

**Summary of the 2006 Use of a Notched Wedge  
Joint in Connecticut Pilot Projects  
Phase 1 Interim Report**

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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 as 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 an alternative method of HMA longitudinal joint construction, the Connecticut Advanced Pavement Laboratory (CAP Lab) in cooperation with Connecticut Department of Transportation (ConnDOT) investigated the use of a notched wedge joint on two pilot projects in Connecticut. The first, Project #171-326C, took place on Rt. 15 in Berlin, Connecticut during the month of September, 2006. The second, Project #98-98, took place on Rt. 80 in North Branford during the month of October, 2006. On both 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 insufficient, preliminary results show an increase in density at the joint on the hot side. This is most likely due to the first paver pass providing lateral confinement for the second pass to be compacted against. 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. The acceptance testing conducted by ConnDOT on the joint was particularly successful. Project #171-326C had an overall joint density of 92.5% of Maximum Theoretical Density (MTD) while project #98-98 had an overall joint density of 93.5% of MTD. The placement of the joint did not impede or disrupt the paving process.

It is desired that additional projects be established for investigation into the notched wedge joint in Connecticut. Although the initial data is favorable of the notched wedge joint, it is necessary to secure additional data to verify and justify its use in Connecticut.

## **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 width 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 person's foot or 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 and in some cases milling off the existing wearing surface and replacing it.

The mechanism that drives the 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 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

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 decrease the lateral width of the pavement. As the pavement 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*. (1)

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* (3) indicates such research. The author, M. Shane Buchanan 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 and the long term performance of the longitudinal joint in mind, Apkinar et al. (4) concluded that “Longitudinal joints in asphalt pavements with high densities generally show better performance than those with relatively low densities.”

To slow the rate at which longitudinal joints fail, proper construction techniques that ensure a high density (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.

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. This also commonly referred to as a *conventional* or *vertical* joint. (3) Achieving adequate density on the cold edge of the longitudinal joint is difficult because at the time of its compaction, there was no lateral confinement to compact it against. Therefore, the unconfined edge is able to move laterally when the downward compaction force is applied. Theoretically, the ideal compaction method would provide some sort of lateral confinement on both edges of the 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 observed to be higher. This type of

compaction is not practical for typical construction situations. Thus it would be beneficial to develop a joint method to minimize all of these problems.

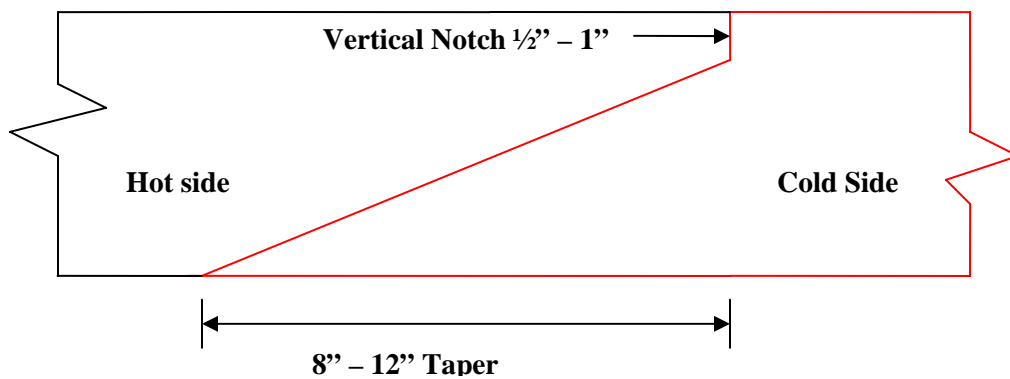
There is a considerable amount of research available that indicates the notched-wedge joint (Figure #1) can be used to achieve a higher level of density than the traditionally used butt joint. One such instance is Buchanan, (3); he reports that in four out of five construction projects (one project each in the States of Colorado, Indiana, Alabama, Wisconsin and Maryland) investigated over the course of that research, the notched wedge joint resulted in an increased centerline density when compared with the traditional butt joint.

### **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 #1). 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. 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.

### **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).



**Figure #1 – Notched Wedge Forming Device**



**Figure #2 – Notched Wedge Joint Diagram**



**Figure #3 – Wedge Compaction Device and Setup**

### **Notched Wedge Pilot Projects:**

The notched wedge joint was trialed 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.

**Project #171-326C Description:** Rt. 15 in Berlin Connecticut was the first pilot project, paved on the nights of September 6<sup>th</sup> and 7<sup>th</sup>, 2006. The 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 75mm (3 inches). A 25mm (1 inch) leveling course of Superpave 9.5mm (0.375 inch) level 3 was placed over the milled surface prior to the wearing surface consisting of a (50mm) 2 inch course of Superpave 12.5mm (0.5 inch) level 3. The notched wedge joint method was trialed 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, 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 (first night) or right shoulder (second night) 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 #3.

