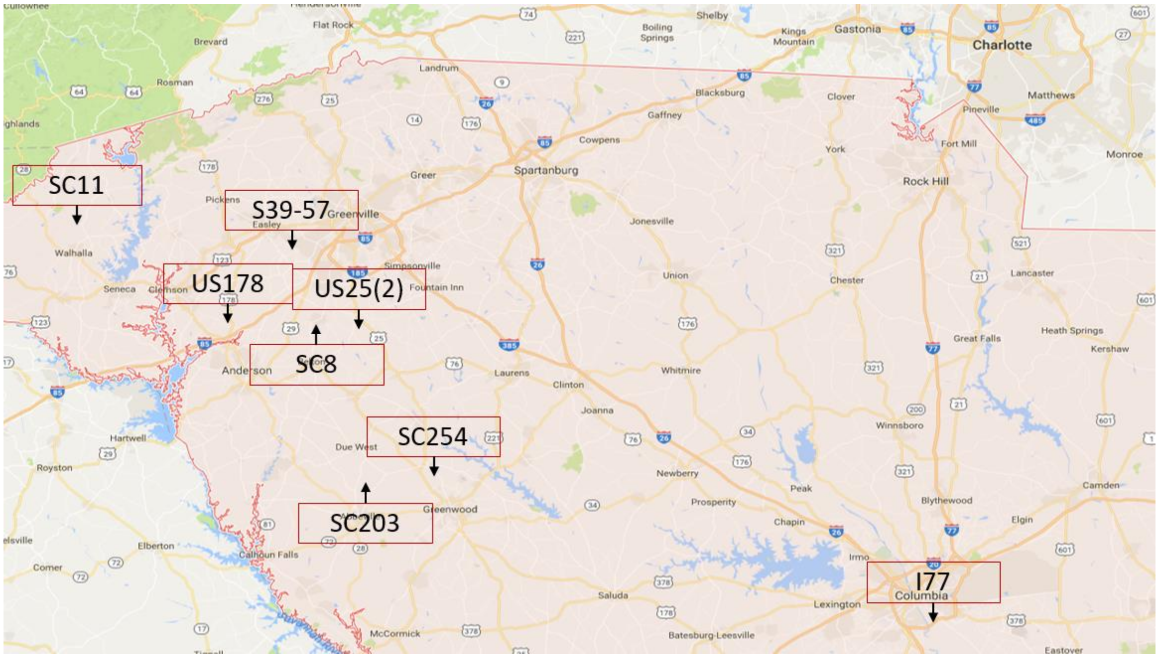


Figure 4.12: Locations of projects evaluated in this study

Project Table and Figure Labels

For each section of the project, information is presented in tables with construction information and figures that present temperature readings, in-place density, in-place infiltration, lab density, lab permeability, ITS, and half core lab density results. To clarify what each label represents, descriptions are included below.

In the construction information of each project, "joint straightness" describes if the joint was constructed straight, straightish, or not straight. To determine the straightness of the joint, a visual observation was made for each project. The "height of joint" indicates the height of the overlapped material at the joint after the paver passed by. The "extent of joint" means the distance between the end gate of the paver screed to the top edge of the unconfined surface.

For the pavement temperature figures, the "hot after pave" and the "cold after pave" labels represent the temperature of hot lane and cold lane, respectively, after the paver passed. Likewise, the "hot before compact" represents the hot lane temperature right before the roller passed. On the x-axis, 0 percent is where the joint is located and 100 percent is the other edge of the lane. If the figure has negative percent and the positive percent, the negative percent indicates the hot lane and the positive percent indicates the cold lane.

The “hot, joint, and cold” labels that are shown in density, air void contents, infiltration, permeability, and indirect tensile strength (ITS) figures represent the cores taken from the middle of the hot lane, the joint, and the middle of the cold lane, respectively. In project half core density figures, the “half hot” and the “half cold” represent the hot side and the cold side, respectively, of the joint core after conducting the ITS test and the “whole joint” represents the density of the joint core before the ITS test.

In the summary of projects tables and figures, J/H represent the average ratios of joint and hot lane measurement of each station. The J/H ratios help to compare the performance of the joint relative to interior of the mat at each station instead of comparing average joint and hot lane measurement of all stations. The C/H represents the average ratios of cold lane and hot lane measurement of each station.

CHAPTER 5. Results and Discussion

US 178 Project

The US 178 Project was constructed using a butt joint technique and information for construction, mix design, and gradation can be found in Table 5.1. Due to safety reasons and other technical issues, some of the construction information in the table could not be obtained. The temperature readings, in-place density, lab density, air void content, lab permeability, ITS, and half core lab density results from this project are presented in Figures 5.2 through 5.8. The summary of all the US 178 results is presented in Table 5.2.

Note: The distance between each temperature reading was approximately 25 - 50 ft. The field infiltration could not be performed due to water leaking through the seal after multiple trials.

Table 5.1: US 178 project information

Construction Information	
Location	US-178
Construction Type	Butt Joint
Compaction at Joint (First Pass)	Hot Overlap
Thickness	2 in
Joint Straightness	Not straight
Joint Cleanness	Clean
Joint Tack Coat	Unknown
Height of Joint	Unknown
Extent of Joint	Unknown
Material Transfer Vehicle	Yes
Night Time Paving	Yes
Mix Design Information	
Type Mix	Surface B
AC Grade	PG 64-22
Design Air Voids (%)	2.9
Target AC (%)	5.7
Average MSG	2.523
Aggregate Gradation	
Sieve	Percent Passing
37.5 mm (1.5")	100.0
25.0 mm (1")	100.0
19.0 mm (3/4")	100.0
12.5 mm (1/2")	99.0
9.5 mm (3/8")	91.0
4.75 mm (No. 4)	63.0
2.36 mm (No. 8)	47.0
0.60 mm (No. 30)	30.0
0.150 mm (No. 100)	10.3
0.075 mm (No. 200)	5.4

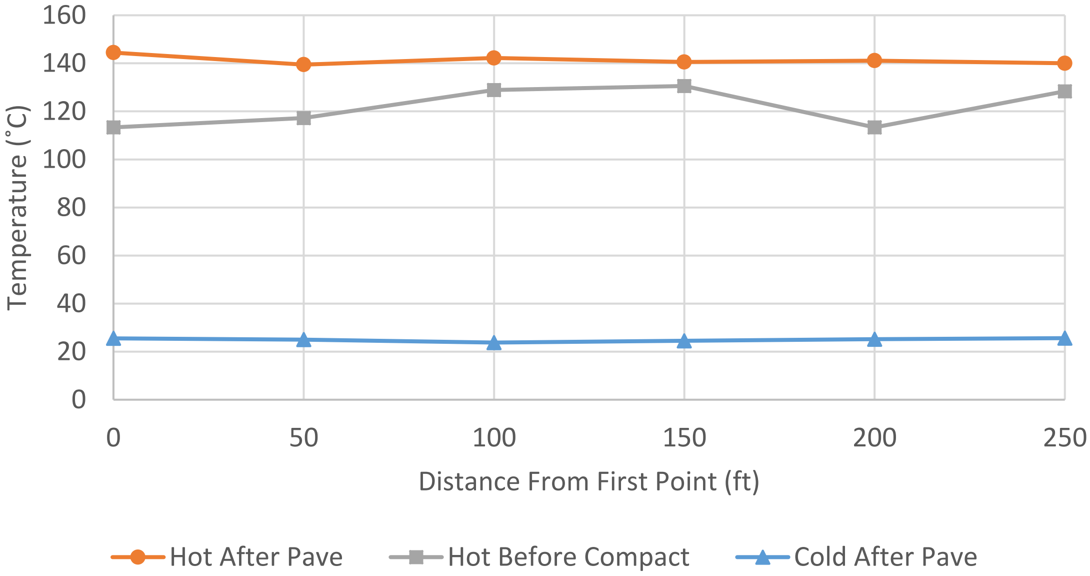


Figure 5.2: US 178 project pavement temperature

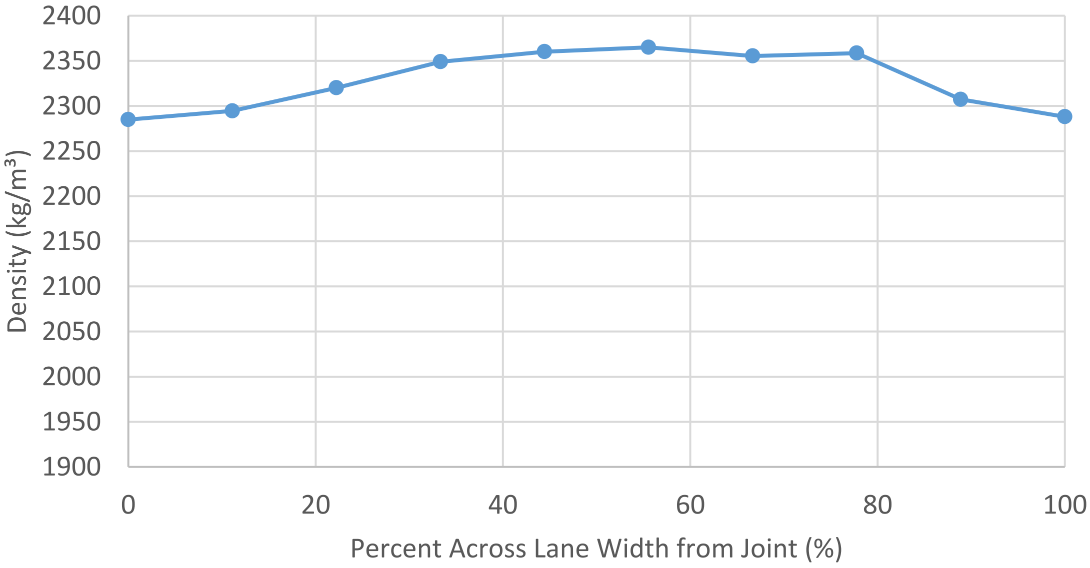


Figure 5.3: US 178 project in-place density measurement (measured with the PQI)

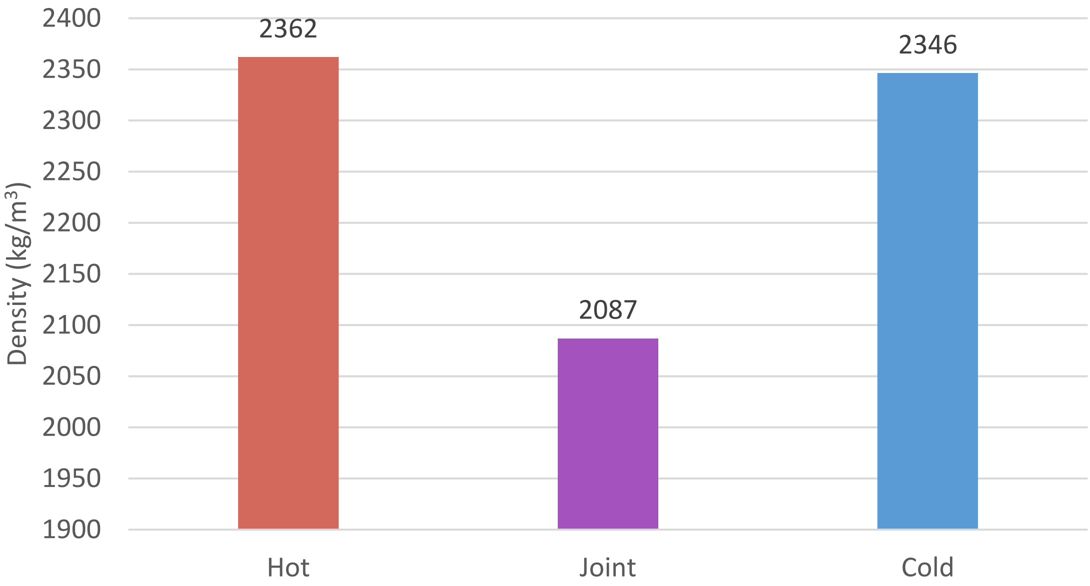


Figure 5.4: US 178 project lab density measurement

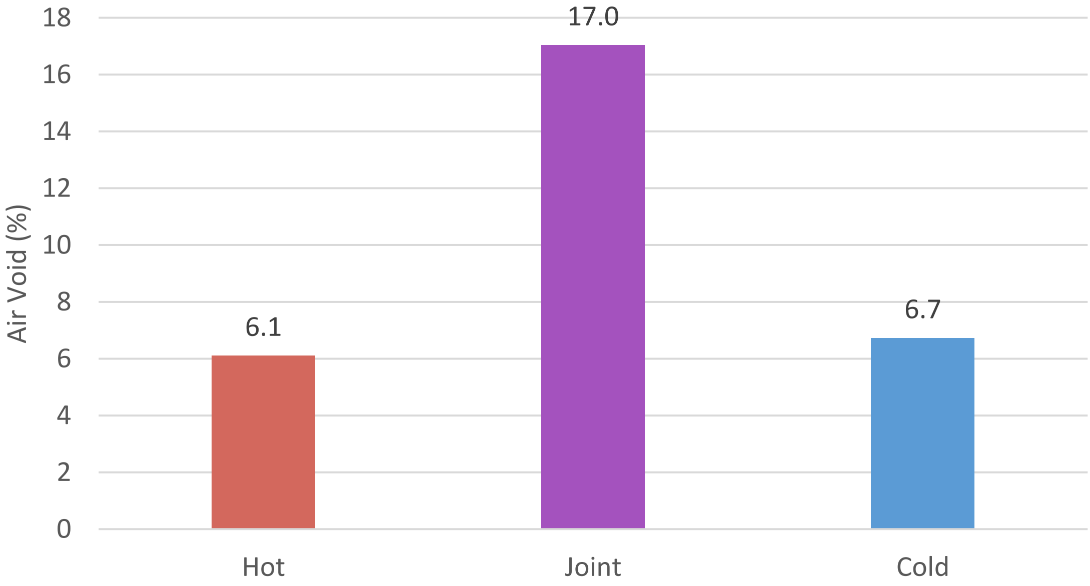


Figure 5.5: US 178 project air void contents

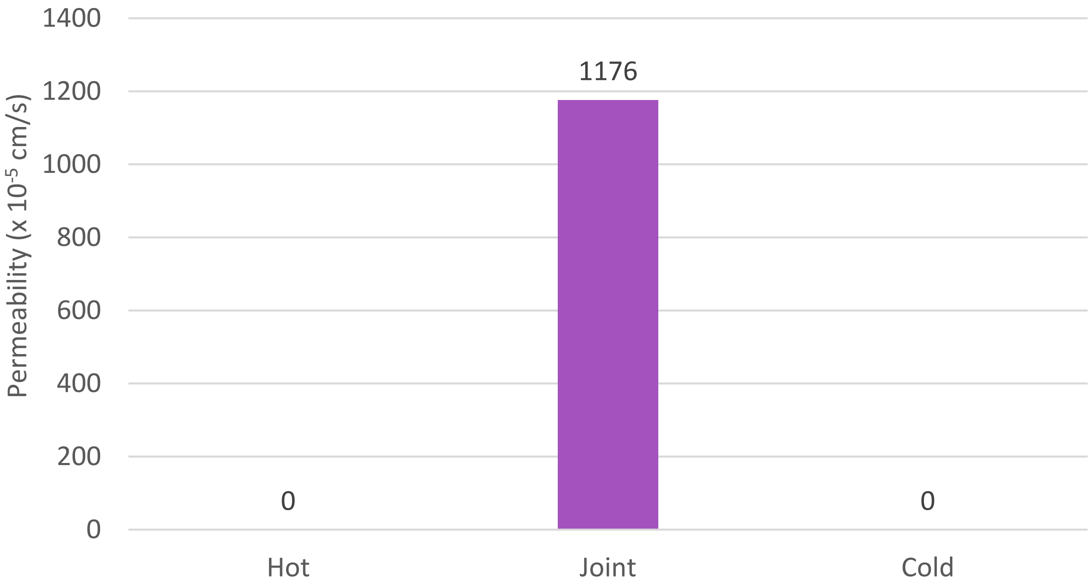


Figure 5.6: US 178 project lab permeability

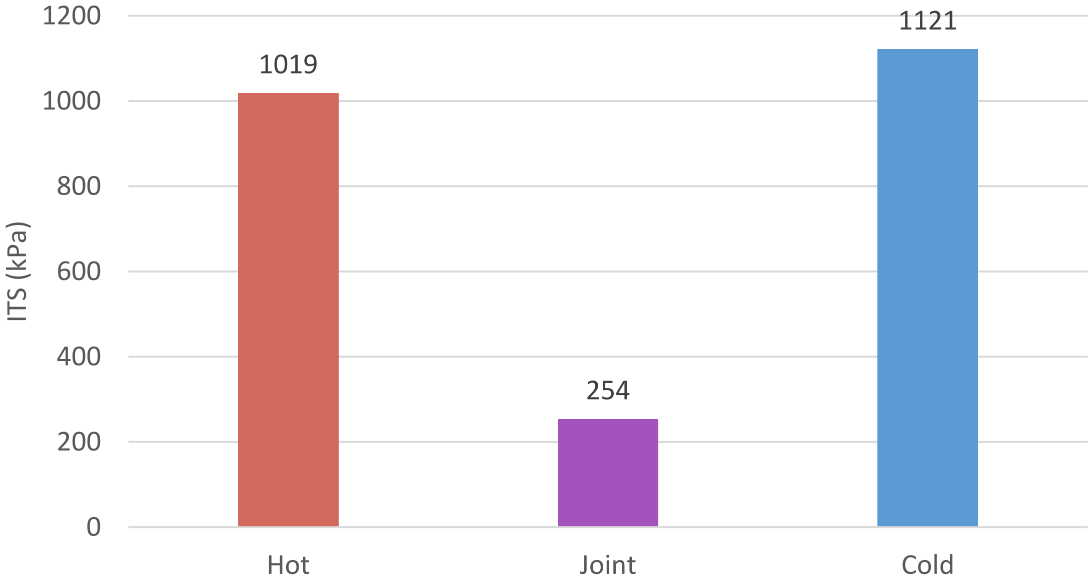


Figure 5.7: US 178 project dry indirect tensile strength (ITS) measurement

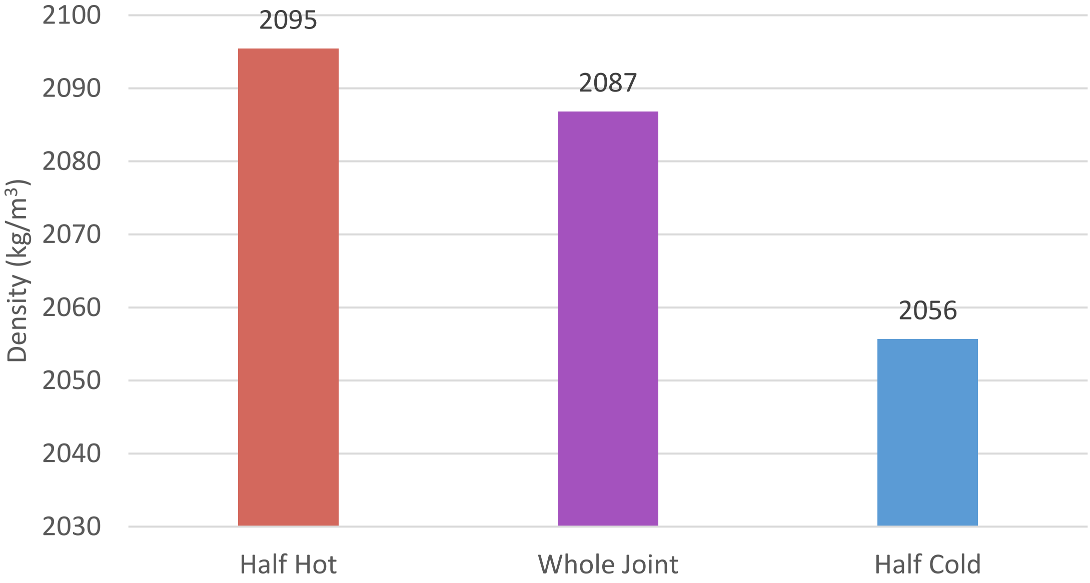


Figure 5.8: US 178 project half core lab density from the joint core

Table 5.2: Summary of US 178 project

Average	**Hot**	**Joint**	**Cold**	**Significant Difference**
Field Density (kg/m³)	2363	2285	.	N/A
Field Infiltration (x 10^{-5} cm/s)	.	.	.	N/A
Lab Density (kg/m³)	2362	2087	2346	N/A
Lab Air Void (%)	6.1	17.0	6.7	N/A
Lab Permeability (x 10^{-5} cm/s)	0	1164	0	N/A
ITS (kPa)	1019	254	1121	N/A
Half Lab Density (kg/m³)	2095	.	2056	N/A

For the US 178 project, only 3 cores (the hot lane, joint, cold lane) were taken from one station and therefore, a statistical analysis to compare the performance between the hot lane and the joint could not be performed. However, based on the results presented in Figures 5.3 through 5.8, the performance of the joint was poorer than the hot lane. The field density at the joint and the free edge was lower than the field density at middle of the hot lane, forming a flat bell-shaped curve. In comparison to the field density result, the lab density at the joint is much lower than the lab density of the hot and cold lane. The lab permeability of the cores taken from the hot lane and the cold lane was almost impermeable, but the joint had a high permeability. The ITS result also shows that the indirect tensile strength at the joint was much lower than the hot and the cold lanes. The hot and cold lane had similar results in all tests.

The lab results in Table 5.2 could be negatively influenced by not icing the surface of coring locations before cutting the cores. It is important to ice the area of interest before coring since the hot asphalt mix may still be hot enough to deform while coring. It should be noted, however, that the cores were cut from the middle of the hot lane and the joint using the same procedure. This was a nighttime paving project and there was limited visibility for paving or rolling operators to identify the joint up ahead and the poor visibility could have caused poor compaction of the joint.

SC 203 Project

The SC 203 overlay was constructed using a safety edge and no compaction was performed on the edge. The safety edge is a sloped pavement edge at the joint, which improves safety of drivers by eliminating a vertical drop off the edge when they are changing a lane from the paved lane to the milled, unpaved lane. Unlike a typical wedge joint, the sloped face of this safety edge was not compacted with any intentionality. This sloped edge was formed by a sloped guide welded inside the paver, but it is not considered a joint compaction devise. It was noted that the joint on SC 203 was compacted first using the hot overlap method and then the hot pinch method on the second pass. The background information that includes construction, mix design, and gradation can be found in Table 5.3. Due to technical problems, limited time, and traffic, some of the construction information could not be obtained. The temperature readings, in-place density, lab density, air void contents, in-place infiltration, lab permeability, indirect tensile strength (ITS), and half core lab density taken from this project are presented in Figures 5.9 through 5.16. The summary of all the SC 203 results is presented in Table 5.4.

Note: The field density was only recorded at station 252+10 and the field infiltration at 255+10 could not performed because of limited time and limited traffic control. The cores taken from this project were cut by the onsite quality control manager who used a 145 mm (5.7 in) inner diameter core bit, which was smaller compared to the Clemson research core bit size used on the other projects. The ITS for the joint core at station 253+10 could not be performed because the specimen was not cut with the joint in the center. The numerical values with stars are not included in the statistical analysis because cores were not cut right on the joint.

Table 5.3: SC 203 project information

Construction Information	
Location	SC-203
Construction Type	Safety Edge
Compaction at Joint (First-Second))	Hot Overlap - Hot Pinch
Thickness	1.75 in
Joint Straightness	Straightish
Joint Cleanness	Clean
Joint Tack Coat	Yes
Height of Joint	Unknown
Extent of Joint	Unknown
Material Transfer Vehicle	Yes
Night Time Paving	No
Mix Design Information	
Type Mix	Surface C
AC Grade	PG 64-22
Design Air Voids (%)	3.6
Target AC (%)	5.5
Average MSG	2.434
Aggregate Gradation	
Sieve	Percent Passing
37.5 mm (1.5")	100.0
25.0 mm (1")	100.0
19.0 mm (3/4")	100.0
12.5 mm (1/2")	100.0
9.5 mm (3/8")	95.1
4.75 mm (No. 4)	68.7
2.36 mm (No. 8)	47.8
0.60 mm (No. 30)	26.2
0.150 mm (No. 100)	9.9
0.075 mm (No. 200)	4.5

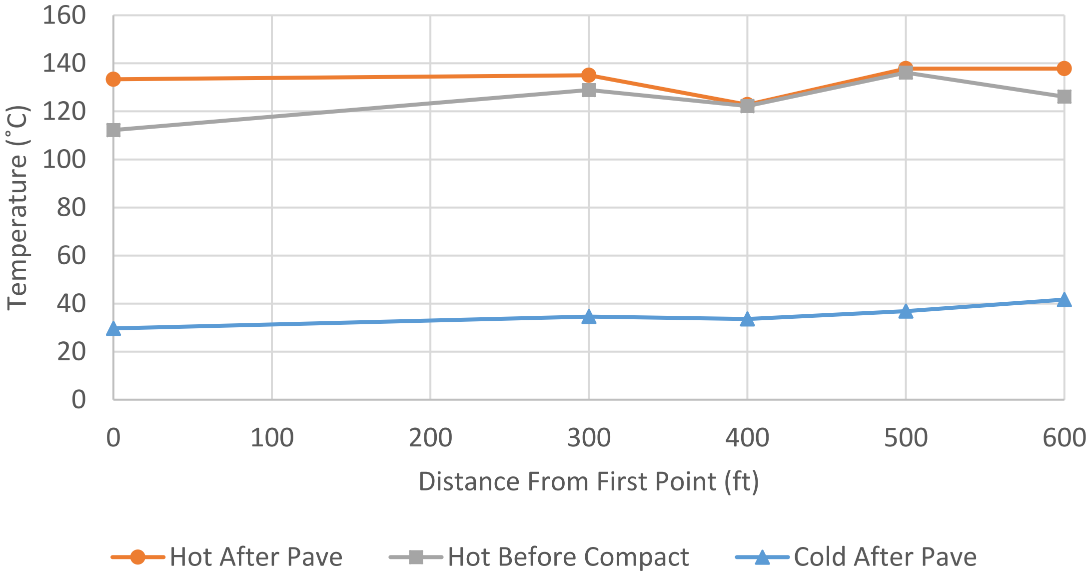


Figure 5.9: SC 203 project pavement temperature

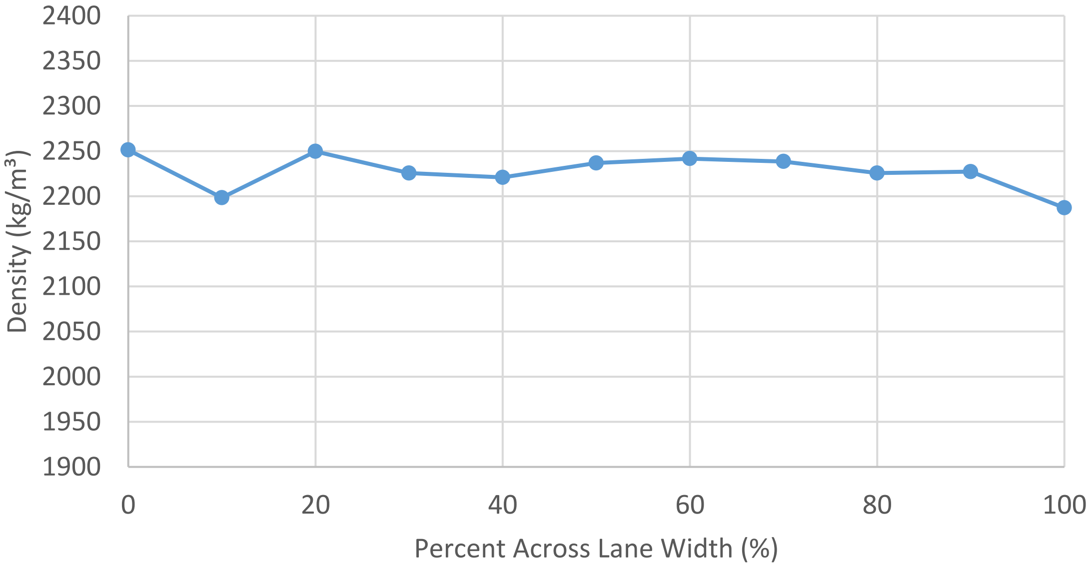


Figure 5.10: SC 203 project in-place density measurement (measured with the PQI)

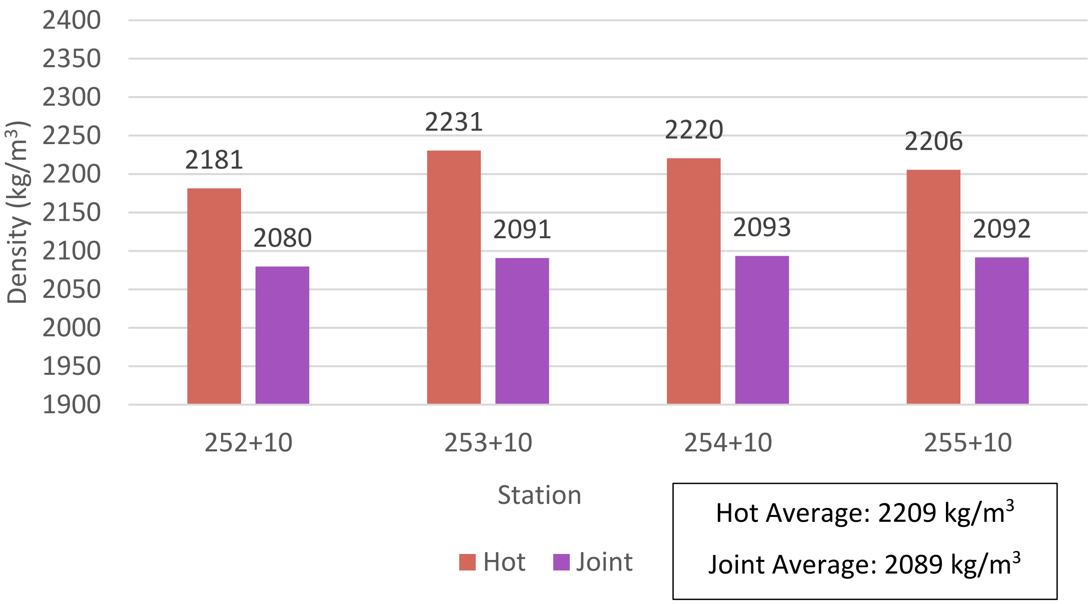


Figure 5.11: SC 203 project lab density measurement

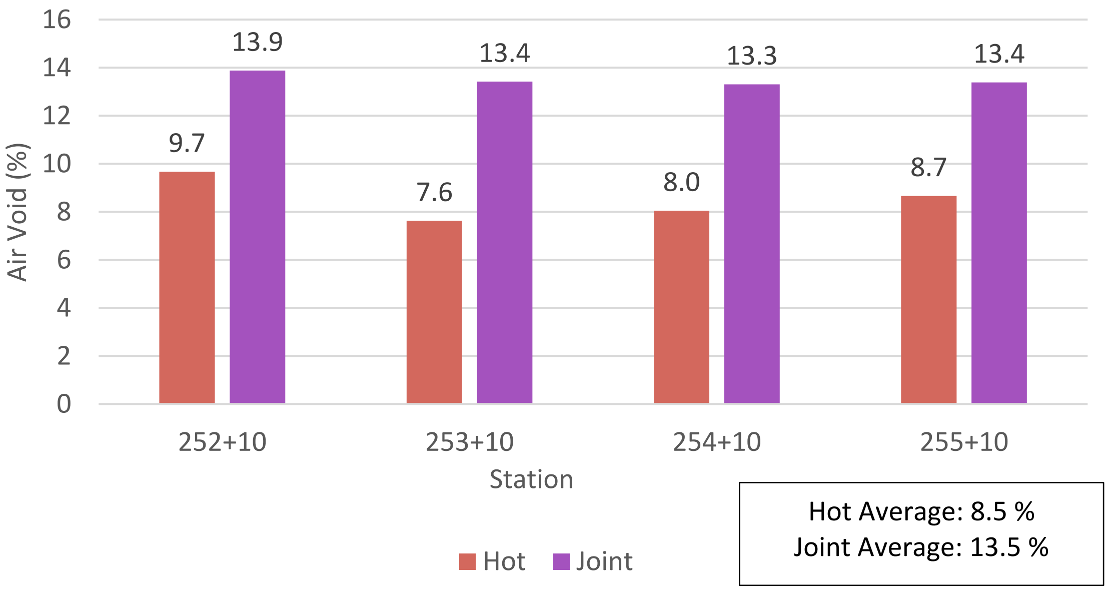


Figure 5.12: SC 203 project air void contents

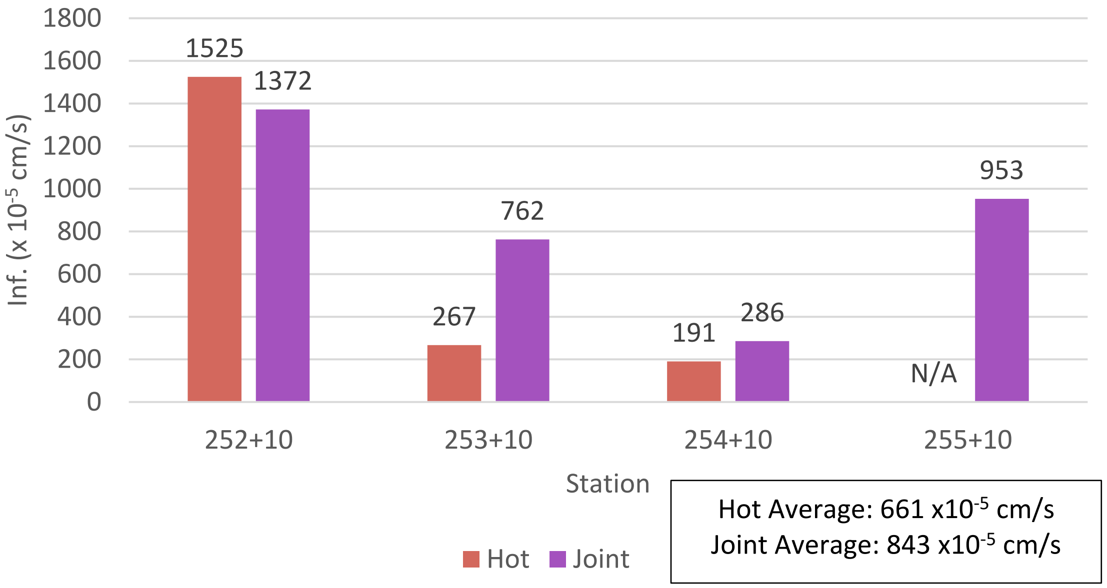


Figure 5.13: SC 203 project in-place infiltration measurement

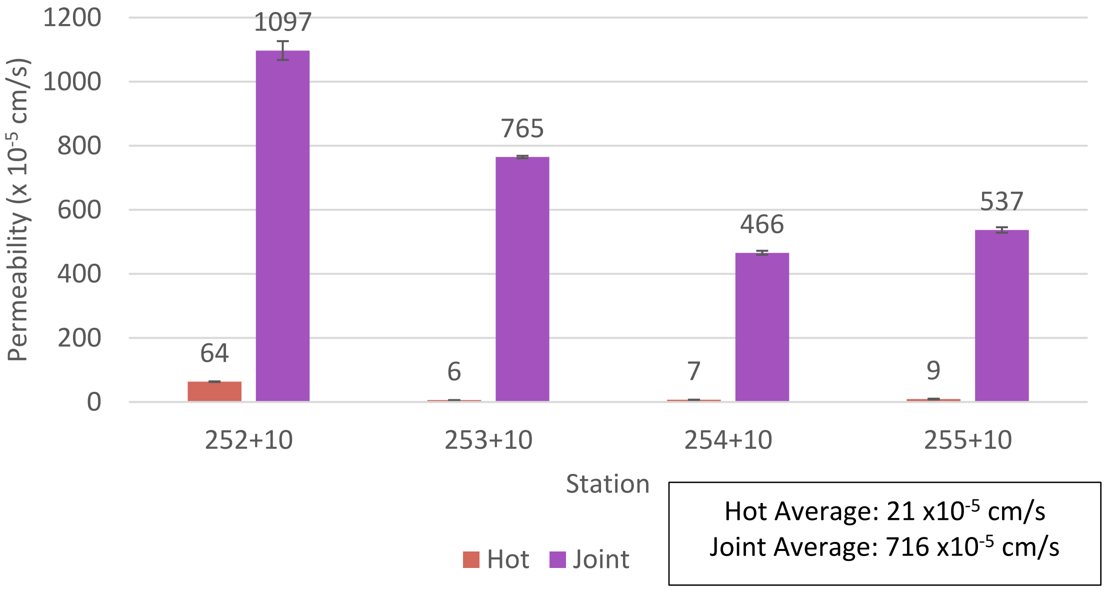
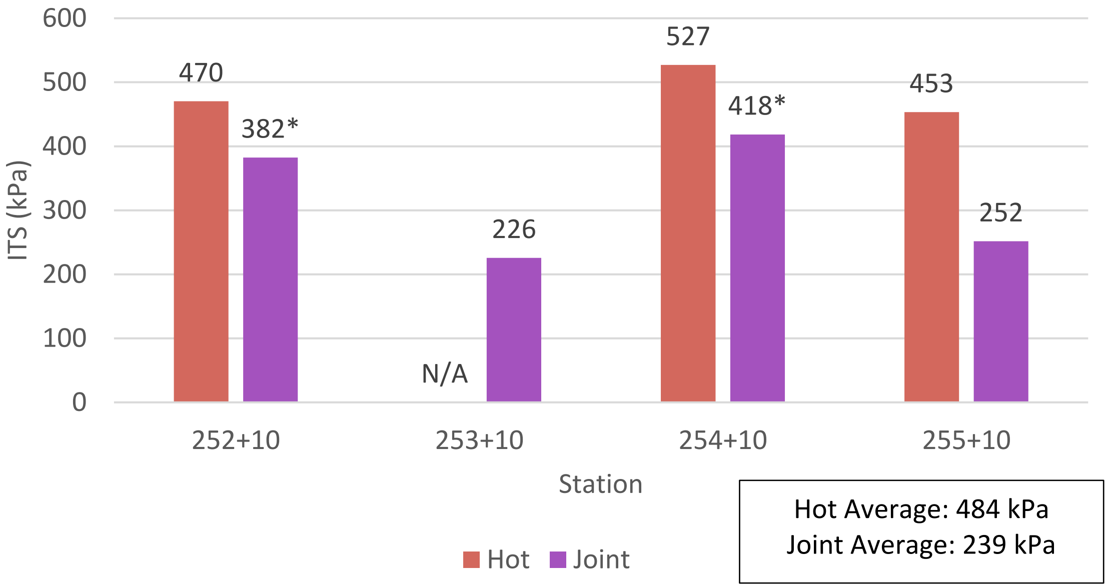
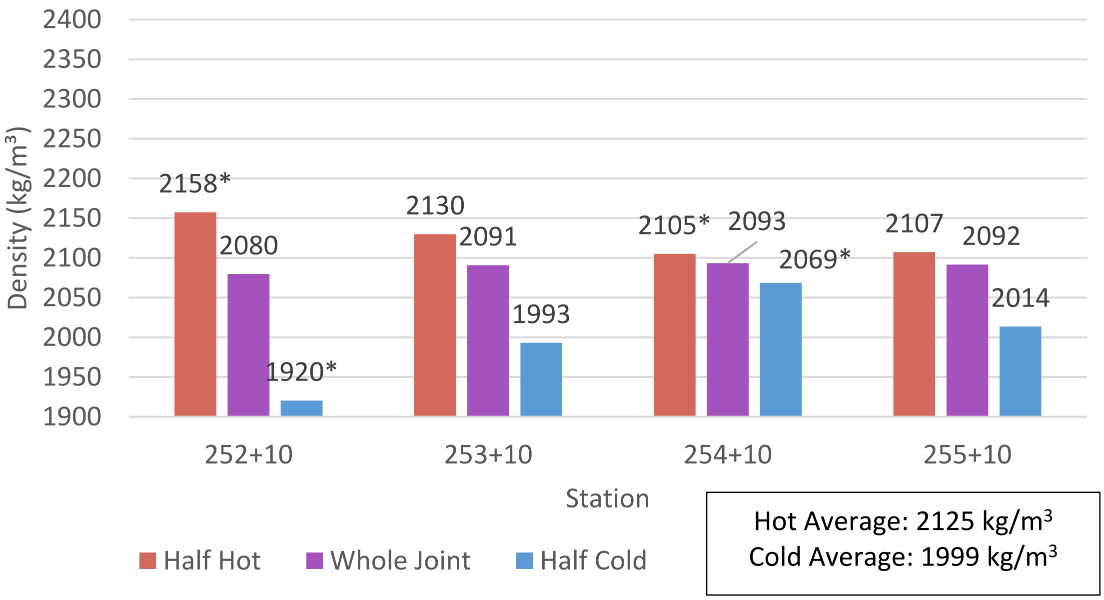


