Comparison of the Use of a Notched Wedge Joint vs. Traditional Butt Joints in Connecticut Phase 1 Report

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16. Abstract
Performance of Hot Mix Asphalt (HMA) longitudinal joints have been an item of increasing scrutiny in Connecticut. The traditional butt joint has typically been the method used in Connecticut. These joints have been reportedly opening up creating a longitudinal crack at the joint thus contributing significantly to the premature failure of the wearing surface. It has been widely speculated that alternative longitudinal joint construction methods could be employed to reduce the rate at which joints fail. Here, the Notched Wedge Joint is investigated along with the traditionally used butt joint for comparison purposes. Two resurfacing projects were constructed in Connecticut during the 2006 paving season that utilized the notched wedge joint construction method. These projects were investigated as to their nuclear density and volumetric density from cut cores along the longitudinal joints. Also investigated during the 2006 construction season were several resurfacing projects which utilized the traditional butt joint.

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Executive Summary

Traditional butt joints have been the customary method used in constructing longitudinal joints in hot mix asphalt (HMA) pavements in Connecticut in past years. The longitudinal joints on many Connecticut roadways have cracked or pulled apart thus expediting premature failure of the roadway and causing safety hazards to bicyclists, motorcyclists and pedestrians. The anticipated cause for this joint failure is a lack of material at the joint during the compaction phase of construction. Over the course of the expansion and contraction of the pavements due to thermal cycling, the area of the longitudinal joint generally does not contain enough material to fully recover from the contraction. This results in a void area at the interface of the two paver passes. As time progresses and further thermal cycling takes place, this void increases in size to the point where it may be as wide or wider than the thickness of the wearing surface. This, in addition to safety hazards, allows water and incompressible materials to penetrate between pavements layers.

In an effort to evaluate and compare an alternative method of HMA longitudinal joint construction, with traditional longitudinal butt joint construction, the Connecticut Advanced Pavement Laboratory (CAP Lab) in cooperation with Connecticut Department of Transportation (ConnDOT) and Federal Highway Administration (FHWA) investigated the use of a notched wedge joint on two pilot projects in Connecticut and compared the collected data with data collected from several butt joint construction projects throughout Connecticut during the same construction season. On all of the evaluated projects, several nuclear density profiles were measured across the longitudinal joint at various random locations. Measurements were taken 1 foot on the cold side of the joint, 6 inches on the cold side of the joint, on the joint itself, 6 inches on the hot side of the joint and 1 foot on the hot side of the joint. Each measurement consisted of the average of 2 nuclear density readings at each point. This created a density profile across the joint which was investigated. At each location, five cores were cut from 1 foot on the cold side, 6 inches on the cold side, on the joint, 6 inches on the hot side and 1 foot on the hot side. Each core was extracted five longitudinal feet from the previous core. In all, there were 50 nuclear density measurements taken from each random location and five extracted cores which were taken into the laboratory and measured volumetrically.

Although data is thus far limited, preliminary results show an increase in density at the joint on the hot side as compared with the cold side for both construction methods. This is most likely due to the first paver pass providing lateral confinement for the second pass to be compacted against regardless the method used. There is no free space for the material to move laterally and so it must compact against the previously placed pavement thus increasing the level of density relative to the cold side of the joint.

It is desired that additional projects be established for investigation into the notched wedge joint in Connecticut. Additional data from notched wedge joint projects is needed to establish conclusive results with respect to the comparison with butt joint construction.

Background:

Longitudinal joints in hot mix asphalt (HMA) paving are formed where the edge of one paver pass interfaces with the edge of the next paver pass. Longitudinal joints tend to split apart at this interface so as to cause a crack that has the potential to be the full depth of the wearing surface. As time progresses, the width of the crack at the longitudinal joint interface increases as the processes and mechanisms that initially caused the joint to split continue to occur. This is especially dangerous with respect to pedestrians, bicyclists and motorcyclists as the opening of the joint has the potential to be as wide as a bicycle tire or motorcycle tire. The infiltration of water into the crack, as well as raveling of the material at the joint, may also increase the rate at which the longitudinal joint will open up, thus significantly contributing to the premature failure of the roadway. In the event the longitudinal joints have opened up significantly, maintenance of the pavement must be performed, which entails crack sealing and filling, patching and in some cases milling off the existing wearing surface and replacing it.

The primary mechanism that drives longitudinal joint failures is environmental stresses. The asphalt binder in the HMA pavement expands and contracts every day through the normal temperature cycling experienced by the pavement. As the asphalt binder expands on the upward trend of the thermal cycle, it tends to push the aggregates in the pavement upward by a very small amount as there is less confinement in that direction and the pavement expands in the direction of least resistance. As the asphalt binder cools on the downward trend of the thermal cycle, it contracts, trying to return to the original thickness of the pavement. Unfortunately, the internal friction of the aggregates prevents the pavement from returning exactly to the original compacted thickness. Therefore, the

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pavement gets faintly thicker after each temperature cycle. The compounding effect of this slight increase in thickness after each temperature cycle eventually causes enough of a change in thickness to cause a decrease the lateral width of the pavement. As the pavement structure has a finite volume, one of its dimensions must adjust in order to maintain this finite volume and compensate for the increased thickness. As most paver passes are between 12-14 feet wide, width has the least frictional resistance to overcome for a dimensional adjustment. This adjustment causes the longitudinal joints to open up. A lack of material at the interface of the two passes is responsible for the lack of density and thus weakness at the joint as is described in Chapter 16 of the *NETTCP Paving Inspector Manual.* (*NETTCP, 2006*)

A significant effect of the opening of the longitudinal joints in cold-climate regions such as Connecticut is water infiltration into the crack. Once water infiltrates the crack, the pavement layer interfaces are also subject to this infiltrated water. The primary concern with water infiltration is the freezing and expansion of it once it has penetrated the surface of the pavement. As water expands when it freezes, this causes stresses within the longitudinal joint as well as between the pavements layers which lead ultimately to the failure of areas of the pavement where this has occurred as well as contributing to the premature failure of the roadway as a whole.

Research has been conducted in the past that has pointed out significantly lower density of the pavement across the longitudinal joint as compared with the surrounding pavement. A report in Transportation Research Record 1712, titled *Evaluation of Notched-Wedge Longitudinal Joint Construction* (Buchanan, 2002) indicates such

research. The author calls attention to research conducted at the National Center for Asphalt Technology (NCAT) that concluded longitudinal joints in several cases exhibit densities between 1-2 percent of maximum theoretical density less than the surrounding pavement. With this notion and the long term performance of the longitudinal joint in mind, Apkinar et al. concluded that "Longitudinal joints in asphalt pavements with high densities generally show better performance than those with relatively low densities." (Akpinar, 2004)

To slow the rate at which longitudinal joints fail, proper construction techniques that ensure a high density and the proper amount of material along the longitudinal joint and compaction effort are essential. Increased longitudinal joint densities ensure there is enough material present to allow for the vertical thickness increases without requiring the material at the longitudinal joint to split in order to conform to the dimensional changes of the pavement.

Objective:

The purpose of this study was to evaluate the constructability and durability of an alternate Hot Mix Asphalt (HMA) longitudinal joint method, the notched wedge joint (Figure 2), and compare the measurable properties of this construction method with those of the traditional joint construction method used in Connecticut. The notched wedge joint is a longitudinal joint method being investigated to improve upon the State's standard longitudinal joint method known as a butt joint. Constructability includes the time, effort, equipment to form and compact the material at the joint and the resulting in-place density upon completion. The two different longitudinal construction joint methods are to be compared on the basis of these items. Durability includes the long term

performance of the joints which will be evaluated according to their ability to delay the formation of cracks at the joint as well as minimizing the width of the crack that forms.

Longitudinal Joint Construction

Connecticut State of the Practice

The traditional method for constructing a longitudinal joint in Connecticut is a butt joint which "butts" the hot material from the second pass to the cold material from the first pass creating a nearly vertical interface. Achieving adequate density on the cold edge of the unconfined longitudinal joint is difficult because at the time of its compaction, there is no lateral confinement to compact it against. Therefore, the unconfined edge is able to move laterally when the downward compaction force is applied, thereby reducing its density. The second paver pass is then placed and material is compacted using one of two techniques. The first rolling technique keeps the roller approximately 6 inches off the joint on its first pass and then overhangs the first paver pass (the cold side) by 6-12 inches on the second pass. This technique is often called pinching the joint as it provides confinement on both sides of the joint before the material is actually compacted at the joint. The second, less common, way of compacting the joint is for the roller on its first pass to be primarily on the cold side with a 6-12 inch overlap onto the hot side. The overhang onto the hot side is what is used to compact the joint. Theoretically, the ideal compaction method would provide some sort of lateral confinement on both edges of the paver pass such that the density at the longitudinal joint would approach the same density found at the center of the mat where it is expected and generally observed to be higher. This type of compaction is not practical for typical construction situations. Thus, it

would be beneficial to develop a joint construction method to minimize all of these problems.

Literature Review:

(*Fleckenstien et al, 2002*) **Compaction at the Longitudinal Construction Joints in Asphalt Pavements**

Kentucky Transportation Center

Improper longitudinal joint construction in Kentucky was recognized as an origin leading to premature failure of HMA pavements. It is believed that this is caused by a lack of proper compaction at the longitudinal joints and that this lack of compaction, in turn, leads to increased levels of permeability. This permeability is said to accelerate the deterioration of the pavement. Some problem areas were recognized in Kentucky as exhibiting these types of premature failures. Review of these locations indicated that the construction joints were allowing water to enter the pavement rapidly. The problems encountered as a result of this include de-bonding of surface layers, mixture stripping, oxidizing and hardening of the asphalt binder, all of which contribute to the premature failure of the roadway. It was stated that several pavements in Kentucky have been resurfaced or were in the process of being resurfaced as a result of premature failure caused by the lack of compaction and poor construction of the longitudinal joints.

The purpose of this investigation was to evaluate different methods of longitudinal joint construction on HMA pavements. The intention was to specifically investigate the intensity of water infiltration and material segregation at the constructed joint and

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conclude their effect on the performance of the longitudinal joint. This research was to take place on both existing and new construction/surfacing projects. Another intention of this research was to determine the best methods and techniques for constructing a longitudinal joint. This determination would be made by reviewing methods, construction practices, experiences and specifications of not only Kentucky, but outside agencies, states and countries who take part in joint construction and whose experiences would prove beneficial to establishing and determining the best practice for longitudinal joint construction and the elimination of longitudinal joint segregation. The final objectives of this project were to specify the proper construction methods to ensure proper compaction at the construction joint and to review different equipment and attachments for improving the level of compaction at the unsupported edgeof the pavement mat.

This research included the examination of longitudinal joint construction and techniques on twelve different construction projects. Each project included both a control section as well as a section in which the experimental method was used. On some of these projects more than one method was used. The following longitudinal joint construction methods were observed:

- Notched wedge joint (12:1)
- Restrained edge
- Joint re-heater
- Joint Maker

Some joint adhesives were also studied and included in this report. They were Crafco® and joint tape by Tbond®. The following actions were taken following final compaction on each project: nuclear density tests were performed, permeability/vacuum tests were performed, and cores were cut from the mat. Both core samples and field tests were performed at the centerline of the longitudinal joint and at six inches, 18 inches, and six feet on either side of the longitudinal joint.

There were four notched wedge joint projects used. Contractors usually built their own notched wedge equipment however one of the contractors purchased equipment from a manufacturer. Both devices were said to produce joints that appeared to be similar by eye. The specs on the joints were a 0.5 inch upper and lower notch and a 12:1 taper between them. The equipment for making the notched wedge joint is mounted on the paver just even with the end gate and adjustments are made for the formation of the wedge. The edge is compacted with a small roller (~400lb.) that is pulled behind along the wedge.

A few minor issues were noticed with the use of the notch wedge joint. These include preserving the upper notch during compaction, raveling of the outside or lower portion of the wedge, and the small tow behind roller picking up aggregate. Another issue was observed during construction of a base course using the notched wedge joint; the equipment used to form and compact the wedge put enough drag on the paver to twist it out of plane while paving. This made use of the ski poles difficult. All of these problems were corrected for and controlled.

Analysis of the notched wedge joint data from the cores shows that the density, on average, increases in comparison with the control section. Only on one project was the density at the joint not seen to increase. This may be due to the surface being constructed over a new base course. It is speculated that the new base course may be increasing the over all density of the control section and decreasing the overall difference between the notched wedge joint section and the control section.

The data indicates that the overall mat density has increased as a result of the notched wedge joint as well. This is because the wedge restrains lateral movement of the mat during construction. The permeability and field vacuum tests indicate that the permeability at the joint decreases with use of the notch wedge joint as well and that the permeability at the notched wedge joint is less than any other portion of the mat.

Recommendations that were made regarding use of the notched wedge joint include use on lifts that are 1.5 inches or larger, use of a strike off plate on the small roller used for compacting the wedge, a nonstop paving train in order to reduce segregation and raveling, and keeping the end gate down and flush with the surface of the lift.

The restrained edge joint construction method was used on four resurfacing projects. The cost of this equipment was $10,000. A hydraulic arm attaches the restrained edge wheel to the breakdown roller. This arm is also used to raise and lower the wheel and as such control the vertical force on the edge of the mat.

The device was first used on a 1 inch resurfacing project and results were positive. It left a smooth edge and densely compacted edge on the mat. The second project the restraining wheel was used on was a 1.5 inch lift. It was found that the beveled restraining wheel did not provide enough height to accommodate the thickness of the lift and two passes with the breakdown roller were necessary before the restraining wheel could be used. It was said that the two passes of the breakdown roller before the wheel was used likely reduced the effectiveness of the restraining method and allowed the material to be pushed laterally since it wasn't restrained for those two passes. On the third project the wheel was used on the beveled wheel dimensions were increased to cover the entire uncompacted face of the freshly placed mat. The mix was said to be slightly tender. The mix pushed upward in between the main drum and the restraining wheel. When this was then compacted after the first pass, a longitudinal crack was formed. This led to the wheel being used only after the initial breakdown which allowed for some lateral movement of the mix thereby reducing overall effectiveness.

Analysis from the collected data showed that the overall density of the joint improved with use of the restrained edge equipment on all observed projects in comparison with the control sections. Permeability tests conducted on the restrained edge joint indicate that a lower permeability can be achieved at the HMA joint when using the restrained edge joint as opposed to the control section as well. A recommendation that was made for the use of the restrained edge method was to obtain or modify restraining wheels to fit the lift at hand. For instance if a 2 inch lift is being constructed, the vertical distance between the top and bottom of the bevel on the wheel should suit that particular lift such that there is no material build up in between the main drum and the restraining wheel.