Figure 5.14: SC 203 project lab permeability



Hot Average: 484 kPa
Joint Average: 239 kPa

Figure 5.15: SC 203 project dry indirect tensile strength (ITS) measurement



Hot Average: 2125 kg/m^3
Cold Average: 1999 kg/m^3

Figure 5.16: SC 203 project half cores lab density from the joint cores

Table 5.4: Summary of SC 203 project (H = hot lane or half hot, J = joint, C = half cold, N/A = limited data)

Average	**Hot**	**Joint**	**Cold**	**Significant Difference**
Field Density (kg/m³)	2226	2224	.	No (H vs J)
Field Infiltration (x 10^{-5} cm/s)	661	843	.	No (H vs J)
Lab Density (kg/m³)	2209	2089	.	Yes (H vs J)
Lab Air Void (%)	8.5	13.5	.	Yes (H vs J)
Lab Permeability (x 10^{-5} cm/s)	22	716	.	Yes (H vs J)
ITS (kPa)	484	320	.	N/A (H vs J)
Half Lab Density (kg/m³)	2125	.	1999	No (H vs C)

Significant differences between the hot lane and the joint were found in lab density, air void content, lab permeability, and ITS results at the 5% significance level. Therefore, the lab results from the SC 203 project show the performance of the joint cores was less than the hot lane cores. The same data trend was seen in the project as the US 178 project except for the in-place infiltration result at station 252+20. Additionally, the density of the halves from the joint cores showed significant differences between the hot lane core and the cold lane core, indicating the hot side of the joint core had statistically higher density compared to the cold side of the joint core. The hot side of the joint core will likely will have higher density than the cold side because the hot side had the confined edge during construction while the cold side did not.

US 25 Project

In SCDOT District 3, the surface layer of US 25 was constructed using a safety edge technique, but no special compaction was performed on the sloped edge. The information for construction, mix design, and gradation can be found in Table 5.5. Some of the construction information could not be obtained because there was limited space or opportunity during construction. The temperature readings (Figure 5.17), in-place density (Figure 5.18), lab density (Figure 5.19), air void content (Figure 5.20), in-place filtration (Figure 5.21), lab permeability (Figure 5.22), indirect tensile strength (ITS) (Figure 5.23), and half core lab density (Figure 5.24) taken from this project are presented below. Table 5.6 provides a summary of all project data.

Note: The in-place density was measured using a Troxler nuclear density gauge instead of using a non-nuclear gauge. For all other projects, a PQI non-nuclear gauge was used to measure in-place density.

Table 5.5: US 25 project information

Construction Information	
Location	US-25
Construction Type	Safety Edge
Compaction at Joint (First Pass)	Hot Overlap
Thickness	2.5 in
Joint Straightness	Straightish
Joint Cleanness	Clean
Joint Tack Coat	Yes
Height of Joint	Unknown
Extent of Joint	Unknown
Material Transfer Vehicle	Yes
Night Time Paving	No
Mix Design Information	
Type Mix	Surface B
AC Grade	PG 64-22
Design Air Voids (%)	3.1
Target AC (%)	5.7
Average MSG	2.433
Aggregate Gradation	
Sieve	Percent Passing
37.5 mm (1.5")	100.0
25.0 mm (1")	100.0
19.0 mm (3/4")	100.0
12.5 mm (1/2")	99.0
9.5 mm (3/8")	90.0
4.75 mm (No. 4)	60.0
2.36 mm (No. 8)	45.0
0.60 mm (No. 30)	25.0
0.150 mm (No. 100)	8.0
0.075 mm (No. 200)	4.0

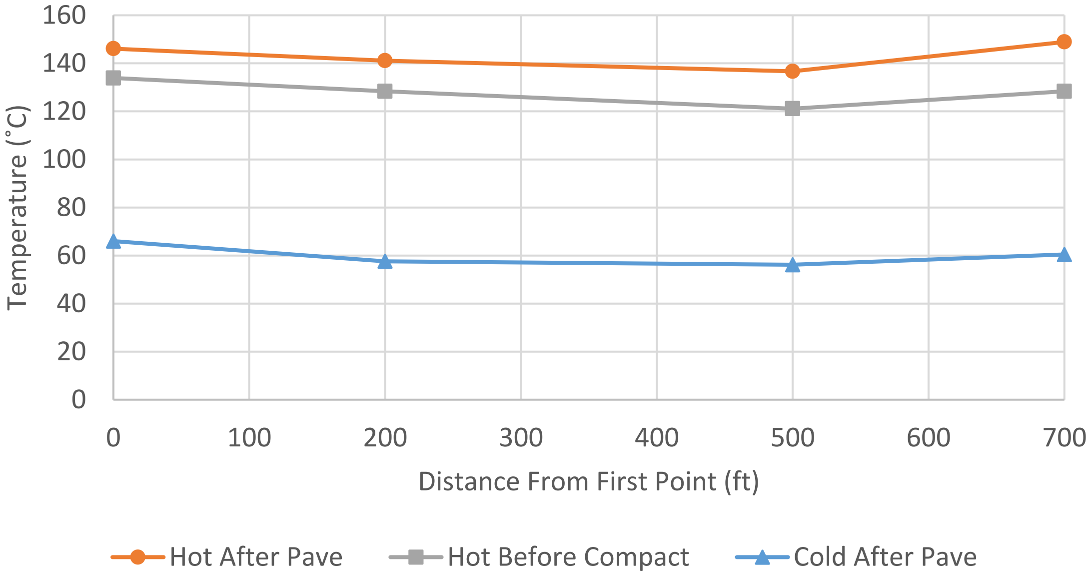


Figure 5.17: US 25 project pavement temperature

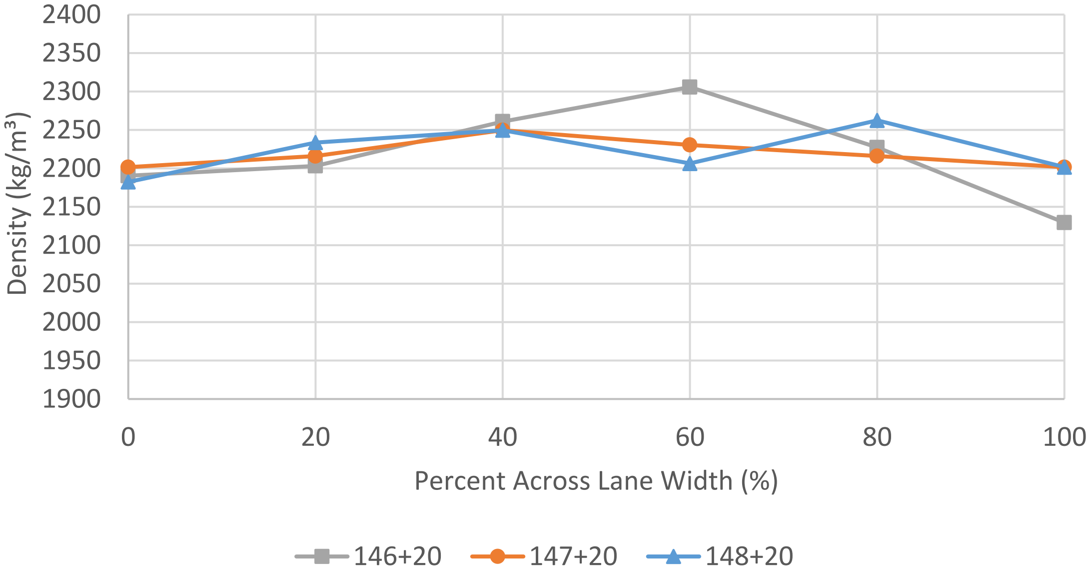


Figure 5.18: US 25 project in-place density measurement (measured with the Troxler nuclear density gauge)

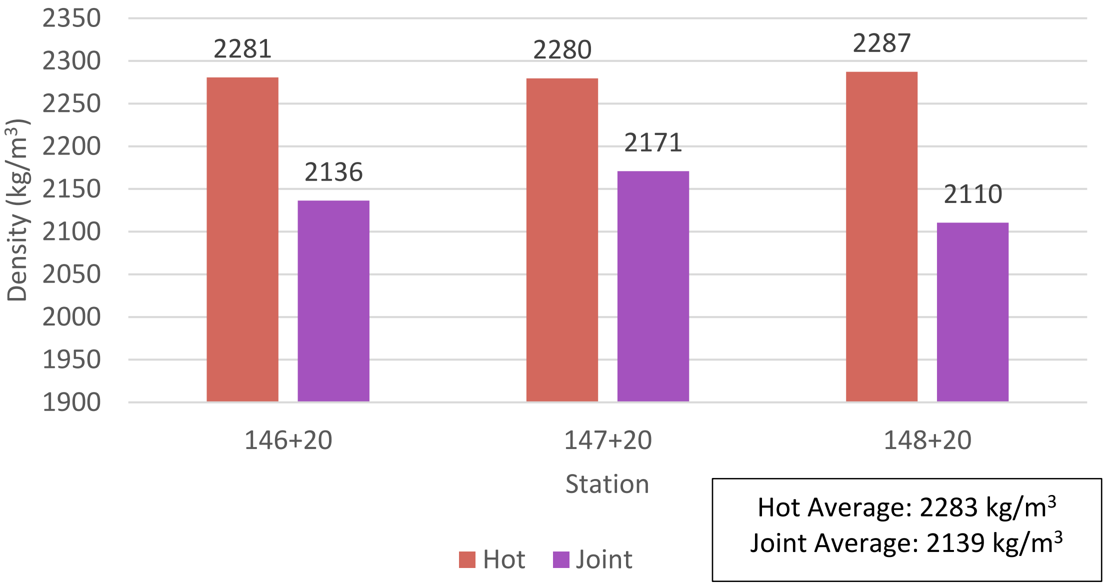


Figure 5.19: US 25 project lab density measurement

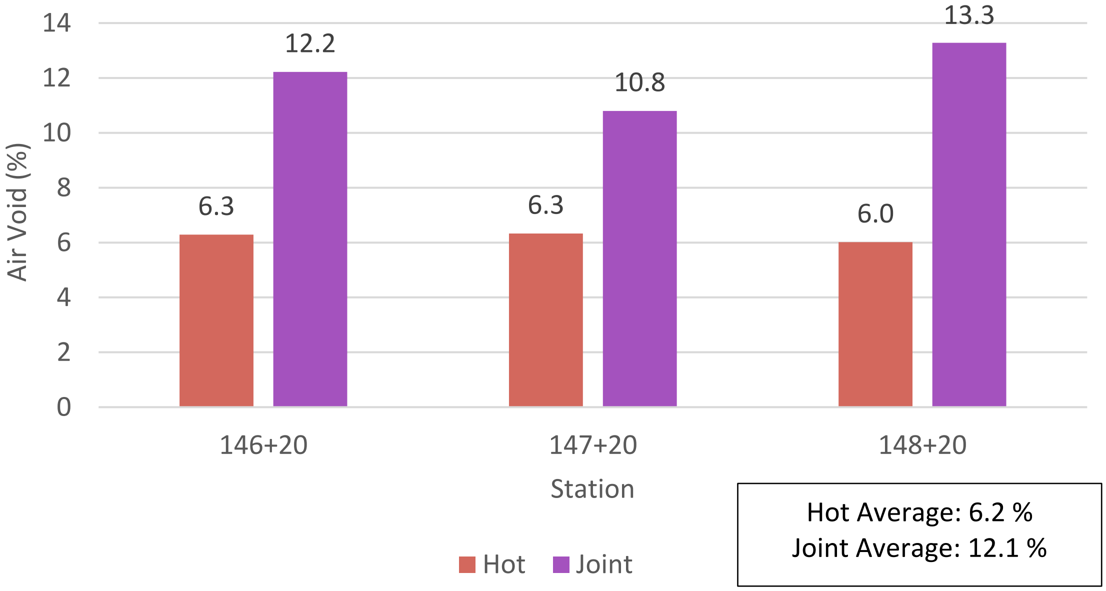
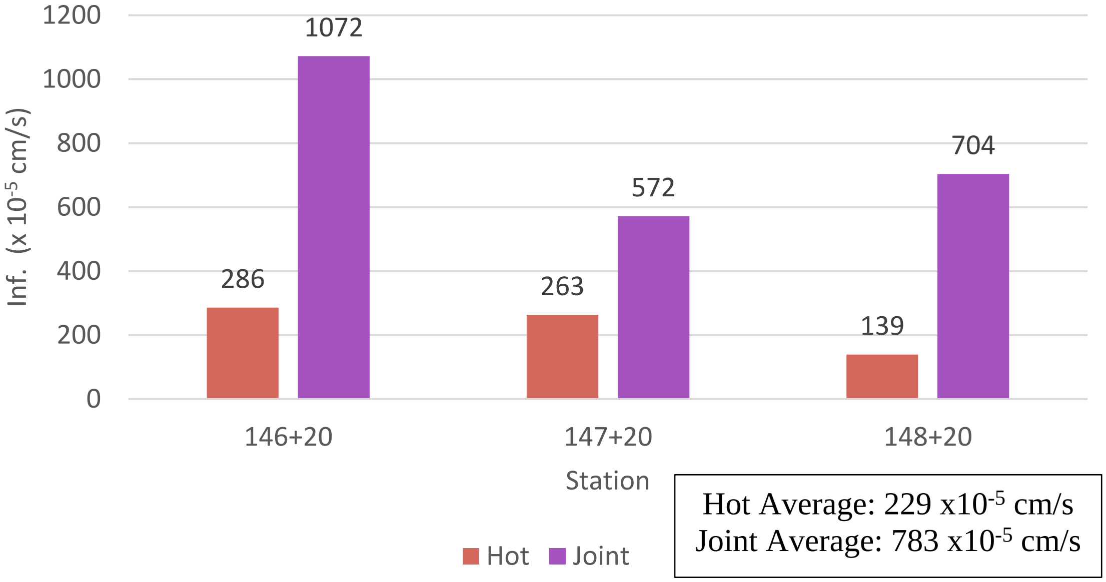
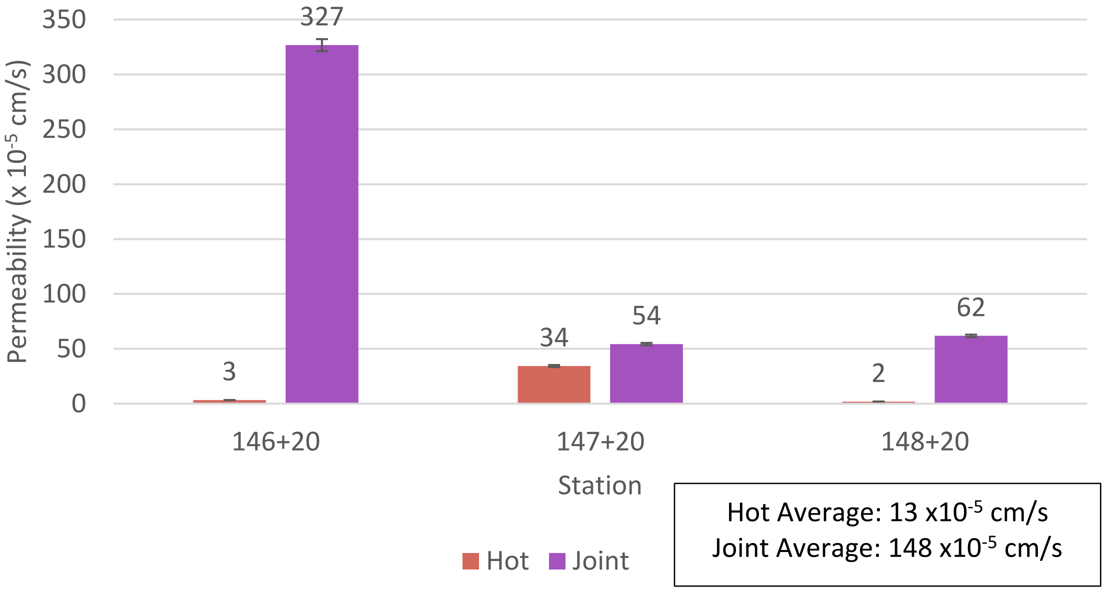


Figure 5.20: US 25 project air void contents



Hot Average: 229 x10^{-5} cm/s
Joint Average: 783 x10^{-5} cm/s

Figure 5.21: US 25 project in-place infiltration measurement



Hot Average: 13 x10^{-5} cm/s
Joint Average: 148 x10^{-5} cm/s

Figure 5.22: US 25 project lab permeability

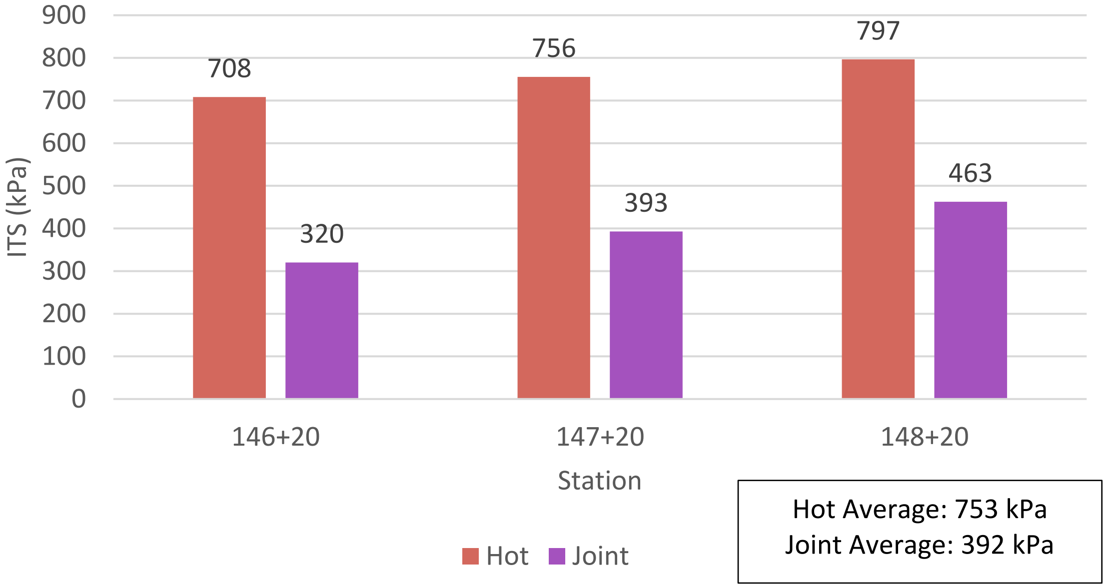


Figure 5.23: US 25 project dry indirect tensile strength (ITS) measurement

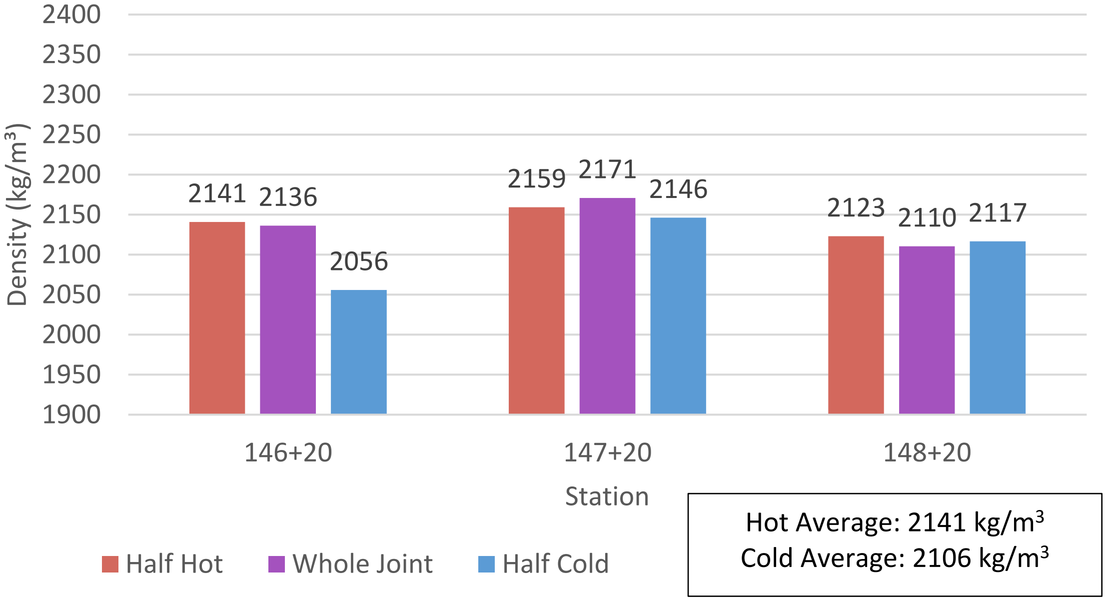


Figure 5.24: US 25 half cores lab density from the joint cores

Table 5.6: Summary of US 25 project (H = hot lane or half hot, J = joint, C = half cold, N/A = limited data)

Average	**Hot**	**Joint**	**Cold**	**Significant Difference**
Field Density (kg/m³)	2250	2191	.	No (H vs J)
Field Infiltration (x 10^{-5} cm/s)	229	783	.	No (H vs J)
Lab Density (kg/m³)	2283	2139	.	Yes (H vs J)
Lab Air Void (%)	6.2	12.1	.	Yes (H vs J)
Lab Permeability (x 10^{-5} cm/s)	13	148	.	No (H vs J)
ITS (kPa)	753	392	.	Yes (H vs J)
Half Lab Density (kg/m³)	2141	.	2106	No (H vs C)

Out of all the asphalt resurfacing projects, this was the only project with statistical differences ($\alpha = 0.05$) between the hot lane and the joint for field density and it is important to note that this project is the only project where density was measured using the nuclear density gauge. The sensitivity of a nuclear density gauge may be greater than the non-nuclear density gauge to differentiate the density differences between the joint and the interior of the mat. The lab permeability (hot lane and joint) and half lab density (half hot and half cold core) results were the only tests that did not have significant difference. The field infiltration and lab permeability at station 146+20 measured high differences between the joint and the hot lane compared to two other stations, but no other tests resembled similar results at the same station.

During resurfacing of the Highway US 25, it was observed that the plant mix was adhering to the breakdown roller during compaction due to a malfunction of the water pump to the roller's front wheel. There were few occasions when the main breakdown roller had to be set aside to address the issue.

US 25 (2) Project

The US 25 highway was revisited to collect more data on the safety edge joint. The same information for construction, mix design, and gradation can be found in Table 5.7, but US 25(2) had a slightly different maximum specific gravity. The second day of temperature readings, in-place density, lab density, air void content, in-place infiltration, lab permeability, indirect tensile strength (ITS), and half core lab density taken from this project is shown in Figures 5.25 through 5.32. The summary results are displayed in Table 5.8.

Table 5.7: US 25(2) project information

Construction Information	
Location	US-25 (2)
Construction Type	Safety Edge
Compaction at Joint (First Pass)	Hot Overlap
Thickness	2.5 in
Joint Straightness	Straightish
Joint Cleanness	Clean
Joint Tack Coat	Yes
Height of Joint	Unknown
Extent of Joint	Unknown
Material Transfer Vehicle	Yes
Night Time Paving	No
Mix Design Information	
Type Mix	Surface B
AC Grade	PG 64-22
Design Air Voids (%)	3.1
Target Asphalt Content (%)	5.7
Average MSG	2.440
Aggregate Gradation	
Sieve	Percent Passing
37.5 mm (1.5")	100.0
25.0 mm (1")	100.0
19.0 mm (3/4")	100.0
12.5 mm (1/2")	99.0
9.5 mm (3/8")	90.0
4.75 mm (No. 4)	60.0
2.36 mm (No. 8)	45.0
0.60 mm (No. 30)	25.0
0.150 mm (No. 100)	8.0
0.075 mm (No. 200)	4.0

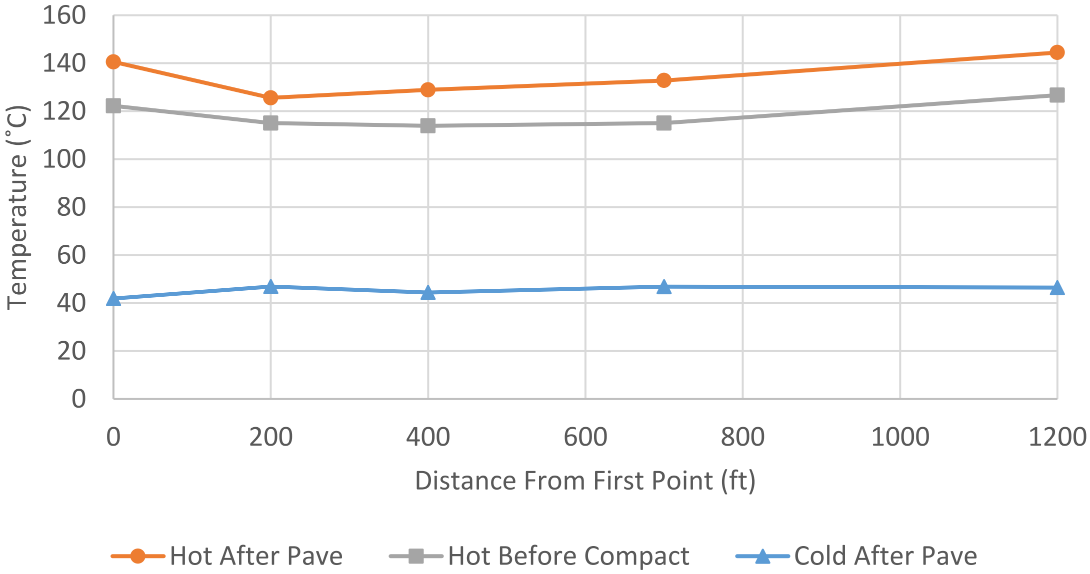


Figure 5.25: US 25(2) project pavement temperature

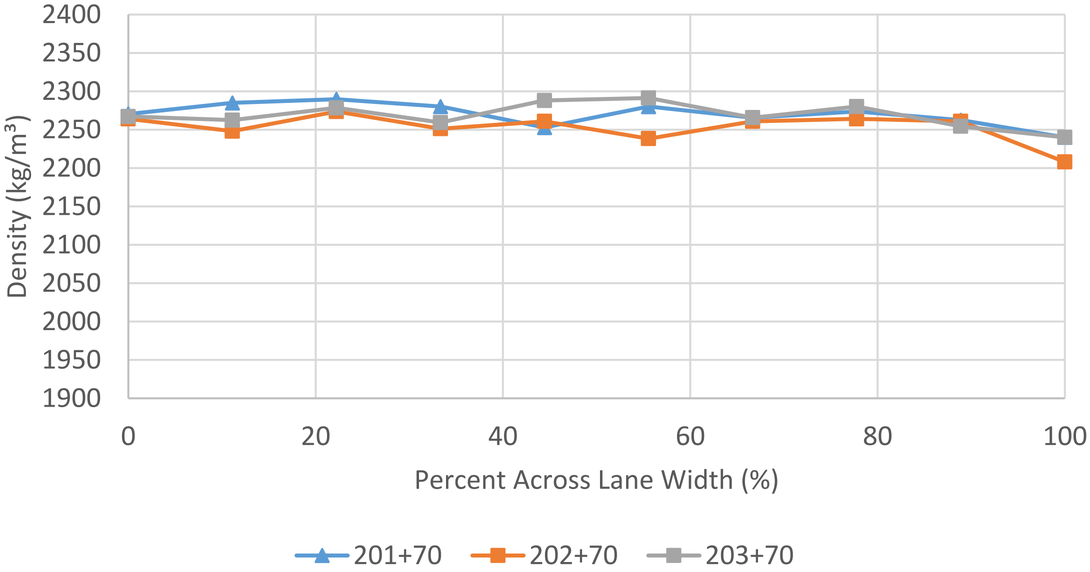


Figure 5.26: US 25(2) project in-place density measurement (measured with the PQI)

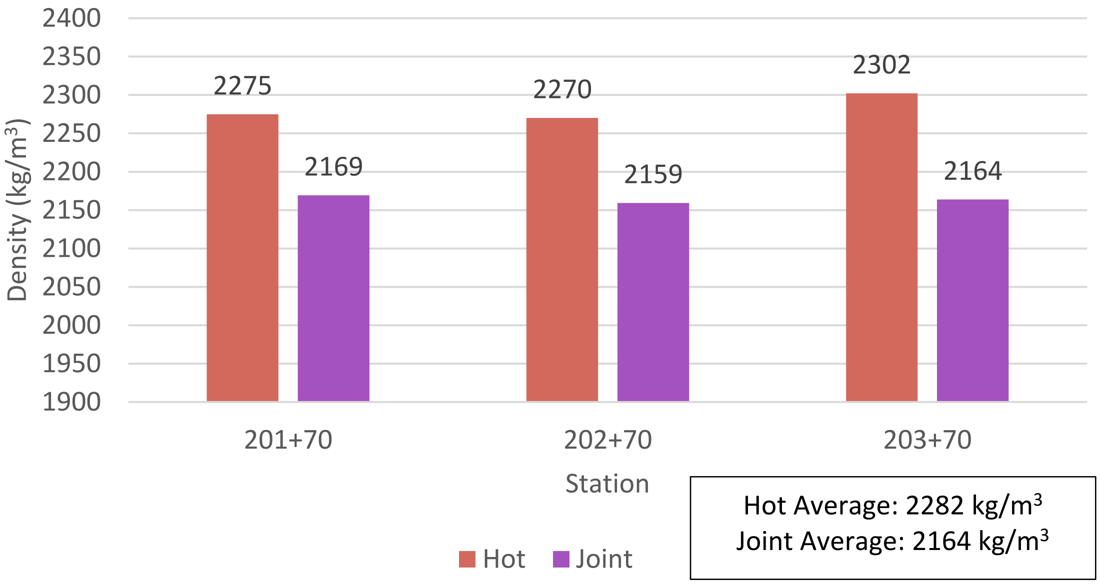


Figure 5.27: US 25(2) project lab density measurement

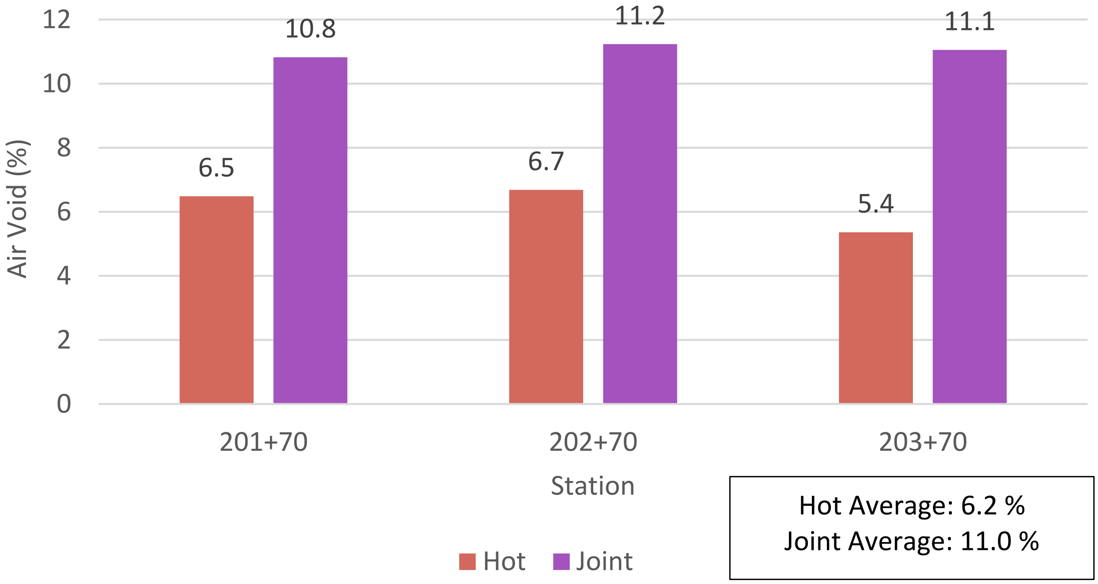
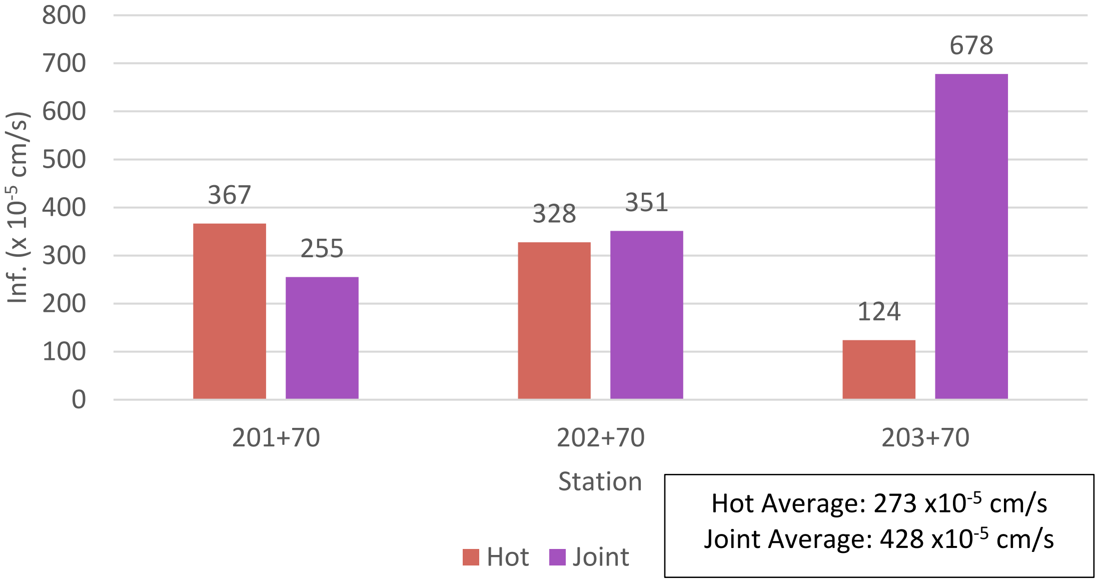
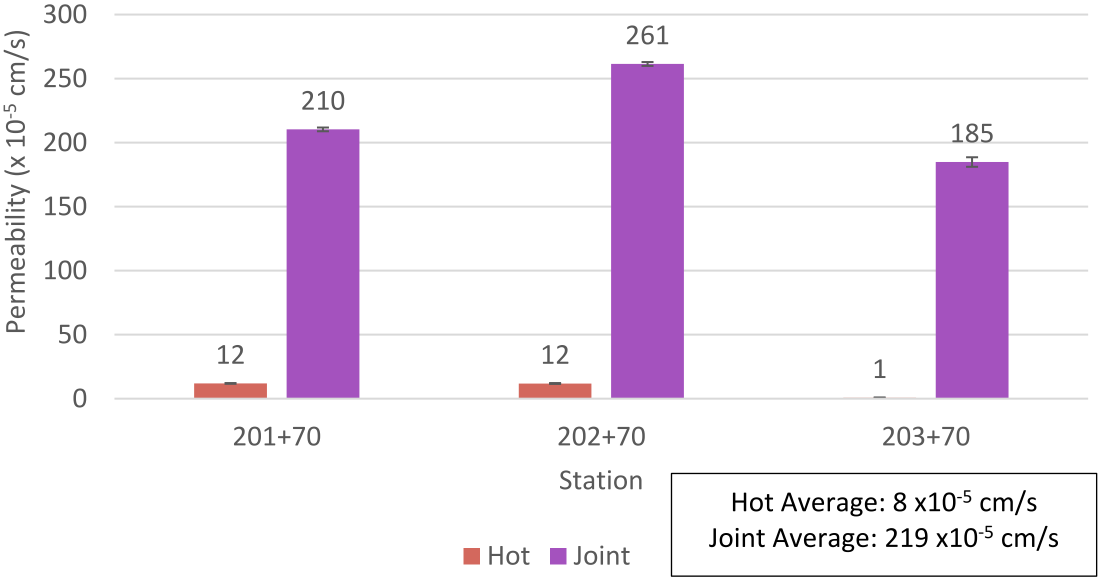