The Joint Maker® system by Trans Tech was observed on three construction projects. This is a non-mechanical piece that mounts 0.5 inches above the screed interface and forms a 30 degree upward angle with the surface of the pavement. The Joint Maker adds initial compaction to the mix prior to the material being passed over by the screed. A Kicker Plate was used in conjunction with the Joint Maker on some of the projects. The Kicker Plate mounts adjacent to the end gate and forces a more vertical edge on the face of the joint. A Joint Matcher was used on some projects as well. The Joint Matcher automatically controls the edge gate so that the joints are matched more readily.

There were some construction problems with this equipment. The first problem was the confusion in setting up the equipment. The contractor was uncertain as to how the device mounted as well as its proper positioning. Another problem with the equipment use was the dragging of the mix however this was corrected by pre heating the device prior to paving.

After analysis of the data collected on the projects that were constructed with the Joint Maker equipment it was observed that the equipment only very slightly improved joint density in comparison with the control section. Permeability tests showed varying results. The laboratory permeability tests showed higher permeability values at the joints and the field permeability tests showed lower permeability values at the joints. It was stated that due to the low level of improvement, there was no reason to continue using or testing the devices.

The research team reviewed some information from the state of New Hampshire where a Ray-Tech® infrared joint re-heater was tested in the field. Results showed that the air voids content of cores taken from the control section joint were ~20 percent higher than those taken from the section where the joint re-heater was used. The research team elected to use this same system in its own study. The system is intended to work by reheating the surface of the first mat that was paved initially until it reaches a plastic state thereby increasing compaction capabilities at the joint. This is intended then to make the joint less permeable and denser than conventional joint construction methods.

Two of the heaters are pulled about 100 feet ahead of the paver and the third is mounted directly on the paver. The first two heaters are intended to provide initial heat to raise the temperature of the pavement and the third is intended to bring the pavement back to its plastic state immediately prior to the placement of the second mat. Temperature averages immediately after exposure to the third heater were shown to be approximately 375° F.

Some problems that were encountered with this system were related to construction rate. The contractor could not use the ski poles due to the heater being mounted on the paver. The heaters caused the paving train to move slower as well because additional time was needed for the heat to penetrate the mat.

Results from the core testing on this project showed that the overall density of the joint and entire mat was increased in the test section in comparison with the control section. The permeability of the test section also was reduced in these areas. The system was not fully functional at the time of the project and the asphalt was said to be scorched in some

areas. The research team recommended that the attachments be better constructed such that the ski poles can be used in order to better control smoothness. Though the research team found some positive results with this system, they also stated that further investigation is needed.

In addition to the joint construction methods described, two types of joint adhesives were also tested. The first was a hot-melt poured adhesive by Crafco® and a joint tape called Tbond®. The Crafco material was used on conventional joints, a notched wedge joint and a restrained edge joint. The material is applied similarly to the way crack sealant is applied. The joint tape was applied to conventional joints as well as notched wedge joints. The tape is delivered in rolls in boxes and applied with tack or hammered onto the pavement.

The only real issues that presented themselves during construction were the additional man power required for the application of the adhesives as well as some protection needed to prevent pickup of the adhesives by construction traffic.

 Tests conducted on the pavements after construction concluded that lower permeabilities were achieved with use of either joint adhesive. The Tbond joint tape showed significant improvement in the reduction of permeability at the joint when used in conjunction with a notched wedge joint. This was attributed to the adhesive being able to spread out horizontally more readily on the slope of the wedge than on the conventional joint which was used in the control section. Density was said to be higher at the notched wedge joint with the tape as opposed to the notched wedge joint without the tape.

The research team suggests that while both materials reduce the overall permeability of the joint, they are both also more labor intensive and require additional personnel. It was stated that the Crafco material was not quite as labor intensive as the Tbond joint tape.

An analysis of the densities measured on all of the three initial joint construction method projects showed that the highest overall average percent density at the joint was achieved with the restrained-edge joint construction method. Analysis also shows that the notched-wedge joint increases density across the entire mat.

An overall analysis of the permeabilities measured on all of the three initial joint construction methods showed that the notched wedge joint had the highest reduction in permeability. The restrained-edge method showed the second highest reduction in permeability and the joint-reheater showed little to no reduction permeability at the joint.

The research team collected preliminary performance data at the three, four, five, and six year mark and have stated that the joints constructed with the adhesives were performing as well if not better than the joints constructed with out the adhesives.

(*Kandhal et al, 1997*) **Longitudinal Joint Construction Techniques For Asphalt Pavements** NCAT – Auburn University

The NCAT research team for this project recognized that lower densities as well as surface irregularities cause distresses such as cracking and raveling and eventually lead to premature failure of the longitudinal joint. This report focuses on thirty different test sections in the states of Michigan, Wisconsin, Colorado, and Pennsylvania. In these test sections, the following construction methods were studied; rolling from the hot side, rolling from the cold side, rolling from the hot side 6 inches away from the joint, (12:1) tapered joint with 12.5 mm offset without tack coat, (12:1) tapered joint with 12.5 mm offset with tack coat, edge restraining device, cutting wheel with tack coat, cutting wheel without tack coat, Joint Maker, tapered (3:1) joint with 25 mm vertical offset, rubberized asphalt tack coat, NJ wedge (3:1) and infrared heating. Each test section was 500 ft. long.

Rolling from the hot side entailed maintaining the majority of the rolling wheel on the freshly placed (hot) side of the joint with no more than a six inch overlap to the cold side. Rolling from the cold side entailed the same manner in which the previous method except naturally the majority of the rolling wheel remained on the cold side of the joint. Rolling from the cold side was done in static mode. Rolling from the hot side 6 inches from the joint was intended to cause the material to push laterally towards the joint in order to achieve higher density. The tapered (12:1) joint with 12.5 mm offset without tack coat is constructed with two overlapping wedges. This is done by tapering the edge of the first paved lane with a slope of (12:1) and leaving a 12.5 mm vertical offset between the pavement surface and the top of the wedge so that the top of the second lift has some lateral restraint during compaction. When the adjacent lane is paved, this wedge is then overlapped. The tapered (12:1) joint with 12.5 mm offset with tack coat is constructed in

a similar manner to the previously stated method excepting a layer of tack coat applied to the unrestrained tapered edge of the first mat. The edge restraining device by its very nature is a device that provides compaction restraint at the edge of the first pass. The device is a wheel attached to the roller on a mechanical arm which rolls along the edge of the mat pinching the unrestrained edge of the first pass. This is intended to increase the density of the unrestrained edge. The cutting wheel with tack coat is a method by which 1.5 – 2 inches of the newly placed, unrestrained and low density edge of the pavement is cut off just after compaction is complete. A 10" cutting wheel attached to an intermediate roller is generally used to achieve this. The newly formed vertical edge of the pavement is then tack coated prior to the placement of the adjacent mat. The cutting wheel without tack coat is the same process as the previously stated method excepting the use of tack coat. The tapered (3:1) joint with vertical 25 mm offset is a method by which the unrestrained edge of the 2 inch lift is offset vertically 1 inch and tapered on a (1:3) slope. The vertical face of the unrestrained edge was not tacked however the tapered surface of the edge was tacked and rolling of the joint was done from the hot side. The rubberized asphalt tack coat was used on the unconfined, untapered edge of the first mat the day after it was placed immediately prior to placement of the adjacent mat. The New Jersey Wedge (3:1) was constructed by attaching a sloping steel plate to the corner of the paver screed extension. An infrared heater was then pulled along the tapered edge of the first pass prior to the placement of the second pass. The heater increased the temperature of the edge of the first pass to about 200° F. The joint was then rolled from the hot side.

On each test section, a minimum of six sets of cores were taken. A set consisted of one core taken directly on the joint and another taken 300 mm away from the joint. The

different joint construction methods were ranked based on the density of the obtained cores from those test sections.

On the Michigan project which consisted of seven test sections, the (12:1) tapered joint with a 12.5 mm tapered offset both with and without tack and the cutting wheel with tack coat gave the best results (highest joint densities). Of the rolling patterns that were experimented with, rolling from the hot side gave the best results followed by rolling from the hot side 6 inches from the joint.

Three years after the Michigan sections were completed, visual observations were made as to the performance of the joints constructed using the different methods. There were significant amounts of cracking at each test section except for the two test sections utilizing the (12:1) taper with 12.5 mm offset both with and without tack. There was no significant difference found in the performance of the 12:1 tapered joint with tack coat and without tack coat. It was stated that the performance ranking of the different joint construction methods used relied heavily on the overall density of the joint at the time of construction.

On the Wisconsin project which consisted of eight test sections, the edge restraining device and the cutting wheel gave the best initial results (highest densities). These two methods were followed by the 12:1 taper and the Joint Maker. Of the three rolling techniques used on this project, rolling from the hot side gave the best results followed by rolling from the hot side 6 inches away from the joint.

Four years after construction of the sections in Wisconsin, visual observations were made as to the performance of the different joint construction methods used and it was found that the joints were cracked in all eight sections. In all eight sections the cracks have shown at least some amount of spalling. The width of cracking was variant however and the joint construction methods were ranked as follows based on visual observation:

1. Edge-Restraining Device

2. Tapered 12:1 joint with tack coat

3. Tapered 12:1 joint without tack coat

4. Joint maker

5. Cutting Wheel with tack coat

6. Rolling from the hot side (butt joint)

7. rolling from the hot side 6 inches away from the joint (butt joint)

8. Rolling from the cold side (butt joint)

It was stated by the research team that the differences seen in the performances of the different joints were only subtle. It was stated that the 12:1 tapered joint was not constructed with any vertical offset such as in the Michigan project and this may have factored into its failure. It was also stated that the overall performance of the joints on this project appeared to be influenced by the original density as measured from the cores that were tested at the time of construction.

On the Colorado project which consisted of seven test sections, the 3:1 taper with 25 mm vertical offset produced the best results (highest density). This was followed in ranking

by the cutting wheel with tack coat. Rolling from the hot side gave the least density when the 3:1 taper without the 25 mm vertical offset was used.

Two years after construction, visual observations were made as to the overall performance of these different joint construction methods and they were ranked as follows:

1. Tapered 3:1 joint with 25 mm vertical offset
2. Cutting Wheel with tack coat
3. Rubberized asphalt tack coat (butt joint)
4. Cutting Wheel with out tack coat
5. Tapered 3:1 joint rolling from hot side 6 inches away from joint
6. Tapered 3:1 joint rolling from hot side
7. Tapered 3:1 joint rolling from cold side

The research team stated that better evaluation of long term performance would involve further observation in coming years. It was also stated that with further observation in the future, these rankings are likely to change.

On the Pennsylvania project which consisted of eight different test sections, the Edge-restraining device produced the best initial results (highest density) at the joint followed by the cutting wheel with tack coat, Joint Maker, and rolling from the cold side techniques. While the Edge Restraining Device provided the highest density average, they were all reported as generating similar densities. The methods reported to produce

the lower densities were rolling from the hot side 6 inches from the joint, rubberized asphalt tack coat and the NJ Wedge (3:1) Taper techniques.

One year after construction the sections were revisited for performance observation however the sections had yet to develop any cracks. Some sections had developed raveling at the joint in variable widths up to three inches. After the visual observations, the eight different techniques used on these sections were ranked as follows:

1. Cutting wheel
2. Rubberized asphalt tack coat (butt joint)
3. Rolling from the hot side (butt joint)
4. Joint Maker
5. Rolling from the hot side six inches from joint (butt joint)
6. Rolling from the cold side (butt joint)
7. Edge restraining Device
8. New Jersey 3:1 Taper with infrared heater.

The research team reports that although the edge restraining device produced a high density at the joint, the long term performance may be dependent upon the experience of the roller operator. The operator must keep the device aligned correctly throughout compaction of the joint. The research team also states that the rankings are likely to change in coming years as the cracking and raveling of the joints in the long term will be more prevalent than after just one year.

The final conclusions drawn on the overall results of this experiment are based on 12 different joint construction techniques constructed on 30 different test sections. They were all evaluated once during a span of one to four years after construction. It was found that the general performance of the joint depends on the density measured at the time of constructions. That is, the higher the density was immediately after construction, the higher the overall performance ranking was when the sections were revisited. As of the conclusion of this report, the four different projects all had different joint construction methods that were performing better than the rest. Of the three rolling techniques used on the butt joints, rolling from the hot side turned out the best performing joint followed by rolling from the hot side six inches from the joint.

The research team at this point has recommended that the Michigan 12:1 Tapered joint with the 25 mm vertical offset yields the best chances of achieving an acceptable longitudinal joint. The 25 mm vertical offset is a necessary component of this joint construction method. The cutting wheel as well, as the restraining edge device also have promising potential however they are both operator dependant and therefore may lack consistent results from project to project. A butt joint is not desirable and the hot side should overlap the cold side by at least 1 to 1.5 inches. Rolling should always be conducted from the hot side of the joint using a vibratory roller. It was recommended that paver manufacturers are suggested to construct pavers with a steel plate that attaches to the screed in order to achieve a taper such as that in the Michigan wedge as well as some vibratory or tamping mechanism for the unconfined edge to achieve better density values initially. The final recommendation made by the research team is that the

specification for joint density be set at no more than two percent less than what is specified for the mat.

(*Kandhal et al, 2002*)   **Evaluation of Eight Longitudinal Joint Construction Techniques for Asphalt Pavements in Pennsylvania.** NCAT – Auburn University

This report gives the six year evaluation of the performance of the eight different longitudinal joint construction methods that were used in the NCAT project described in the previous sections of this literature review for the test sections that were constructed in Pennsylvania in 1995.

The density tests on cores that were taken directly on the joint as well as on the area 300 mm away from the joint show the Edge-restraining device provided the highest density values. This was followed in order by the cutting wheel, the Joint Maker, rolling from the cold side, rolling from the hot side 6 inches away from the joint, rolling from the hot side, rubberized asphalt tack coat and the NJ wedge (3:1) with infrared heating. The areas where the edge-restraining device was used having the higher density is consistent with the initial long term field observation results made at one year after construction.