Figure 5.28: US 25(2) project air void contents



Hot Average: 273 x10^{-5} cm/s
Joint Average: 428 x10^{-5} cm/s

Figure 5.29: US 25(2) project in-place infiltration measurement



Hot Average: 8 x10^{-5} cm/s
Joint Average: 219 x10^{-5} cm/s

Figure 5.30: US 25(2) project lab permeability

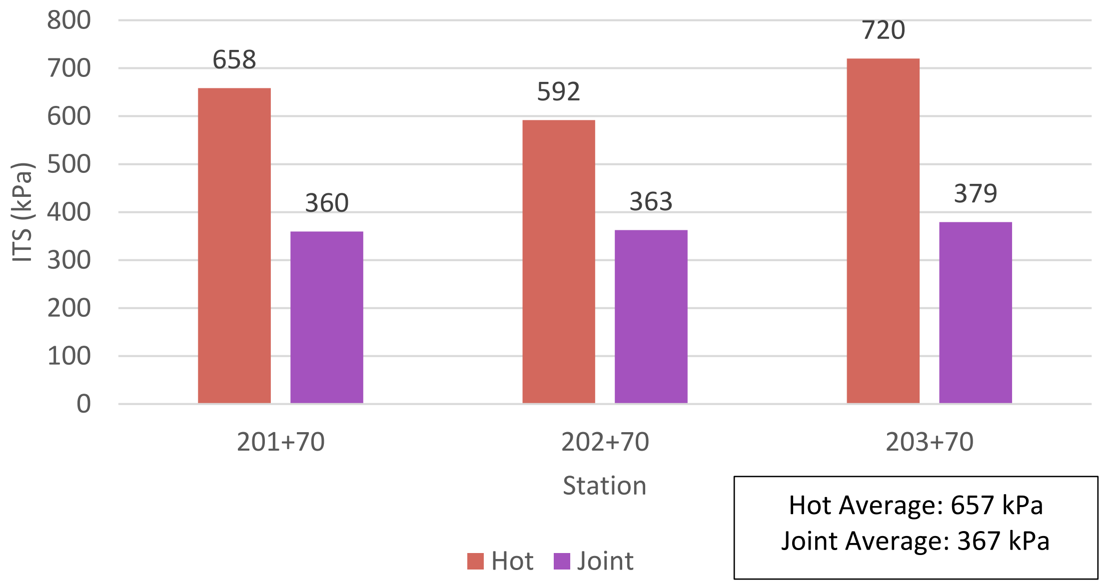


Figure 5.31: US 25(2) project dry indirect tensile strength (ITS) measurement

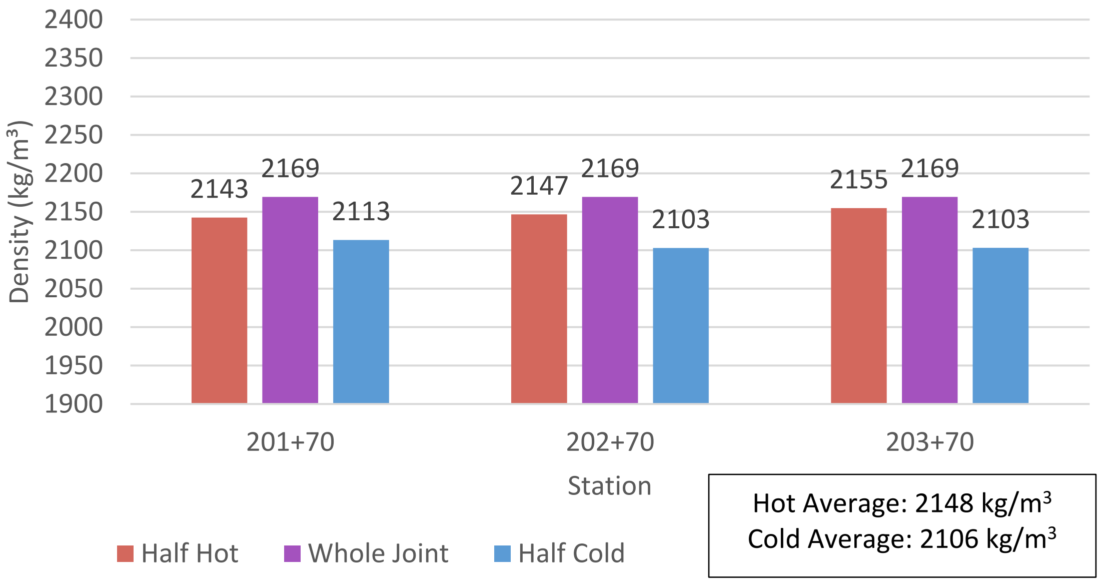


Figure 5.32: US 25(2) half cores lab density from the joint cores

Table 5.8: Summary of project US25(2) (H = hot/half hot, J = joint, C = half cold, N/A = limited data)

Average	**Hot**	**Joint**	**Cold**	**Significant Difference**
Field Density (kg/m³)	2269	2266	.	No (H vs J)
Field Infiltration (x 10^{-5} cm/s)	273	428	.	No (H vs J)
Lab Density (kg/m³)	2282	2164	.	Yes (H vs J)
Lab Air Void (%)	6.2	11.0	.	Yes (H vs J)
Lab Permeability (x 10^{-5} cm/s)	8	219	.	Yes (H vs J)
ITS (kPa)	657	367	.	Yes (H vs J)
Half Lab Density (kg/m³)	2148	.	2106	Yes (H vs C)

For the US 25(2) project results, the lab results indicated there were significant differences between the hot lane and the joint, and half hot core and the half cold core at the joint with the significance level of 5%. Even though the US 25(2) project is the same site as the US 25 project, the results of the statistical analysis were different than the previous project in field density, field infiltration, lab density, and half lab density. For other testing, it could be explained by differences in the weather, possible change in members of the construction crew, different number of compaction passes, materials used in the mix, and other possible changes.

The vibratory breakdown roller issue, which was seen on the first visit to this project, was not witnessed on this visit. This may have improved the field density and field infiltration results compared to the first visit.

I-77 Project

Interstate 77 near Columbia, SC was overlayed with surface type A using a butt joint technique. The information on construction, mix design, and gradation is summarized in Table 5.9. Due to malfunctions of the equipment and timing of the night, the field observations could not be performed to acquire all the information needed for Table 5.9. Figures 5.33 through 5.38 display the in-place density, lab density, air void content, lab permeability, indirect tensile strength (ITS), and half core lab density results. The average values are summarized in Table 5.10.

Note: Like the US 178 project, the field infiltration test could not be performed due to water leaking through seal after multiple trials.

Table 5.9: I-77 project information

Construction Information	
Location	I-77
Construction Type	Butt Joint
Compaction at Joint (First Pass)	Unknown
Thickness	2 in
Joint Straightness	Unknown
Joint Cleanness	Unknown
Joint Tack Coat	Unknown
Height of Joint	Unknown
Extent of Joint	Unknown
Material Transfer Vehicle	Yes
Night Time Paving	Yes
Mix Design Information	
Type Mix	Surface A
AC Grade	PG 76-22
Design Air Voids (%)	2.8
Target AC (%)	5.3
Average MSG	2.439
Aggregate Gradation	
Sieve	Percent Passing
37.5 mm (1.5")	100.0
25.0 mm (1")	100.0
19.0 mm (3/4")	100.0
12.5 mm (1/2")	97.0
9.5 mm (3/8")	84.0
4.75 mm (No. 4)	53.0
2.36 mm (No. 8)	31.0
0.60 mm (No. 30)	17.0
0.150 mm (No. 100)	8.0
0.075 mm (No. 200)	4.0

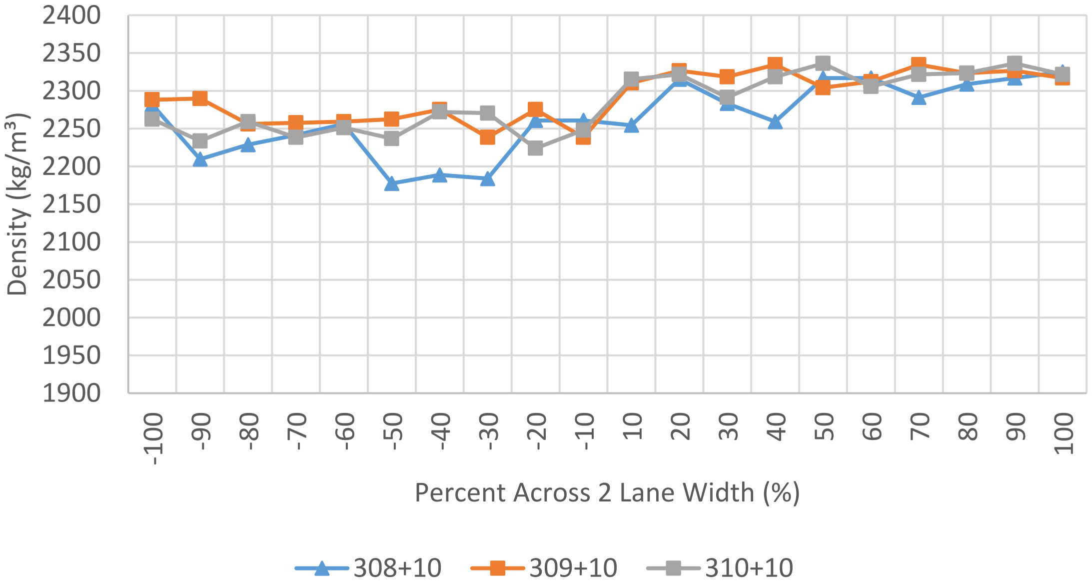


Figure 5.33: I-77 project in-place density measurement (measured with the PQI)

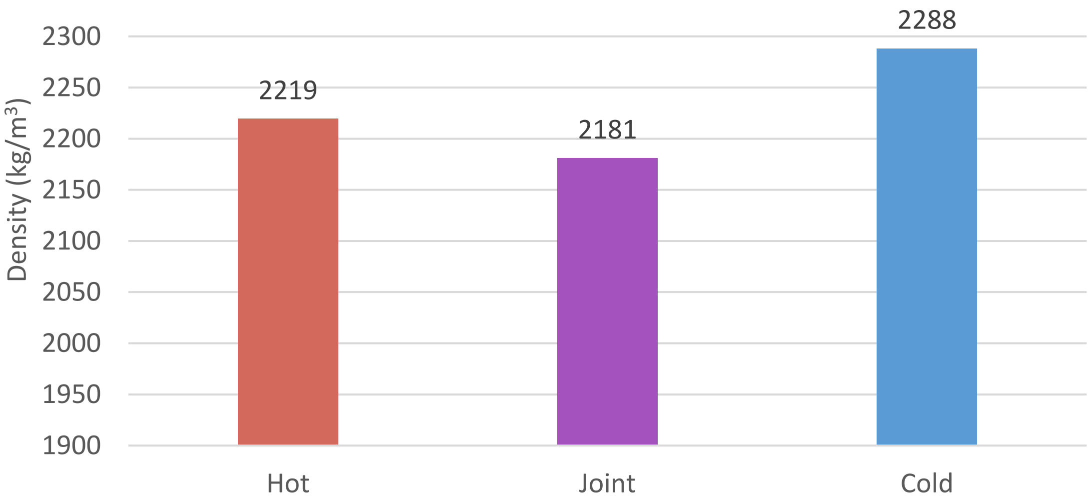


Figure 5.34: I-77 project lab density (station 308+10)

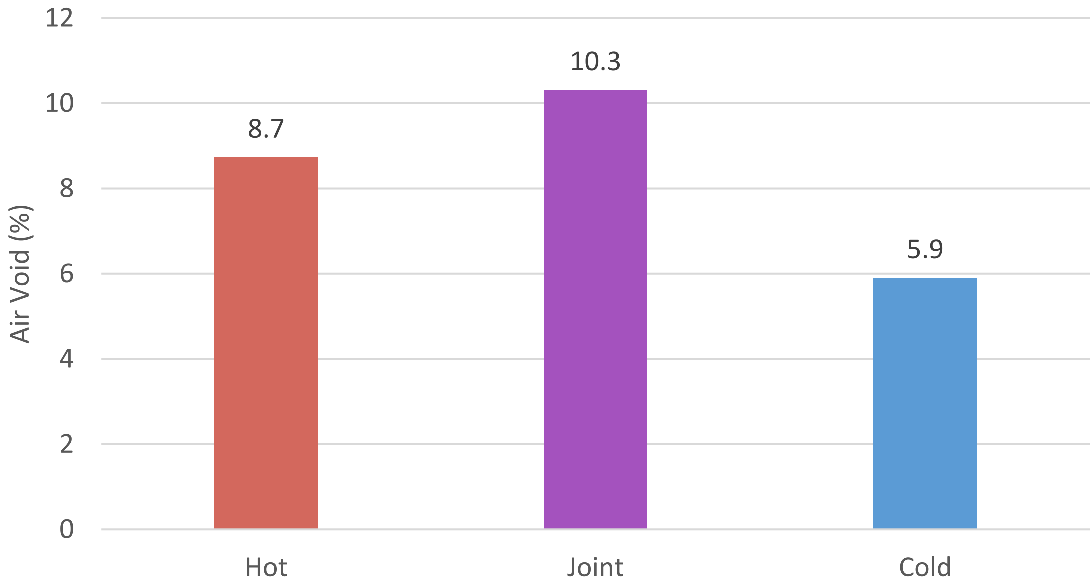


Figure 5.35: I-77 project air void contents (station 308+10)

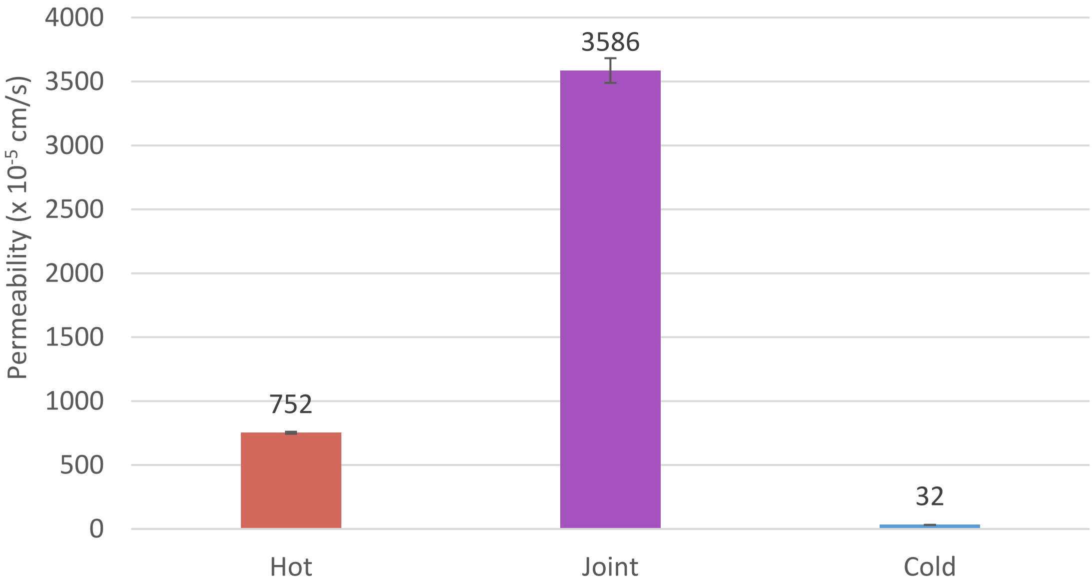


Figure 5.36: I-77 project lab permeability (station 308+10)

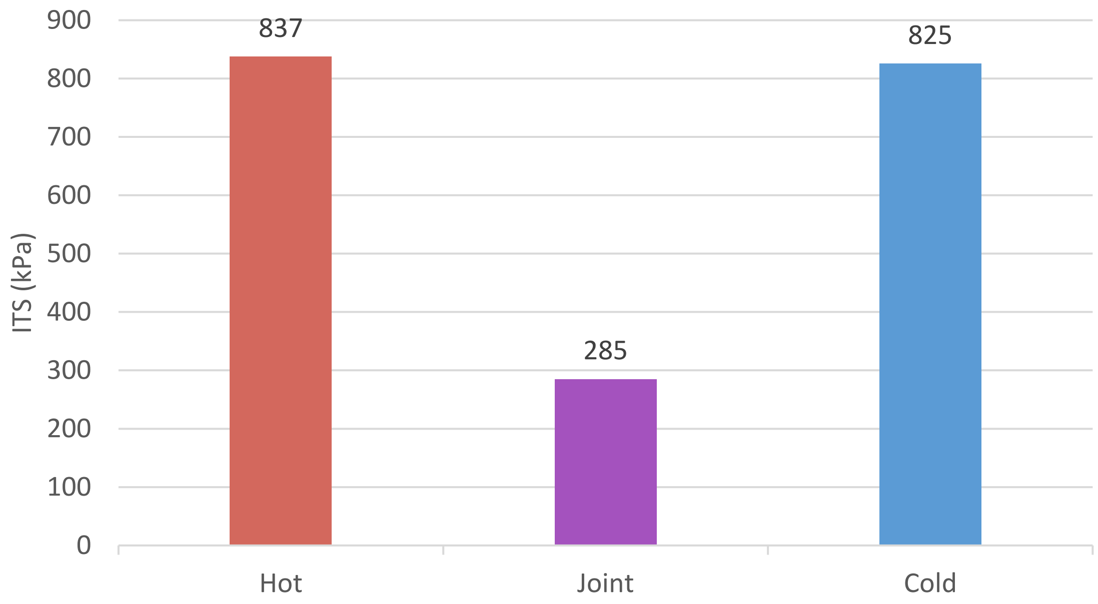


Figure 5.37: I-77 project dry indirect tensile strength (ITS) measurement (station 308+10)

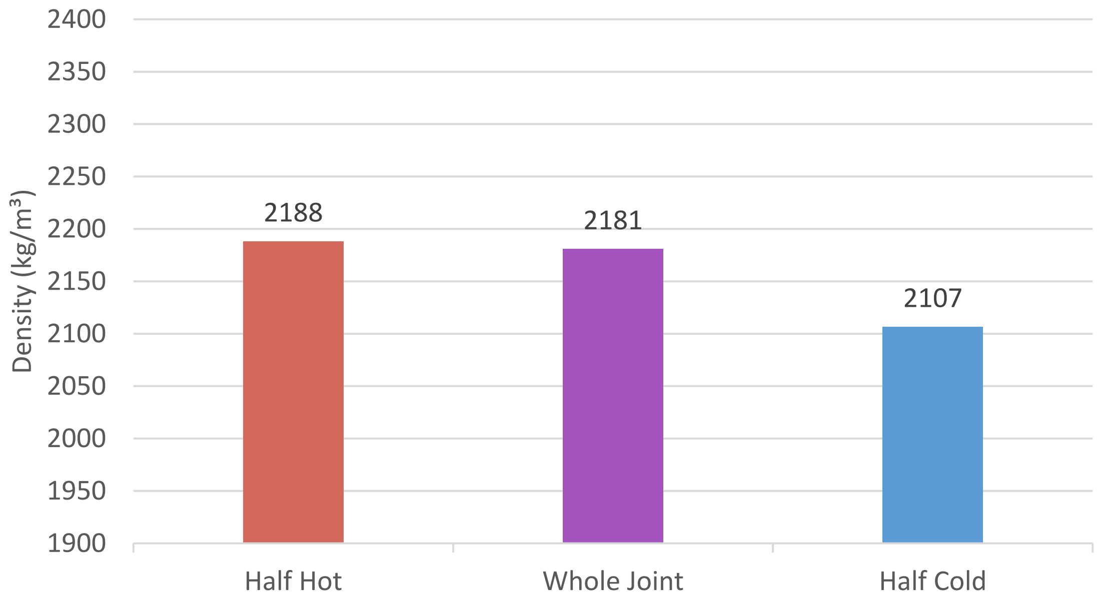


Figure 5.38: I-77 half core lab density from the joint core (station 308+10)

Table 5.10: Summary of project I-77 (H = hot/half hot, J = joint, C = half cold, N/A = limited data)

Average	**Hot**	**Joint**	**Cold**	**Significant Difference**
Field Density (kg/m³)	2207	2258	2298	No (H vs J) Yes (C vs J)
Field Infiltration (x 10^{-5} cm/s)	.	.	.	N/A
Lab Density (kg/m³)	2219	2181	2288	N/A
Lab Air Void (%)	8.7	10.3	5.9	N/A
Lab Permeability (x 10^{-5} cm/s)	752	3586	32	N/A
ITS (kPa)	837	285	825	N/A
Half Lab Density (kg/m³)	2188	.	2107	N/A

For the I-77 project, cores were obtained from only one station due to technical difficulties. Due to the limited sample size, a statistical analysis could not be performed except for the field density. The in-place density was conducted at three stations that were spaced 100 ft apart and there were no significant differences found at the significance level of 5%. However, the field density difference between the cold lane and the joint was statistically significant. Like previous projects, the joint had the lowest results for lab density and ITS, and the highest results for air void contents and lab permeability.

SC 8 Project

The SC 8 project was constructed using a butt joint technique and a surface type B mix was used. The construction, mix design, and gradation information can be found in Table 5.11. The graphical results for temperature readings, in-place density, lab density, air void content, in-place infiltration, lab permeability, indirect tensile strength (ITS), and half core lab density are presented in Figures 5.39 through 5.46. The results are summarized in Table 5.12.

Note: For the SC 8 project, temperature was measured after the first roller pass due to safety reasons. The surface of the field testing and coring location was a slightly downhill grade.

Table 5.11: SC 8 project information

Construction Information	
Location	SC 8
Construction Type	Butt Joint
Compaction at Joint (First Pass)	Hot Overlap
Thickness	1.75 in
Joint Straightness	Straightish
Joint Cleanness	Loose Aggregate
Joint Tack Coat	Yes
Height of Joint	0.25 in
Material Transfer Vehicle	No
Night Time Paving	No
Mix Design Information	
Type Mix	Surface C
AC Grade	PG 64-22
Design Air Voids (%)	4.3
Target AC (%)	5.9
Average MSG	2.505
Aggregate Gradation	
Sieve	Percent Passing
37.5 mm (1.5")	100.0
25.0 mm (1")	100.0
19.0 mm (3/4")	100.0
12.5 mm (1/2")	99.0
9.5 mm (3/8")	95.0
4.75 mm (No. 4)	69.0
2.36 mm (No. 8)	52.0
0.60 mm (No. 30)	33.0
0.150 mm (No. 100)	11.0
0.075 mm (No. 200)	5.0

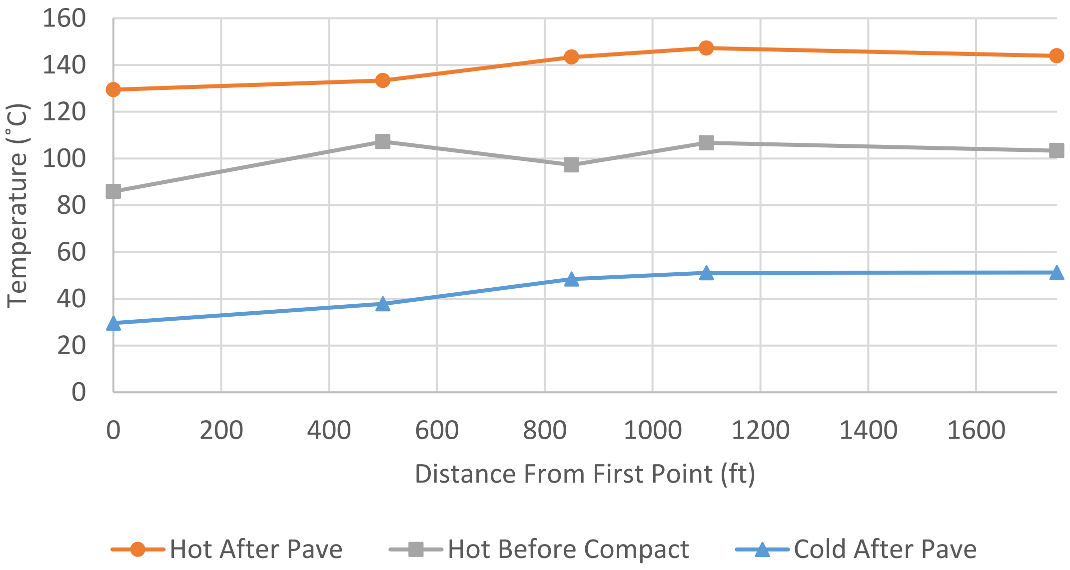


Figure 5.39: SC 8 project pavement temperature

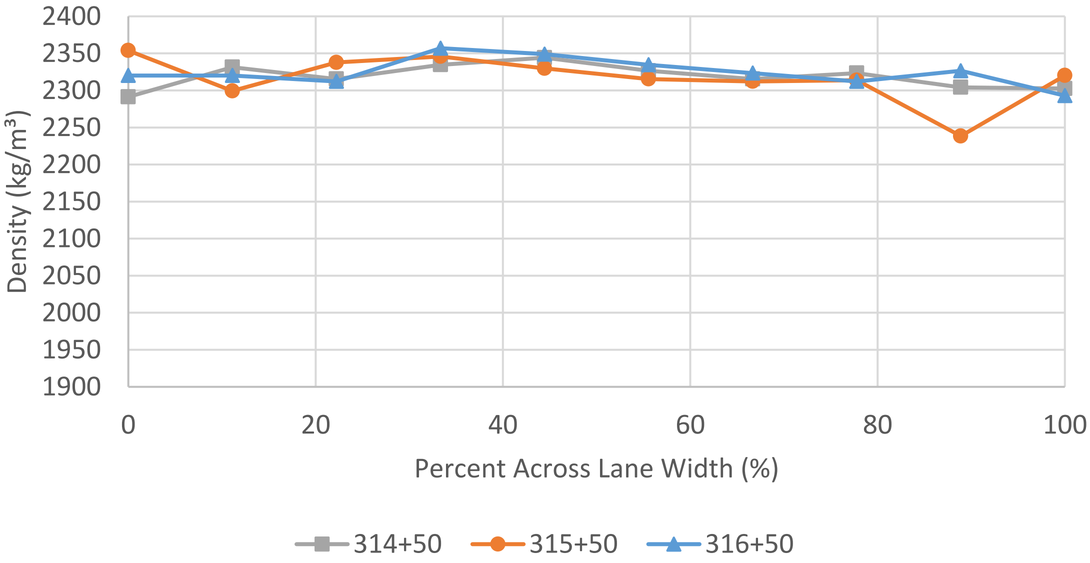


Figure 5.40: SC 8 project in-place density measurement (measured with the PQI)

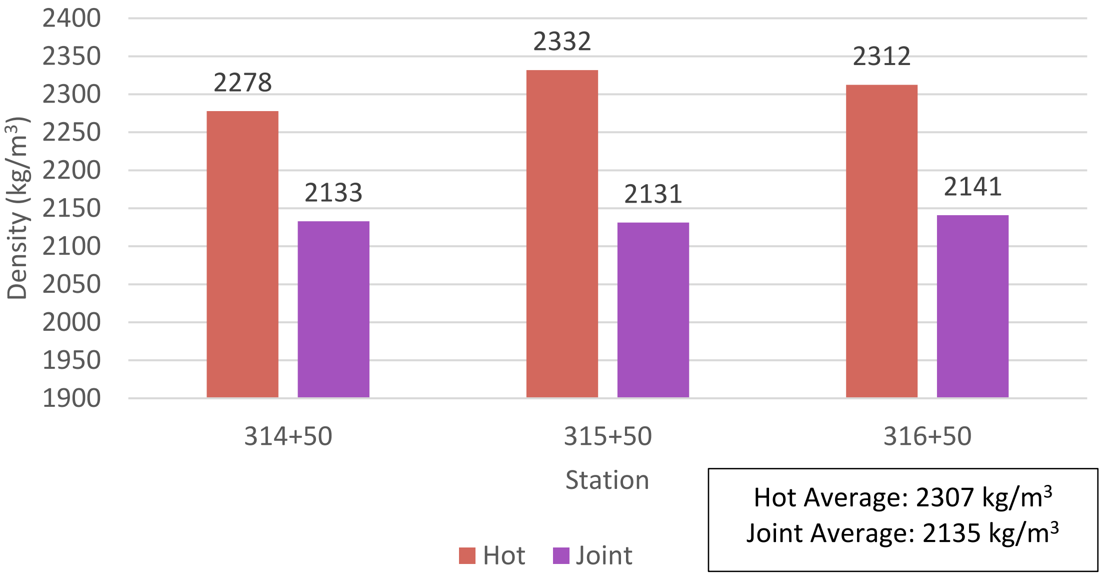


Figure 5.41: SC 8 project lab density measurement

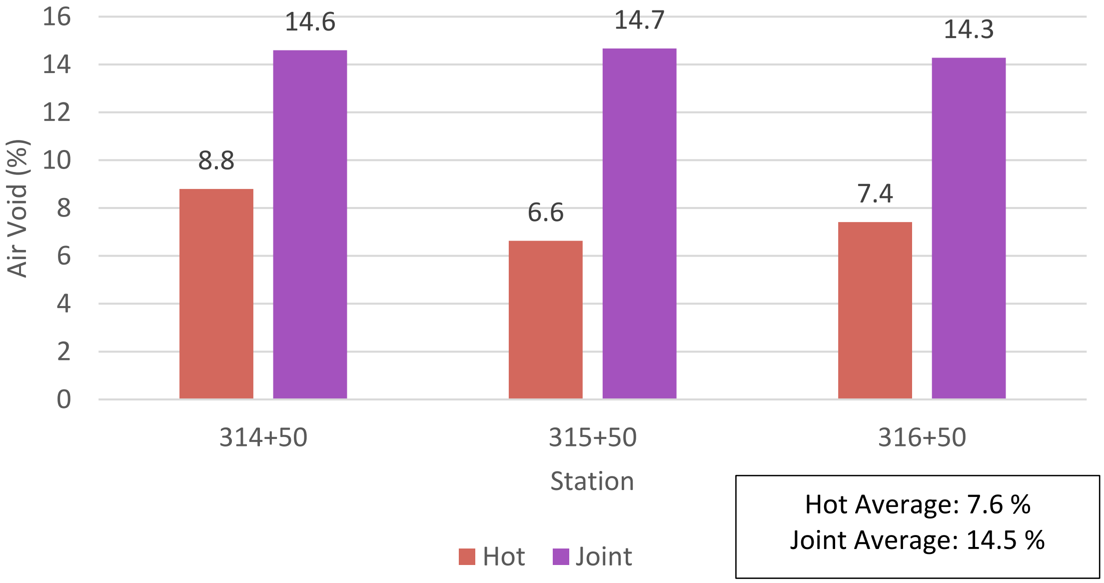
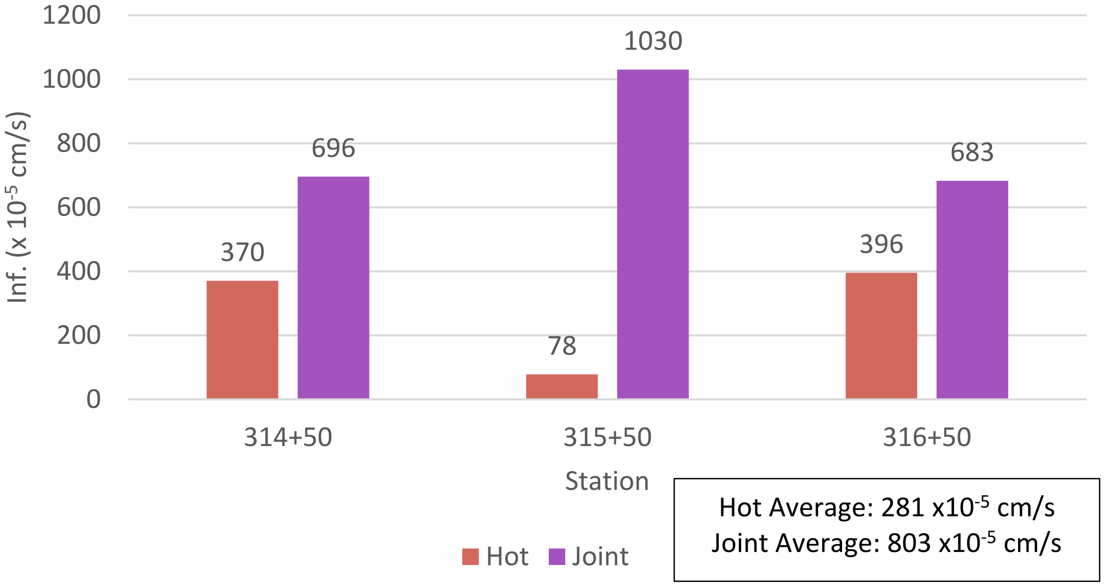
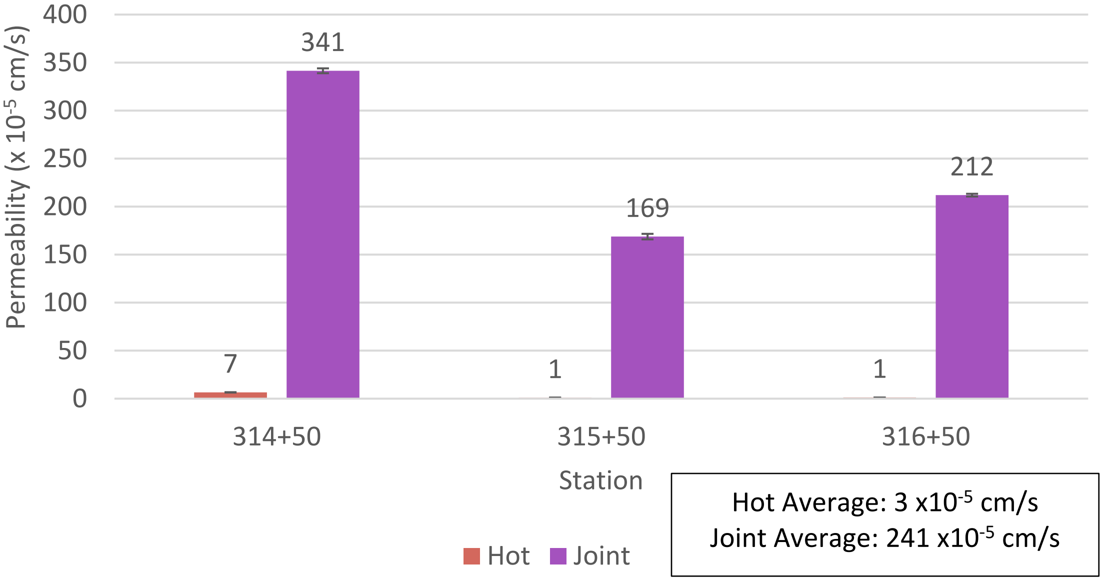