Visual observations were made at the six year mark as well. These observation gradings were based on the percent length of the joint which exhibited cracking as well as the width of any cracking and the percent length and severity of any raveling the joints exhibited. They were ranked according to these criteria at the six year mark as follows:

1. Rubberized joint material (butt joint)

2. Cutting wheel

3. Rolling from the hot side six inches away from the joint (butt joint)

4. NJ Wedge (3:1)

5. Edge restraining device

6. Joint-Maker

7. Rolling from the hot side (butt joint)

8. Rolling from the cold side (butt joint)

The section with the rubberized joint material visually appeared to be performing better than all of the other sections even though the density measured on the joint in this section was among the worst.

The following observations were made by the research team. The long term performance of the joints constructed during this project is influenced by the level of density shown at the time of construction as well as is shown during long term visual performance observations. It is recommended that the average air voids content at the joint not exceed ten percent of maximum theoretical density. It was stated by the authors that the performance ranking from year to year changed from 1997 to 2001 as expected and stated in the previously reviewed report. It was expected that some joints would change as the initial appearance of a constructed joint may be better than others however that joint may also deteriorate faster than others when subjected to further extreme environmental conditions over coming years. Similarly, a joint with low density and less than desirable

initial appearance may exhibit more durability over time and maintain its integrity longer than other methods as is the case with the rubberized asphalt tack coat. It was also recommended by the research team that rubberized joint material or a notched wedge joint be used because they perform more consistently than the other methods. Rolling from the hot side 6 inches away from the joint seemed to work best according to the research team and is recommended as the preferred method. The final recommendation made was a specification of joint density set at 2 percent lower than that of the mat and that joint density is measured on cores as opposed to nuclear density as there are seating problems when the gauge is used.

(*Toepel, 2003*) **Evaluation of Techniques for Asphaltic Pavement Longitudinal Joint Construction --** Wisconsin Department of Transportation

In 1993 the Wisconsin Department of Transportation initiated this research project in an effort to accompany the NCAT Auburn research that was described in the previous two reviewed documents. Initial reported results in the NCAT study reported the wedge joint to be one of the best performing methods among reviewed techniques. This however was not the case in Wisconsin. Possible reasons for this include lack of proper equipment as well as lack of experience with the wedge joint at the time of placement.

In this research, eight different longitudinal joint construction methods were studied. They are as follows: conventional method, wedge joint with truck tire rolling, wedge joint without rolling, wedge joint with steel side roller wheel, wedge joint with rubber

side roller wheel, wedge joint with tag along roller, cut joint method and conventional joint with edge restraining device. It should be noted that in the NCAT study, the wedge joints that were constructed in Wisconsin did not have a ½ inch vertical offset like the Michigan wedge joints did, nor were the faces of the wedges compacted. With that in mind, the primary focus of this research was on the wedge joint.

The conventional joints constructed in this research conformed to the basic industry standard butt-type joint. This entails a tack coat placed on the edge of the cold lane and the second pass slightly overlaps the first pass. The breakdown roller first compacts the joint by rolling 4-6 inches away on the hot side to move the material laterally towards the joint and on the second pass, the roller overlaps the cold side by six inches. The wedge joint method in this project utilized a shoe attached to the end of the screed to create a wedge with a ½ inch vertical offset and a 12:1 taper which was tacked prior to the placement of the hot side of the joint. The cut joint method removes approximately 2 inches of the unrestrained material from the compacted joint. A tack coat is applied to the vertical cut edge of the pavement. The conventional method with the edge constraint device provides restraint on the edge (cold side of the joint) material during compaction. This is accomplished via the attachment of a tapered restraining wheel to the breakdown roller. This is intended to reduce the amount of creep that experienced by the normally unsupported edge of the pavement.

The test sections constructed for this research ranged from just less than one mile to over 2 miles. At the time of construction, density tests were conducted both by means of a nuclear density gauge as well as using cut cores and testing them volumetrically in the

laboratory. Nuclear density was read directly at the joint, as well as one foot, and five feet away from the joint on both sides. Cores were cut from the centerline as well as one foot away from the centerline of the joint. There were seven equally spaced locations throughout each section which were selected for testing. After some evaluation it was determined that the nuclear gauge values were not reliable and the laboratory testing of the cut cores was selected as the chosen method of density determination for this project.

All longitudinal joint construction methods utilized on this project produced density gradients with the vortex of each plot taking seat at the joint. The upper or surface layer of an HMA pavement is specified at a minimum of 92 percent of maximum theoretical density in Wisconsin. The only two methods that were found to produce acceptable densities were the wedge with the steel wheel side roller and the wedge with the tag along roller attached to the paver.

Performance rankings of each of the longitudinal construction joint techniques took place in the summer of 2003, ten years after placement of the HMA pavement. It was found that after ten years, from a broad standpoint, the wedge joint methods performed better that the other joint methods. In fact, as was the case immediately after construction, the wedge joint with the steel wheel side roller and the wedge joint with the tag along roller attached to the paver performed the best out of all the joints. The research team reported that the wedge joint with the steel wheeled side roller was the most construction friendly and also the only one to rank top 3 in each of the performance reviews which were conducted at the time of construction as well as 2, 3, 4, 5 and 10 years.

Conclusions of this research state that the wedge joint is the best performing joint of the eight joint construction methods tested. It was stated as being desirable because it does not create debris such as the cut joint does and it is significantly safer for traffic to traverse the construction zone over a wedge than a butt-style pavement edge. The conclusions also state that Wisconsin has made a Special Provision Longitudinal Joint Specification that allows the contractor to utilize a wedge joint if desired.

Recommendations from the research team include investigation into the use of nuclear density gauges for measuring compaction at the joints, investigation into the use of wedge joints with the steel roller over various subgrades, additional methods of evaluating longitudinal joints during construction, investigation into other states success with the use of joint reheaters and joint adhesives. Also included in the research team's recommendations are that the previously described Special Provision Longitudinal Joint Specification be changed such that use of a wedge joint becomes a requirement as opposed to an option.

(*Akpinar et al, 2004*)   **Longitudinal Joint Construction for Hot Mix Asphalt Pavements -** Kansas State University

This research was comprised of a literature review of several different factors affecting the quality and performance of longitudinal joints, different methods of constructing longitudinal joints as well as compaction techniques with respect to longitudinal joints. This research involved an extensive review of the NCAT project described in previous

sections of this report. The findings of this research are as follows: the longitudinal joints in HMA that exhibit the best performance are those which also exhibit the highest values of measured density. Longitudinal joint construction protocol and specifications across the country and from state to state vary greatly. The ability of a roller to change vibratory characteristics rapidly in order to accommodate changes in the conditions of the job is important however the research team suggests that there is a lack of an acceptable and standard rolling pattern procedure.

The recommendations made by the study team include specifying the exact location of a longitudinal joint on the roadway during the design phase in an effort to minimize direct load application. The compaction technique recommended by the research team is rolling from the hot side and overlapping the roller 6 inches over the cold side for butt joints. The research team indicates that wedge joints could be constructed and observed experimentally. The research team recommends that the joint have the same full depth density, smoothness and texture specifications as the rest of the HMA mat.

(*Estakhri, 2001*) **Density Evaluation of the Longitudinal Construction Joint of Hot-Mix Asphalt Pavements** – Texas Transportation Institute

Recognizing the inferior performance of longitudinal joints in comparison with the rest of the HMA pavement mats in Texas lead to this research investigation. The objectives of this research were to investigate the density of the longitudinal joints of numerous HMA pavements in Texas to determine if low density of longitudinal joints is a problem. Another objective of this research was to review aviation construction data involving

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specification of joint density and determine if this specification can be met by paving contractors. The final objective was to modify HMA specifications to require density measurements at the longitudinal joint if it is justified.

In light of the nature and methods of the research involved with this study and its similarity to other previously mentioned studies with respect to some of the actual research work as well as the findings, the entire scope of this research will not be detailed here however the objectives previously mentioned will be matched with their respective outcomes and results in the following paragraphs.

With respect to the first objective (determining if a problem exists in Texas with low density at longitudinal joints), indeed a problem existed. Low density was found in the first paved lane along the unrestrained pavement edge. This was investigated on 35 different pavements throughout Texas and these findings compared with density in the center of the paved lane almost always produced a significant difference. On a scale of percentage of maximum theoretical, this range was 4% to 5%.

The review of aviation construction data where a longitudinal joint density specification existed, it was found that the contractors involved with these construction projects were routinely able to meet density requirements.

It was stated at the close of the findings and recommendations of this report that Texas DOT implemented a longitudinal joint density specification. This specification requires the contractor to perform a density test at each construction sub lot. This measurement

has to take place within two feet of the edge of the pavement mat and compared with a measurement taken on the interior of the mat (more than two feet from the unconfined edge. When the difference of this comparison exceeds more than 5 pcf, the sub lot fails and the contractor must take corrective measures to improve the joint density during construction. When two consecutive verifications fail, HMA production must cease and the contractor must change his operation or the production operation and two consecutive verification sub lots must be accepted before operations can continue.

(*Marquis, 2001*)   **Longitudinal Joint Study – Final Report**. – State of Maine Department of Transportation

The Maine Department of Transportation recognized that the premature degradation of longitudinal joints on their highways and roads in the past has increased the cost of maintenance and caused an unacceptable amount of reflective cracking when they are overlaid. The purpose of this research was to experiment with new longitudinal joint products as well as different longitudinal joint rolling techniques in an effort to produce joints with higher densities and ultimately increase the service life of the pavement structure.

The experimental section utilized for this research consisted of six subsections; four 1970 ft. sections, one 2300 ft. section and one 1640 ft. section. Three different rolling techniques, a cutting wheel and the Joint Maker product similar to the one used in both the Kentucky Transportation Center project as well as the NCAT project were used in this experiment.

The contractor purchased the Joint Maker as a package from Transtech Systems Inc. The package included the Joint maker as well as a kicker plate and an edge follower. The kicker plate mounts on the outside edge of the endplate ski. The kicker plate is an adjustable raking edge that collects loose and excess HMA material that has leaked out from the screed to the adjacent previously paved cold mat. The intention of the kicker plate is to windrow the material directly over the joint where it is needed the most in order to increase density. The edge follower is a device intended to automate the closure or overlap of the longitudinal joint. It is a non-contact sensing unit that is used to automatically position the end-gate. It is intended to eliminate excess overlap and the need for a screed operator during the placement of the material on the closing of the longitudinal joint.

In the first test section, the first pass was paved with a Joint Maker on both the left and right end plate. This pass was rolled in such a manner that the breakdown roller makes its first pass on the hot side of the mat and then the mat is rolled from the cold side to the hot side. This pattern was recommended by Transtech. The second mat in the first section was paved using a Joint Maker on the right side end plate and a kicker plate and a Joint Follower on the left side. The second pass was rolled from the cold to the hot side as per recommendation by Transtech.

The second section was a butt joint control section. The rolling took place from the cold side of the mat to within six inches of the joint. Then the joint was overlapped by two feet over the cold mat.

In the third section, Technique A was used. Technique A consists of a first roller pass from the hot side with a six inch overlap to the cold side of the mat and follow up rolling from the hot side to the cold side.

The fourth section was paved and finished using Technique B. Technique B utilized a static roller pass from the cold mat with a six inch overlap on the hot map and follow up rolling in vibratory mode from the cold side to the hot side.

Technique C was used on the fifth section. A first pass six inches from the joint was followed by a second pass which pinched the joint. The mat was then rolled from the hot side to the cold side.

The sixth section involved the use of a cutting wheel attached to a grader. The first 2 inches of the leading edge was cut off and discarded. Tack was then applied to the joint prior to paving the next pass. The mat was rolled from the cold side to within six inches of the joint and finally pinched with two feet of the roller over the cold mat.

Of the several techniques that were used in this experimentation, sections one (Joint Maker on both the left and right end plate), section three (first roller pass from the hot side with a six inch overlap to the cold side), section five (a first pass six inches from the joint was followed by a second pass which pinched the joint) and section six (cutting wheel attached to a grader) exhibited characteristics that were decidedly unfavorable whether upon review of the site a given time later or during construction. The section

five rolling technique was not suggested by the authors as an alternative rolling technique due to the time consuming nature of the process which designates the breakdown roller to roll the entire mat. The section three rolling technique was also not recommended because it created a ridge at the center of the mat which was difficult and time consuming to smooth out. The edge trimming process that was used in section six was also not recommended because keeping a straight edge on the mat was difficult. The section one process using the Joint Maker exhibited the highest amount of joint separation during long term observation. It was however, stated by the authors that the Joint Maker equipment precompacted the mix before rolling took place and combined with the rolling scheme from section two, this could form a quality joint.

Section four (static roller pass from the cold mat with a six inch overlap on the hot map and follow up rolling in vibratory mode from the cold side to the hot side) revealed the least amount and severity of cracking upon revisiting and the authors state that the rolling technique used could be used as a standard in an effort to reduce the amount of centerline cracking. Section two (butt joint control section) was also stated as having a very low amount and severity of centerline cracking. The authors suggest that a conscientious paving crew combined with this compaction scheme should be used in order to prevent premature cracking at the joint.

(Denehy, 2005) Constructability of Longitudinal Construction Joints in Hot-Mix Asphalt Pavements with Sealers to Retard Future Deterioration. -- New York State Department of Transportation.

A task force on longitudinal joints recommended to NYSDOT that a notched wedge joint be added to their specifications as an alternative to the traditionally used butt joint. The task force also recommended to NYSDOT that the rolling pattern specification include the following method of compaction: rolling from the hot mat with six inches of overlap onto the cold mat for one pass towards and away from the paver and then rolling commence from the low side to the high side. Specification changes were made by the task force upon approval.

NYSDOT also experimented with the use of TransTech's Joint Maker. The experiment involved two 305m sections of new pavements on three different projects to compare the Joint Maker to the traditional butt joint. The density at the longitudinal joints on all three test projects were lower where the Joint Maker had been used than where the traditional butt joint was used. In light of this outcome NYSDOT did not pursue the Joint Maker further.

Upon review of several other studies regarding longitudinal joint construction, NYSDOT decided to investigate use of longitudinal joint sealers. Three projects were selected as pilot test sections for trial of the sealers and placement variations.

The first project utilized a notched wedge joint with a 12.5 mm notch and a 1:8 wedge. Preceding placement of the second pass, Crafco Inc, placed joint sealer using crack sealing equipment. The sealant covered the notch and covered the wedge only partially. A pickup truck was driven over the sealant to test for possible pick up which did not occur. During compaction of the first paver pass, the roller rolled the edge of the notch

but did not go further than the edge of the notch. The second mat was placed overlapping the cold mat by 25 mm to 40 mm. A vibratory roller was used to compact the joint immediately after paving. The roller overlapped the cold mat by 150 mm to 200 mm. Rolling of the rest of the mat took place from the low side to the high side. The author states that there were no adverse affects caused by the use of the sealant material. The rollers did not pick up any of the sealant and there was only a thin line of the sealant visible after compaction.