Figure 5.42: SC 8 project air void contents



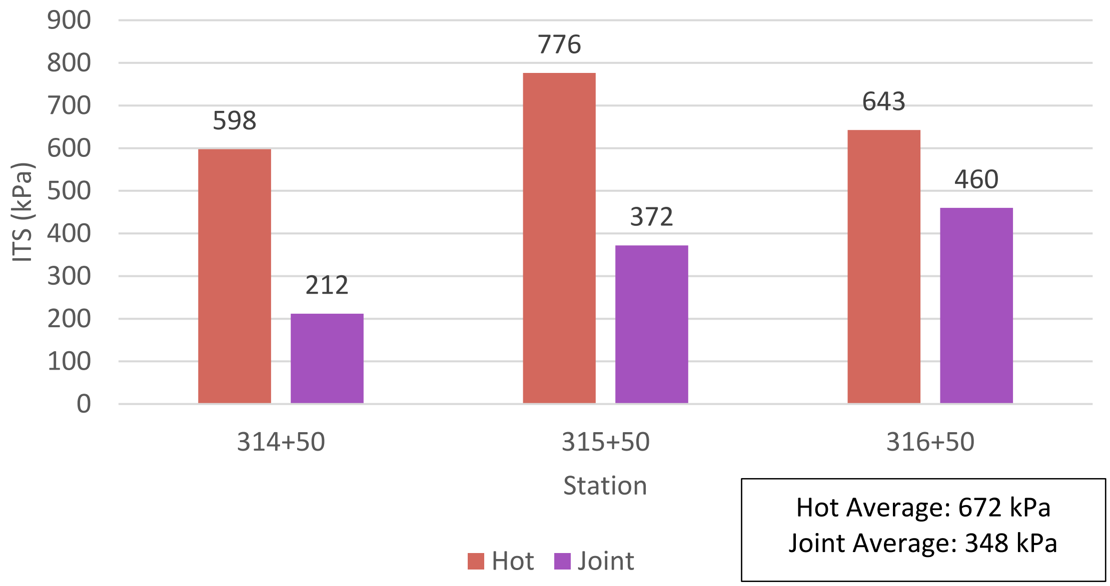
Hot Average: 281 x10^{-5} cm/s
Joint Average: 803 x10^{-5} cm/s

Figure 5.43: SC 8 project in-place infiltration measurement



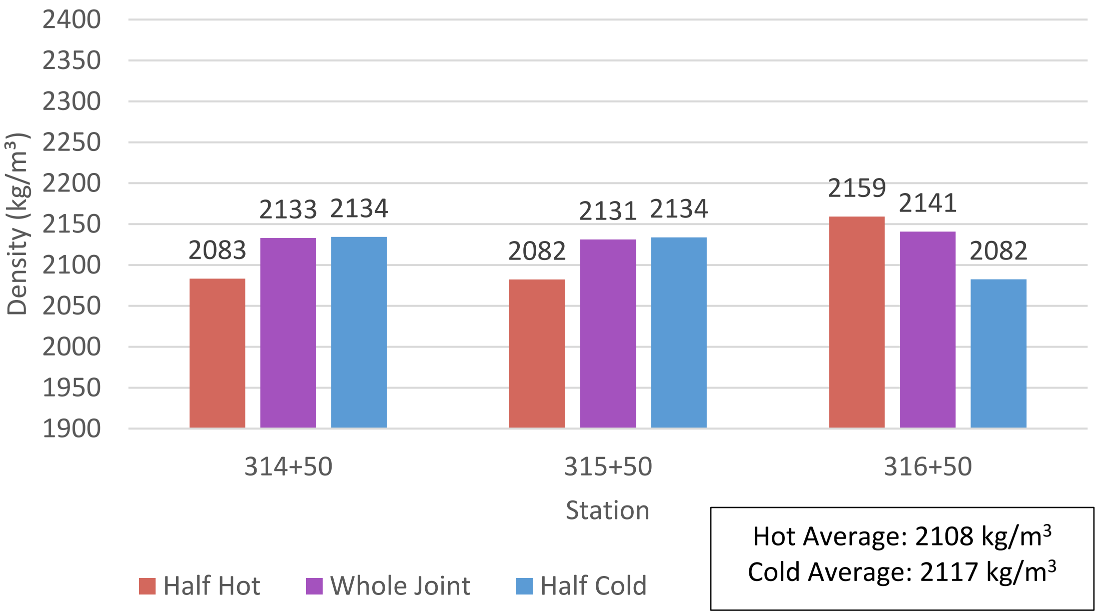
Hot Average: 3 x10^{-5} cm/s
Joint Average: 241 x10^{-5} cm/s

Figure 5.44: SC 8 project lab permeability



Hot Average: 672 kPa
Joint Average: 348 kPa

Figure 5.45: SC 8 project dry indirect tensile strength (ITS) measurement



Hot Average: 2108 kg/m^3
Cold Average: 2117 kg/m^3

Figure 5.46: SC 8 half cores lab density from the joint cores

Table 5.12: Summary of SC 8 project (H = hot/half hot, J = joint, C = half cold, N/A = limited data)

Average	**Hot**	**Joint**	**Cold**	**Significant Difference**
Field Density (kg/m³)	2333	2319	.	No (H vs J)
Field Infiltration (x 10^{-5} cm/s)	281	803	.	No (H vs J)
Lab Density (kg/m³)	2307	2135	.	Yes (H vs J)
Lab Air Void (%)	7.6	14.5	.	Yes (H vs J)
Lab Permeability (x 10^{-5} cm/s)	3	241	.	Yes (H vs J)
ITS (kPa)	672	348	.	Yes (H vs J)
Half Lab Density (kg/m³)	2108	N/A	2117	No (H vs C)

The results showed that the hot lane had statistically better performance than the joint with respect to in-place infiltration, lab density, air void, lab permeability, and ITS results. The low lab permeability results show that the hot lane was almost impermeable, like the US 178 project. The SC 8 project followed similar trends and the performance of the joint was less than the hot lane for every metric evaluated.

This project was the only project without a material transfer vehicle (MTV) on site possibly because this was surface type C road, which will have lower traffic volumes than roads paved with surface type A and B.

S 39-57 Project

The S 39-57 project was constructed using a safety edge technique, but no compaction was conducted on the sloped edge. The information for construction, mix design, and gradation can be found in Table 5.13. The individual measurement of temperature, in-place density, lab density, air void content, field infiltration, lab permeability, indirect tensile strength (ITS), and half core lab density are located in Figures 5.47 through 5.54. The results are summarized in Table 5.14.

Table 5.7: S 39-57 project information

Construction Information	
Location	S-39-57
Construction Type	Safety Edge
Compaction at Joint (First-Second)	Hot Overlap - Hot Overlap
Thickness	1.5 in
Joint Straightness	Not Straight
Joint Cleanness	Clean
Joint Tack Coat	Yes
Height of Joint	0.25 in
Extent of Joint	1.5 in
Material Transfer Vehicle	Yes
Night Time Paving	No
Mix Design Information	
Type Mix	Surface C
AC Grade	PG 64-22
Design Air Voids (%)	3.9
Target AC (%)	5.9
Average MSG	2.459
Aggregate Gradation	
Sieve	Percent Passing
37.5 mm (1.5")	100.0
25.0 mm (1")	100.0
19.0 mm (3/4")	100.0
12.5 mm (1/2")	99.2
9.5 mm (3/8")	95.8
4.75 mm (No. 4)	67.2
2.36 mm (No. 8)	49.4
0.60 mm (No. 30)	3.4
0.150 mm (No. 100)	12.2
0.075 mm (No. 200)	5.1

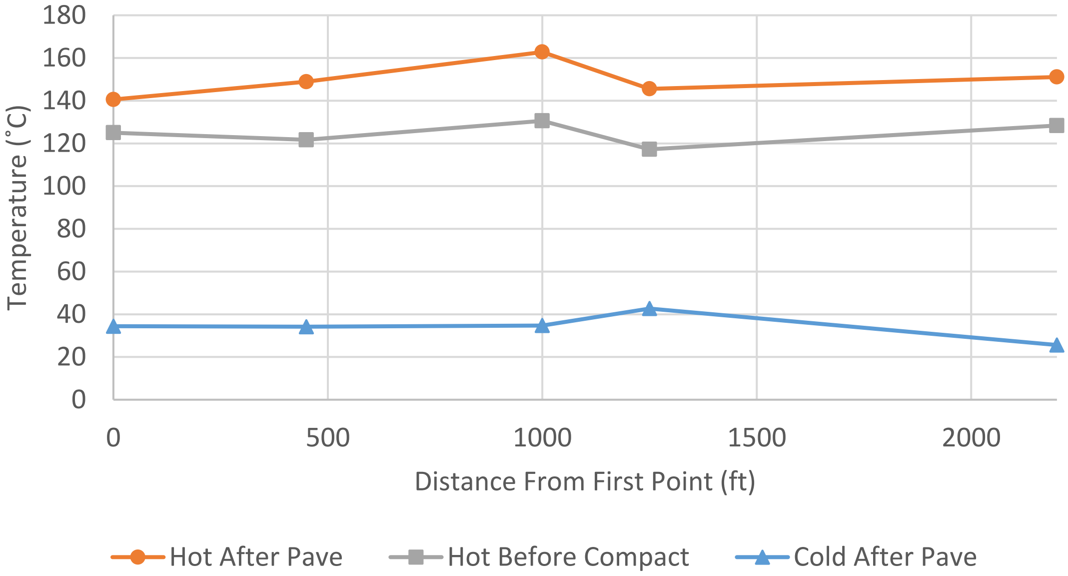


Figure 5.47: S 39-57 project pavement temperature

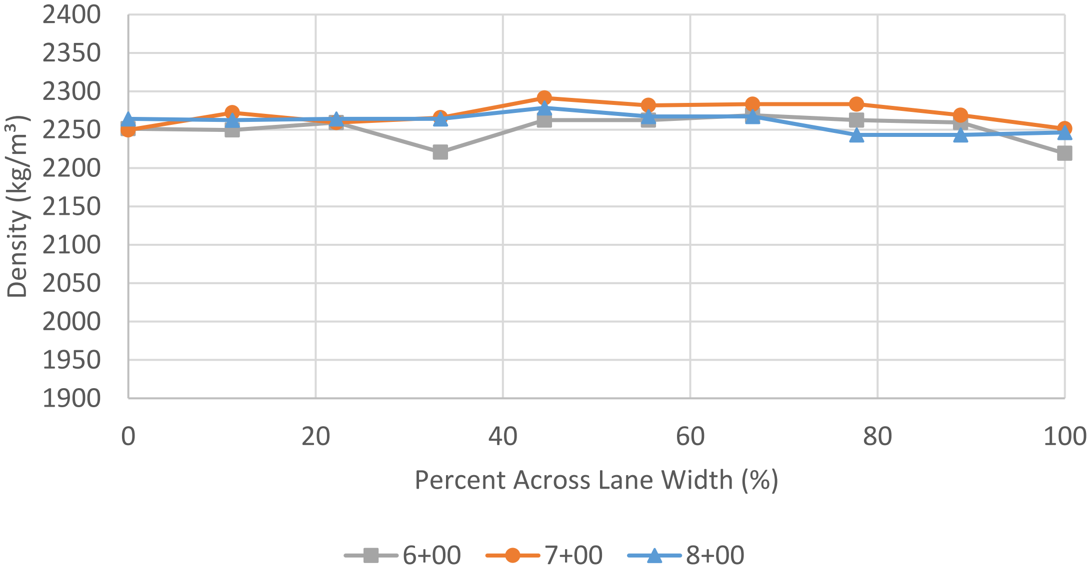


Figure 5.48: S 39-57 project in-place density measurement (measured with the PQI)

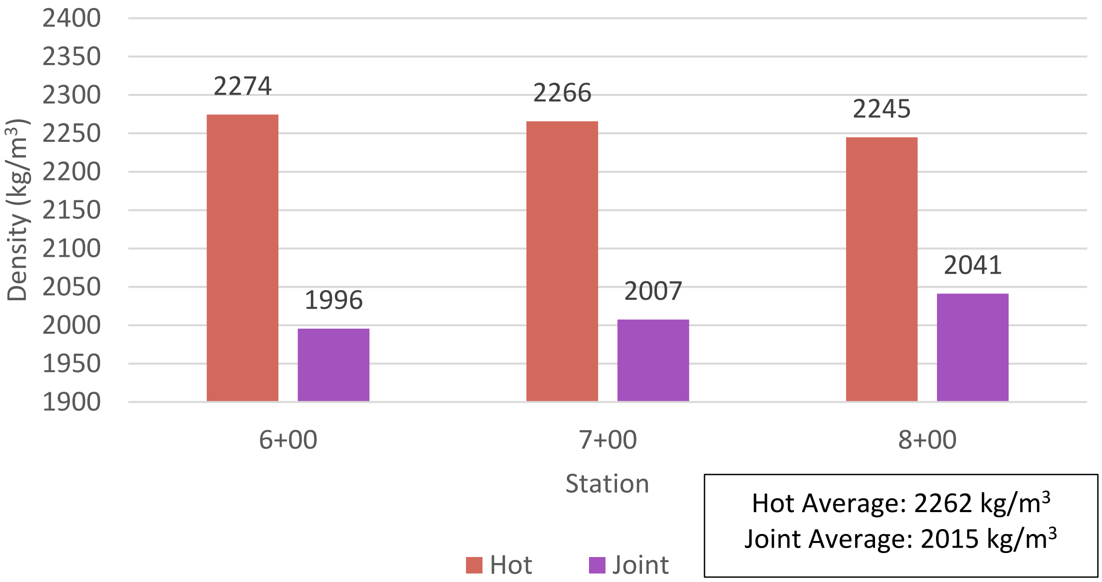


Figure 5.49: S 39-57 project lab density measurement

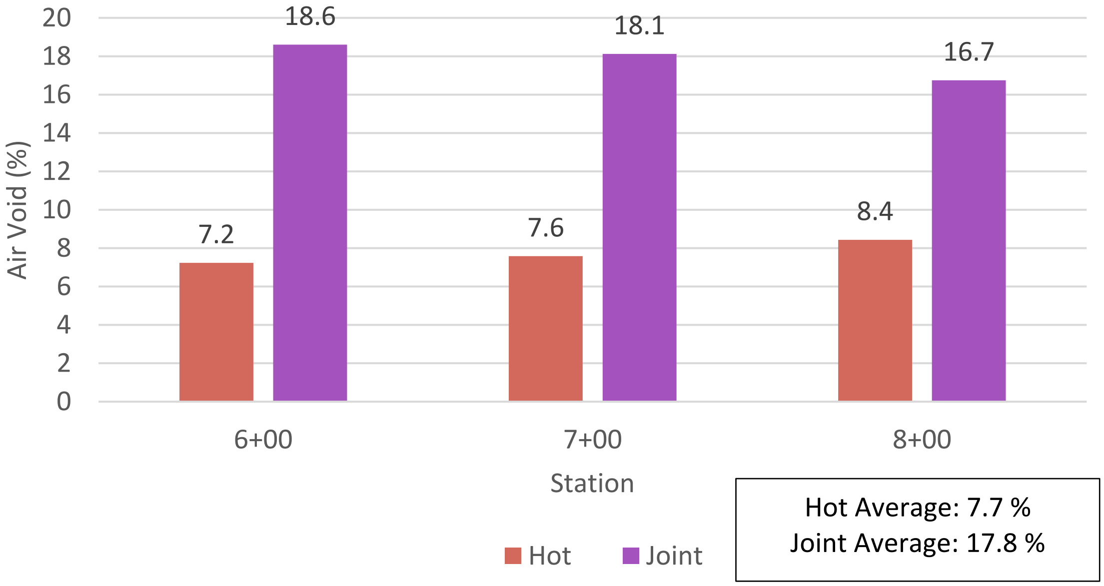


Figure 5.50: S 39-57 project air void contents

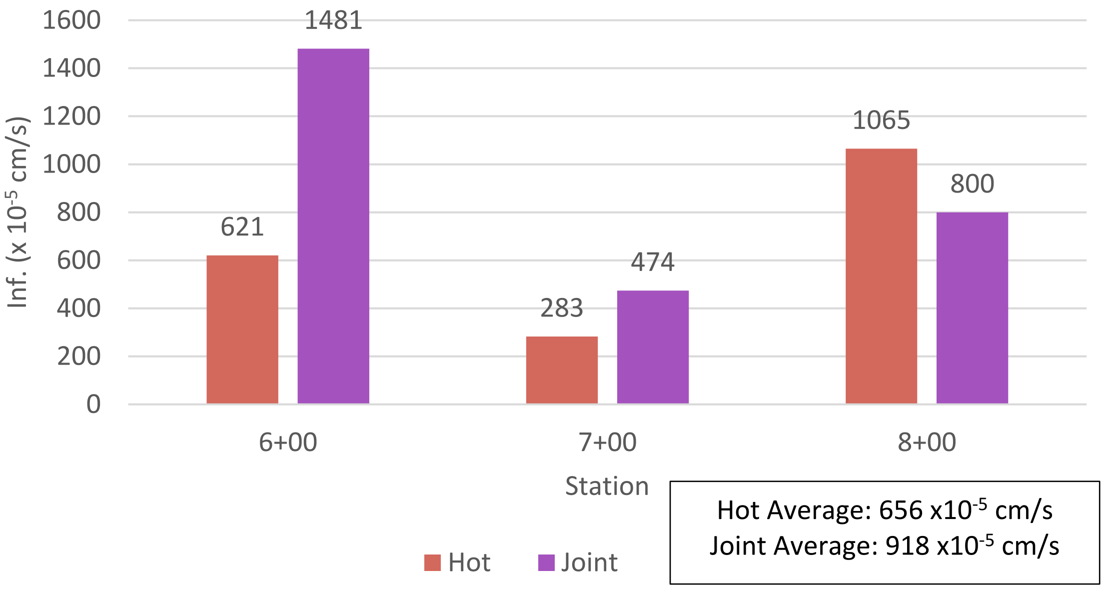


Figure 5.51: S 39-57 project in-place infiltration measurement

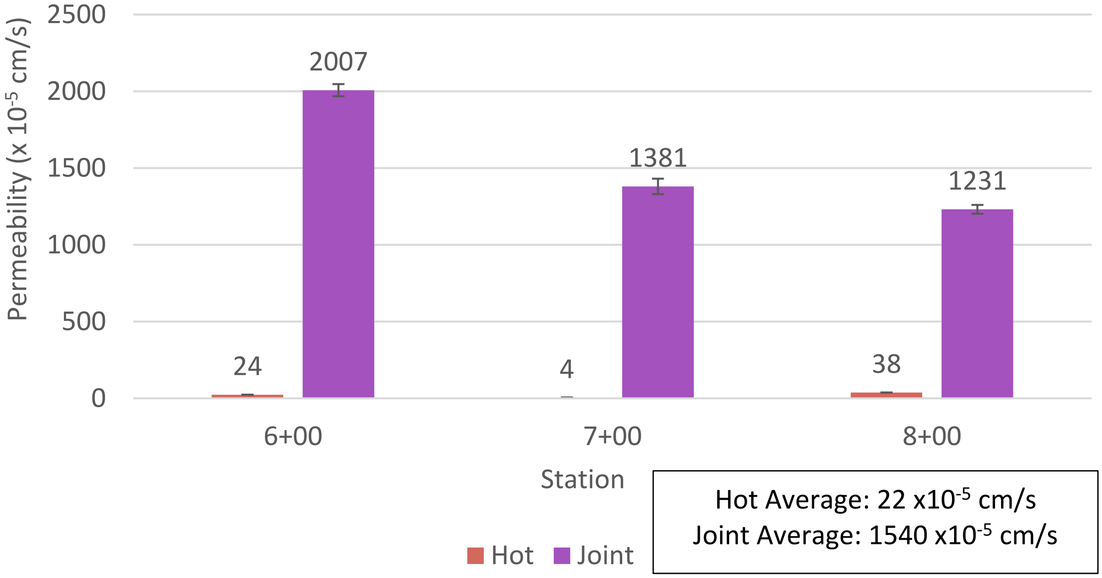
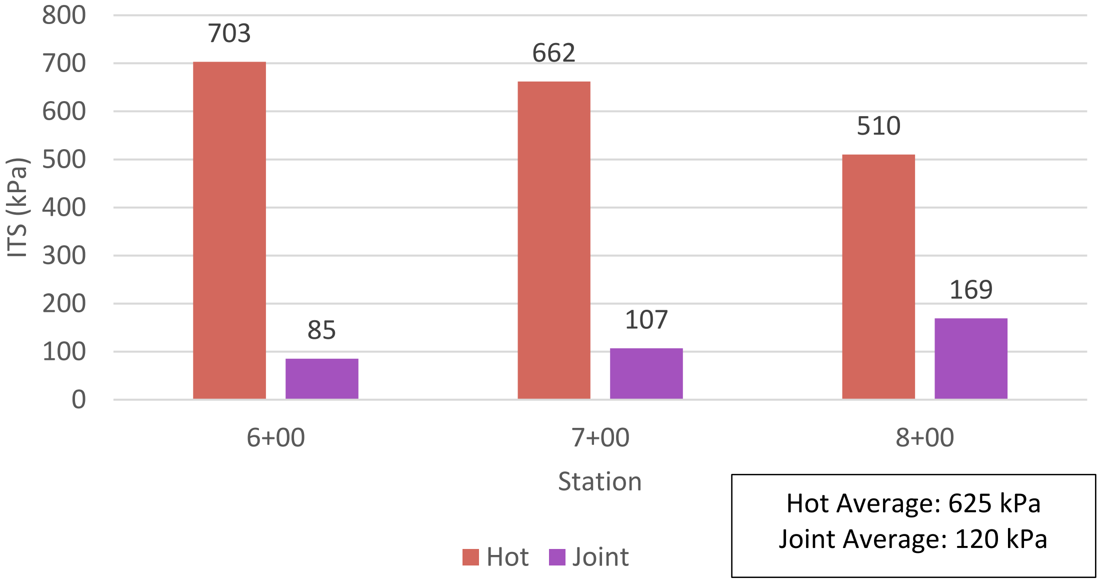
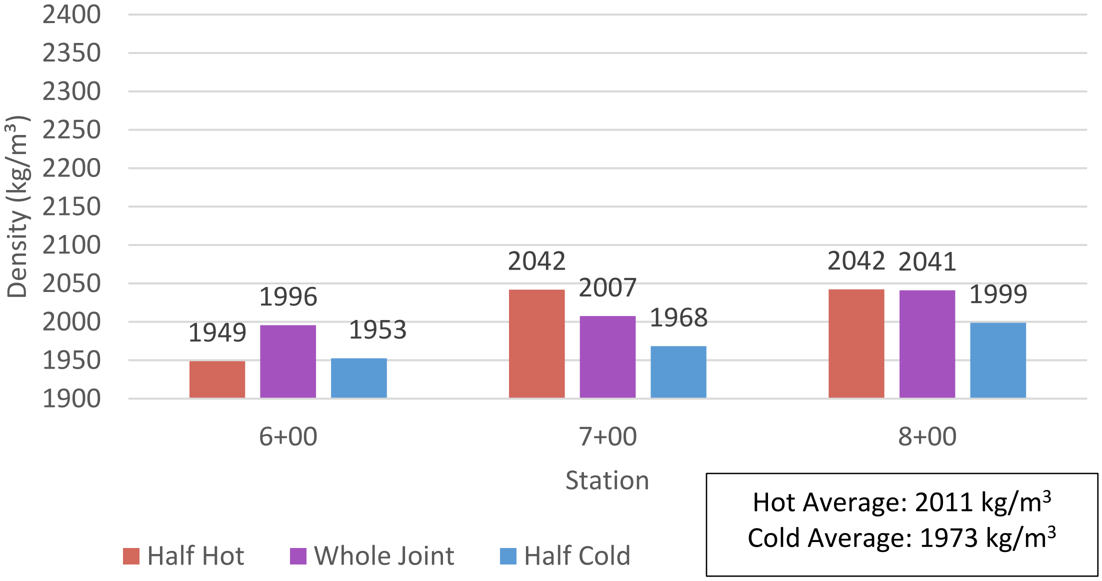


Figure 5.52: S 39-57 project lab permeability



Hot Average: 625 kPa
Joint Average: 120 kPa

Figure 5.53: S 39-57 project dry indirect tensile strength (ITS) measurement



Hot Average: 2011 kg/m^3
Cold Average: 1973 kg/m^3

Figure 5.54: S 39-57 half cores lab density from the joint cores

Table 5.14: Summary S 39-57 project (H = hot/half hot, J = joint, C = half cold, N/A = limited data)

Average	**Hot**	**Joint**	**Cold**	**Significant Difference**
Field Density (kg/m³)	2274	2258	.	No (H vs J)
Field Infiltration (x 10^{-5} cm/s)	281	803	.	No (H vs J)
Lab Density (kg/m³)	2262	2015	.	Yes (H vs J)
Lab Air Void (%)	7.7	17.8	.	Yes (H vs J)
Lab Permeability (x 10^{-5} cm/s)	22	1540	.	Yes (H vs J)
ITS (kPa)	625	120	.	Yes (H vs J)
Half Lab Density (kg/m³)	2011	N/A	1973	No (H vs C)

When the S 39-57 project results for the hot lane and joint were compared, significant differences with a significance level of 5% were seen in lab density, air void, lab permeability, and ITS results. Like the previous projects, the field and lab density and ITS results were low at the joint compared to the hot lane. Additionally, as expected, the air void contents, lab permeability, and field infiltration results were high at the joint. Station 8+00 had higher in-place infiltration measurements at the hot lane compared to the joint, but no similar behavior was seen for lab permeability results at the same station.

This project had the cleanest joint out of all construction projects because the construction crew used a small motorized road sweeper to remove dirt and loose aggregates. Based on recommendations from the survey in Chapter 3, a clean joint with no loose aggregates could improve the performance of the asphalt joint.

SC 254 Project

SC 254 was a 4-lane resurfacing project that was constructed using a safety edge, but no compaction was conducted on the edge, similar to other projects. The joint was compacted using the hot overlap method for the first pass and hot pinch for the second pass. The information for construction, mix design, and gradation are presented in Table 5.15. The temperature readings, in-place density, lab density, air void content, field infiltration, lab permeability, indirect tensile strength (ITS), and half core lab density data taken from this project are presented in Figures 5.55 through 5.62. The results are summarized in Table 5.16.

Table 5.15: SC 254 project information

Construction Information	
Location	SC-254
Construction Type	Safety Edge
Compaction at Joint (First-Second)	Hot Overlap - Hot Pinch
Thickness	2 in
Joint Straightness	Straight
Joint Cleanness	Clean
Joint Tack Coat	Yes
Height of Joint	0.25 in
Extent of Joint	4 in
Material Transfer Vehicle	Yes
Night Time Paving	No
Mix Design Information	
Type Mix	Surface B
AC Grade	PG 64-22
Design Air Voids (%)	3.0
Target AC (%)	5.5
Average MSG	2.436
Aggregate Gradation	
Sieve	Percent Passing
37.5 mm (1.5")	100.0
25.0 mm (1")	100.0
19.0 mm (3/4")	100.0
12.5 mm (1/2")	99.0
9.5 mm (3/8")	92.0
4.75 mm (No. 4)	60.0
2.36 mm (No. 8)	44.0
0.60 mm (No. 30)	25.0
0.150 mm (No. 100)	9.3
0.075 mm (No. 200)	4.7

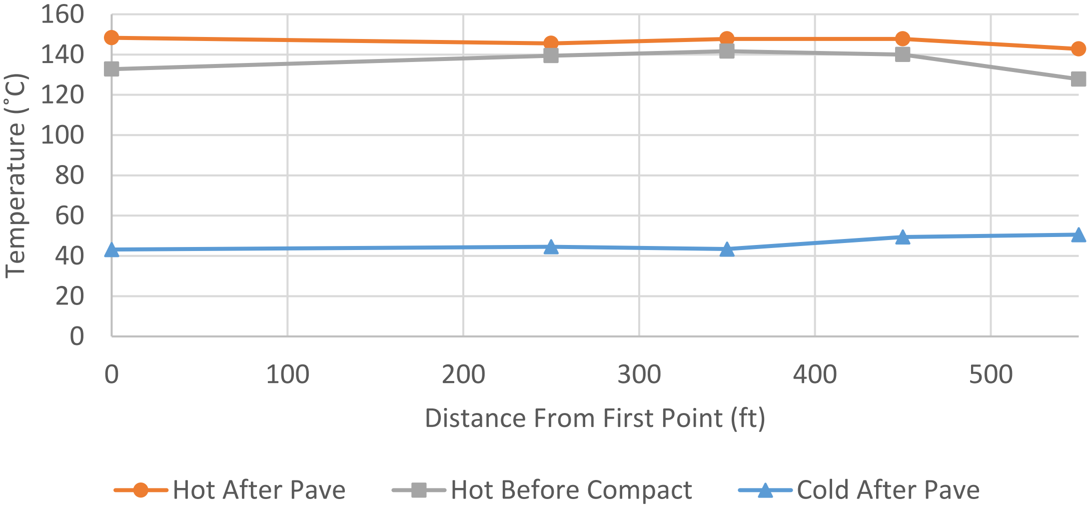


Figure 5.55: SC 254 project pavement temperature

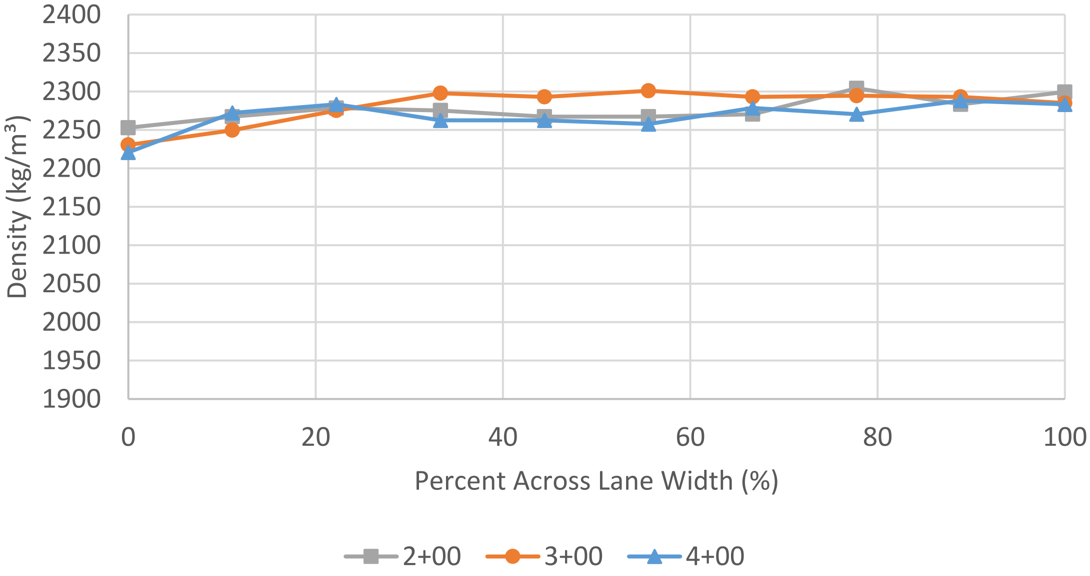
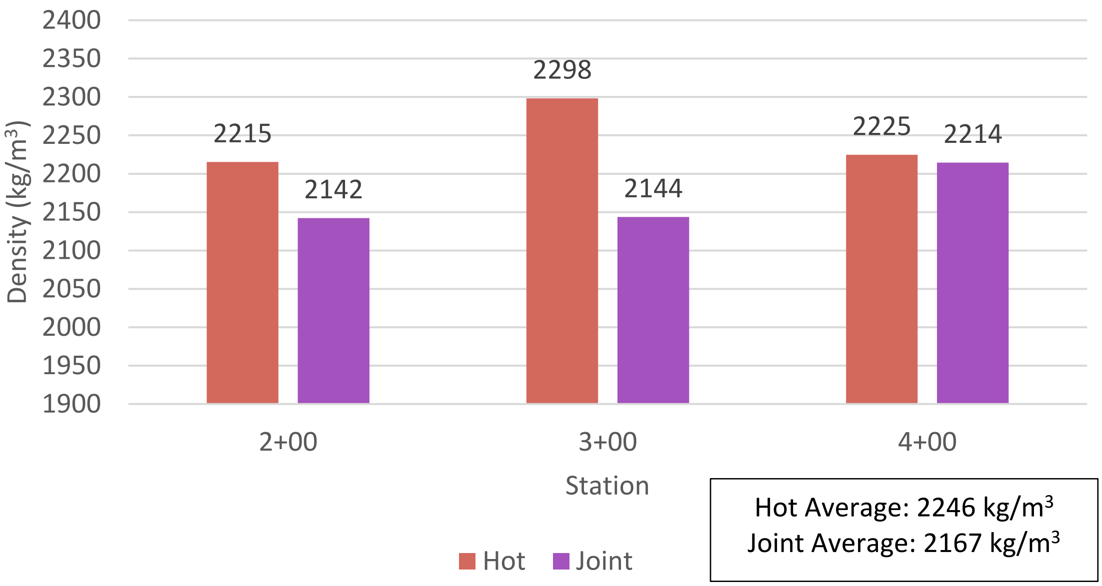
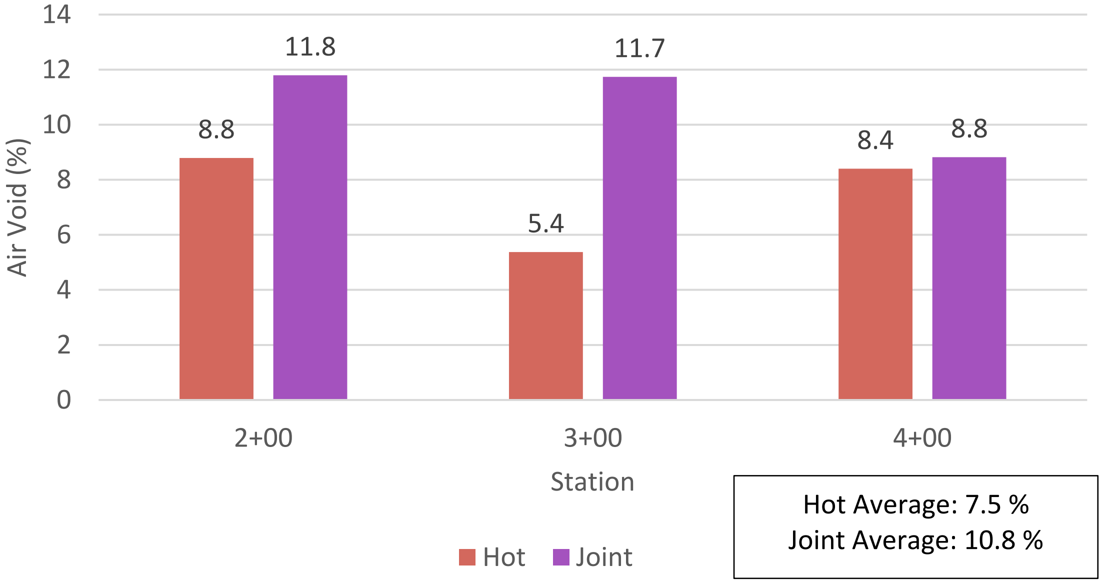