The second project which sealant was used on also involved a 1:8 notched wedge joint. The rolling process of the first mat was exactly the same as the preceding project. Deery sealant was used on this section and was placed using crack sealing equipment. This material was placed such that it formed a band of sealant in the middle third of the taper of the wedge. The author states that this material became tacky very quickly (within a few minutes) as did the previous project. There was no difference in installation time and the placement of the second paver pass as well as compaction procedures and rolling patterns were exactly the same. Also like the previous project, paving was not negatively affected. There was no pick up of the sealant by the rollers. The sealant was not visible on the completed joint because the band was placed in the middle third of the wedge taper.

The third project utilized a conventional butt joint. Conventional joint sealing equipment was used to place the Asphalt Materials Inc. sealant. The author reports that this material was thicker than either the Deery or Crafco sealants and achieving placement at the right thickness was difficult with a 50 mm sealing shoe. The contractor switched the

application method to use a conical wand head with a nozzle of an ellipsoid shape and application proceeded with ease following that. The author reports that there was little volume of sealant needed for this project. This caused concern that the large kettle may have overheated the sealant. Switching of the application nozzle was also said to take a considerable amount of time which may have lead to some overheating of the material. The butt joint was completely covered by the joint sealant and it was reportedly tacky within a few minutes as were the previous two projects. Installation time was not negatively affected and only a thin line of the sealant material was visible after compaction of the joint.

In conclusion, the author reports no significant difficulties or problems with the installation of the three different sealants by three different contractors on the three different projects which were geographically separated into the extreme eastern part of NY state, the extreme western part of NY state and one section which is more centrally located within the state. It was recommended by the author that larger scale projects be undertaken on the installation of these sealants to investigate their performance with use in longitudinal joint construction.

(Buchanan, 2000) Evaluation of Notched Wedge Longitudinal Joint Construction

This research consisted of the evaluation and comparison of the in place density of two longitudinal joint construction methods; the notched-wedge joint and the traditional butt joint (also referred to as a vertical or conventional joint). These comparisons took place

on five projects, one in each of the following states: Colorado, Indiana, Alabama, Wisconsin and Maryland. This research was conducted based on the notion that increased density of the longitudinal joints would improve the overall life of the pavement. At each site there were two test sections each a minimum of 1000 feet in length. One test section was used to monitor the conventional joint while the other was used to monitor the notched wedge joint. In each section, three test locations were selected at random. At each test location there were five core samples extracted spanning the joint. The sequence of extraction was as follows: a core was cut 18 inches from the centerline of the pavement on the hot side of the joint. Moving 6 inches in the direction of paving and 12 inches toward the centerline, a second core was extracted for the hot side. Then moving 6 inches back against the direction of paving and directly on top of the centerline a third core was extracted. Again moving back 6 inches against the direction of paving and 6 inches to the cold side, a fourth core was extracted. Finally moving 6 inches in the direction of paving and 12 more inches away for the centerline on the cold side, a fifth core was extracted. Each test location then consisted of 2 cores cut from 18 inches away from the centerline (one on the cold side and the other from the hot side), 2 cores cut from 6 inches away from the centerline (one on the cold side and the other from the hot side) and one core cut from the centerline.

Density observations indicate a lower density at the 6 inch location on the hot side for 4 of the 5 projects. This was attributed to achieving insufficient density of the wedge itself. Whether this would cause a problem in the future or not would ultimately depend on the level of density of the material in the upper half of the wedge. The author states that as long as the density achieved in the upper portion of the wedge is sufficient to keep the

joint impermeable, future problems would be less likely to occur. Also concluded was that the density of the material 18 inches on either side of the joint generally was not impacted by the method of longitudinal joint construction.

The use of the notched wedge joint increased the centerline density on 4 of the 5 projects. The increase was attributed to the added level of confinement present due to the wedge of the first paver pass. It was indicated that the lower density of the centerline on one project may have been due to the thickness of the lift which was 4 inches. All of the other sites consisted of no more than a 2 inch lift thickness.

Traditional Butt Joint Construction Method:

The traditional butt joint is constructed by butting the edge of the second paver pass with the edge of the first paver pass and finally compacting the joint. It is stated in Chapter 10 of *NETTCP Paving Inspector Manual (NETTCP, 2006*) that the hot material from the second paver pass is placed against the edge of the first pass and an overlap of 1 to 1.5 inches should be used in order to ensure an adequate amount of material for compaction. This is shown in Figure 1 which was extracted from Chapter 10 in the NETTCP manual. This method was used on 6 of the 8 projects investigated during the 2006 construction season while one of the projects utilized both the notched wedge joint and the traditional butt joint.
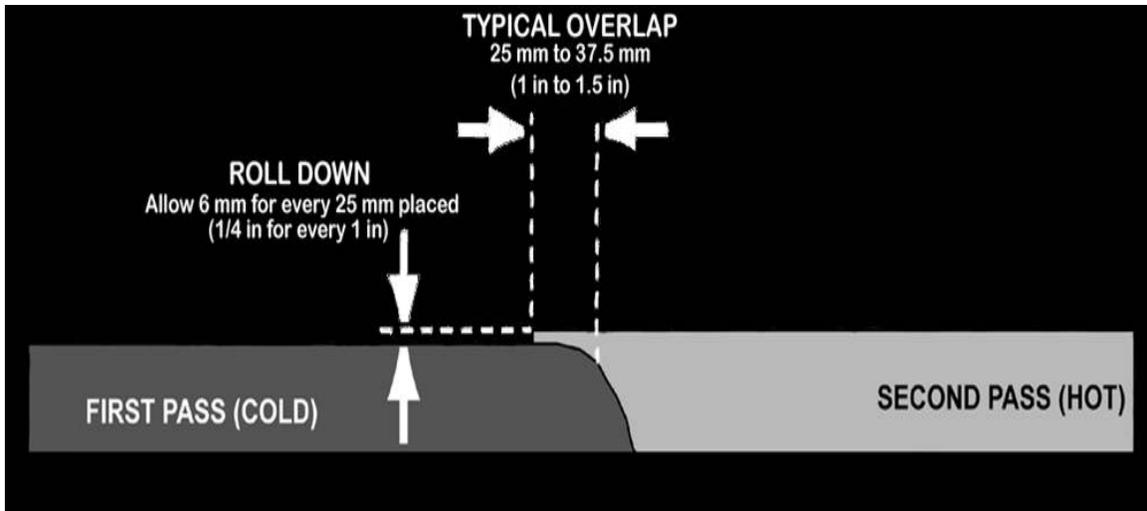
Figure 1. Typical Butt Joint Construction Protocol

Table 1 shows the 2006 projects that utilized the traditional butt joint method which were investigated for the purposes of this research. Also shown in Table 1 are the average density measurements that were taken by Connecticut DOT for acceptance both on the mat as well as the joint.

Table 1. Acceptance Density Values (Butt Joint Projects)

Project #	Town	Route	Mat % MTD (Acceptance)	Joint % MTD (Acceptance)
172-364C	N. Stonington	184	92.7%	93.1%
171-326C	Berlin	15	No Data	No Data
172-363F	Salem	354	92.9%	92.4%
172-363F	Montville	82	93.6%	92.1%
173-381C	Easton	59	93.0%	92.8%
172-363A	Killingly	6	92.8%	92.2%
174-332H	Kent	341	92.1%	91.2%

Notched Wedge Pilot Projects:

The notched wedge joint was tried on two ConnDOT projects. The first was a Vendor-in-Place (VIP) State Project on Route 15 in Berlin; Project #171-326C. The second was a Construction Project on Route 80 in North Branford, Project #98-98. Both projects were paved at night.

Notched Wedge Construction Method:

The notched wedge joint was formed by using a Contractor supplied device attached within the wing of the paver to form its shape (Figure #2). The device was designed to create a notched wedge joint to meet the State's trial specifications. The device allowed for adjustment in the formation of the wedge in its length and slope. The depth of the notch is also adjustable. To compact the wedge, a vibrating plate compactor was used. The plate is connected to the paver and is set just behind the wing directly over the wedge (Figure #3). The resulting notched-wedge joint is shown in Figure #4.
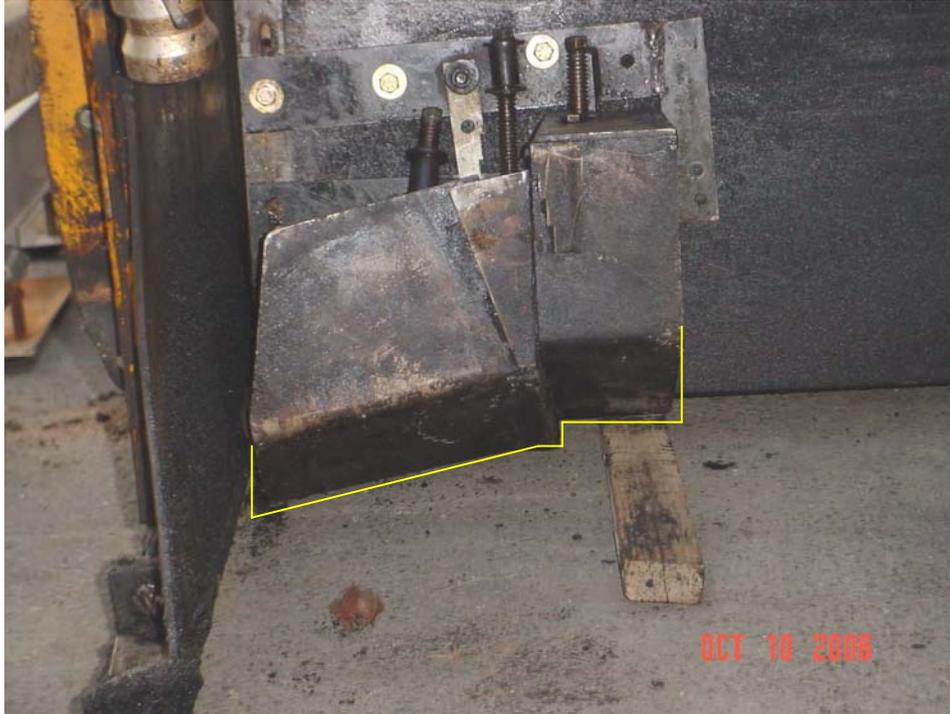
Figure #2 Notched Wedge Forming Device

Figure #3 Wedge Compaction Device and Setup
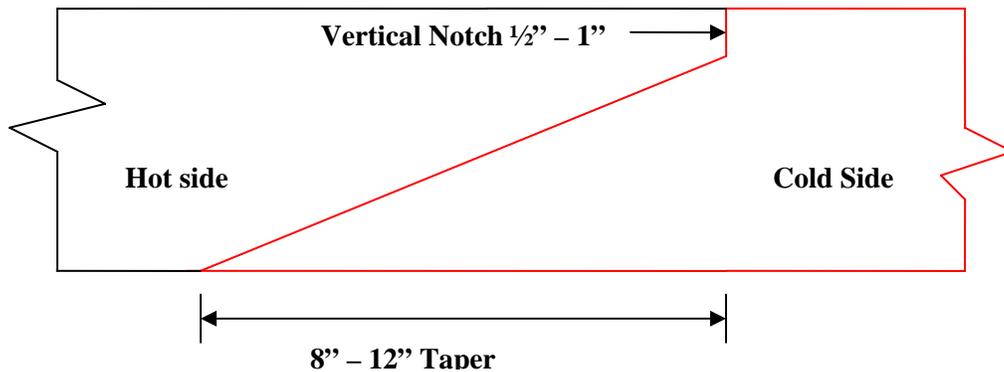
Figure #4 Notched Wedge Joint Diagram

Project #171-326C Description:

Rt. 15 in Berlin Connecticut was the first pilot project, paved on the nights of September 6th and 7th, 2006. The asphalt material was supplied by Tilcon Connecticut's Plainville plant. The material was also placed by one of Tilcon's paving crews. The roadway had a Portland Cement Concrete base overlaid with bituminous concrete. The bituminous concrete surface was first milled at a depth of 75 mm (3 inches). A 25 mm (1 inch) leveling course of Superpave 9.5 mm (0.375 inch) level 3 was placed over the milled surface prior to the wearing surface consisting of a (50 mm) 2 inch course of Superpave 12.5 mm (0.5 inch) level 3. The notched wedge joint method was tried on the top course between the right and left travel lanes in the northbound direction only. Longitudinal joints for the right shoulder and left turn lanes consisted of the standard butt joint. The southbound lanes consisted of the standard butt joint method for all longitudinal joints.

To allow for a continuous paving operation, two pavers were used. A small paver was used to pave the left turn lanes and gore areas and right shoulder out in front of the main paver. This allowed the main paver, utilizing the notched wedge joint equipment, to pave

the left travel lane and shoulder in a single pass without interruption. The main paver simply matched the butt joint along the left turn lanes as it passed. These butt joints were constructed in a hot state as opposed to the notched wedge joints which were constructed over two nights. An effort was made to locate the notched wedge joint over the centerline longitudinal joint of the concrete base.

Project Equipment: Tilcon had modified some equipment to help in the compaction of the notched wedge joint. In order to attach the vibrating plate to the paver, mounting points were welded or cut into the wing of the paver. A welded steel pipe, chain binder and chains were used to attach the plate at various points. The chain mounts were adjustable to keep the plate parallel to paving. The vibrating plate was connected to run off the hydraulic system of the paver's vibrating screed so they started and stopped in unison. To ensure that the vibrating plate's width matched that of the wedge, it was further modified by cutting off a portion of the base and welding it back at an angle to prevent it from dragging on the base which is pointed out by the arrow in Figure #4.

Additional equipment used in the paving operation included a Roadtec SB-2500 Material Transfer Vehicle (MTV) and the TOPCON non-contact automatic grading system. Tack coat was applied with special attention to ensure proper coverage to include under the wedge portion of the joint. This was considered important to achieve sufficient bonding of the material forming the joint to help prevent raveling when exposed to traffic.