Figure 5.56: SC 254 project in-place density measurement (measured with the PQI)



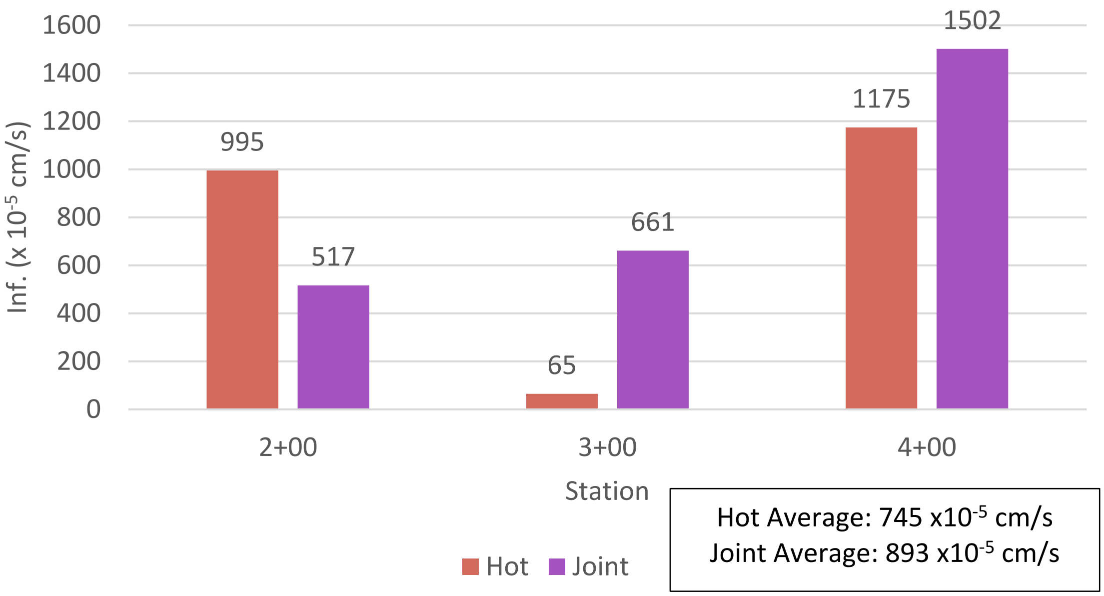
Hot Average: 2246 kg/m^3
Joint Average: 2167 kg/m^3

Figure 5.57: SC 254 project lab density measurement



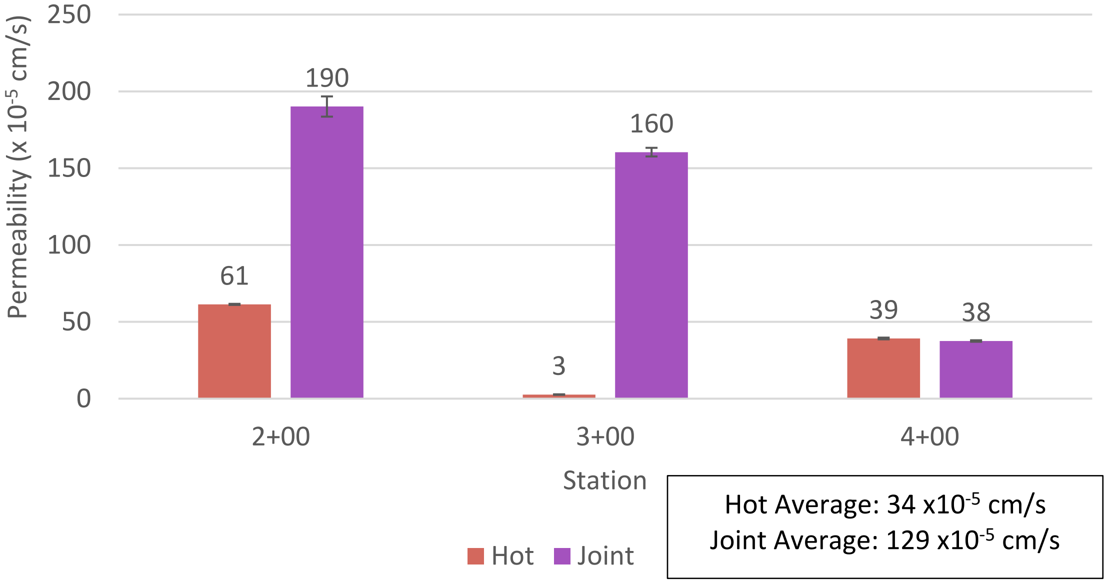
Hot Average: 7.5 %
Joint Average: 10.8 %

Figure 5.58: SC 254 project air void contents



Hot Average: 745 x10^{-5} cm/s
Joint Average: 893 x10^{-5} cm/s

Figure 5.59: SC 254 project in-place infiltration measurement



Hot Average: 34 x10^{-5} cm/s
Joint Average: 129 x10^{-5} cm/s

Figure 5.60: SC 254 project lab permeability

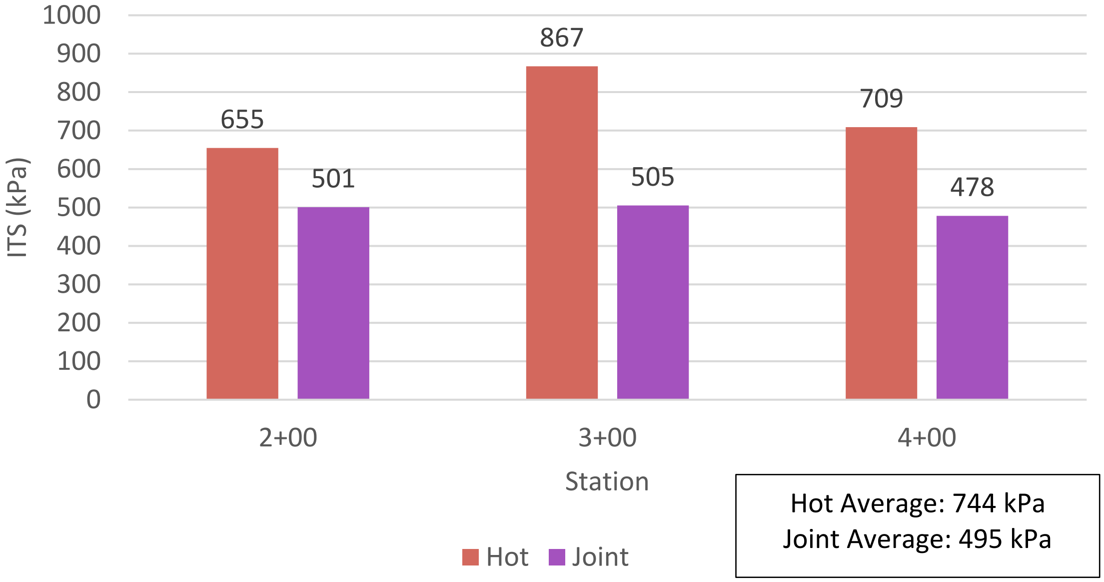


Figure 5.61: SC 254 project dry indirect tensile strength (ITS) measurement

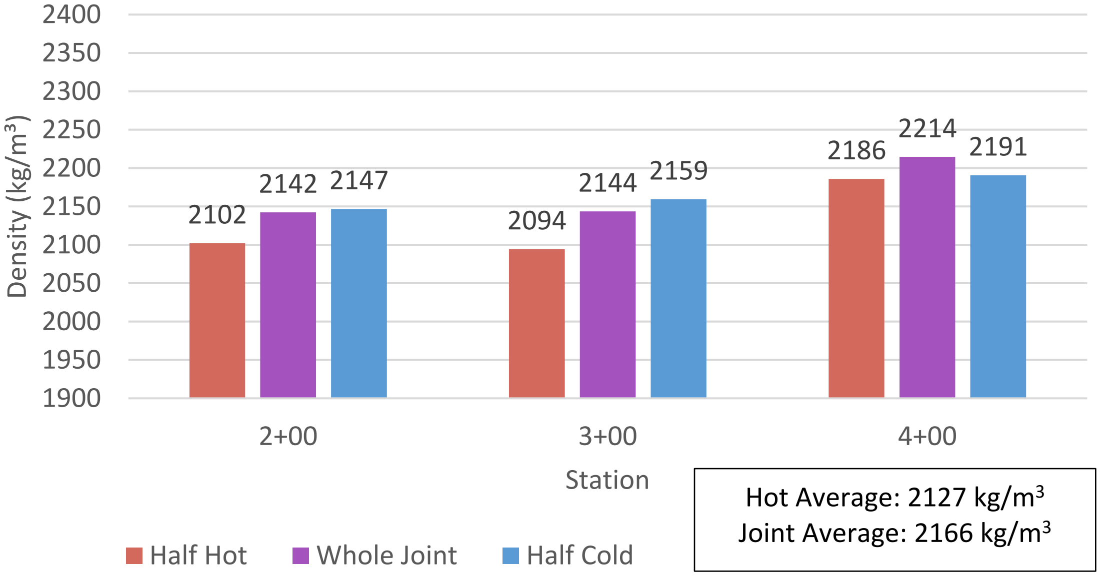


Figure 5.62: SC 254 half cores lab density from the joint cores

Table 5.16: Summary of SC 254 project (H = hot/half hot, J = joint, C = half cold, N/A = limited data)

Average	**Hot**	**Joint**	**Cold**	**Significant Difference**
Field Density (kg/m³)	2275	2249	.	No (H vs J)
Field Infiltration (x 10^{-5} cm/s)	745	893	.	No (H vs J)
Lab Density (kg/m³)	2246	2167	.	No (H vs J)
Lab Air Void (%)	7.5	10.8	.	No (H vs J)
Lab Permeability (x 10^{-5} cm/s)	34	129	.	No (H vs J)
ITS (kPa)	744	495	.	No (H vs J)
Half Lab Density (kg/m³)	2127	.	2166	No (H vs C)

When the statistical analysis was performed for the SC 254 project between the hot lane and the joint, ITS was the only result that had statistically significant result. The ITS average of 744 kPa in the interior portion of the hot lane and the ITS average of 495 kPa at the joint demonstrate that the ITS at the joint is weaker than the hot lane. Out of all the asphalt resurfacing projects, all projects but SC 254 exhibited significantly different ITS results. The ITS results demonstrate the strength of adhesion between the matching lanes at the joint. The half lab density results did show significant differences between the hot side and the cold side.

SC 11 Project

Highway SC 11 was the last project visited and it was constructed with a safety edge without compaction on the edge. The joint was compacted with the hot overlap method for the first and second pass at the joint. The mix design and aggregate gradation information can be found in Table 5.17. Due to the heavy traffic, the cold lane temperature could not be measured. The temperature readings, lab and field density, air void contents, field infiltration, lab permeability, ITS, and half core density are found in Figures 5.63 through 5.70. The results are summarized in Table 5.18.

Note: The cores for the SC 11 project were taken on a slightly curved section of road, which may influence the test results.

Table 5.17: SC 11 project information

Construction Information	
Location	SC-11
Construction Type	Safety Edge
Compaction at Joint (First-Second)	Hot Overlap - Hot Overlap
Thickness	2 in
Joint Straightness	Straightish
Joint Cleanness	Loose Aggregate
Joint Tack Coat	Yes
Height of Joint	0.25 in
Extent of Joint	1 in
Material Transfer Vehicle	Yes
Night Time Paving	No
Mix Design Information	
Type Mix	Surface B
AC Grade	PG 64-22
Design Air Voids (%)	3.8
Target AC (%)	5.9
Average MSG	2.456
Aggregate Gradation	
Sieve	Percent Passing
37.5 mm (1.5")	100.0
25.0 mm (1")	100.0
19.0 mm (3/4")	100.0
12.5 mm (1/2")	99.0
9.5 mm (3/8")	95.0
4.75 mm (No. 4)	67.0
2.36 mm (No. 8)	50.0
0.60 mm (No. 30)	33.0
0.150 mm (No. 100)	12.0
0.075 mm (No. 200)	4.0

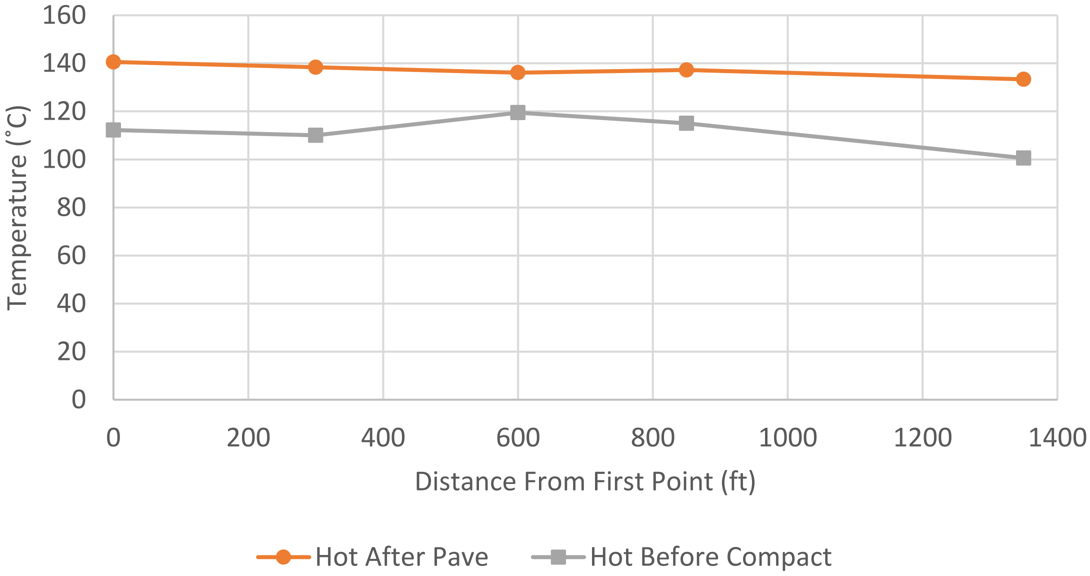


Figure 5.63: SC 11 project pavement temperature

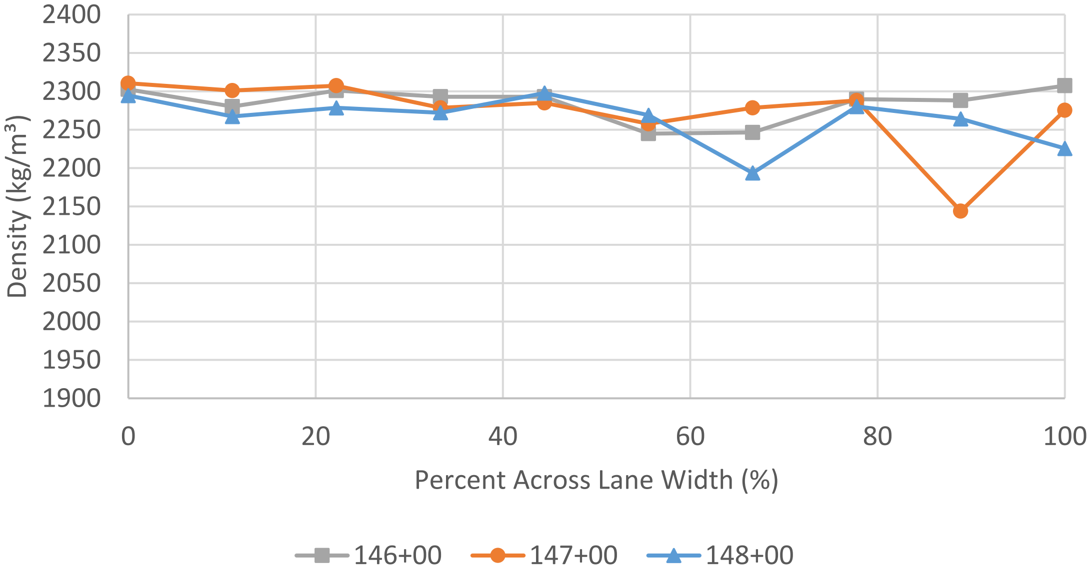


Figure 5.64: SC 11 project in-place density measurement (measured with the PQI)

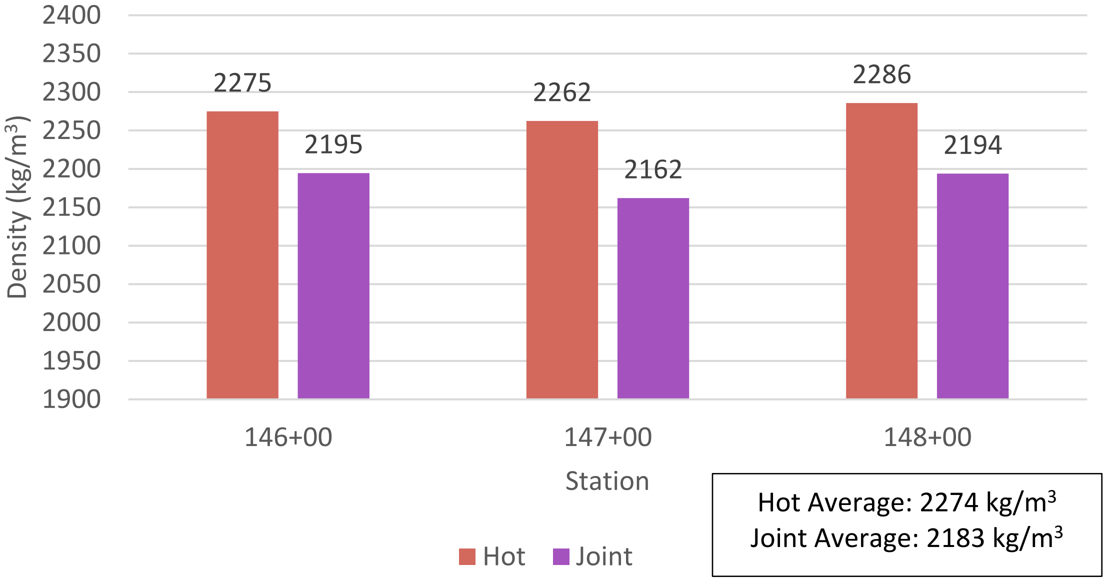


Figure 5.65: SC 11 project lab density measurement

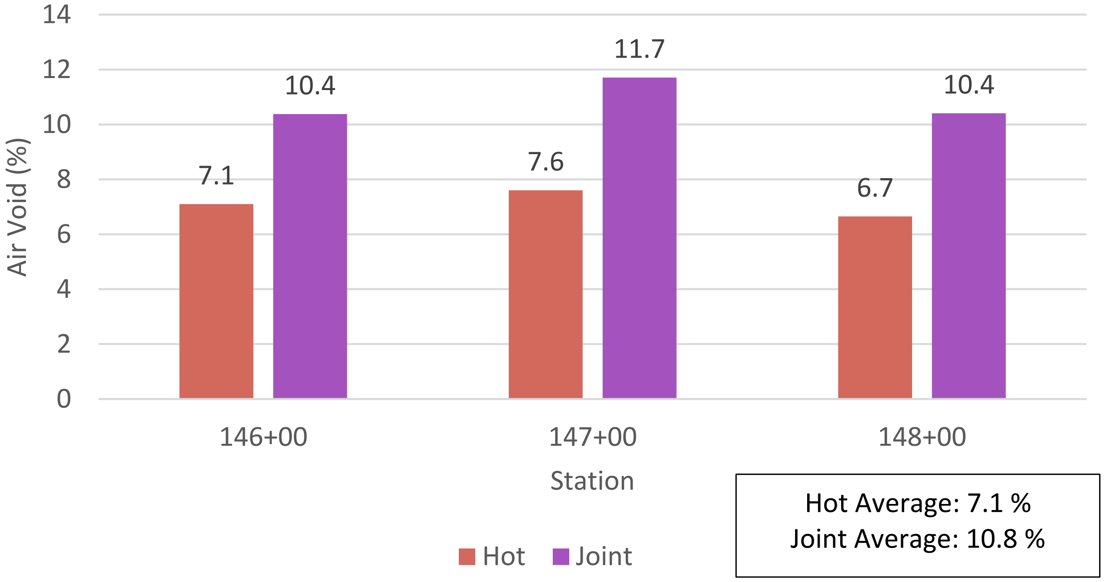


Figure 5.66: SC 11 project air void contents

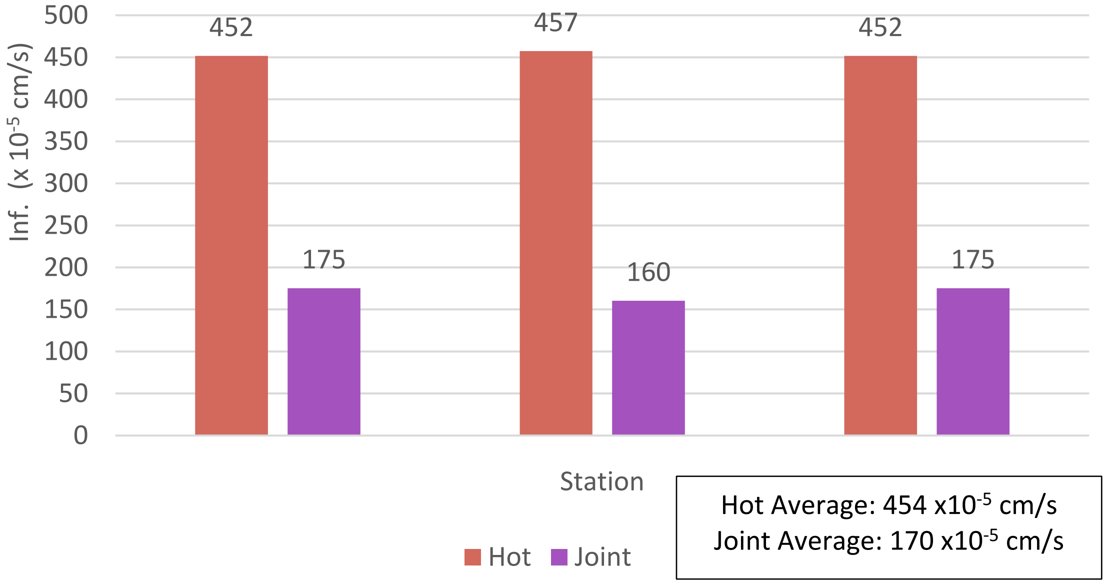


Figure 5.67: SC 11 project in-place infiltration measurement

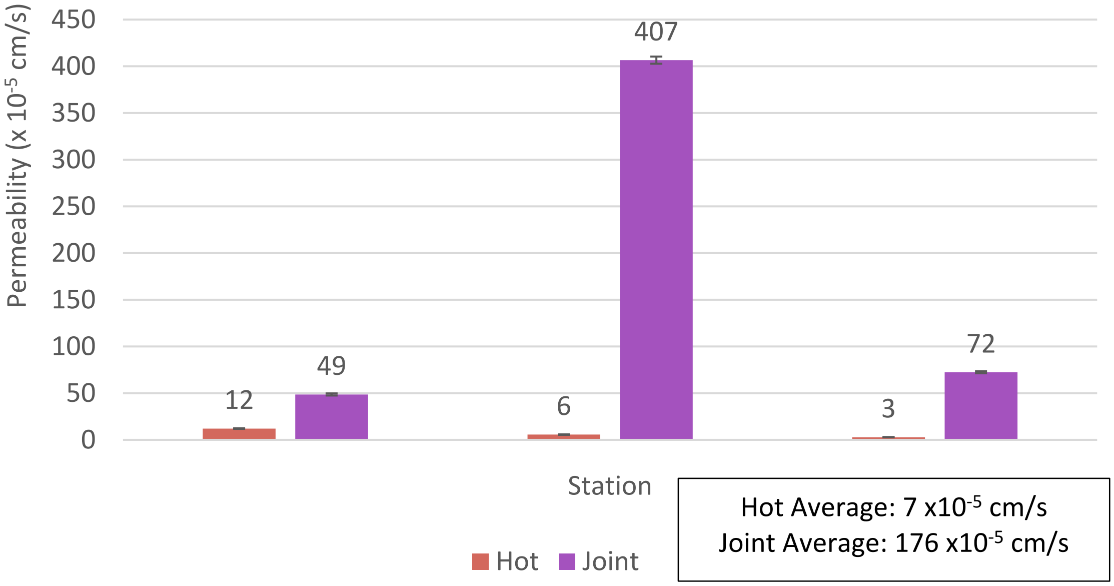


Figure 5.68: SC 11 project lab permeability

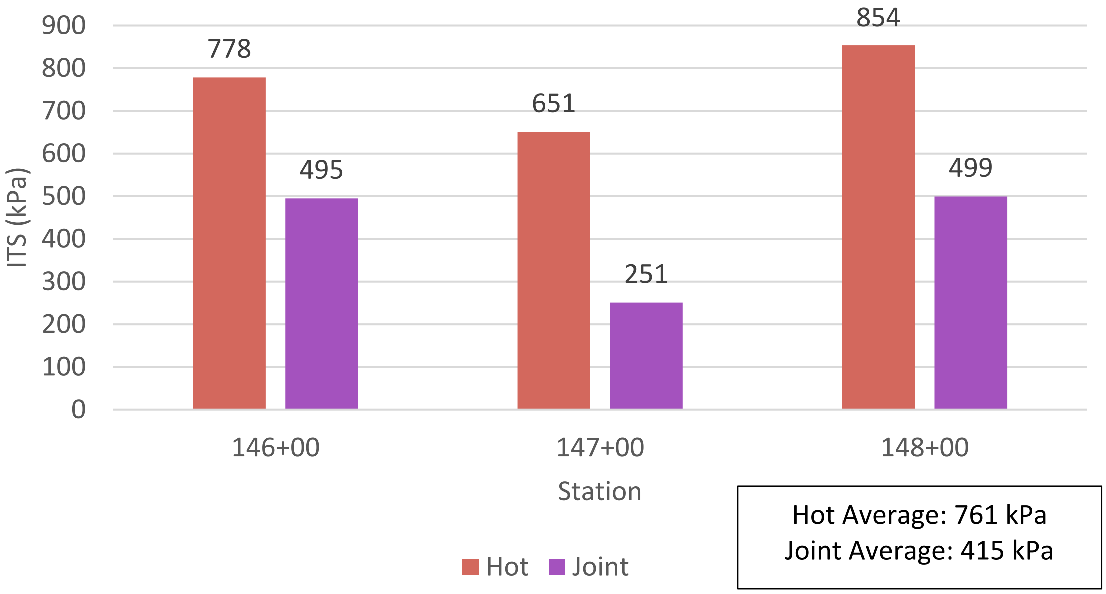


Figure 5.69: SC 11 project dry indirect tensile strength (ITS) measurement

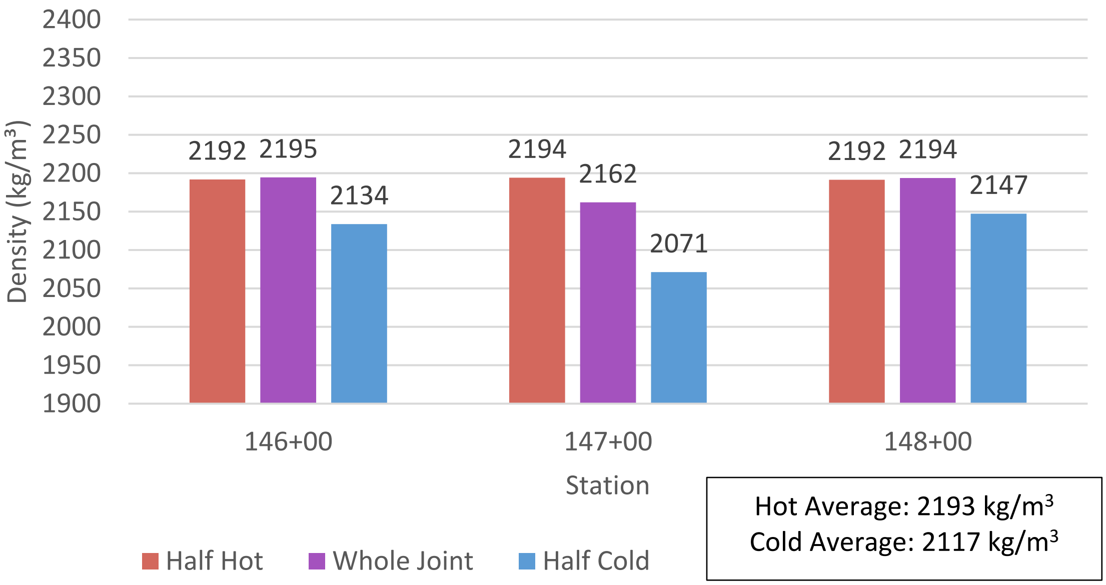


Figure 5.70: SC 11 half cores lab density from the joint cores

Table 5.18: Summary of SC 11 project (H = hot/half hot, J = joint, C = half cold, N/A = limited data)

Average	**Hot**	**Joint**	**Cold**	**Significant Difference**
Field Density (kg/m³)	2274	2293	.	No (H vs J)
Field Infiltration (x 10^{-5} cm/s)	454	170	.	Yes (H vs J)
Lab Density (kg/m³)	2274	2183	.	Yes (H vs J)
Lab Air Void (%)	7.1	10.8	.	Yes (H vs J)
Lab Permeability (x 10^{-5} cm/s)	7	176	.	No (H vs J)
ITS (kPa)	761	415	.	Yes (H vs J)
Half Lab Density (kg/m³)	2193	.	2117	No (H vs C)

The performance of the hot lane was significantly higher than the joint with respect to field infiltration, lab density, air void, and ITS. It is important to note that all the infiltration results were higher at interior of the mat compared to joint.

The asphalt construction crew for SC 11 project had difficulty in compacting the joint to the same level of the existing lane at the start of the project. To correct the issue, a small vibratory roller was placed in front of the main, vibratory roller to compact the joint as soon as the paver passed by. Because the small roller was only focused on compacting the joint, the quality of the joint may have improved by doing so. The placement of the small roller occurred after the temperature measurement. Therefore, the temperature reading does not reflect the changes in the compaction order.

Other Performance Factors

The performance of longitudinal joints were measured in the field and lab using density, infiltration, permeability, and ITS tests. However, aside from direct measurement, other observations were made regarding the quality of longitudinal joint construction. According to the South Carolina Standard Specifications for Highway Construction (SCDOT 2007), it is required to arrange the width of the lanes to offset the joint of each successive course from the previous course. However, when performing asphalt resurfacing projects, some of the quality control managers stated that it is difficult to determine where the joint of the underlying course is located after milling the surface layer. Offsetting the joint can improve the performance of the joints by minimizing the chance of infiltrated water from seeping through all the joints of different layers. For future asphalt pavement construction, joint locations of underlying courses should be recorded for future resurfacing projects.

During asphalt pavement construction and resurfacing projects, it is sometimes difficult to identify which rolling pattern is practiced due to the limited space at the joint from the incoming traffic. Therefore, the roller operators were not always able to maintain the hot overlap method without running over traffic cones near the joint. Rather than compacting 6 to 12 in away from the joint or over the joint, it was observed that the majority of the roller drum was over the joint by 3 in or less. In addition, sometimes, the rollers were compacting in a curvy pattern along the joint to avoid traffic cones. It may be helpful to have a camera or mirror attached to the side of the roller for experienced and novice roller operators to see where the wheels are actually passing. Moreover, there should be at least 6 to 8 in of space between the joint and the traffic cones, if possible.

Result Summary

Temperature

The temperature of asphalt mix is considered a key component to producing quality asphalt pavement. To observe how the temperature influenced the quality of the joints in this study, the temperature of the mix after a paver passed and the temperature before the first roller pass was measured. The change in asphalt temperature before compaction from all of projects is illustrated in Figure 5.71 and this bar chart demonstrates that SC 8 had the highest temperature drop after the paver passed by. The SC 8 project was the only project without a material transfer vehicle (MTV) on site, but as previously mentioned, the temperature was measured after the first roller pass due to safety reasons. Typically, a MTV helps to re-blend the mix from the delivery truck and transfers the mix to the paver by conveyor belt. For many asphalt construction projects, the MTV can improve the pavement quality by minimizing the thermal and material segregation. Relating to the temperature loss, most projects could potentially be improved by decreasing the distance between the paver and the first roller.

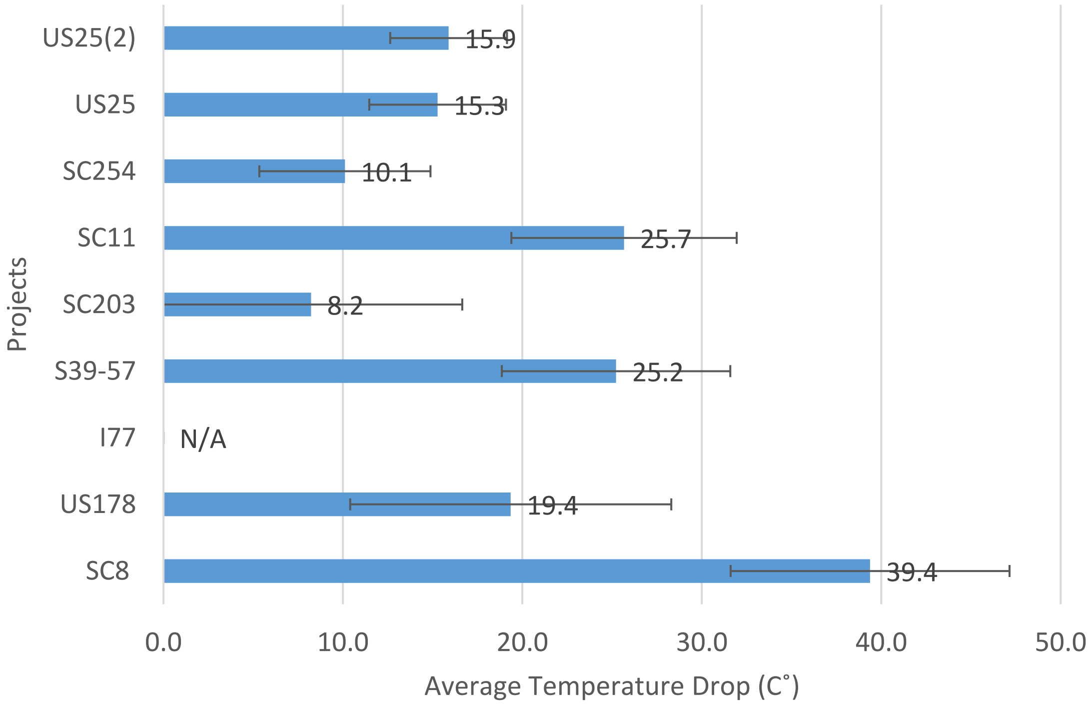


Figure 5.71: Projects temperature drop before the joint compaction

Air Voids

The quality of a joint can be assessed by comparing to the quality of interior portions of the pavement. The air void results for all projects are summarized in Table 5.19 and Figure 5.72. In comparison, the air voids of all joint cores had almost twice as much air voids as the hot lane cores. Additionally, all the average air void J/H ratios were greater than 1, indicating higher air void at the joint. Air voids could be high at the joint because joints are not compacted appropriately. Even though reducing the air void content at joint to the same level as the hot lane may not be possible because of the hardened edge of cold lane, more effort could be taken to lower the air void content at the joint..