Field Observations – Constructability: After some minor adjustments, the wedge attachment appeared to function well. The plate compactor seemed to work very well

also. Density was not measured on the actual taper of the joint however it appeared to be smooth and uniform. Minor adjustments were made throughout the night to achieve and maintain the desired notch depth, slope of the wedge and position of the compactor. There were no major problems with the functionality of the attachment or the vibrating plate compactor. The only significant incident occurred when the wing of the paver with the attachment was inadvertently closed. This severed a chain connection to the vibratory plate which was quickly repaired and paving continued.

By using this new joint method, the contractor was able to complete the entire travel lane in a single pass. This eliminated the need for 2 transverse construction joints and having to back up the paver for multiple passes. Not having to back the paver up between passes and change warning sign patterns saved a considerable amount of time and effort. Adjustments to maintain the proper notched wedge required minimal down time.

On the second night, the notched wedge joint was completed. One issue was placing tack coat on the wedge portion of the joint. The tack coat was placed using a tack truck and the difficulty was to not over spray tack material onto the finished surface. The result was that the coverage varied. On average only the bottom half of the wedge was coated. The trial specifications called for the entire wedge and notch to be coated. This was not possible with the tack coat application method being used.

Field Observations - ConnDOT Pavement Advisory Team – Traffic on Open Joints:
The notched wedge joint was inspected and evaluated the following day. A video recording of the construction and daily traffic use of the joint was made by ConnDOT's

Pavement Advisory Team . The joint held up very well to traffic with minimal raveling.

Cars and trucks alike had no problem traversing the joint while changing lanes. Some

large loose aggregate was noticed in the travel lanes later that morning after the notched

wedge joint was exposed to traffic for a few hours. At approximately 10:30 AM a

sweeper was used to clean the travel lanes of the loose aggregate. No problems or claims

of damage were reported.

Field Observations – Acceptance Testing of the Joint: Nuclear density tests performed

by ConnDOT for acceptance on the notched wedge joint averaged 92.5% of Maximum

Theoretical Density (MTD) with no failing tests. The procedure ConnDOT used on the

joints for acceptance testing on this project is as follows: All ConnDOT nuclear density

measurements were taken after the hot side of the joint was paved and compacted.

ConnDOT personnel placed the gauge immediately to the hot side of the line that formed

once the joint was completed.   Because the joint was a notched wedge joint, this

positioned the gauge directly over the top of the wedge.   Two thirty second

measurements were made per location.   The gauge was rotated 180º between

measurements.   There were 6 joint measurements taken by ConnDOT for acceptance

testing.

The CAP Lab completed their nuclear density testing and core sampling. Cores were

taken at 3 longitudinal joint locations. 5 cores were extracted at each location.

Project #98-98 Description:

Rt. 80 in North Branford, Connecticut was the second pilot project investigated. It was paved on the nights of October 10th -12th, 2006. The material was supplied by Tilcon Connecticut's North Branford plant. The material was placed by CT Paving. A 50 mm (2 inches) course of Superpave 12.5 mm level 2 was used. This was a full depth reconstruction project with a bituminous concrete base. The base course was 150 mm (6 inches) of Superpave 37.5 mm level 2. The lift directly below the top 50 mm lift was 40 mm of Superpave 12.5 mm level 2. Since there was no underlying concrete longitudinal joint for reference on this project, the notched wedge joint was located in the normal location for all bituminous longitudinal joints; offset a minimum 6 inches from the underlying longitudinal joint. The notched wedge joint was used for the wearing surface only. Some milling took place at transitions.

Project Equipment: The contractor utilized the same notched wedge joint device and vibrating plate as the contractor in the previous pilot project. They modified their paver to adapt to the new equipment. However, there were some mechanical improvements to the device and vibrating plate setup. The vibrating plate had new mounting locations. While the primary attachment was still mounted to the wing, the chain attachments were mounted to the body of the paver. This eliminated the danger of cutting the chain when closing the wing. A ratcheting device (chain binder) was added to the chain mount to make it easier to adjust the angle of the vibrating plate. Figure #5 shows the setup used on this pilot project.
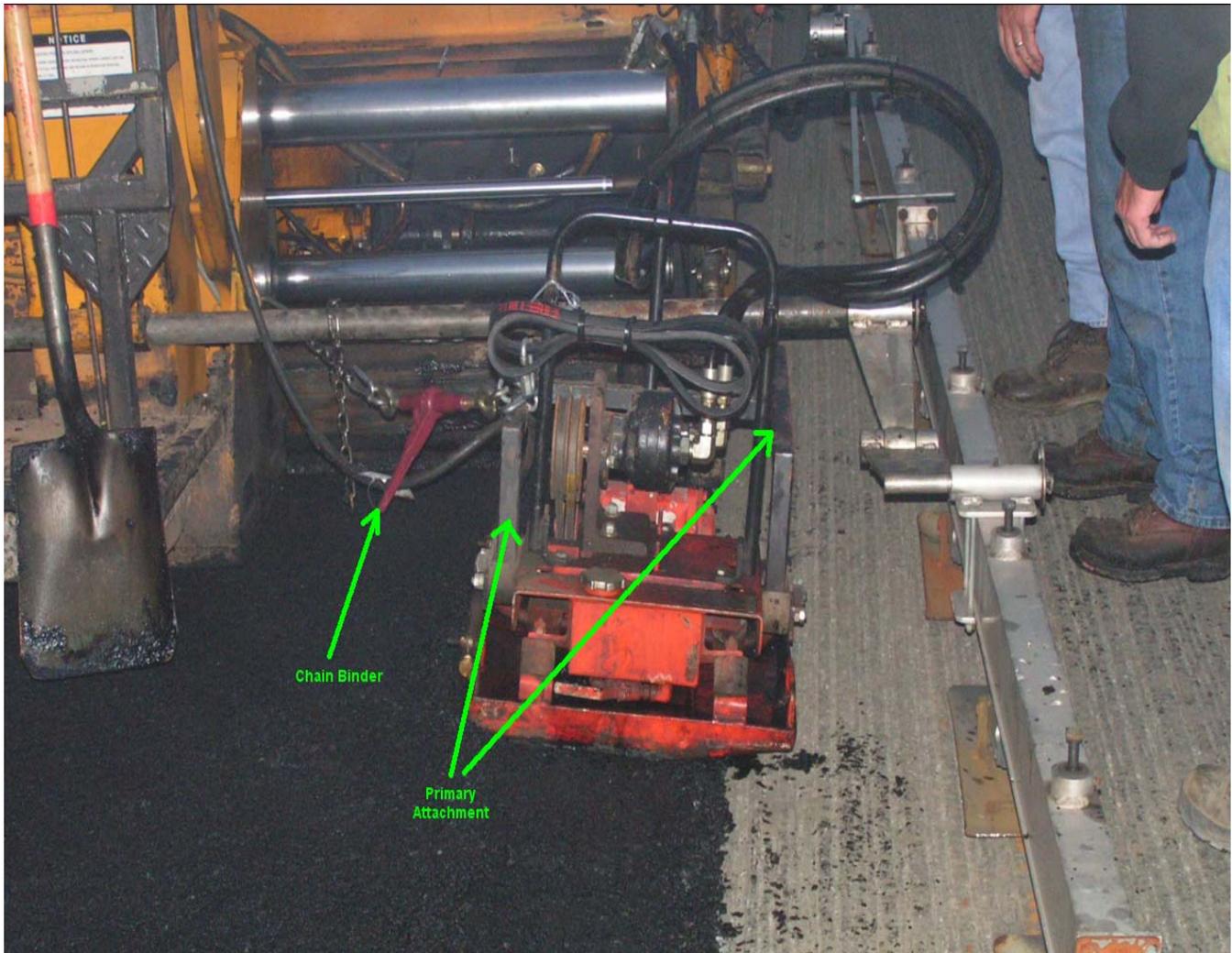
Figure #5 Compaction Device Setup and Attachments

This project was shorter in overall paving lane length and did not have a center median area or any left or right turning lanes. Therefore, there was no need for a second paver and only a single paver was used. A Material Transfer Vehicle was not incorporated to the placement of this material. A 30 foot long contact ski was used for automatic grade control.

Field Observations – Constructability: The first night, October 10, 2006, the westbound travel lane and shoulder were placed. Again, the entire travel lane and shoulder were completed eliminating all transverse construction joints. By paving both the travel lane

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and shoulder, the exposed notched wedge joint was at the centerline of the roadway (Figure #6). This also meant that a completed joint was formed between the shoulder and westbound travel lane that same night. Tack coat on the joint was again an issue. The majority of the joint had only the bottom half coated as shown in Figure #7.   This problem will need to be addressed on future trial or study projects incorporating the notched wedge joint method.

Figure #6 Traffic On Open Notched Wedge Joint

Tack Coat

Cold Side

8" – 12" Taper
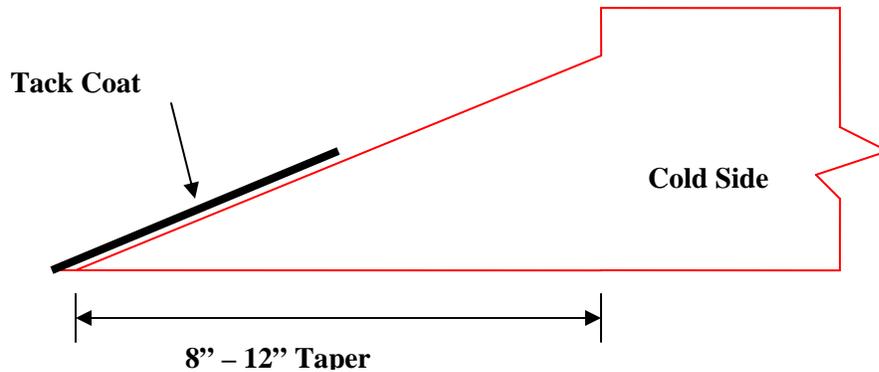
Figure #7 Tack Coat On Bottom Half of Wedge

The two west bound lanes being paved remained closed to traffic through the course of the first night's paving so the exposed notched wedge which would connect the shoulder with the travel lane was not subjected to any traffic. On the second night, the eastbound travel lane was paved and the traffic was all shifted into the west bound travel lanes. During paving of the eastbound lane and shoulder, the notched wedge joint separated the construction zone from the traffic. Thus the only traffic to traverse the exposed wedge was traffic needing to cross the eastbound lanes to access a business or side road which was infrequent. The eastbound shoulder was paved on the third night.

*Field Observations – ConnDOT Pavement Advisory Team Traffic on Open Joints***:**

The construction and use of the exposed joint as it was opened to traffic was filmed once again by ConnDOT's Pavement Advisory Team. Because the joint was located at the centerline of opposing traffic it was not traversed as regularly as it was on the previous project. It was only traversed when cars were entering/exiting businesses and side streets. This resulted in very little loose aggregate visible in the travel lanes. No additional

sweeping was performed as it was deemed not to be necessary. Once again cars and trucks had no problem traversing the notched wedge joint (Figure #8).

Figure #8 Traffic Traversing Open Joint

Field Observations – Acceptance Testing of the Joint: Nuclear density tests performed by ConnDOT for acceptance on the notched wedge joint averaged 93.5% of Maximum Theoretical Density (MTD) with no failing tests. The procedure ConnDOT used on the joints for acceptance testing was similar to the procedure used on Project 171-326C. All ConnDOT nuclear density measurements were taken after the hot side of the joint was paved and compacted. ConnDOT personnel placed the gauge immediately to the hot side of the line that formed once the joint was completed. Because the joint was a notched

wedge joint, this positioned the gauge directly over the top of the wedge. Two thirty second measurements were made per location. The gauge was rotated 180º between measurements. There were 5 joint measurements taken by ConnDOT for acceptance testing each night. There were three nights of testing which resulted in a total of 15 nuclear density measurements taken on the joint for acceptance over the course of the project.

The Connecticut Advanced Pavement Laboratory was on site again to core the notched wedge joint. District III performed the nuclear density testing for acceptance.

Field Evaluation Plan at Time of Construction

CAP Lab personnel were onsite with the tools necessary for obtaining all data and samples pertinent to evaluating the longitudinal joint on all projects. (Project #174-332H, Rt. 341, Kent is an exception as CAP Lab personnel were not present during paving. As such there is no nuclear density data for this project.) The equipment included a drill with a 6 inch coring bit, generator, cooling water, distance measurement devices, digital camera, infrared temperature gun and a nuclear density gauge.

It was desired at the outset of this research that profiles be obtained that demonstrated the behavior of density from the cold side of the joint across to the hot side of the joint. If such profiles could be obtained, this may explain a great deal about the problem with the premature failure of the longitudinal joints. More specifically, it was desired to determine what the density of the material was on both sides of the joint as well as

directly on the joint for comparison purposes. If this information could be obtained, it may provide insight as to the effectiveness of the added confinement provided by the wedge joint during compaction.

This data was obtained through vigorous nuclear density testing of the material and finally extraction of cores in each nuclear density test location for laboratory measurement. Unfortunately, while it is possible to perform non-destructive nuclear density tests immediately adjacent to one another, it is not possible to cut cores immediately adjacent to one another in the form of a profile for a number of reasons. These reasons include: each core that would be cut would have been disturbed by the extraction of the previous core and the damage to the mat may have been problematic. It was determined then that nuclear density profiles would be measured across the joint starting 1 foot from the joint on the cold side and continuing in 6 inch increments to 1 foot from the joint on the hot side (Figures #9, #10). It was decided that this would take place every 5 feet in the direction of paving. A core would be extracted from the first profile in the location where the nuclear density testing took place 1 foot from the joint on the cold side. Moving to the next profile which would be 5 feet in the longitudinal direction, a core would be extracted in the location where the nuclear tests were performed 6 inches from the joint on the cold side. 5 feet from that location in the direction of paving another core would be extracted directly on the joint where nuclear measurements took place. This would be repeated for core extraction 6 inches from the joint on the hot side and finally 1 foot from the joint on the hot side. Thus five nuclear density profiles and five cores would be obtained over each 20 foot section (Figure #10).

Figure 9. Profile View of Core Extraction Protocol
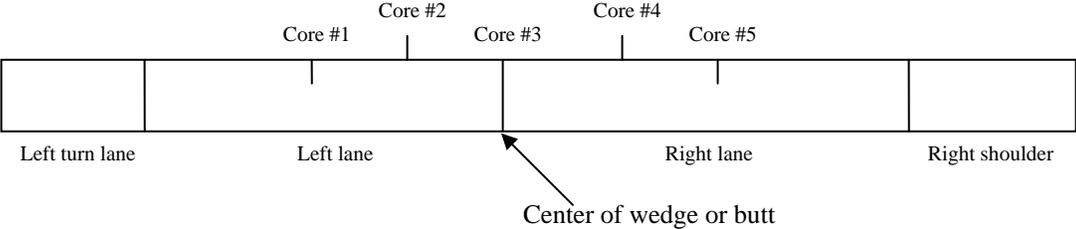
Figure #10

◯ = Core Locations
+ = Nuclear Measurement Locations

* Nuclear Density measurements will be made 12" and 6" to the left of the joint as well as on the joint and 12" and 6" to the right of the joint at each of the five core locations in each of the day's sections. This is a total of 25 nuclear density measurements per section.

** Five longitudinal feet as well as 6 transverse inches will separate each of the core locations in each section.

Center Line / Joint

12"

6"

Section 3

6"

12"

Section 2

Section 1

53
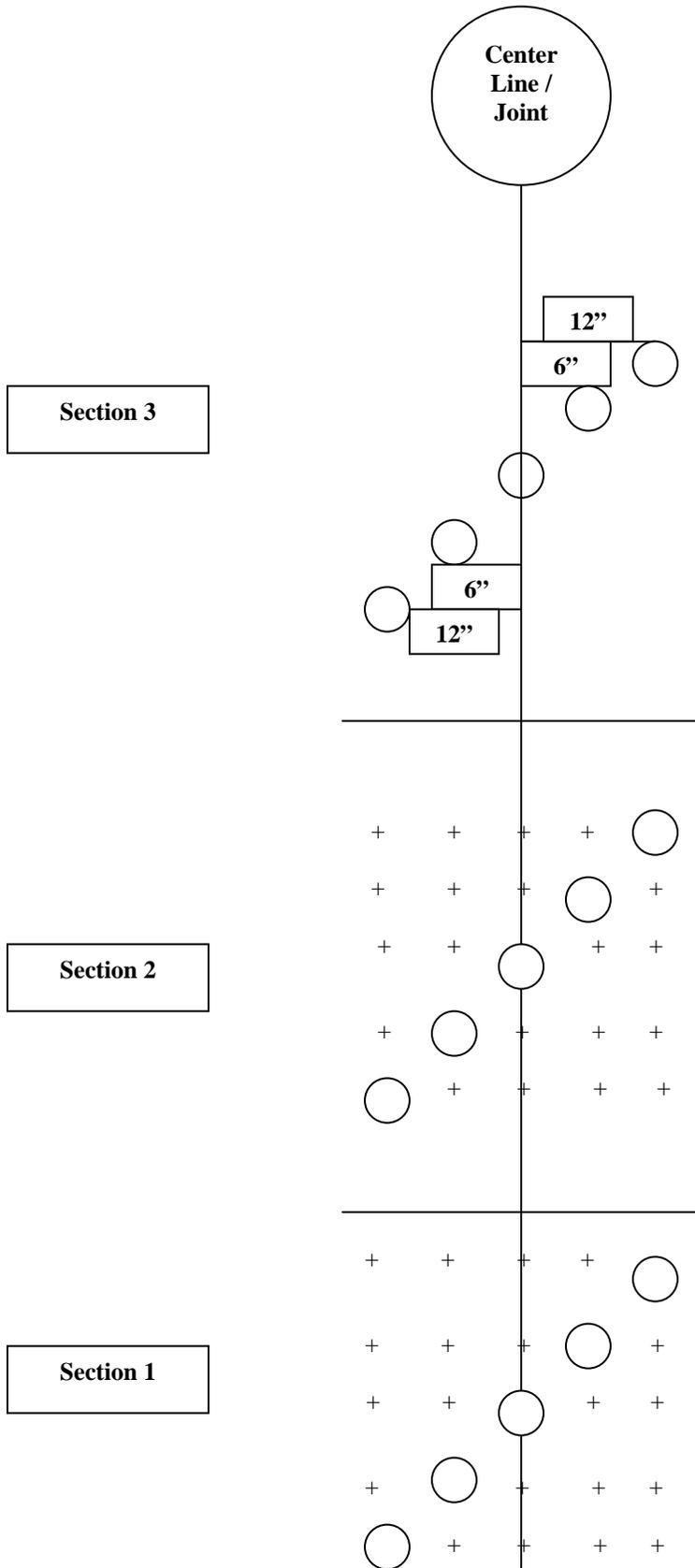
Once paving began, CAP Lab personnel performed a daily standard count with the nuclear density gauge as well as generating random locations for each test section. Care was taken to give adequate time and distance (~300-350 feet) for the paving crew to make necessary adjustments before CAP Lab personnel began collecting data. The distance of paving as well as quality and presence of traffic control on each particular day or night ultimately dictated how many sections of data were possible to collect. Some days or nights were longer than others however on average, 2 to 3 sections per day or night were possible. 60 second counts were used with the nuclear density gauge and each location was measured twice rotating the nuclear density gauge 180° between measurements and the average of the two readings was used. This equates to 50 minutes of nuclear gauge measurement per section which attributes to the difficulty in getting all of the data collected. Once the nuclear density data was collected, cores were extracted, labeled and brought to the CAP Lab for volumetric measurement.

Analysis of Field Data:

Data Storage: A FileMaker Database developed by CAP Lab was used to hold all of the data pertinent to the projects including date, route, town, joint type, section number, core location, core ID, project specific notes, volumetric data from the plant, nuclear density values, volumetric core density values as measured by CAP Lab, and project specific numerical summaries of all the measurement data. The data was all filed by individual nuclear density profile. This means that for each core that was cut, the nuclear density profile at that location within each section along with data pertinent to the project comprised one record within the database. Each section of data collected then, entailed

five records. There are a total of 185 records that contain all the data collected from the 2006 construction season for this research. It is important to note that not all 185 cores were usable in the data analysis which is explained in the following section.

Notched Wedge Correction Factors: ConnDOT Report No. CT-2242-F-05-5; *Correlation of Nuclear Density Readings with Cores Cut from Compacted Roadways* (*Padlo et al, 2005*) illustrates a method by which an average error can be calculated utilizing cores to develop a correlation factor to be added to nuclear density gauge values on a project/mix specific basis. It was desired that this procedure be investigated for use on longitudinal joints. This procedure involves cutting a predetermined number of cores to be used in the correlation. In addition to the cores cut on the longitudinal joints, cores were also extracted from areas on the mat that were not close to the joint. The purpose of these cores was to develop a correction factor that would not only be applicable to mat nuclear density readings but also used to determine its applicability to the longitudinal joint nuclear density readings.   Upon attempting to develop this correlation, it was quickly realized that an inadequate number of cores were cut from the center parts of the mat.   The correlation report stated above prescribes that 10 cores be cut for the correlation. There were not 10 random mat cores cut on either of the projects where the notched wedge joint was utilized. It was attempted to develop the correction with the few random mat cores that were cut however the attempt was unsuccessful. In the second phase of this project, additional cores will be cut from the mat such that the correlation can be attempted in accordance with the procedure outlined in Report No. CT-2242-F-05-5.

Instead, all of the cores cut from the longitudinal joint locations were used to develop the longitudinal joint correction factor since the nuclear density data could be directly compared to the laboratory core values. As prescribed by the correlation procedure, readings with errors in excess of +2% were discarded and not used in the correlation procedure. The correction factor procedure subtracts the volumetric density value from the nuclear density value to obtain the error. The reason these core density values are discarded is because errors in excess of +2% generally indicate a broken or damaged core resulting in a lower volumetric density and thus a large error. Table 2 shows the number of cores that were deemed invalid for use for each of the notched wedge joint projects.

Table 2. Discarded Core Values (Notched Wedge Joint)

Project	Town	Route	Total Cores	Cores Discarded as Unusable
171-326C	Berlin	15	15	6
98-98	North Branford	80	20	1

For Project# 171-326 there were 6 cores that were discarded as a result of differences in excess of 2% and for Project# 98-98 there was one core discarded. Each project also had one core for which data was not available due to the core being obviously broken and as such, not useable. Once a correction factor was calculated for the two individual projects, that value was applied to the nuclear density readings that had been taken where cores were cut, and compared to the laboratory density values. This correction factor was applied to all of the nuclear density readings on the two projects. The error prior to the application of the correction factor is shown for both projects in Table #3.

<div align="center">**Table #3 % Density Error by Project Prior to Correction**</div>

Project	Sample Size	Error % Compaction Before Correction Factor
171-326	8	-0.2
98-98	18	-0.2

Initial Profile Analysis: After the correction factors had been applied, an overall average was taken of nuclear density by profile location. That is all of the nuclear densities for the location 1 foot from the joint on the cold side were averaged. This was repeated for the locations 6 inches from the joint on the cold side, the joint location, 6 inches from the joint on the hot side and 1 foot from the joint on the hot side. This included data from both projects. The averages can be seen in Table #4.

<div align="center">**Table #4 - Corrected Nuclear Density Averages by Profile Location**</div>

Joint Location (within the density profile)	A	B	C	D	E
Sample Size	35	35	35	35	35
Average Density (%MTD)	90.5	88.6	88.9	91.1	90.1

A = 1 foot cold side   B = 6 inches cold side   C = joint location   D = 6 inches hot side   E = 1 foot hot side

As a quick check for relevance, the same averages were computed for the volumetric density values of the cores by profile location, albeit the sample size was only about $1/5^{th}$ that of the nuclear density values. These averages are shown in Table #5.

<div align="center">**Table #5 – Core Density Averages by Profile Location**</div>

Joint Location (within the density profile)	A	B	C	D	E
Sample Size	7	7	6	7	6
Average Density (%MTD)	89.3	88.1	86.6	89.7	91.0

A = 1 foot cold side   B = 6 inches cold side   C = joint location   D = 6 inches hot side   E = 1 foot hot side

In comparison, the average values are relatively close between the nuclear density averages and the core averages. The largest difference was at location C which was the joint location itself. The nuclear density values at these locations were slightly higher

than the volumetric density values of the cores. This may be due, in part to the irregularities at the joint location. The nuclear gauge in some cases needed to be shifted slightly in the transverse direction from the joint in order to ensure adequate contact at the interface of the pavement and the nuclear density gauge. To make a statistical comparison between the two sets would be premature due to the very small sample size.

Figure #11 shows a plot of the average nuclear density behavior. The cold side of the joint overall appears to maintain lower density and more specifically the area of lowest density occurs from 6 inches on the cold side of the joint to the joint location itself. This may be due in part to less lateral confinement present during the compaction of the first paver pass. During the compaction of the second paver pass, the first paver pass provides the lateral confinement that the second pass can be compacted against. This holds true for traditional butt joints as well. Figure #12 shows the data plotted in the same manner for the volumetric core data as a quick check. It is important to note that although the volumetric core data was averaged and plotted, there were no statistical analyses conducted on the core data due to the inadequate sample size. All of the following statistical analyses were conducted using the nuclear density values.

Figure #11 – Notched Wedge Average % Corrected Nuclear Density by Profile Location

Average % Nuclear Density by Profile Location (Notched Wedge Joints)
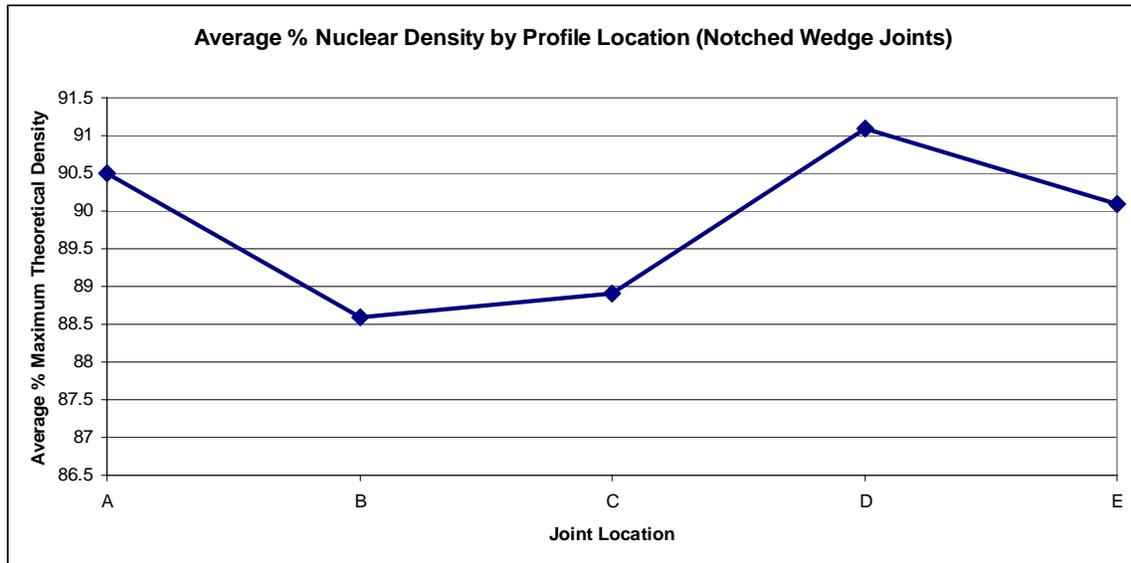
A = 1 foot cold side   B = 6 inches cold side   C = joint location   D = 6 inches hot side   E = 1 foot hot side