Table 5.19: Air void summary of projects (SD = standard deviation, CV = coefficient variation, N/A = limited data)

Project	**Average Void Content**				
	Hot (%)	**Joint (%)**	**J/H**	**J/H SD**	**J/H CV (%)**
SC8	7.6	14.5	1.93	0.277	16.7
US178	6.1	17.0	2.79	N/A	N/A
I77	8.7	10.3	1.18	N/A	N/A
S39-57	7.7	17.8	2.32	0.301	11.7
SC203	8.5	13.5	1.60	0.140	9.7
SC11	7.1	10.8	1.52	0.054	3.7
SC254	7.5	10.8	1.53	0.589	43.9
US25	6.2	12.1	1.95	0.252	12.9
US25(2)	6.2	11.0	1.80	0.223	13.4

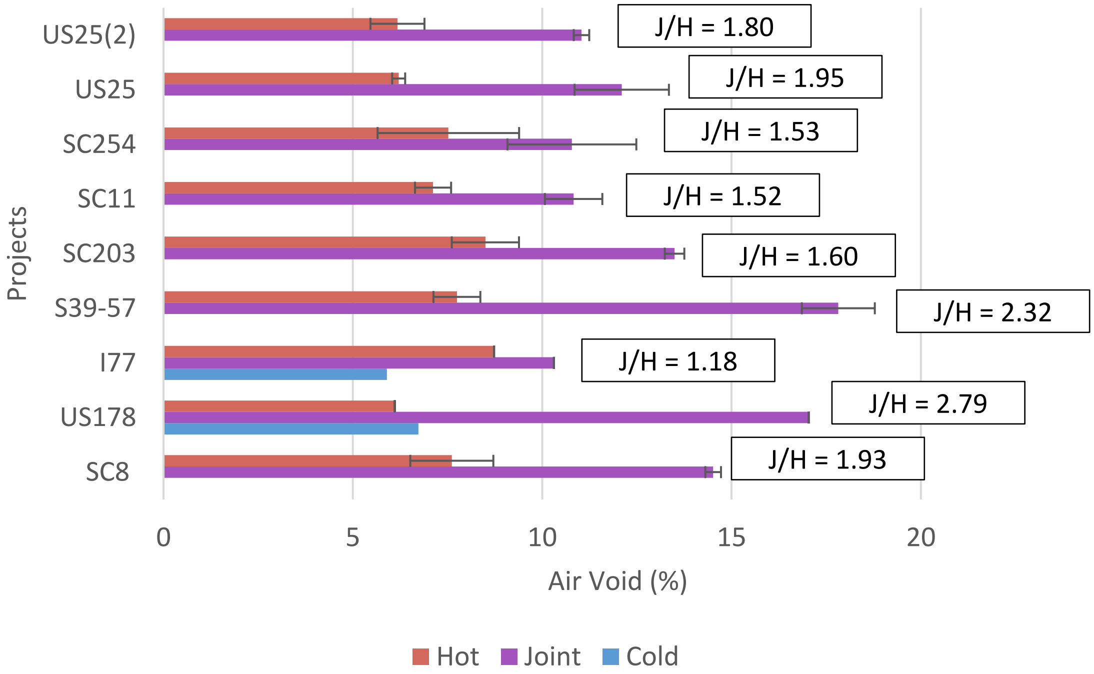


Figure 5.72: Projects air void content (J/H = ratio of joint and hot lane)

Density

Density is the most common method used to monitor the quality of the pavement mat during construction and it also has been one used to check the quality of the joint. From the lab density results summarized in Table 5.20 and Figure 5.73, the density of the joint is lower than the interior of the lane. However, the summarized field density results displayed in Table 5.21 and Figure 5.74 do not show significant differences between the density of the joint and the hot lane. When comparing the in-place density and lab density, the density gauges accurately determined the density of interior portions of the pavement, assuming lab density results represent the actual pavement quality. However, the density gauges were not able to accurately determine the density of the joints. The majority of field density measurements were off by more than 100 kg/m^3 (6.25 lb/ft^3) compared to lab density measurements. Moreover, the average J/H ratios of the field density were closer to 1 compared to the lab density, indicating that the differences in density of the joint and the hot lane are small. It may be possible that there is a limit to the impedance spectroscopy technology and radioactive responses for checking the quality of the joint due to the high percentage of air voids.

Table 5.20: Lab density summary of projects (SD = standard deviation, CV = coefficient variation, N/A = limited data)

Project	**Average Lab Density (kg/m³)**				
	Hot (kg/m³)	**Joint (kg/m³)**	**J/H**	**J/H SD**	**J/H CV (%)**
SC8	2307	2135	0.93	0.011	1.22
US178	2362	2087	0.88	N/A	N/A
I77	2219	2181	0.98	N/A	N/A
S39-57	2262	2015	0.89	0.016	1.85
SC203	2209	2089	0.95	0.007	0.73
SC11	2274	2183	0.96	0.005	0.47
SC254	2246	2167	0.97	0.031	3.25
US25	2283	2139	0.94	0.015	1.58
US25(2)	2282	2164	0.95	0.007	0.78

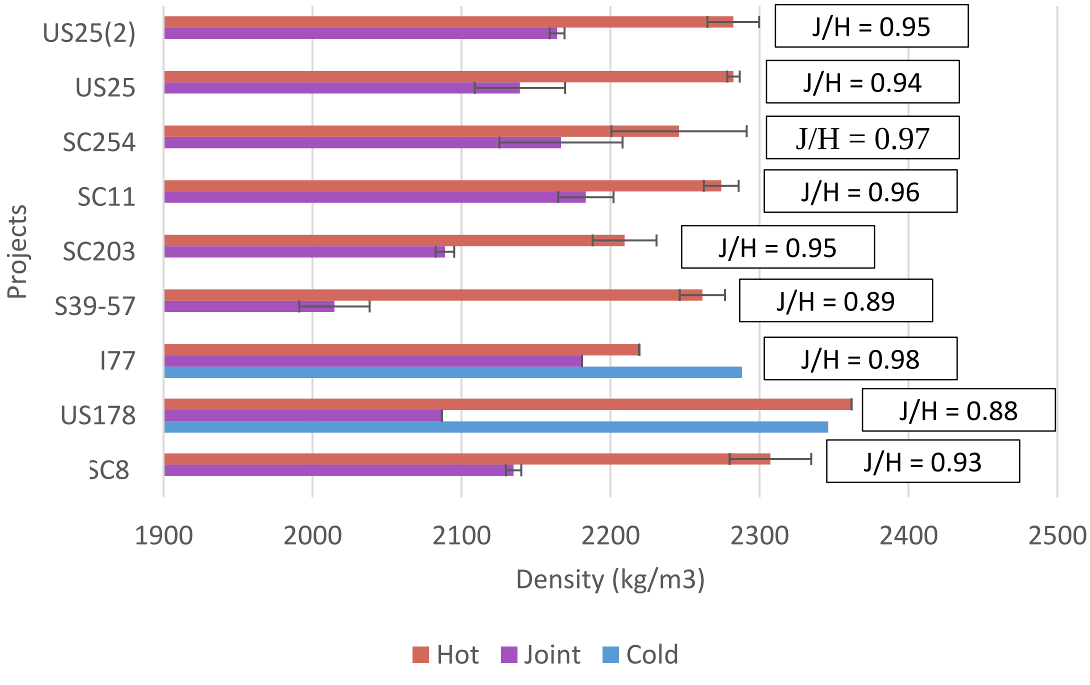


Figure 5.73: Projects lab density from SC-T-68 (J/H = ratio of joint and hot lane)

Table 5.21: Field density summary of projects (SD = standard deviation, CV = coefficient variation, N/A = limited data)

Project	**Average Field Density**				
	Hot (kg/m³)	**Joint (kg/m³)**	**J/H**	**J/H SD**	**J/H CV (%)**
SC8	2333	2319	0.99	0.007	0.67
US178	2363	2285	0.97	N/A	N/A
I77	2242	2271	1.01	0.009	0.93
S39-57	2274	2258	0.99	0.004	0.38
SC203	2226	2224	1.00	0.009	0.86
SC11	2274	2293	1.01	0.008	0.82
SC254	2275	2249	0.99	0.012	1.19
US25	2250	2191	0.97	0.013	1.31
US25(2)	2269	2266	1.00	0.009	0.86

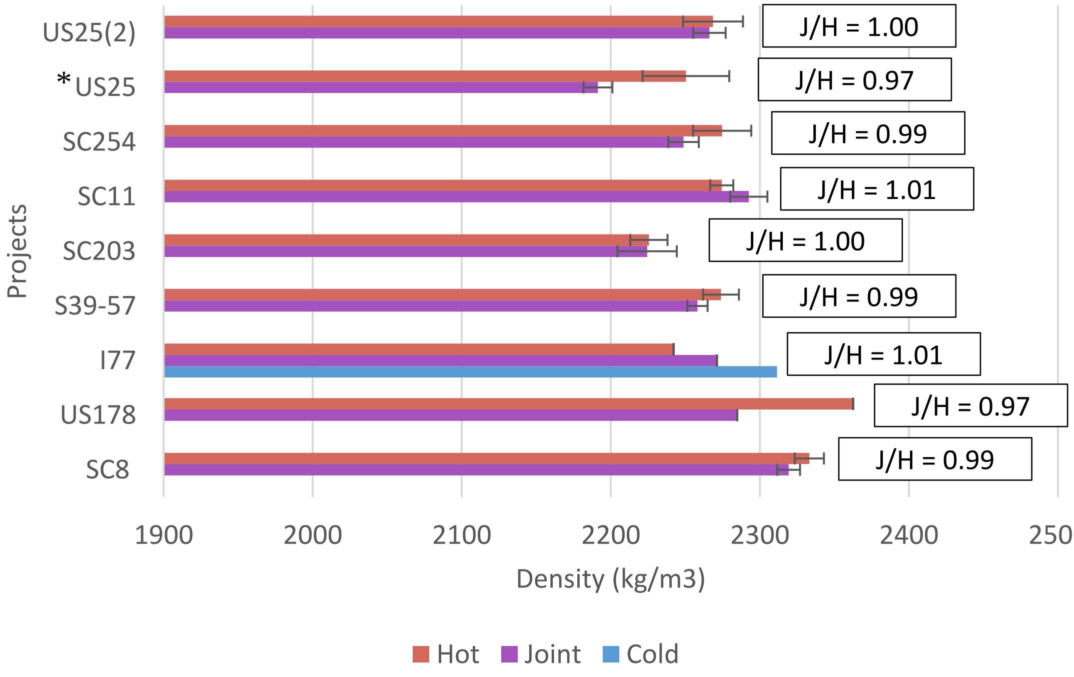


*Figure 5.74: Projects field density using a non-nuclear and nuclear density gauge (J/H = ratio of joint and hot lane, nuclear density gauge marked with *)*

All of the in-place density and lab density data are plotted in Figure 5.75 and based on the figure, the relationship between in-place density readings obtained using density gauges and density measurement from SC-T-68 have a weak linear relationship. Similarly, Chen et al. stated that the PaveTracker, another non-nuclear density gauge, does not have a strong relationship to AASHTO T 166 (SC-T-68) nor the CoreLok method, which is another method used to measure core density in the lab (2013). As previously mentioned, the relationship improves if only the in-place density and lab density of the hot cores are compared without joint data as shown in Figure 5.76. To observe if there was a pattern among just joint data, Figure 5.77 was created, but no pattern was observed. This was expected because the joint density in the field was measured 1 foot away from the joint and the lab density was measured from a core taken directly on the joint.

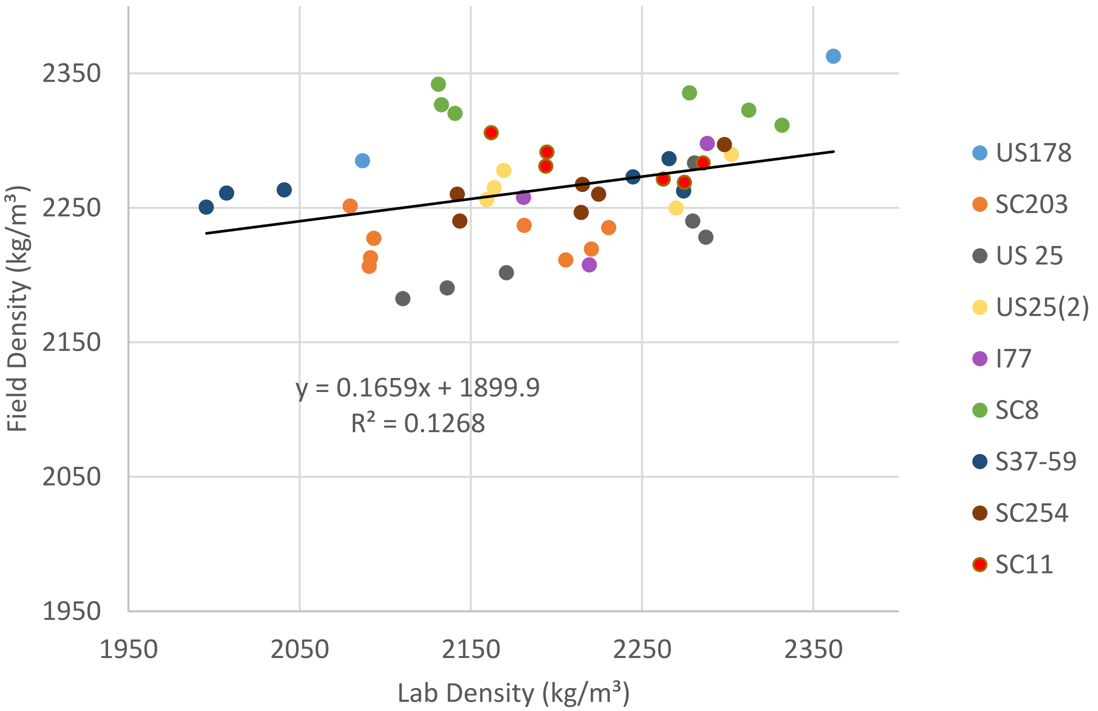


Figure 5.75: Relationship between field density and lab density of all data

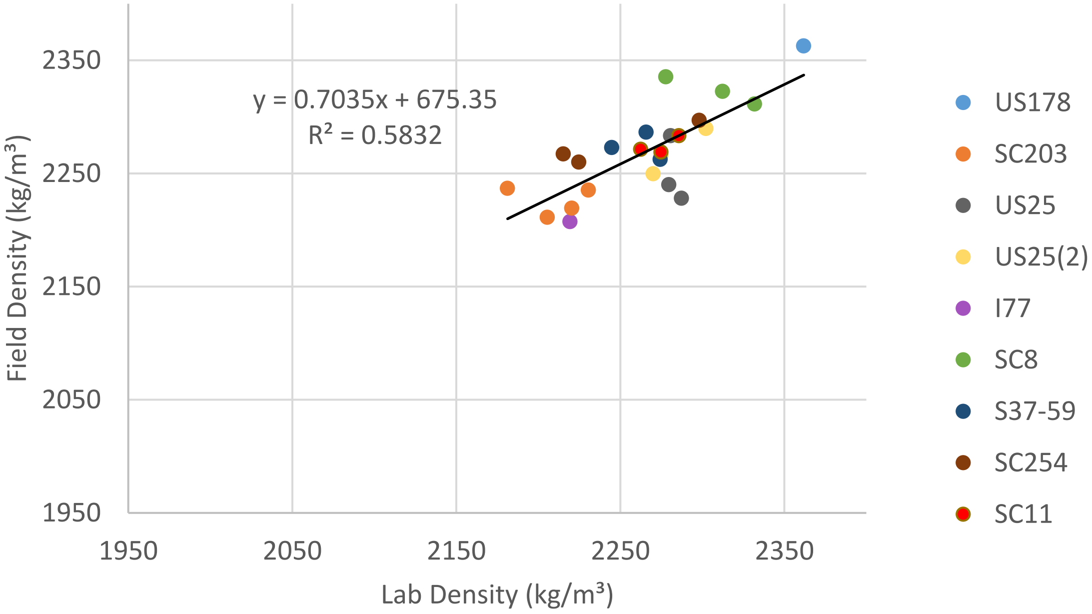


Figure 5.76: Relationship between field density and lab density of only hot core data

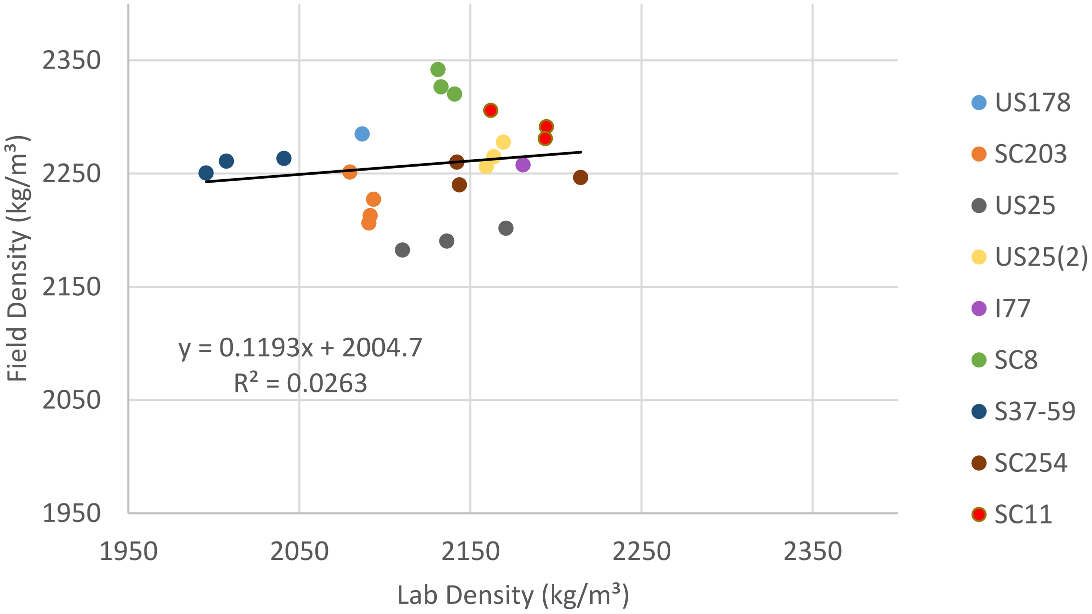


Figure 5.77: Relationship between field density and lab density of only joint core data

Permeability

Longitudinal joint cracking occurs due to weak density and inadequate materials at the joint, but it is believed that most deterioration occurs when water starts to penetrate at the joint. Mallick et al. stated two reasons that field infiltration measurement is needed when evaluating the performance of asphalt pavement at the longitudinal joint. First, the permeability is more related to durability issues resulting from moisture damage, premature oxidation and cracking. Second, they also referenced other authors' experiences describing the difficulty of determining density at the joint using a field density gauge (2006).

When all of the in-place infiltration results (Table 5.22 and Figure 5.78) of the hot lane and the joint are compared, the infiltration at the joint was slightly higher than the hot lane. In some cases, the infiltration rate at the hot lane was higher than the joint. The laboratory permeability results (Table 5.23, and Figure 5.79) of the hot lane and the joint followed the same trend of in-place infiltration results, but there were significant differences between the hot lane and the joint. The reason for the higher permeability measurements at the joint compared to the hot lane is high air void and low density at the joint. Zube concluded that dense-graded asphalt with greater than 8% air void content will experience high permeability (1962), and Choubane et al. recommend the air void to be 6% or less to achieve impermeability (1998). In contrast to these two previous studies, Brown et al. claimed compacted asphalt with 5% to 7% air void content could still measure high permeability coefficient (2004).

When the field infiltration and lab permeability results are compared, the results are significantly different from one to another for the hot lane and the joint. The significant differences can be seen in J/H ratios also. The differences could be because, in the field, the water can move horizontally after penetrating the surface of the asphalt for the infiltration test, but the water is only allowed to move vertically for lab permeability test. Even though the area of interest was not the same for the joint in-place infiltration and lab permeability, measuring the in-place infiltration 1 ft from the actual joint should still well represent the quality of the joint. If the in-place infiltration was conducted on the actual joint without the water leaking issue, then the value could be higher than the purple bars that are depicted in Figure 5.78. The standard deviation of the two figures show that the lab permeability results are more repeatable. Similarly, Chen et al. stated that the NCAT permeameter is less reliable than the laboratory K-W permeameter (FM-5-565) and concluded no permeability criteria was determined due to its poor relationship with in-place air voids (2013).

Table 5.22: Field infiltration summary of projects (SD = standard deviation, CV = coefficient variation, N/A = limited data)

Project	**Average Field Infiltration**				
	Hot (x 10^{-5} cm/s)	**Joint (x 10^{-5} cm/s)**	**J/H**	**J/H SD**	**J/H CV (%)**
SC8	281	803	5.62	6.61	118
US178	.	.	N/A	N/A	N/A
I77	.	.	N/A	N/A	N/A
S39-57	656	918	1.60	0.82	51
SC203	661	843	1.75	1.00	57
SC11	454	170	0.38	0.02	6
SC254	745	893	4.01	5.40	135
US25	229	783	3.66	1.45	39
US25(2)	273	428	2.41	2.65	110

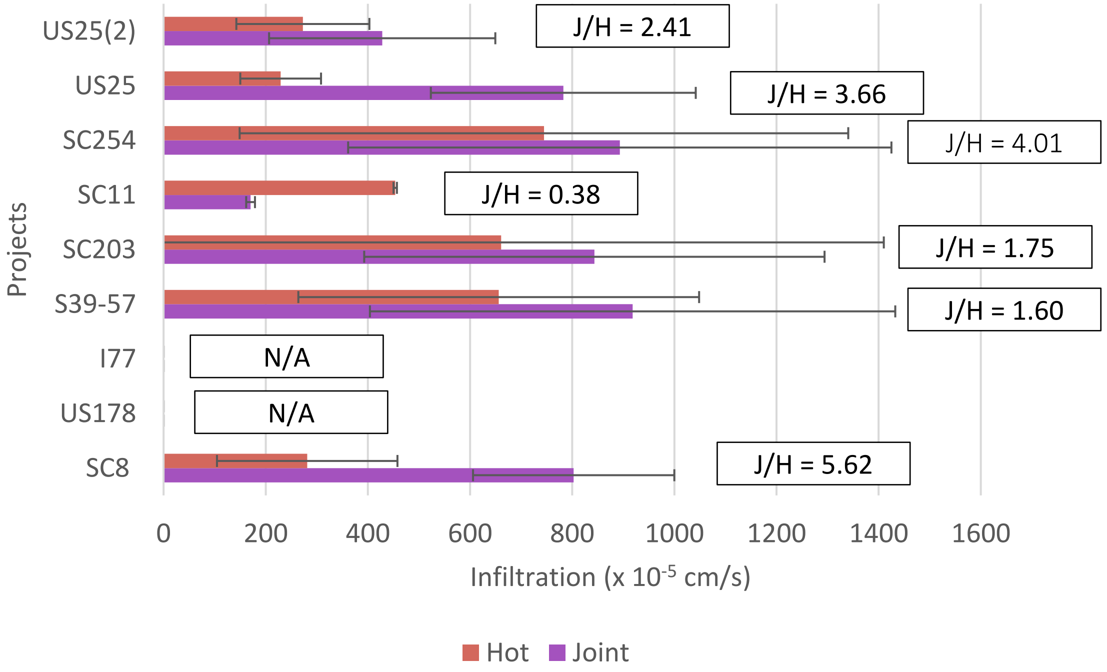


Figure 5.78: Projects in-place infiltration (J/H = ratio of joint and hot lane)

Table 5.23: Lab permeability summary of projects (SD = standard deviation, CV = coefficient variation, N/A = limited data)

Project	**Average Lab Permeability**				
	Hot (x 10^{-5} cm/s)	**Joint (x 10^{-5} cm/s)**	**J/H**	**J/H SD**	**J/H CV (%)**
SC8	3	241	137	74	54
US178	0	1176	64065	N/A	N/A
I77	752	3586	5	N/A	N/A
S39-57	22	1540	159	175	110
SC203	21	716	92	45	67
SC11	7	176	34	35	103
SC254	34	129	21	33	157
US25	13	148	45	49	111
US25(2)	8	219	96	133	138

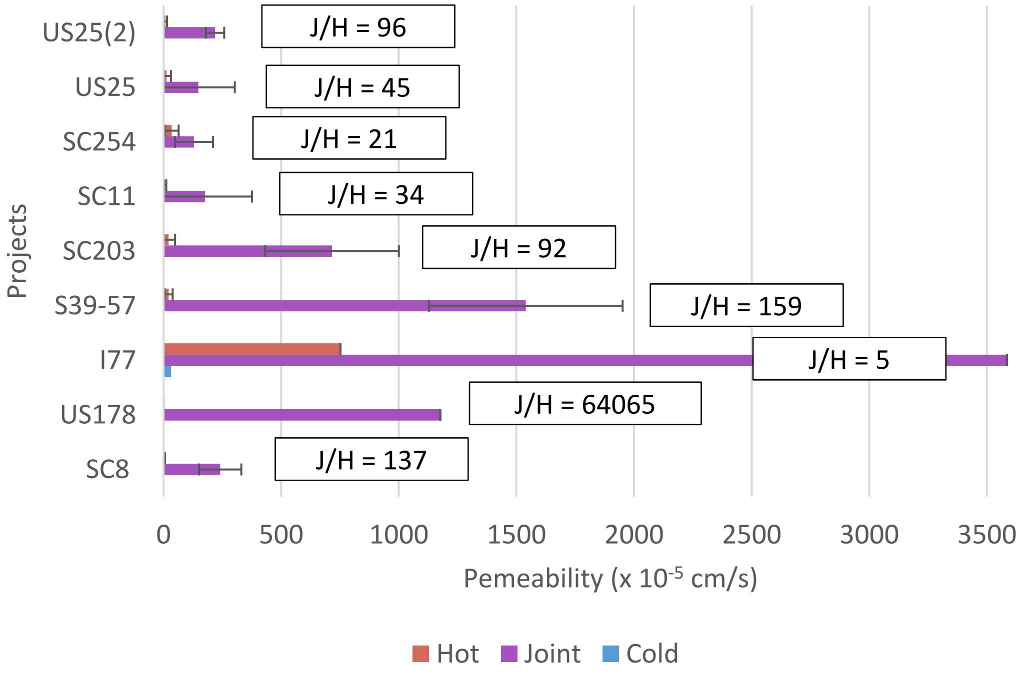


Figure 5.79: Projects lab permeability following FM 5-565

The non-linear, indirect relationship between lab density and permeability is displayed in Figure 5.80. This shows that when the density of the asphalt decreases, the permeability increases exponentially. When the asphalt pavement is less dense, it results in higher void content allowing for the water flow thorough the asphalt material structure.

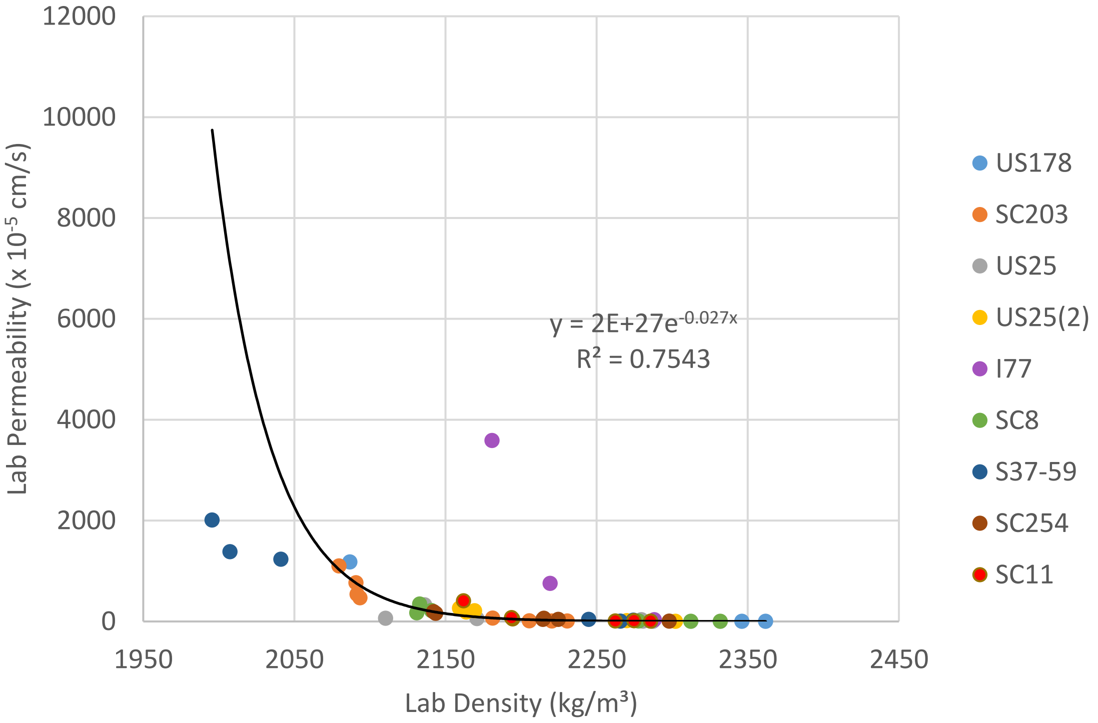


Figure 5.80: Relationship between lab density and lab permeability

Indirect Tensile Strength

The indirect tensile strength testing is typically used to measure moisture susceptibility of asphalt specimen by applying indirect tension, but it can also be used to determine the bonding strength of the joint. If the indirect tensile is high, then it indicates that the bond strength at the joint is high as well. The ITS results (Table 5.24 and Figure 5.81) follow the same trend as density (and air voids). The ITS J/H ratios were much lower than the density J/H ratios. The ITS values of joint cores were much lower than the ITS of the hot lane cores because the joint cores are composed of the cold lane bonded to the hot lane while the hot lane cores were only composed of single material. Temperature differences between the cold and the hot lane cause a weak bond between the two edges. Additionally, the joint is usually not well compacted compared to the remainder section, which results in weaker ITS at the joint. To minimize issues at the joint, quality control managers and inspectors should ensure there is proper compaction and the use of stronger tack coat could potentially minimize longitudinal joint cracking.

Table 5.24: Indirect tensile strength summary of projects (SD = standard deviation, CV = coefficient variation, N/A = limited data)

Project	**Average ITS**				
	Hot (kPa)	**Joint (kPa)**	**J/H**	**J/H SD**	**J/H CV (%)**
SC8	672	348	0.52	0.183	35.5
US178	1019	254	0.25	N/A	N/A
I77	837	285	0.34	N/A	N/A
S39-57	625	120	0.20	0.112	54.5
SC203	484	239	0.56	N/A	N/A
SC11	761	415	0.54	0.132	24.7
SC254	744	495	0.67	0.091	13.6
US25	753	392	0.52	0.064	12.5
US25(2)	657	367	0.56	0.045	8.0

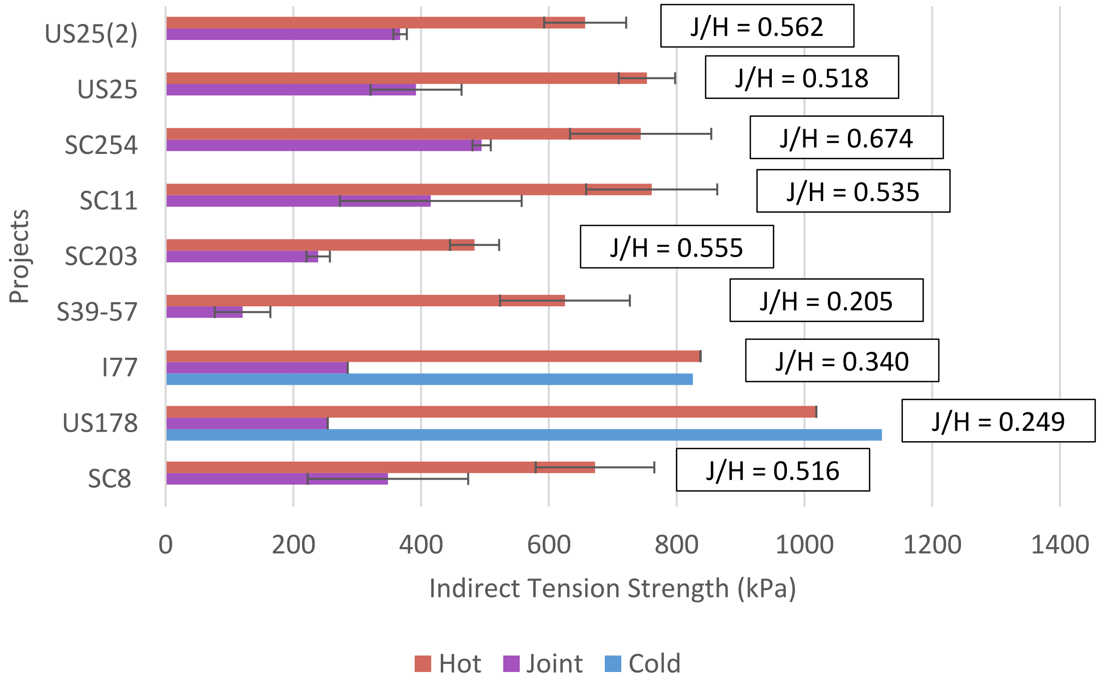


Figure 5.81: Projects indirect tension strength (J/H = ratio of joint and hot lane)

The linear relationship between lab density and ITS results are shown in Figure 5.82, which resembles findings by Chen et al. (2013). The hot and cold lane and joint data are combined into one figure and the result still showed a direct, strong relationship between two variables.

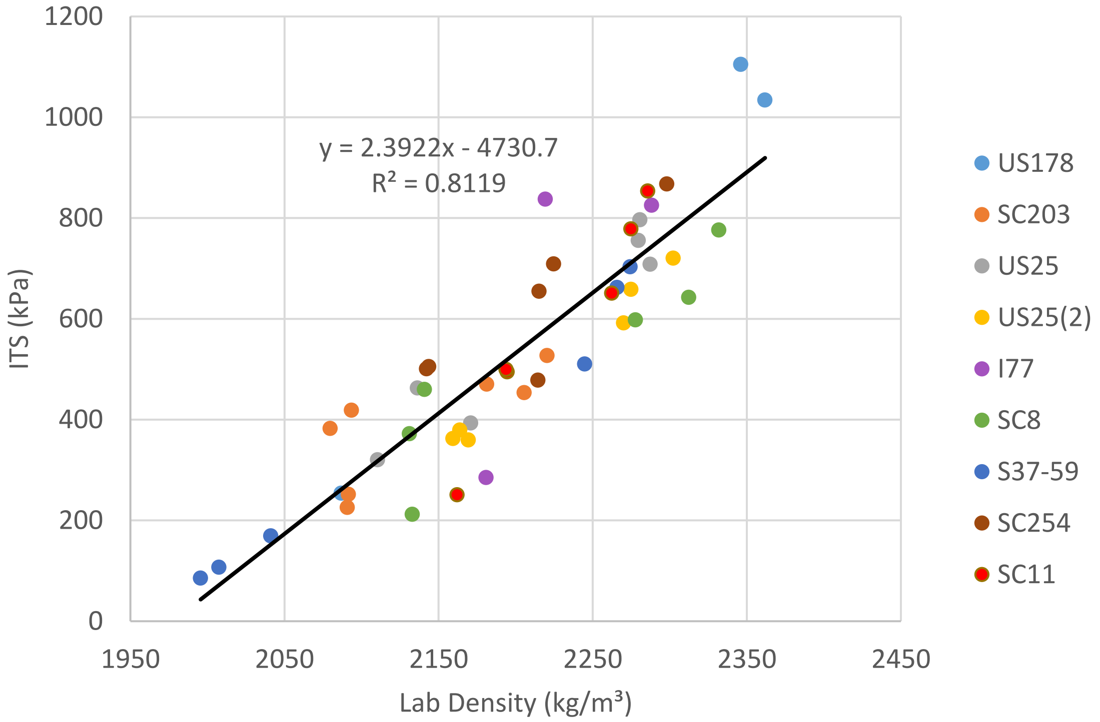


Figure 5.82: Relationship between indirect tensile strength and lab core density

Half Core Density

The broken joint cores after the ITS testing were tested using the SC-T-68 method to determine the density of the hot lane and the cold lane at the joint. All of the densities of half cores (the hot and cold lane) are shown in Table 5.25 and Figure 5.83. Except for the SC 254 and SC 8 projects, all the hot half cores had slightly higher density results than the cold half core, confirming the results from Estakhri et al. (2011). The hot half cores have a tendency to measure higher density because the hot lane is constructed against the confined edge of the cold lane, which was unconfined during compaction. The confined edges provide structural support for asphalt mix to lean against during compaction.