Figure #12 – Notched Wedge Average % Corelok Core Density by Profile Location

Average % Volumetric Core Density by Profile Location (Notched Wedge Joints)
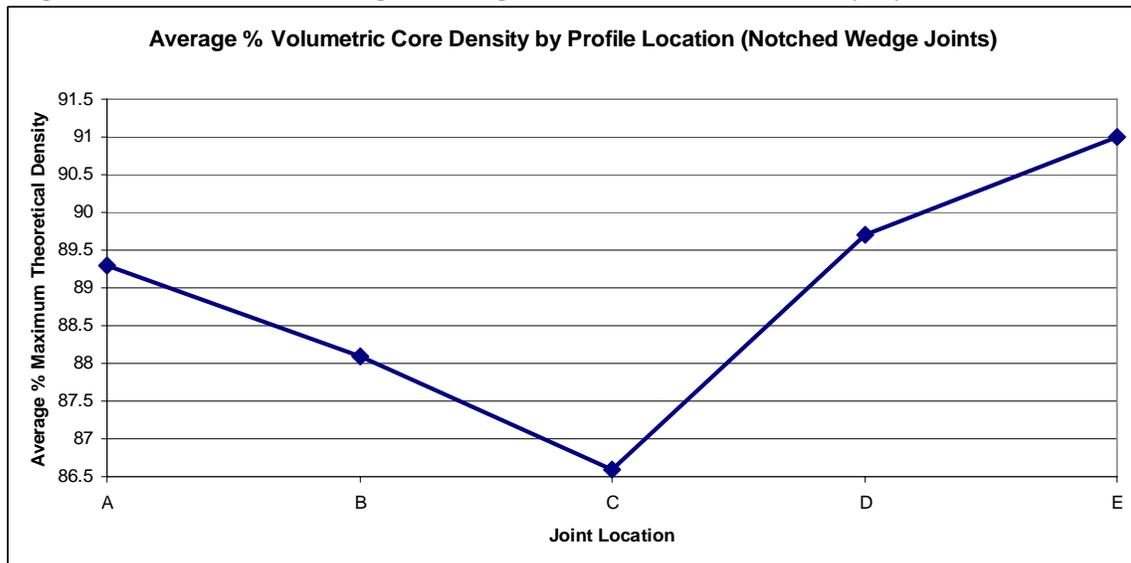
A = 1 foot cold side   B = 6 inches cold side   C = joint location   D = 4 inches hot side   E = 1 foot hot side

Also of importance are the population comparisons between profile location datasets. In addition to a graphical depiction of the differences in density from location A to location B and from B to C etc… a statistical population comparison was conducted to determine if in fact these differences were significant. This was done with four simple, single factor analyses of variance (ANOVA). The ANOVA takes into consideration the mean value, standard deviation and sample size of both populations. A statistic (*F*) is then calculated based on these three factors. Then, given the sample size, a value for which this statistic is compared against (*Fcrit*) is derived. *F*crit is the value for which the statistic *F* must not exceed in order for a statistical difference between sample sets to be non-existent. This was all done on a spreadsheet program with data analysis tools. The comparisons are shown in Appendix A

Considering both Figure #11 and Appendix A, the graphical differences between density profile A and B can be explained by the magnitude of the statistic *F*. The drop in density from 1 foot on the cold side to 6 inches on the cold side is shown both in the plot as well as the amount that the statistic *F* exceeds the critical value of *F*. This may again be due to the lack of lateral confinement as the edge of the cold pass is compacted.

This is not the case for the comparison between location B and location C. It can be seen in the plot that the density average increases slightly at the joint location but that the magnitude of the difference is not nearly as drastic as the first comparison. This is evident not only by viewing the slope of the line between them but also by comparing the *F* statistic with the critical value of *F*. *F* did not exceed *Fcrit* in this comparison and thus there is no statistically significant difference between the average density at the joint and

the average density 6 inches from the joint on the cold side. This reinforces that the lowest area of density across the joint profile is from 6 inches on the cold side to the joint itself.

The comparison between the joint and 6 inches from the joint on the hot side indicates a drastic increase in density on the hot side of the joint. *Fcrit* was indeed far exceeded by the statistic *F* in this comparison as can be seen in Appendix A. This is also evident in the slope increase between these two points on the plot. This is most likely due to the presence of the already placed cold side to act as lateral confinement for the hot side of the joint.

There is also a statistically significant difference between locations D and E. The average density value decreases from 6 inches on the hot side to 1 foot on the hot side. Although the difference is significant, the difference between *F* and *Fcrit* is not nearly as large as the differences seen between A and B and between C and D. It can also be seen that the average density value 1 foot from the joint on the hot side is very near the average density value 1 foot on the cold side. This indicates the non-homogeneous nature of the density around the joint and that those conditions become more homogeneous toward the center of the mat.

Traditional Butt Joint Correction Factors: The same method of correction utilizing the average error value from ConnDOT Report No. CT-2242-F-05-5n was used in determining the nuclear density values for six of the seven projects where the butt joint was used. Such was the case as CAP Lab personnel were not present to obtain nuclear

density data for Project #174-332H. For this project only core density values are available.

Upon attempting to develop this correlation based on cores cut from the mat, it was quickly realized that an inadequate number of cores were cut from the center parts of the mat on these projects as well as for the projects where the notched wedge joint was used. The correlation report prescribes that 10 cores be cut for the correlation. There were not 10 random mat cores cut on any of the projects where the notched wedge joint was utilized. As this was the case, the same treatment was given to the nuclear density values from the butt joint project as were given to the notched wedge joint projects. Thus all of the cores cut from the joints on the six pertinent butt joint projects were used to generate correction factors. The same restrictions were placed on measurements where the nuclear gauge value exceeded the volumetric core value by +2%. These values were discarded and not included in any measurement calculations or analysis as it is suspected that the core is most likely damaged or broken resulting in a significantly higher nuclear gauge value than volumetric density value. Table #6 shows the number of discarded core values per project while attempting to generate correction factors for the nuclear gauge values on the butt joint projects.

Table 6. Discarded Core Density Values (Butt Joints)

Project	Town	Route	Total Cores	Cores Discarded as Unusable
172-364C	N. Stonington	184	10	1
171-326C	Berlin	15	10	0
172-363F	Salem	354	20	4
172-363F	Montville	82	15	2
173-381C	Easton	59	30	3
172-363A	Killingly	6	25	3
174-332H	Kent	341	40	0 (No nuclear data obtained)

In total, 13 of 150 cores cut on projects where the butt joint was used were not useable for correction factor determination because they yielded errors in excess of +2%. Unlike the projects for which the notched wedge joint was used, there were no cores which were discarded because they were obviously and visibly broken or damaged. The correction factors were determined and applied for each profile location for each project. The averages were then computed per profile location across the joint for all projects. The graphical profile comparison of nuclear density to volumetric core density for each of the individual projects is shown in Appendix B. Figure #13 shows the overall comparison of average nuclear density values to average core density values both before and after the application of the correction factor.

Figure #13 Butt Joint Plot of Correction Factor Effect

Correction Factor Effect of Density By Profile Location

A = 1 foot cold side   B = 6 inches cold side   C = joint location   D = 4 inches hot side   E = 1 foot hot side
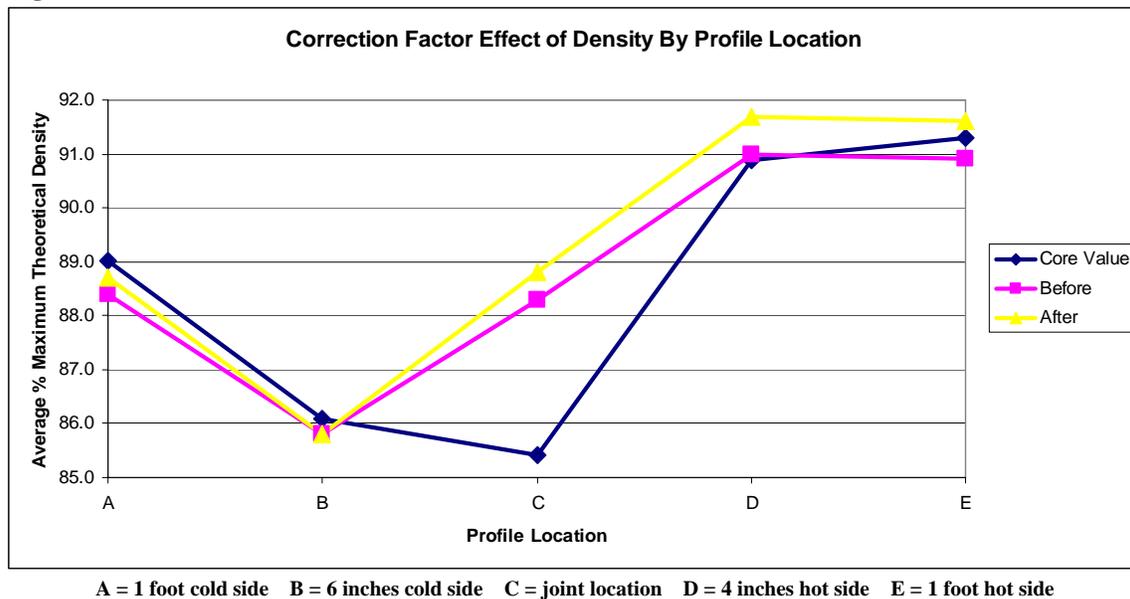
It should be noted that all of the cores that were deemed unusable were taken from locations B and C. There were 3 cores from location B and 10 cores from location C that

were measured in excess of 2% MTD less than the average nuclear value for that specific location. Locations B and C also correspond to the areas within the average profile that exhibit the lowest density. Therefore, the fact that the correction factor appears to be least effective in location C (the joint location) may be due in part to there being ten less cores for this area than in locations A, D and E. It should also be noted that the data used to compile the comparison for Table #6 does not include data from Project 174-332H, Rt. 341 in Kent. There are no nuclear density data available for that project. All further data analyses and comparisons will, however, include and use volumetric core density data from that project.

Initial Profile Analysis:

After the correction factor inclusion had taken place for the butt joint projects, the average of the core values and corrected nuclear density values by profile location were further analyzed. It was necessary to analyze the performance of the butt joint alone before any comparison could be made with the notched wedge joint. The average nuclear density value per profile location for all of the butt joint projects is shown in Table #7 and the average core density values are shown in Table #8.

Table 7. Butt Joint Corrected Nuclear Density Averages by Profile Location

Joint Location (within the density profile)	A	B	C	D	E
Sample Size	110	110	110	110	110
Average Density	88.7	85.8	88.8	91.7	91.6

Table 8. Butt Joint Core Density Averages by Profile Location

Joint Location (within the density profile)	A	B	C	D	E
Sample Size	30	27	20	30	30
Average Density	89.0	86.1	85.4	90.9	91.3

Keeping in mind that the sample size of the core data set can at best, be only $1/5^{th}$ the size of the nuclear density data set when all nuclear data are available, in this case it appears that that ratio is incorrect. This is due solely to the fact that CAP Lab cut 40 cores (8 sections) along the longitudinal joint on Rt. 341 in Kent for which there is no nuclear density data available. The two sets of data are shown in profile in Figure #14.

Figure #14. Core and Corrected Nuclear Density by Profile Location

A = 1 foot cold side   B = 6 inches cold side   C = joint location   D = 4 inches hot side   E = 1 foot hot side
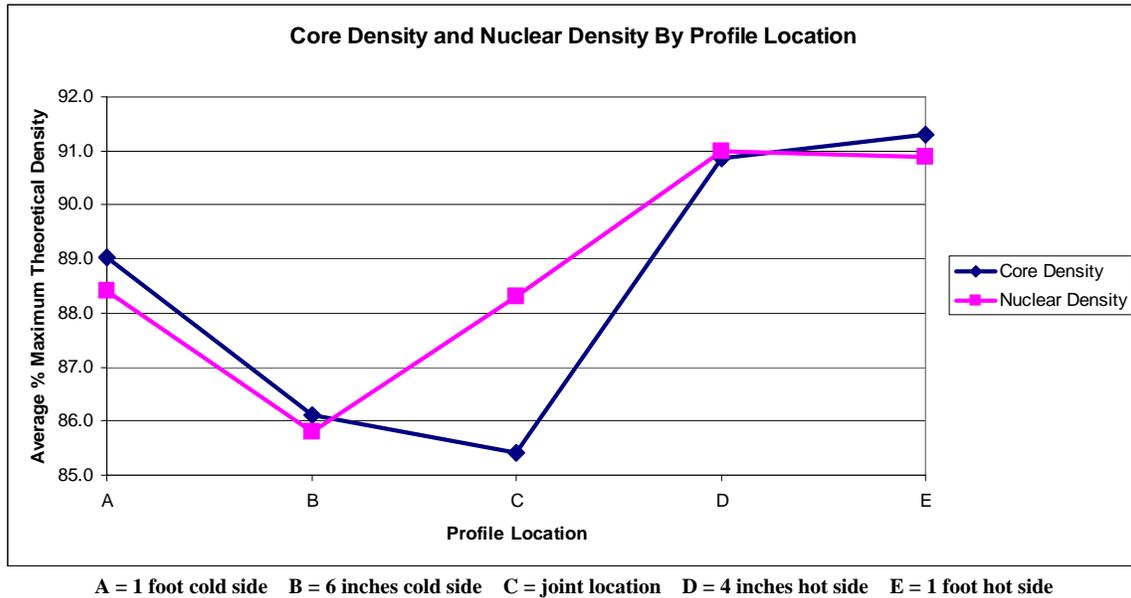
In comparison, though there are no nuclear measurements that correspond to the Rt. 341, Kent core data, when this data is added to the core data, the trends and actual average

data points come much closer together, particularly with respect to the joint location. The trend shows that the nuclear density profile data is consistently slightly higher than the volumetric core density data which adds confidence in that the differences are less sporadic.

Given the data and graphical depictions of the density in Tables 7, 8 and Figure 14, it is clear that the density in the vicinity of 6 inches on the cold side to the joint location itself (Locations B and C) exhibit a significantly lower density value than all of the other areas (Locations A, D and E). It can also be observed that the density at Locations D and E exhibit the highest level of density within the profile. The difference from Location C to Location D, is largest (most significant) change in density over the profile whether looking at nuclear density data or volumetric core data. This may be due in part to the presence of lateral confinement from the previous pass when paving the second pass and finishing the longitudinal joint.

The population comparisons between profile locations for the butt joint were done using the core density values as opposed to the nuclear density data. This was done differently than for the projects which utilized the notched wedge joint. It was desirable to utilize the nuclear data as it came from a much larger data set than the core data and in that the differences in average values were small as is seen in Figure 14. This however was not possible due to having no nuclear density measurements from the Rt. 341, Kent project.

The statistical breakdown of the comparison from location to location within the butt joint data set is shown in Appendix B. It can be seen in comparing the *F* statistic with the Critical Values of *F* from Location A to Location B that there exists a statistically

significant difference in density. This may be attributed to the fact that Location A lies 12 inches from the joint location while Location B only lies 6 inches from the butt location. As the joint location is approached as would be from the center of the mat, it can be expected that the density would drop in a linear fashion. That is for each unit length closer to the unconfined edge of the mat, the density would also drop one unit of measurement due to lack of lateral confinement at the edge of the first pass. This is nearly the case (although not perfectly linear) in Figure 14, shown above. As such, it can be seen that there is an inadequate level of density overall at both this location and the joint location. In looking at what happens when the second pass is placed, given Figure 14, and the Variance Analysis between locations C and D in Appendix B, the density improves drastically. That is there is a very large separation in the statistical density averages between these locations. This vast improvement in the overall density value may be attributed to the fact that there is the first pass for which the edge is there for the edge of the second pass to be compacted against. There exists some level of lateral confinement from the first pass such that the hot side of the joint is allowed to be compacted to a greater degree than was the first. This is similar to the density performances of the notched wedge joint projects previously analyzed.

Comparison: Notched Wedge vs. Butt Joint

It should be noted at this point that for the statistical methods of comparison to be valid, the sample sizes are thus far inadequate. The notched wedge joint data was taken only from 2 projects, which comprised a total of seven sections, or 35 total cut cores and for which 7 were discarded as damaged. The butt joint projects during the 2006 construction

season were more prevalent and there is more data available for those projects. The 2006

butt joint data included 7 projects, which comprised a total of 30 sections, or 150 cut

cores for which 13 were discarded as damaged. The only data that could be looked at, at

this point are the actual density averages to get an idea of how the trends have compared

so far. It would be useless to attempt to draw conclusions from a comparison of

population sets or make any statistical comparisons between the performances of the two

joint construction methods given the insufficient amount of data available for the notched

wedge joint.

Table #9 shows the average nuclear density by profile location between the two joint

construction methods while Table #10 shows the average core density values by profile

location. It should be repeated at this time that there is volumetric core data available for

the Rt. 341, Kent project; however there is no nuclear density data available. This means

that only the core density dataset is included in that data.

Table 9. Corrected Nuclear Density Values

Joint Location (within the density profile) Butt Joint Data	A	B	C	D	E
Sample Size	110	110	110	110	110
Average Density	88.7	85.8	88.8	91.7	91.6
Joint Location (within the density profile) Notched Wedge Joint Data	A	B	C	D	E
Sample Size	35	35	35	35	35
Average Density (%MTD)	90.5	88.6	88.9	91.1	90.1

Figure 15. Butt Joint Vs. Notched Wedge Joint (Nuclear Density)

Comparison: Butt Joint Vs. Notched Wedge Joint (Nuclear Density)
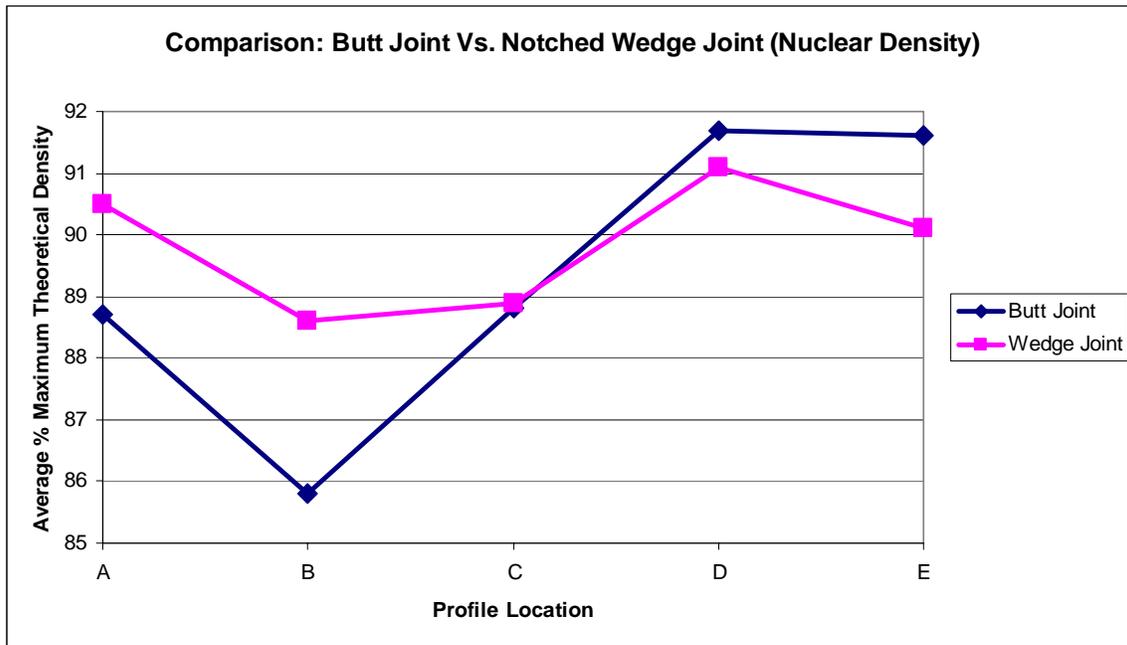
A= 1 foot cold side   B = 6 inches cold side   C = joint location   D = 4 inches hot side   E = 1 foot hot side

Table 10. Core Density Values

| Joint Location (within the density profile) Butt Joint Data	A	B	C	D	E
Sample Size	30	27	20	30	30
Average Density	89.0	86.1	85.4	90.9	91.3
Joint Location (within the density profile) Notched Wedge Joint Data	**A**	**B**	**C**	**D**	**E**
Sample Size	7	7	6	7	6
Average Density (%MTD)	89.3	88.1	86.6	89.7	91.0

Figure 16. Butt Joint Vs. Notched Wedge Joint (Core Density)
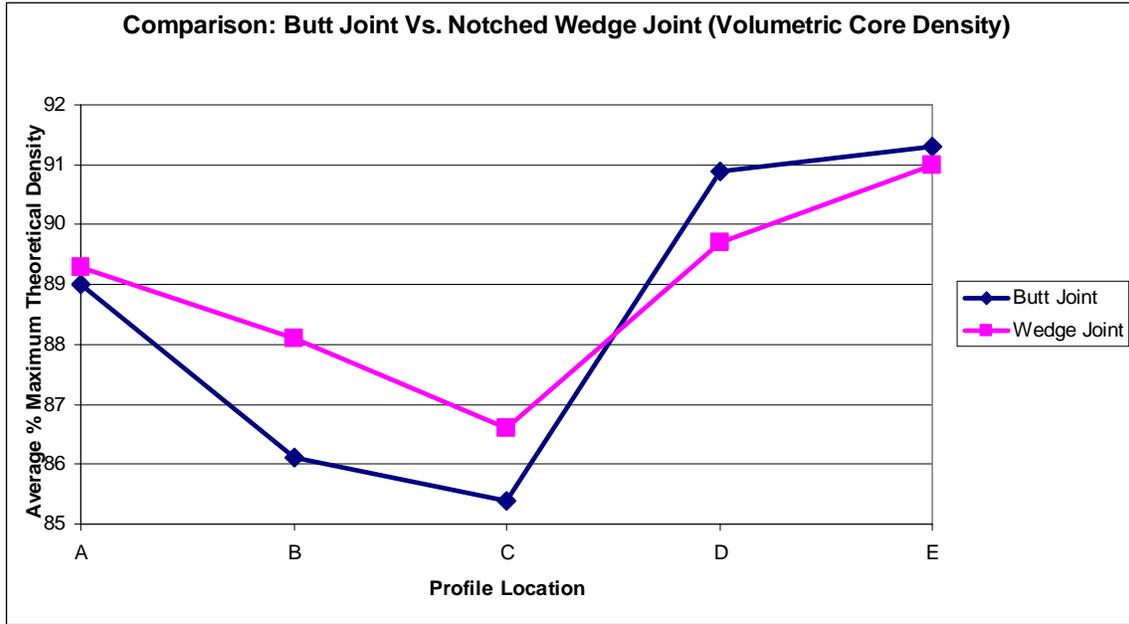
A= 1 foot cold side   B = 6 inches cold side   C = joint location   D = 4 inches hot side   E = 1 foot hot side

It appears, based upon this limited amount of data, that the notched wedge joint provides a higher level of density on the cold side of the joint than does the butt joint. This could perhaps be a result of the material present in the wedge cooling faster and therefore acting as lateral confinement for the material being compacted at locations A and B. The density at the joint itself appears to be higher on the notched wedge joint than the butt joint when examining the core density values. When examining the nuclear density values at the joint location, they appear to be relatively the same between the notched wedge joint and the butt joint. The density at location D (6 inches on the hot side) appears to be approximately 1% lower on the notched wedge joint than the butt joint. The density of the material at location E (12 inches on the hot side) is just slightly lower for the notched wedge joint than the butt joint when examining the core data and approximately 1.5% lower for the notched wedge joint when looking at the nuclear

density values. This is an indication of the density performance only based on the limited data which was collected over the 2006 construction season.

Conclusions

Based on the data seen so far it is evident that if a core correction factor is to be established, more random cores need to be cut from the mat. The correlation procedure prescribes that 10 random cores be cut in order to develop a correction factor that will be beneficial to the accuracy of the nuclear density data. Thus on future pilot projects for which the notched wedge joint is being investigated; there is a need to obtain additional mat cores. If this is not possible or if the correlation does not exist, then a correction factor using cores cut from the joint will be needed.

There is a lower average density value 6 inches on the cold side of the joint than there is 6 inches on the hot side of the joint for both the notched wedge joint comparisons as well as the butt joint comparisons. That can be seen in Table 9. This can be attributed to a lack of lateral confinement on the joint edge during compaction of the first pass or cold side which allows lateral movement of the joint material. This is also evident in the comparisons between the joint location and 6" on the hot side of the joint as is shown for locations C and D in Table #9. There is a large increase in average density between these two locations for both sets of data. This can be seen graphically in Figures 15 and 16. It is speculated at this point that the reason for this increase is the presence of the edge of the first pass (cold side) providing lateral confinement for the material being compacted at the edge of the second pass thus resulting in a much higher density.

The use of the notched wedge joint did not impede the paving process during the two investigated pilot projects. Crews will also become more familiar and efficient with this process as they gain experience with it.

There is a need for further comparison of joint quality and density performance between the notched wedge joint and the traditionally used butt joint. This process is ongoing and will require more data to be collected from projects which utilize the notched wedge joint as there is an insufficient amount of data on the performance of the notched wedge joint at this time. The preliminary results of the comparison between the two different joint construction methods show a higher level of density on the cold side of the joint for the notched wedge joint than for the butt joint. This could be indicative of the wedge material acting as lateral confinement for the material being compacted at the edge during the first pass.

Recommendations

It is recommended at this time that additional projects be identified for which the notched wedge joint would be utilized in order to collect a sufficient amount of data with respect to that joint construction method. This would provide better insight as to the overall performance, density and constructability of this joint method as the data collected so far is inconclusive.

Additional monitoring of the projects investigated in this research should also take place. The long term performance of the stated notched wedge joint projects compared with the

investigated butt joint projects would provide insight as to the effect of age on the performance of each different joint type.

A possible project utilizing a butt wedge with joint adhesive has also been identified for construction in 2007 which would lend itself useful to the purpose of this research.

One-Day Workshop for Study Results

The one-day workshop that was to be part of this project will be delivered at the conclusion of the work conducted during the second year of this study that was added to the project. This allow for the most up-to-date information to be distributed.

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Appendix A – Analysis of Variance For Notched Wedge Joint

Location A and Location B

Anova: Single Factor						
SUMMARY						
Groups	Count	Sum	Average	Variance		
A	35	3168.842	90.53835	6.835277		
B	35	3102.717	88.64905	7.757821		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	62.46555	1	62.46555	8.560972	0.004665	3.981896
Within Groups	496.1653	68	7.296549			
Total	558.6309	69				

Location B and Location C

Anova: Single Factor						
SUMMARY						
Groups	Count	Sum	Average	Variance		
B	35	3102.717	88.64905	7.757821		
C	35	3112.492	88.92834	8.01316		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.365053	1	1.365053	0.173109	0.678673	3.981896
Within Groups	536.2134	68	7.88549			
Total	537.5784	69				

Location C and Location D

Anova: Single Factor						
SUMMARY						
Groups	Count	Sum	Average	Variance		
C	35	3112.492	88.92834	8.01316		
D	35	3190.225	91.14928	3.713419		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	86.32014	1	86.32014	14.72213	0.000275	3.981896
Within Groups	398.7037	68	5.86329			
Total	485.0238	69				

Location D and Location E

Anova: Single Factor							
SUMMARY							
Groups	*Count*	*Sum*	*Average*	*Variance*			
D	35	3190.225	91.14928	3.713419			
E	35	3153.326	90.09504	2.603278			
ANOVA							
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	
Between Groups	19.44986	1	19.44986	6.158237	0.015557	3.981896	
Within Groups	214.7677	68	3.158349				
Total	234.2176	69					

Appendix B – Analysis of Variance For Traditional Butt Joint

Location A and Location B

Anova: Single
Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
A	30	2684.134	89.47114	3.122435
B	27	2344.314	86.82643	6.892019

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	99.39511	1	99.39511	20.26644	3.54E-05	4.016195
Within Groups	269.7431	55	4.90442			

		Total	369.1382	56		

Location B and Location C

Anova: Single
Factor

SUMMARY

Groups	Count	Sum	Average	Variance
B	27	2344.314	86.82643	6.892019
C	20	1715.813	85.79067	4.556463

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	12.32576	1	12.32576	2.087027	0.155482	4.056612
Within Groups	265.7653	45	5.905895			
Total	278.0911	46				

Location C and Location D

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
C	20	1715.813	85.79067	4.556463
D	30	2731.99	91.06632	4.087893

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	333.9901	1	333.9901	78.15616	1.22E-11	4.042652
Within Groups	205.1217	48	4.273369			

Total	539.1118	49

Location D and Location E

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
D	30	2731.99	91.06632	4.087893
E	30	2748.17	91.60566	3.592398

ANOVA

| Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	4.363307	1	4.363307	1.136235	0.290867	4.006873
Within Groups	222.7284	58	3.840145			
Total	227.0917	59				

Appendix C. Before & After Application of Correction Factor (Butt Joint Projects)

Berlin.

Average % Nuclear Density by Profile Location Before Correction Factor

Average % Nuclear Density by Profile Location After Correction Factor

North Stonington

Average % Nuclear Density by Profile Location Before Correction Factor

Average % Nuclear Density by Profile Location After Correction Factor

Salem

Average % Nuclear Density by Profile Location Before Correction Factor

Average % Nuclear Density by Profile Location After Correction Factor

Montville

Average % Nuclear Density by Profile Location Before Correction Factor

Average % Nuclear Density by Profile Location After Correction Factor

Easton

Average % Nuclear Density by Profile Location Before Correction Factor

Average % Nuclear Density by Profile Location After Correction Factor

Killingly

Average % Nuclear Density by Profile Location Before Correction Factor

Average % Nuclear Density by Profile Location After Correction Factor