Table 5.25: Half core density summary of projects (SD = standard deviation, CV = coefficient variation, N/A = limited data)

Project	Average Half Core Density				
	Hot (kg/m³)	Joint (kg/m³)	C/H	C/H SD	C/H CV (%)
SC8	2108	2117	1.00	0.035	3.46
US178	2095	2056	0.98	N/A	N/A
I77	2188	2107	0.98	N/A	N/A
S39-57	2011	1973	0.98	0.019	1.95
SC203	2125	1999	0.95	0.014	1.48
SC11	2193	2183	1.00	0.009	0.92
SC254	2127	2166	1.02	0.015	1.44
US25	2141	2106	0.98	0.020	2.07
US25(2)	2148	2106	0.98	0.005	0.54

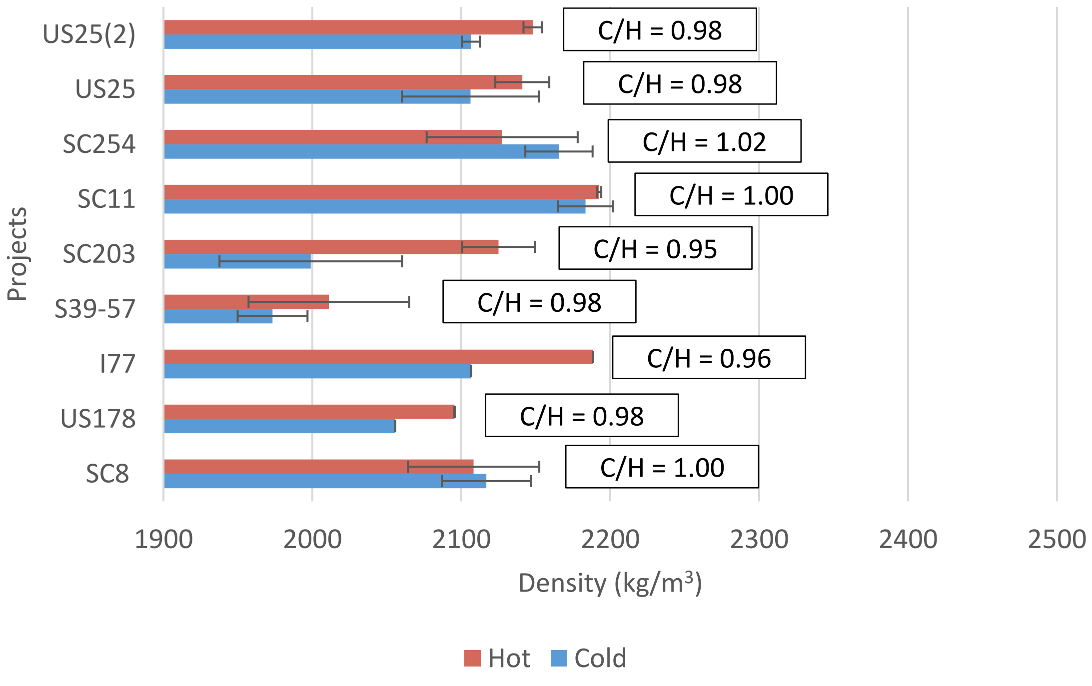


Figure 5.83: Projects half core density (C/H = ratio of hot and cold lane at joint)

Statistical Analysis

The performance of an individual site, joint type, mix type, thickness, and nominal maximum aggregate size (NMAS) could not be compared through tables or figures alone. To evaluate how changes in variables influenced the performance of the joint compared to the middle of the hot lane, the JMP data analysis software was used to perform analysis of variance (ANOVA) by running each pair, student's t-tests with significance of 5%. The connecting letters report for the site (Table 5.26), joint type (Table 5.27), mix type (Table 5.28), thickness (Table 5.29), and NMAS (Table 5.30) are presented below.

Table 5.26: Project sites Student's t-test connecting letters report (= Nuclear density gauge reading)*

Site	Temperature Drop	Field Density	Field Permeability	Lab Density	Lab Permeability	ITS
SC 8	A	BC	A	D	B	ABC
US 178	BC	D	.	E	A	CD
I-77	.	A	.	A	B	BCD
S 39-57	B	BC	A	E	B	D
SC 203	D	ABC	A	BCD	B	ABC
SC 11	B	AB	A	ABC	B	ABC
SC 254	CD	CD	A	AB	B	A
SC 25	CD	D*	A	CD	B	ABC
SC 25(2)	CD	ABC	A	ABCD	B	AB

Among all of the asphalt surfacing projects, no difference in performance was found in field infiltration and only the US 178 project was significantly different from other projects in lab permeability. Statistically, the US 178 project had the worst performance in lab permeability because the middle of the hot lane was almost impermeable while the joint was highly permeable. The results may be altered if there more were core samples from the US 178 project. For field density and lab density, I-77 outperformed in field density and lab density and for the ITS results, SC 254 outperformed other projects. It is difficult to pinpoint why a certain project's joints performed better than another site as there are many variables in asphalt pavement construction, and more research should be conducted with controlled variables.

The connecting letters report of joint construction types of butt joint and safety edge show no significant improvement on the joint for the different performance indicators (Table 5.27). More joint construction techniques should be evaluated for future research.

Table 5.27: Joint types ANOVA connecting letters report

Joint Type	**Field Density**	**Field Infiltration**	**Lab Density**	**Lab Permeability**	**ITS**
Butt	A	A	A	A	A
Safety Edge	A	A	A	A	A

There were three different mix types (surface type A, B, and C) and surface type A showed increased field density of the joint compared to the surface type C (Table 5.28). Surface types A and B showed significantly greater joint performance as indicated by lab density results compared to the surface type C. The surface A mix type may perform better than type C because type A contains PG 76-22 binder which requires higher production temperature and allows pavement to be compacted at a higher temperature. In addition, the surface type A and B mix require more compaction to account for the higher volumes of traffic of the road than type C. Typically, the more compaction is done, the more consolidation of material is observed until the peak point is reached.

Table 5.28: Mix types ANOVA connecting letters report

Mix Type	**Field Density**	**Field Infiltration**	**Lab Density**	**Lab Permeability**	**ITS**
Surface A	A	.	A	A	A
Surface B	AB	A	A	A	A
Surface C	B	A	B	A	A

There were three different thickness (1.5, 2.0, and 2.5 in) of surface layers and the results of the statistical analysis showed that the 2 in and 2.5 in thick joints were more likely to perform better in lab density and ITS results than 1.5 in thick joint (Table 5.29). The thicker joint will likely increase density because there is more asphalt material to compact and the increase in density results in increase in ITS.

Table 5.29: Thickness ANOVA connecting letters report

Thickness	**Field Density**	**Field Infiltration**	**Lab Density**	**Lab Permeability**	**ITS**
1.5 in	A	A	B	A	B
2.0 in	A	A	A	A	A
2.5 in	A	A	A	A	A

The nominal maximum aggregate size (NMAS) is the sieve size that is one size larger than the first sieve that retains more than 10% aggregate. Out of the nine resurfacing projects included in this study, there were only two NMAS categories (9.5 mm and 12.5 mm). The ANOVA revealed there was no significant differences between the two different NMAS.

Table 5.30: NMAS ANOVA connecting letters report

NMAS	**Field Density**	**Field Infiltration**	**Lab Density**	**Lab Permeability**	**ITS**
9.5 mm	A	A	A	A	A
12.5 mm	A	A	A	A	A

CHAPTER 6. Summary, Conclusions, and Recommendations

Premature longitudinal joint cracking typically occurs at the joint where two adjacent pavement lanes meet and failure is typically due to low density, high permeability, and/or low bonding strength. This study observed construction of longitudinal joints in nine asphalt paving projects in South Carolina and compared the performance of the joint and interior portion of the hot lane. Based on the density, permeability, and indirect tensile strength (ITS) results from this research, conclusions related to the performance of longitudinal joints considering individual site, surface mix type, thickness, and nominal maximum aggregate size (NMAS) were made. In addition, the effectiveness of in-place density, lab and in-place infiltration, and ITS were evaluated based on the results.

Conclusions

Based on the results of this study, the following conclusion were made:

- Out of the nine asphalt surfacing construction projects evaluated in this study, eight projects showed significant differences between the interior portion of the pavement and the joint based on density, permeability, and/or ITS based on cores measured in the laboratory. It should be noted that the joint cores were taken directly on the joint.
- When comparing the in-place (mat) density (gauge density) at the middle of the pavement to the edge (at the joint), none of the projects exhibited statistically different readings between the two (i.e., the density near the joint was similar to other areas of the pavement mat). Only one of the projects exhibited statistically different in-situ infiltration rates between the pavement interior and joint edge.
- As the density of asphalt increased, the ITS increased linearly and as the density of asphalt decreased, the lab permeability increased exponentially.
- All the field testing results (density and permeability) had higher variability than lab testing results, indicating the field testing may not be as reliable for checking the quality of the joint.
- The density gauges were more capable of accurately measuring the density of the interior portion the lane when using the cores as a baseline, but the accuracy decreased when measuring density of the joint. This is likely due to the fact that the joint density in the field was measured next to the joint, but the cores were taken on the joint.
- The safety edge joint technique without compaction on the wedge did not significantly improve the performance of the joint compared to the butt joint technique.
- Using the surface type A or B mix and increasing the depth of asphalt pavement, statistically improved density of the joint.
- The survey indicated that more research needs to be conducted in South Carolina to determine the effectiveness of other joint construction techniques.

Recommendations

Based on the findings from this study, recommendations have been developed for implementation and for future study.

Implementation

The review of literature and national survey related to longitudinal joint construction and the results of the field and laboratory study summarized in this report, a set of *Longitudinal Joint Construction Best Practice Guidelines* was developed to be a reference for the SCDOT and paving contractors. These guidelines are included in Appendix C and include the following areas:

- Planning and Design
- Mix Design
- Mix Delivery
- Joint Preparation
- Tack Application
- Paver Operation
- Roller Operation
- Quality Control
- Training

In addition to best practice guidelines, the research team considered potential revisions to SCDOT specifications related to longitudinal joint construction. The SCDOT Standard Specifications (2007), currently address limited general guidance for the construction of longitudinal joints. Based on the results of this study, no specifications are recommended at this time. However, it is recommended that the SCDOT monitor longitudinal joint construction with particular attention to the following:

1. Encourage paving contractors to follow the Longitudinal Joint Construction Best Practice Guidelines in Appendix C. It may be helpful to develop specific training modules for equipment operators and field personnel.
2. Monitor the mat density at the middle of the pavement and near the confined and unconfined edges for comparison. This can be easily done during construction by either contractor or SCDOT personnel. If, over time and with a larger dataset, it is found that there are significant discrepancies between the interior and joint densities, then it may be appropriate to consider a joint density specification.

Future Research

For future longitudinal joint construction research, a lengthy highway test section is needed to reduce the variability of measurements with one contractor for the project. Working with multiple construction companies increases variability on compaction of roller operators, luting practice, amount of material overlapped over the joint, timing of truck deliveries, and many more. Furthermore, different types of joint construction techniques should be researched and constructed on South Carolina roads to determine what are the best and most suitable joint construction techniques considering the traffic, cost, repeatability, and timing. Based on the survey responses, the performance of joint adhesives, notched wedge joint, and sequential mill and fill joint construction techniques should be examined. For the compaction of the joint, the hot pinch method need to be researched compared to the hot overlap method.

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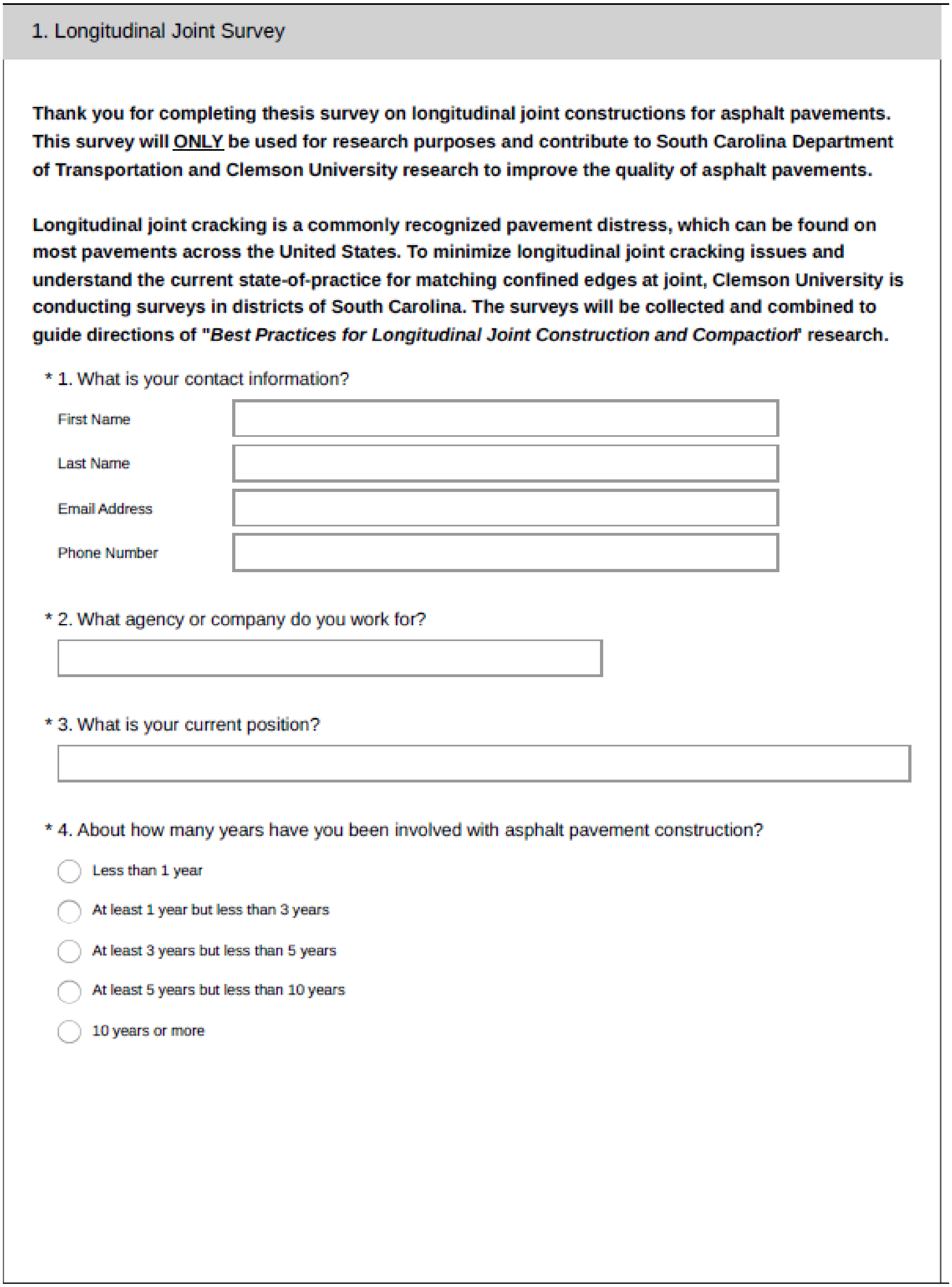
APPENDIX A. SCDOT Longitudinal Joint Survey



1. Longitudinal Joint Survey

Thank you for completing thesis survey on longitudinal joint constructions for asphalt pavements. This survey will ONLY be used for research purposes and contribute to South Carolina Department of Transportation and Clemson University research to improve the quality of asphalt pavements.

Longitudinal joint cracking is a commonly recognized pavement distress, which can be found on most pavements across the United States. To minimize longitudinal joint cracking issues and understand the current state-of-practice for matching confined edges at joint, Clemson University is conducting surveys in districts of South Carolina. The surveys will be collected and combined to guide directions of "*Best Practices for Longitudinal Joint Construction and Compaction*" research.

* 1. What is your contact information?

First Name	
Last Name	
Email Address	
Phone Number	

* 2. What agency or company do you work for?

* 3. What is your current position?

* 4. About how many years have you been involved with asphalt pavement construction?

○ Less than 1 year

○ At least 1 year but less than 3 years

○ At least 3 years but less than 5 years

○ At least 5 years but less than 10 years

○ 10 years or more

2. Longitudinal Joint Survey Continued

* 5. What rolling methods that your crews commonly practice in the field for a**first, second,** and **third** roller pass?

Hot Overlap
When applying hot overlap method, the breakdown roller should be approximately 6 in (152 mm) over the cold lane while the majority part of the roller is on the hot lane.

Hot Pinch
The hot pinch method requires the roller to be placed 6 in (152 mm) away from the joint and requires the roller to be in vibratory mode during compaction.

Cold Roll
The cold roll method requires the roller's majority contact surface to be on the cold lane instead of the hot lane. The roller overlaps from cold lane to hot lane by 6 to 12 in (152 to 304 mm).

First Pass?

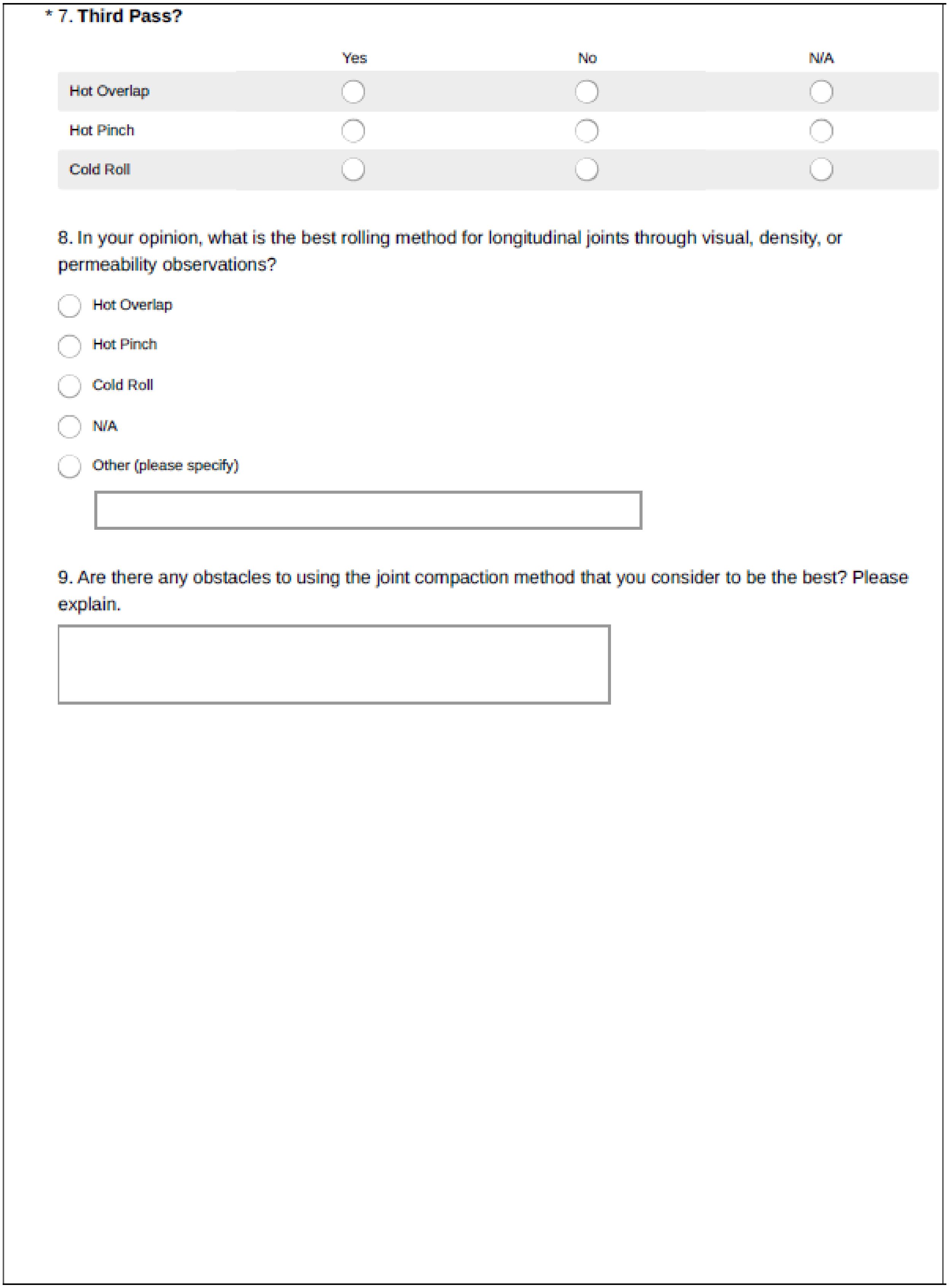
	Yes	No	N/A
Hot Overlap	○	○	○
Hot Pinch	○	○	○
Cold Roll	○	○	○

Other (please specify)

☐

* 6. **Second Pass?**

	Yes	No	N/A
Hot Overlap	○	○	○
Hot Pinch	○	○	○
Cold Roll	○	○	○



* 7. **Third Pass?**

	Yes	No	N/A
Hot Overlap	○	○	○
Hot Pinch	○	○	○
Cold Roll	○	○	○

8. In your opinion, what is the best rolling method for longitudinal joints through visual, density, or permeability observations?

○ Hot Overlap

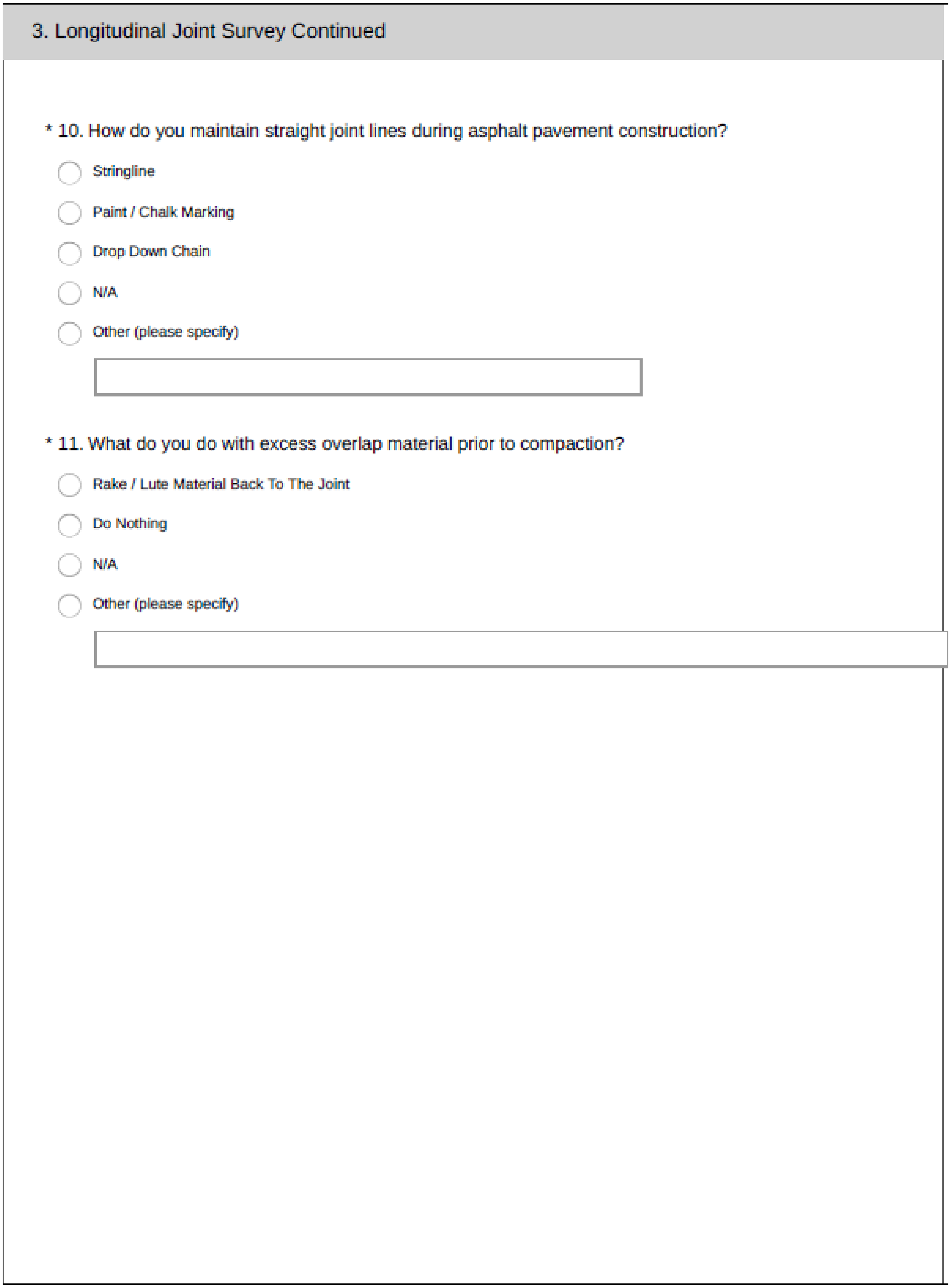
○ Hot Pinch

○ Cold Roll

○ N/A

○ Other (please specify)

9. Are there any obstacles to using the joint compaction method that you consider to be the best? Please explain.



3. Longitudinal Joint Survey Continued

* 10. How do you maintain straight joint lines during asphalt pavement construction?

- ○ Stringline
- ○ Paint / Chalk Marking
- ○ Drop Down Chain
- ○ N/A
- ○ Other (please specify)

* 11. What do you do with excess overlap material prior to compaction?

- ○ Rake / Lute Material Back To The Joint
- ○ Do Nothing
- ○ N/A
- ○ Other (please specify)

4. Longitudinal Joint Survey Continued

* 12. Based on your experience, please rate the **preference** of the following joint construction practices for matching existing asphalt pavements.

Butt Joint - The butt joint is the traditional way of paving asphalt pavement. No specific actions are needed.

Joint Adhesive - A certain chemical product is sprayed on faces of joints to prevent the ingress of water and air. The adhesive can also be sprayed on the edges prior to the placement of adjacent lane.

Wedge Construction - A special plate is attached to a paver to taper and form shoe shaped edges. To compact the wedge, a special side roller must be attached to the roller and different degrees of graduated surfaces, such as 3:1, 6:1, and 12:1 slope, are formed.

Sequential Mill and Fill - Unlike other methods, only one pre-existing asphalt lane is milled and the milled surface is thoroughly cleaned before a paver and a roller are used to fill the milled asphalt pavement. Then, the second pre-existing lane is milled followed by cleaning and filling procedures.

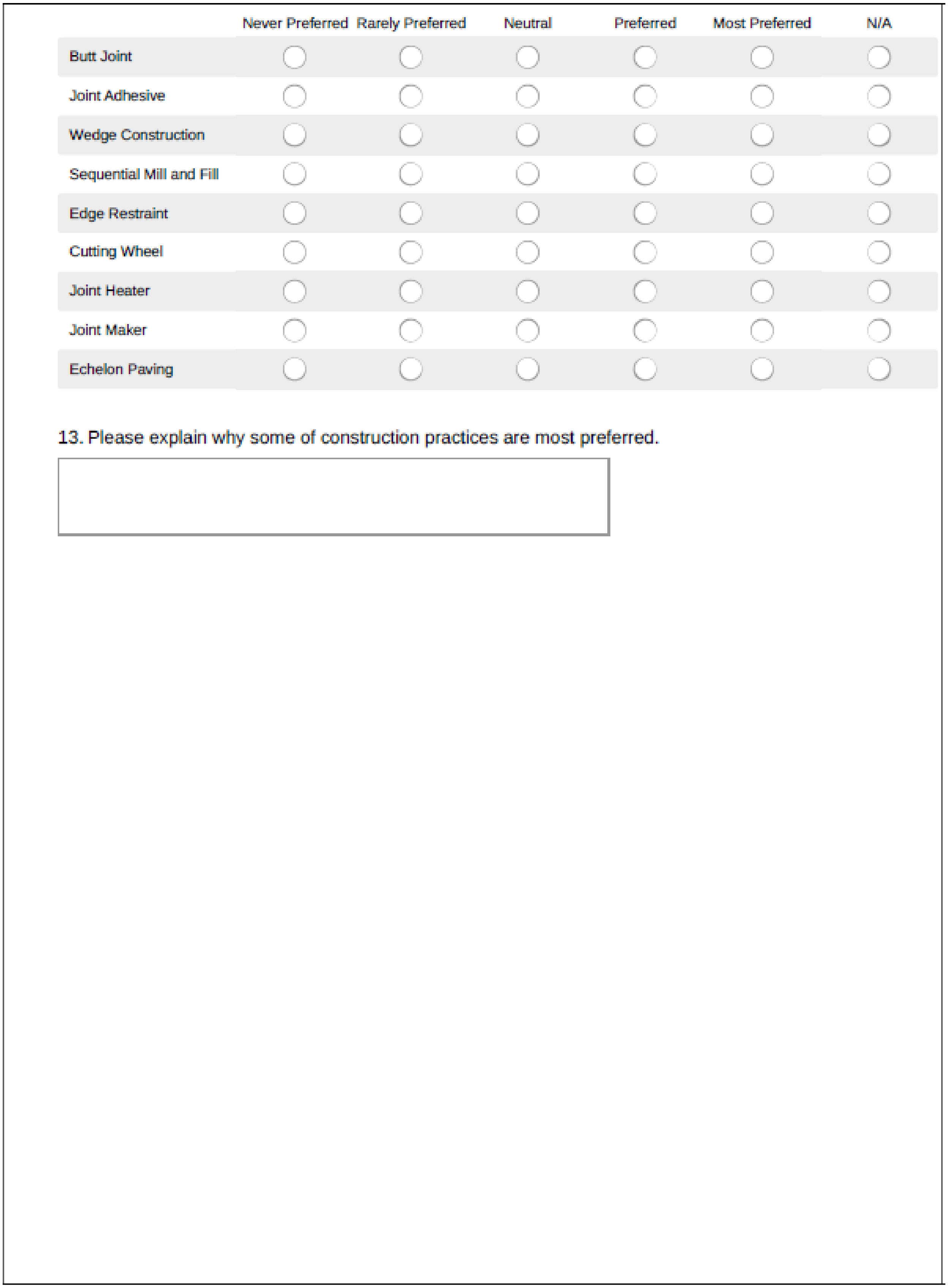
Edge Restraint - During the compaction of asphalt pavement, a hydraulical wheel is attached to a roller to provide confined, vertical edges and prevent horizontal movement of asphalt.

Cutting Wheel - A cutting wheel is attached to a roller or other motorized equipment to cut and remove the low-density material at the edge of asphalt pavements.

Joint Heater - The joint is heated prior to paving by using a propane fired heater, which can be pulled by a small motorized tractor.

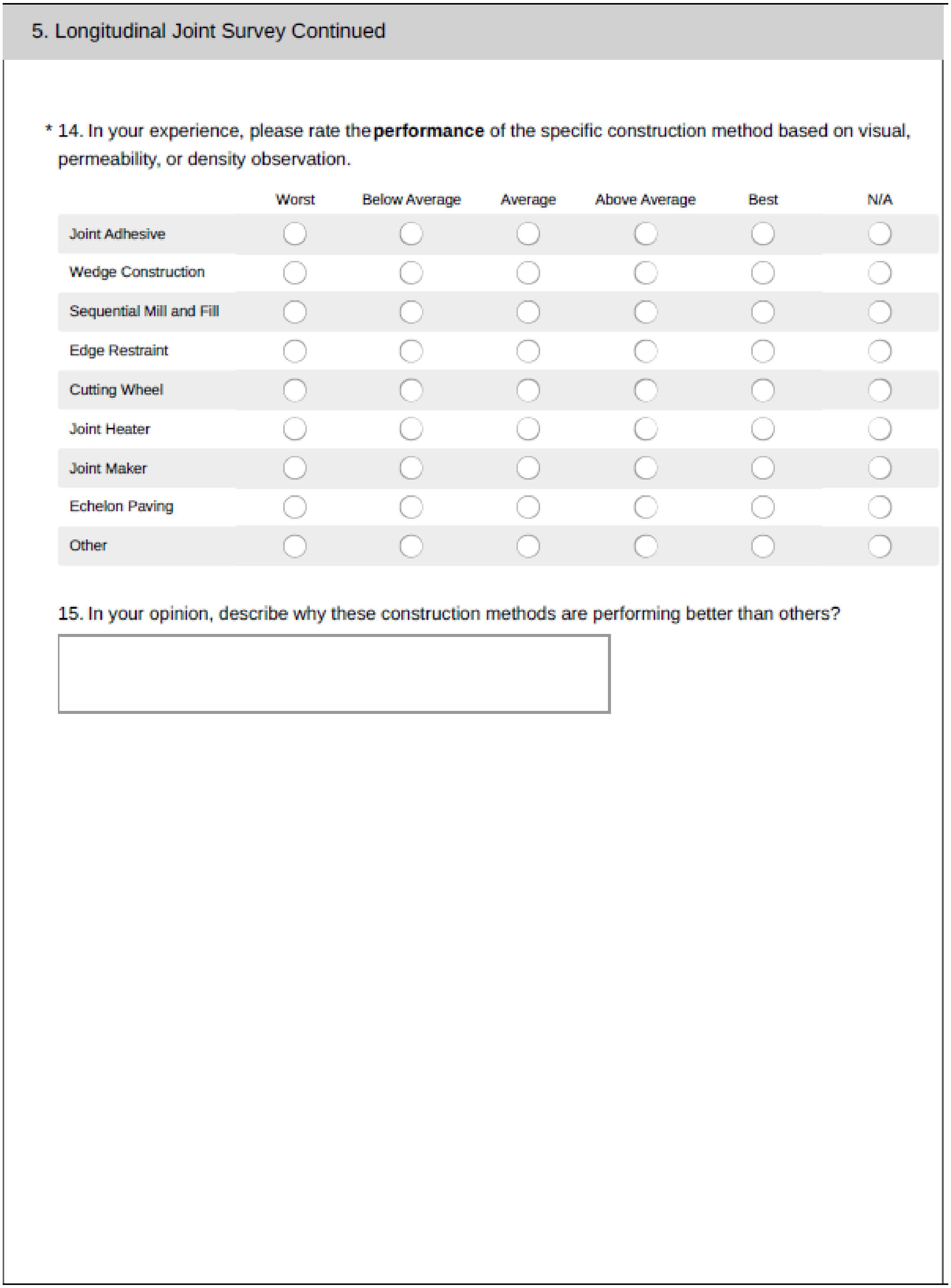
Joint Maker - A kicking plate is attached to the side of paver screed at the corner during construction. It pushes excessive asphalt mixtures back to the longitudinal joint.

Echelon Paving - Multiple pavers are used at the same time to pave multiple asphalt pavements. The second paver remains close behind the first paver on the adjacent lane.



	Never Preferred	Rarely Preferred	Neutral	Preferred	Most Preferred	N/A
Butt Joint	○	○	○	○	○	○
Joint Adhesive	○	○	○	○	○	○
Wedge Construction	○	○	○	○	○	○
Sequential Mill and Fill	○	○	○	○	○	○
Edge Restraint	○	○	○	○	○	○
Cutting Wheel	○	○	○	○	○	○
Joint Heater	○	○	○	○	○	○
Joint Maker	○	○	○	○	○	○
Echelon Paving	○	○	○	○	○	○

13. Please explain why some of construction practices are most preferred.

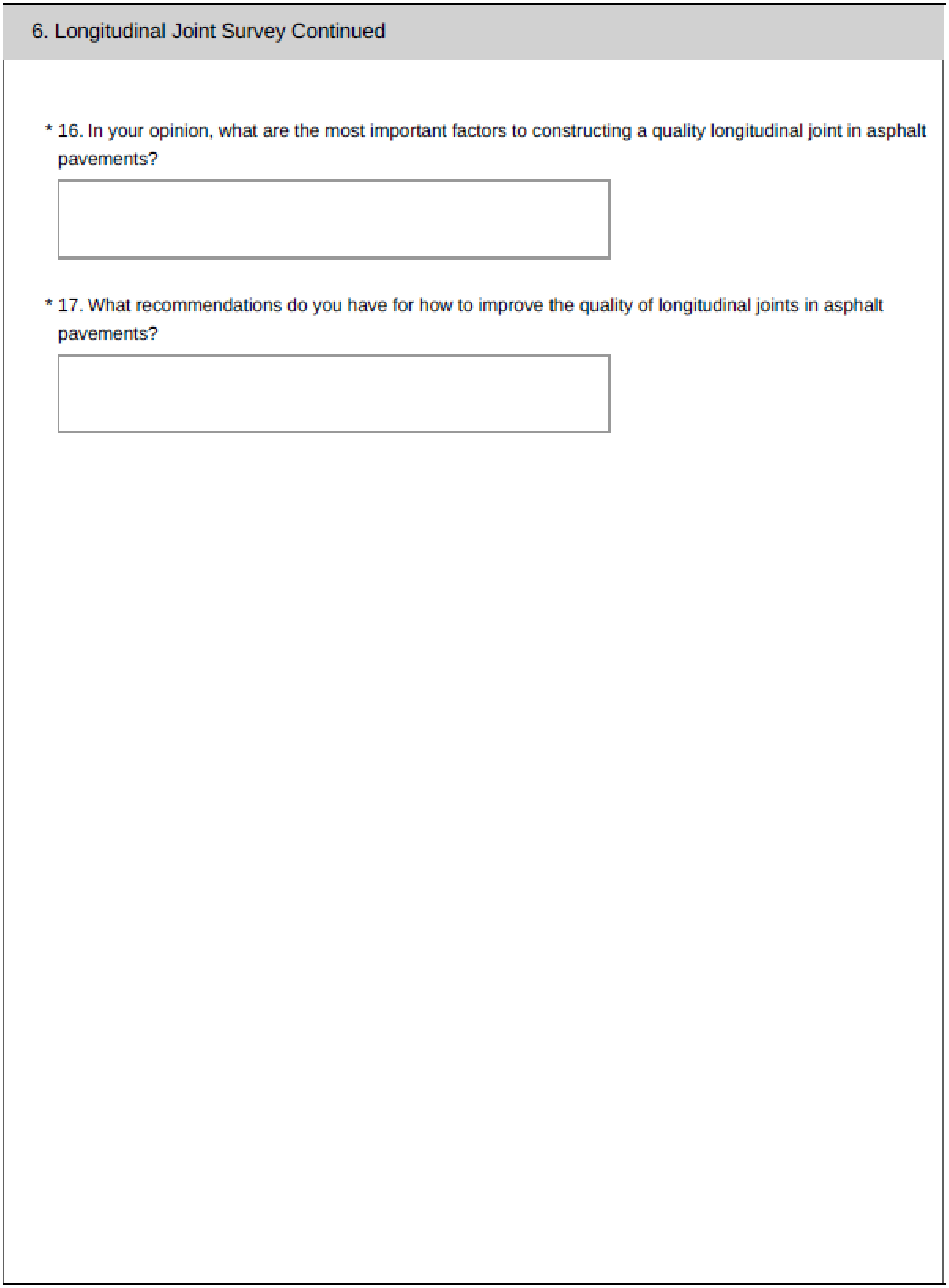


5. Longitudinal Joint Survey Continued

* 14. In your experience, please rate the **performance** of the specific construction method based on visual, permeability, or density observation.

	Worst	Below Average	Average	Above Average	Best	N/A
Joint Adhesive	○	○	○	○	○	○
Wedge Construction	○	○	○	○	○	○
Sequential Mill and Fill	○	○	○	○	○	○
Edge Restraint	○	○	○	○	○	○
Cutting Wheel	○	○	○	○	○	○
Joint Heater	○	○	○	○	○	○
Joint Maker	○	○	○	○	○	○
Echelon Paving	○	○	○	○	○	○
Other	○	○	○	○	○	○

15. In your opinion, describe why these construction methods are performing better than others?

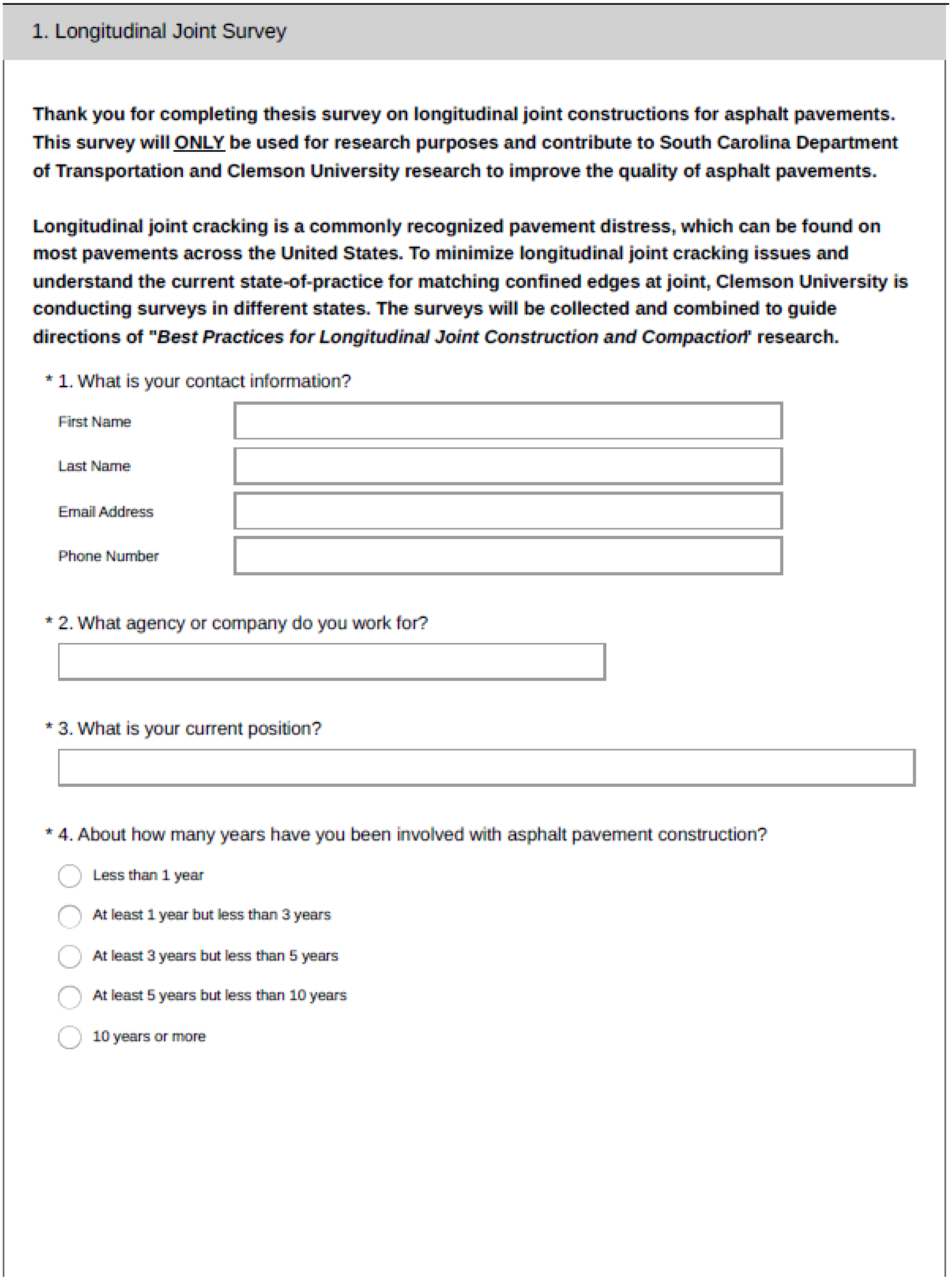


6. Longitudinal Joint Survey Continued

* 16. In your opinion, what are the most important factors to constructing a quality longitudinal joint in asphalt pavements?

* 17. What recommendations do you have for how to improve the quality of longitudinal joints in asphalt pavements?

APPENDIX B. US Longitudinal Joint Survey



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* 1. What is your contact information?

First Name

Last Name

Email Address

Phone Number

* 2. What agency or company do you work for?

* 3. What is your current position?

* 4. About how many years have you been involved with asphalt pavement construction?

○ Less than 1 year

○ At least 1 year but less than 3 years

○ At least 3 years but less than 5 years

○ At least 5 years but less than 10 years

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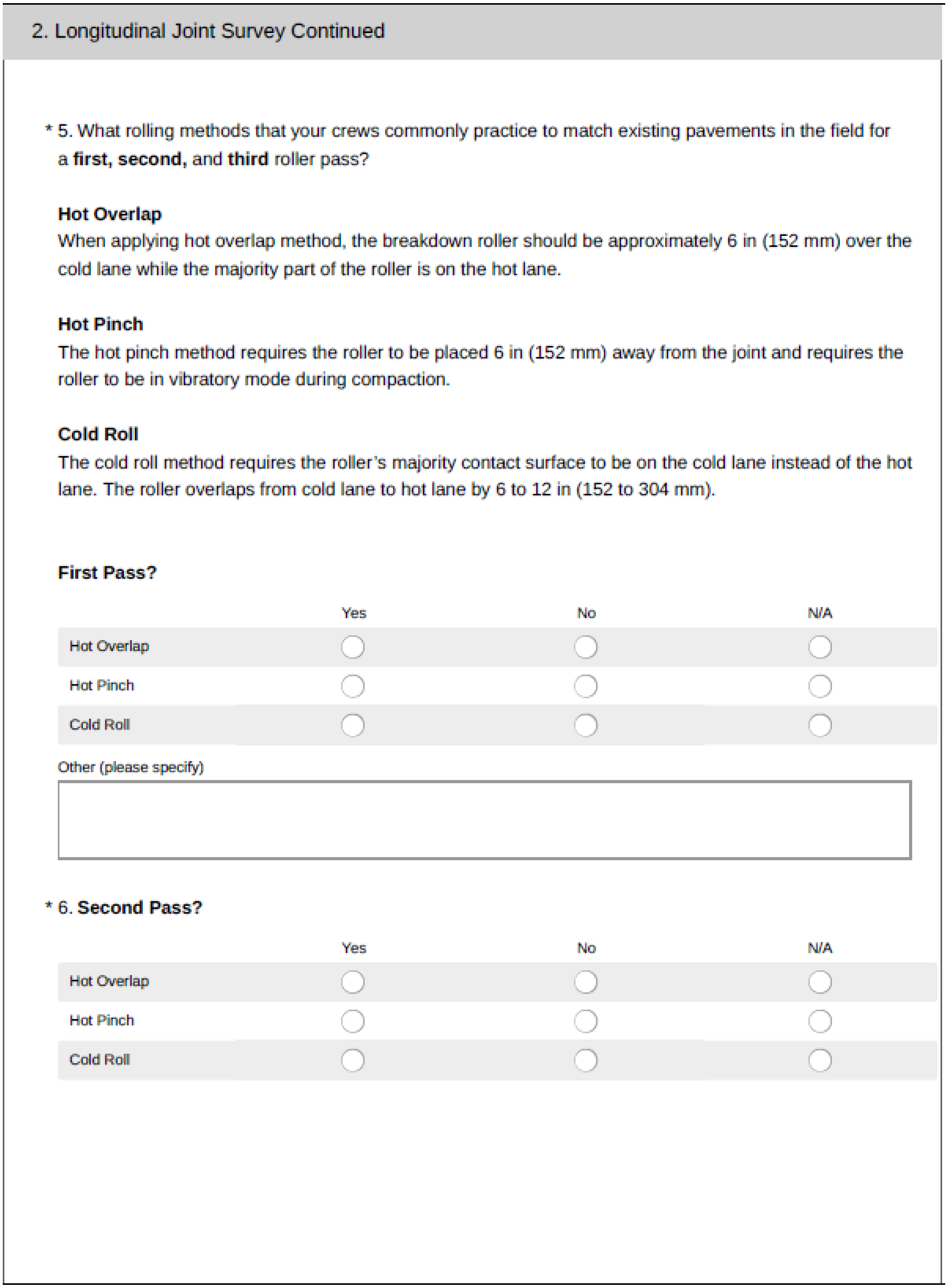

2. Longitudinal Joint Survey Continued

* 5. What rolling methods that your crews commonly practice to match existing pavements in the field for a **first, second,** and **third** roller pass?

Hot Overlap

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Hot Pinch

The hot pinch method requires the roller to be placed 6 in (152 mm) away from the joint and requires the roller to be in vibratory mode during compaction.

Cold Roll

The cold roll method requires the roller's majority contact surface to be on the cold lane instead of the hot lane. The roller overlaps from cold lane to hot lane by 6 to 12 in (152 to 304 mm).

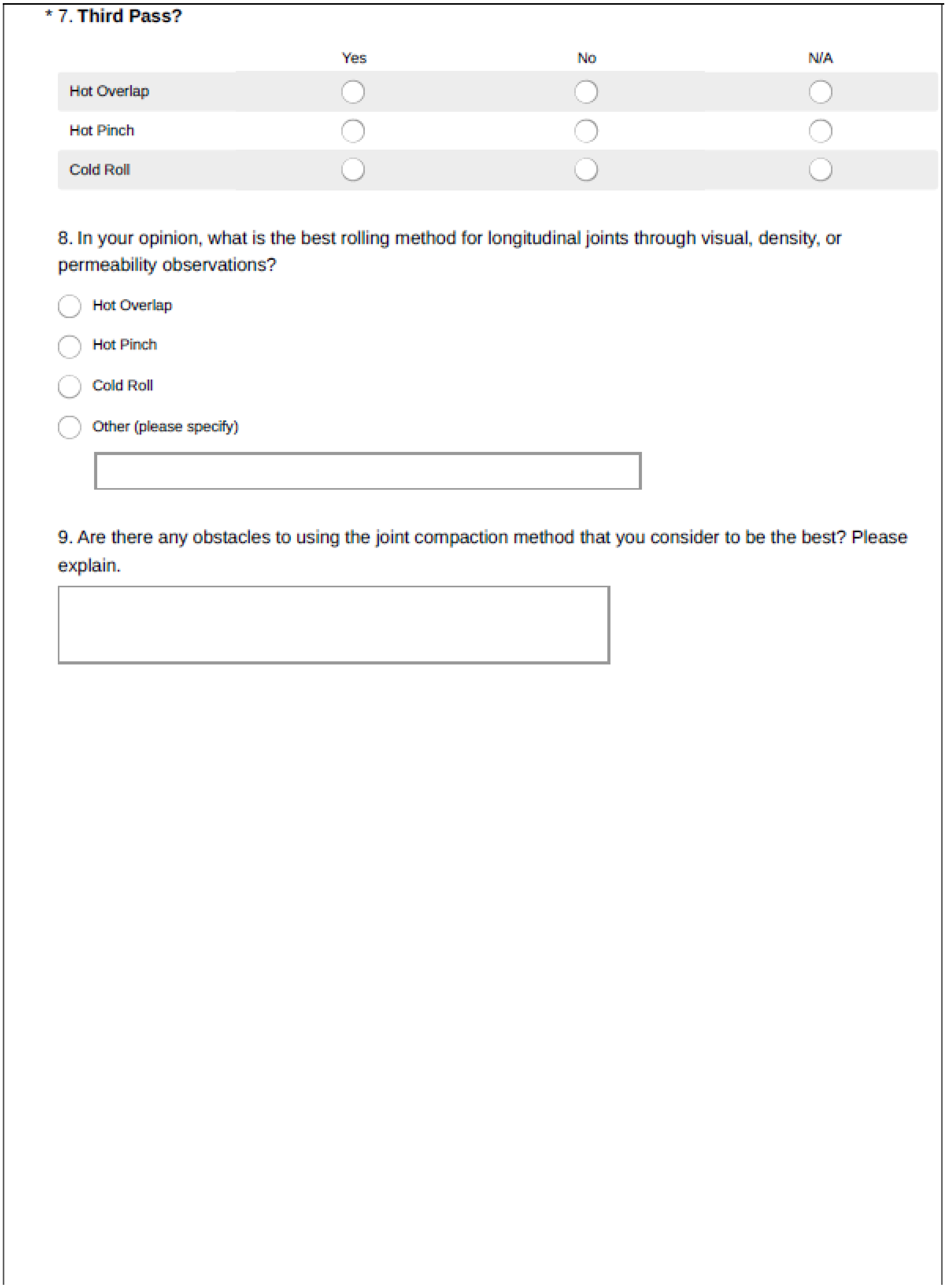
First Pass?

	Yes	No	N/A
Hot Overlap	○	○	○
Hot Pinch	○	○	○
Cold Roll	○	○	○

Other (please specify)

* 6. **Second Pass?**

	Yes	No	N/A
Hot Overlap	○	○	○
Hot Pinch	○	○	○
Cold Roll	○	○	○



* 7. **Third Pass?**

	Yes	No	N/A
Hot Overlap	○	○	○
Hot Pinch	○	○	○
Cold Roll	○	○	○

8. In your opinion, what is the best rolling method for longitudinal joints through visual, density, or permeability observations?

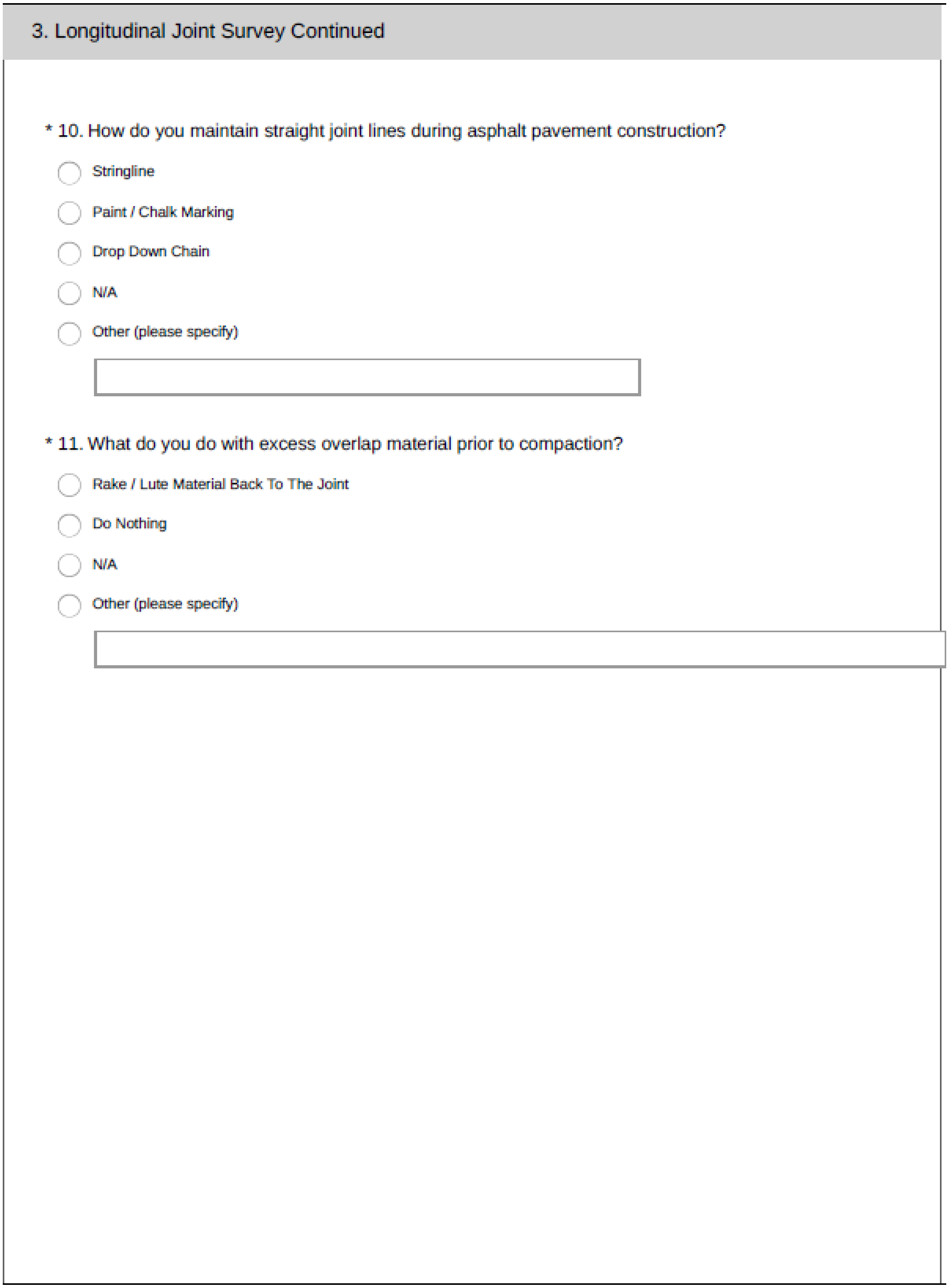
○ Hot Overlap

○ Hot Pinch

○ Cold Roll

○ Other (please specify)

9. Are there any obstacles to using the joint compaction method that you consider to be the best? Please explain.



3. Longitudinal Joint Survey Continued

* 10. How do you maintain straight joint lines during asphalt pavement construction?

○ Stringline
○ Paint / Chalk Marking
○ Drop Down Chain
○ N/A
○ Other (please specify)

* 11. What do you do with excess overlap material prior to compaction?

○ Rake / Lute Material Back To The Joint
○ Do Nothing
○ N/A
○ Other (please specify)

4. Longitudinal Joint Survey Continued

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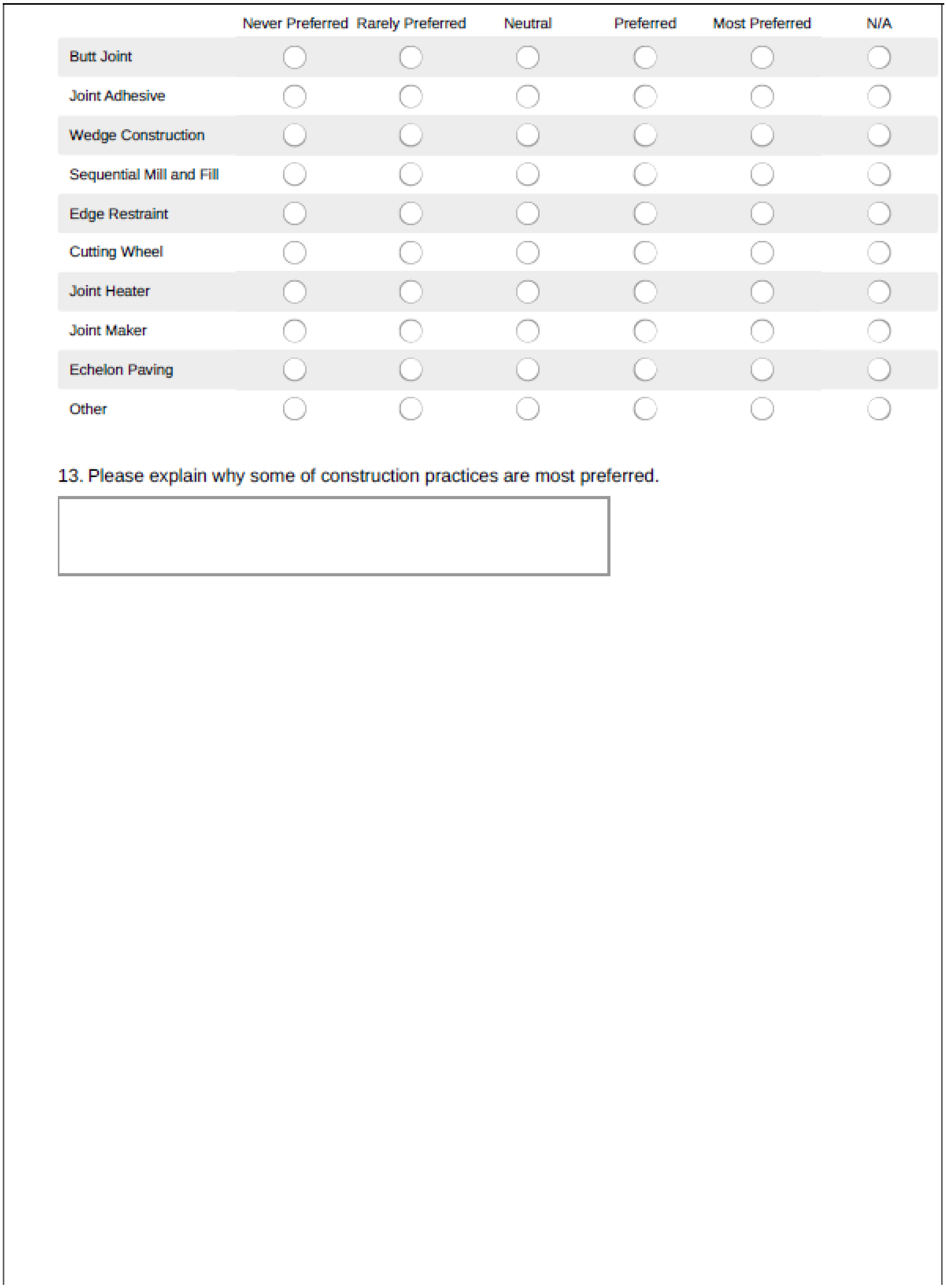


	Never Preferred	Rarely Preferred	Neutral	Preferred	Most Preferred	N/A
Butt Joint	○	○	○	○	○	○
Joint Adhesive	○	○	○	○	○	○
Wedge Construction	○	○	○	○	○	○
Sequential Mill and Fill	○	○	○	○	○	○
Edge Restraint	○	○	○	○	○	○
Cutting Wheel	○	○	○	○	○	○
Joint Heater	○	○	○	○	○	○
Joint Maker	○	○	○	○	○	○
Echelon Paving	○	○	○	○	○	○
Other	○	○	○	○	○	○

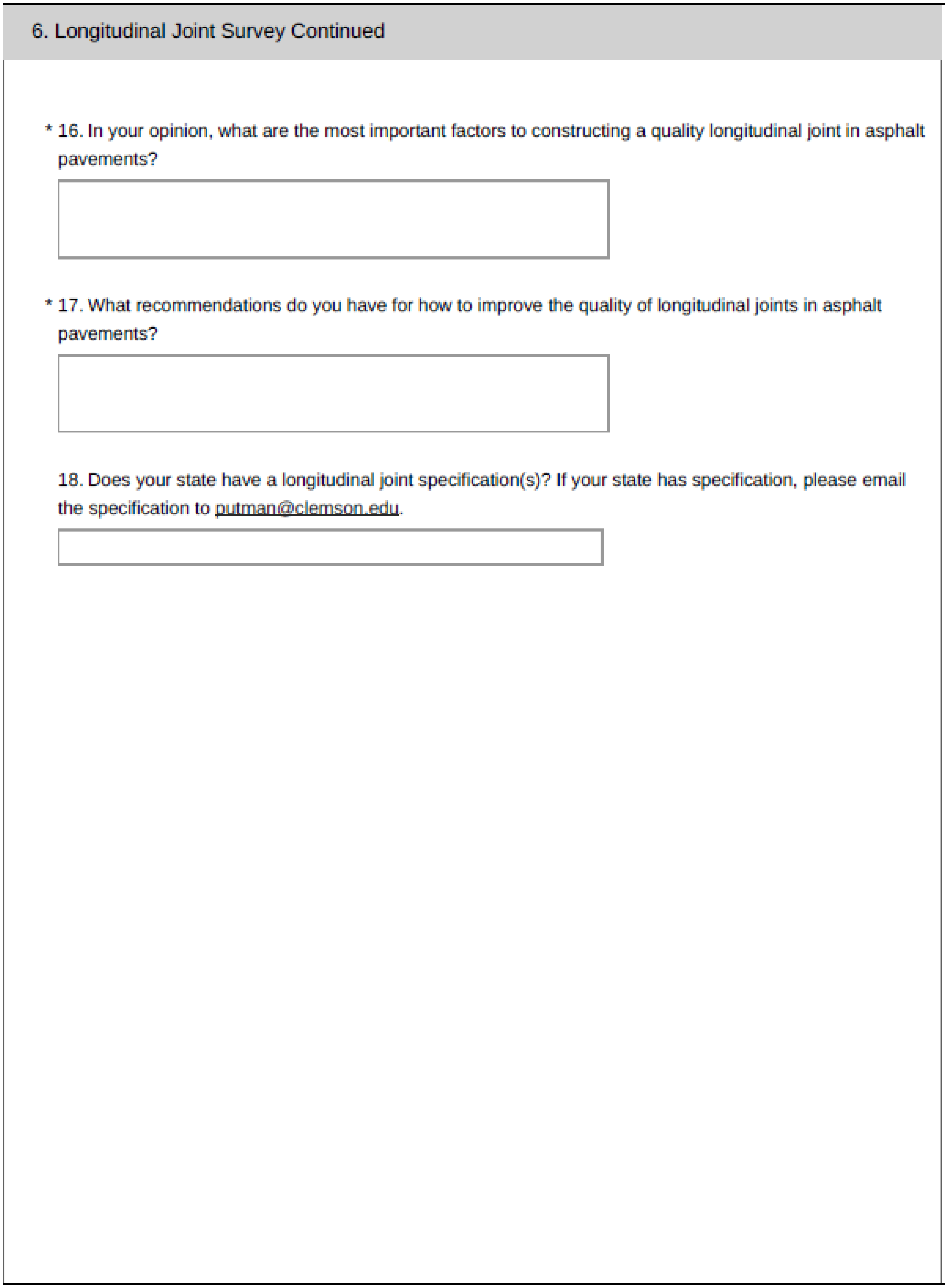
13. Please explain why some of construction practices are most preferred.

5. Longitudinal Joint Survey Continued

* 14. In your experience, please rate the **performance** of the specific construction method based on visual, permeability, or density observation.

	Worst	Below Average	Average	Above Average	Best	N/A
Butt Joint	○	○	○	○	○	○
Joint Adhesive	○	○	○	○	○	○
Wedge Construction	○	○	○	○	○	○
Sequential Mill and Fill	○	○	○	○	○	○
Edge Restraint	○	○	○	○	○	○
Cutting Wheel	○	○	○	○	○	○
Joint Heater	○	○	○	○	○	○
Joint Maker	○	○	○	○	○	○
Echelon Paving	○	○	○	○	○	○
Other	○	○	○	○	○	○

15. In your opinion, describe why these construction methods are performing better than others?



6. Longitudinal Joint Survey Continued

* 16. In your opinion, what are the most important factors to constructing a quality longitudinal joint in asphalt pavements?

* 17. What recommendations do you have for how to improve the quality of longitudinal joints in asphalt pavements?

18. Does your state have a longitudinal joint specification(s)? If your state has specification, please email the specification to putman@clemson.edu.

APPENDIX C. Best Practice Guidelines

Longitudinal Joint Construction Best Practice Guidelines[1]

Planning and Design

- When placing multiple lifts, stagger longitudinal joints by offsetting horizontally between layers by at least 6 inches to avoid multiple joints placed at the same location.
- Do not locate longitudinal joints of surface lifts in the location of wheel paths, recessed pavement markings, and striping.
- The asphalt pavement layer should be at least 4 times the nominal maximum aggregate size (NMAS) for coarse aggregate mixes and 3 times the NMAS of fine aggregate mixes.

Mix Design

- Use finer gradations and the smallest NMAS mix appropriate for the application and add more binder to the mix to lower the air voids, if possible. This will make the surface less permeable.
- Consider using warm mix asphalt (WMA) as a compaction aid, especially when ambient temperatures are lower (e.g., beginning or end of season).

Mix Delivery

- Limit the duration between loading a truck at the plant to unloading at the job site. This will reduce the potential for the mix to cool and could improve the compaction of the mix at the joint.
- Consider using material transfer vehicles (MTV) to minimize temperature loss and segregation.

Joint Preparation

- Maintain straight joint lines during asphalt pavement construction.
    - Set up string-lines to assist equipment operators/drivers in maintaining straight lines during the paving operation.
    - Attach a reference chain or other device to equipment so the reference lines can be easily followed by the paver operator.
    - Ensure lighting is sufficient during nighttime paving projects to ensure that paver and roller operators can easily see the joint during operation.
- Clean the matching edge and joint area with a broom, motorized road sweeper, or air jet to remove loose material before the tack coat is applied and the paver passes.

Tack Application

- Consider using joint adhesive, stronger tack coat, or PG binder to improve the performance of joint. If using an emulsion, consider double tacking the face of the joint.

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[1] (Buncher and Rosenberger 2012; McDaniel et al. 2012; SCAPA/SDOT n.d.)

- Apply additional tack at the joint face using a wand or angled spray bar to assist with adhesion at the joint. Extend the tack application a few inches over the joint to ensure the edge is fully tacked.
- Tack a few inches past the full paving width to ensure the unconfined edge will have minimum movement during the compaction process.
- Allow time for the tack to properly cure (break) before placing the layer of asphalt to minimize movement during the compaction process. This is especially critical near unconfined edges.

Paver Operation

- Ensure lighting is sufficient during nighttime paving projects to ensure the paver operator can easily see the joint during operation.
- Extend augers and tunnels to 12 to 18 inches from the end of the gate to ensure asphalt mix is carried to the joint to minimize segregation or temperature loss.
- Maintain a uniform head of material at the auger to ensure enough material is present at the joint throughout the paving operation. An inconsistent head of material can lead to edge segregation at the joint.
- Ensure the height of the loose (hot) lift is higher than the adjacent (cold) lift so the final compacted height will be slightly higher than the previously constructed mat. Place enough material on the hot side of the joint, so after rolling, the surface of the hot lane is slightly higher (approximately 0.1 inch) than the cold lane. This will prevent bridging of the roller during compaction, maximizing the compaction of the hot-side of the joint.
- Ensure the end gate is extended far enough to allow for approximately 1 - 1½ inch overlap to maintain sufficient material at the joint and prevent starving the joint.
- If the overlap exceeds 1½ inch, carefully remove excess material with a flat-end shovel and do not broadcast the excess across the mat. If necessary, properly bump the joint with a lute, but prevent pushing material out of and away from the joint.
- Pavers should include vibrating features near the edge of the paver to provide higher densities at the confined and unconfined edge.

Roller Operation

Compacting the Confined Edge

Breakdown Roller

- Compact the first pass with a vibratory roller with the drum overlapping the confined edge approximately 6 inches (hot overlap) and the second pass with the edge of the roller 6 inches from the confined edge (hot pinch).

  Alternatively, the first pass can be made with a vibratory roller 6 inches from the edge of the confined edge (hot pinch) followed by overhanging the edge by 6 inches (hot overlay) on the second pass. If stress cracks occur along the pinch lines at the edge of the roller drum during this process, then use the hot overlap for the first pass.
- The height of the hot lane should be approximately 0.1 inch higher than the cold lane at the joint to ensure no bridging effect is occurring from the roller.

Intermediate Roller

- Use a pneumatic tire roller to knead the material into the joint. Run the edge of the front outside tire just on the inside the joint. This will cause the back outside tire to straddle the joint.

Finish Roller

- Use a static steel wheel finish roller to remove tire marks left by the intermediate roller.

Compacting the Unconfined Edge

Breakdown Roller

- Compact the first pass with a vibratory roller overhanging the unconfined edge by approximately 6 inches.

  Alternatively, the first pass can be made with a vibratory roller 6 inches from the edge of the unconfined edge followed by overhanging the edge by 6 inches on the second pass. If stress cracks occur during this process, then use overhang the roller over the unconfined edge on the first pass.
- For a sloped edge or safety edge, compact the face of the wedge using a steel side roller or a tag-along roller. If a wedge is used, make sure there is a notch on the top of the wedge (i.e., notched wedge joint).

Intermediate Roller

- Avoid operating a pneumatic tire roller too close to the unconfined edge as it can cause excessive lateral movement.

Finish Roller

- Use a static steel wheel finish roller to remove tire marks left by the intermediate roller.

General Compaction

- Several roller patterns may work successfully depending on a number of variables, including lift thickness, underlying layer, mix type, aggregate properties, mix temperature, ambient temperature, and compaction equipment, among others. It is important to determine the best roller pattern for a particular project using a test strip.
- Make sure all rollers (breakdown, intermediate, finish) are compacting at the joint.
- Make sure there is enough space for the roller operator to compact over the joint if possible or increase the roller operator’s visibility at the edge of the wheel using a live view camera or mirror.
- Ensure lighting is sufficient during nighttime paving projects to ensure that roller operators can easily see the joint during operation.

Quality Control

- Construct a longitudinal joint as part of the test strip and determine the roller pattern for density at the joint.
- Use a nuclear or non-nuclear density gauge to monitor the quality of the joint. Gauge readings should be taken just off the joint because the gauge will not seat properly is placed directly over the joint.
- If possible, cut cores from the joint to measure density.

- If segregation is observed at the joint, make corrections to prevent it moving forward because segregation leads to lower density and higher permeability. Edge segregation can be minimized by maintaining a consistent head of material above the paver auger and by not operating the augers to fast.

Training

- Develop a communication and training program to re-educate paver operators, roller operators, and field quality control managers.

Other

- Consider sequential mill and fill operations when possible. This can potentially increase the joint density by providing a confined edge for both sides of a longitudinal joint. If mill and fill is feasible:
    - Mill one lane at a time, then pave that same lane before milling the next lane. This will eliminate unconfined edges at the longitudinal joint, which should maximize the density at the joint.
    - Thoroughly clean the milled surface, especially at the base of the vertical milled edge and the confined corner(s).
    - Tack the milled surface as previously recommended.