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. This was possible because vehicles were able to traverse the wedge when it was left open as opposed to the drop-off that would have been left if the traditional butt joint had been used. 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 – 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. 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 aggregate was noticed loose 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.

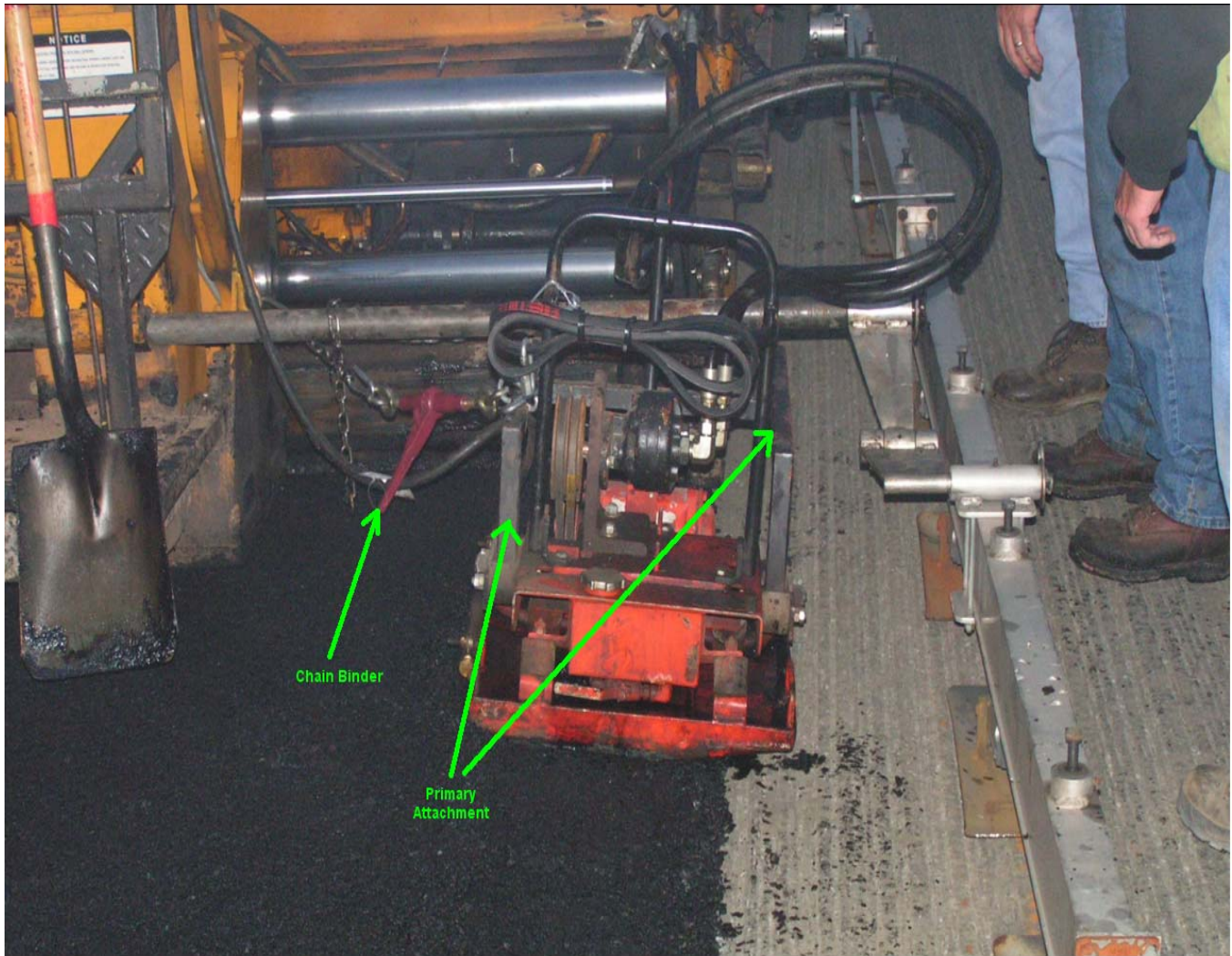
***Field Observations – Acceptance Testing of the Joint:*** Nuclear density tests performed by ConnDOT for acceptance on the notched wedge joint averaged 92.5% of Maximum Theoretical Density (MTD) with no failing tests. The procedure ConnDOT used on the joints for acceptance testing on this project is as follows: All ConnDOT nuclear density measurements were taken after the hot side of the joint was paved. 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 180° 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 10<sup>th</sup> -12<sup>th</sup>, 2006. The material was supplied by Tilcon Connecticut's North Branford plant. The material was placed by CT Paving. A 50mm (2 inches) course of Superpave 12.5mm level 2 was used. This was a full depth reconstruction project with a bituminous concrete base. The base course was 150mm (6 inches) of Superpave 37.5mm level 2. The lift directly below the top 50mm lift was 40mm of Superpave 12.5mm 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 #4 shows the setup used on this pilot project.



**Figure #4 – Project #98-98 Compaction Device Setup and Attachments**

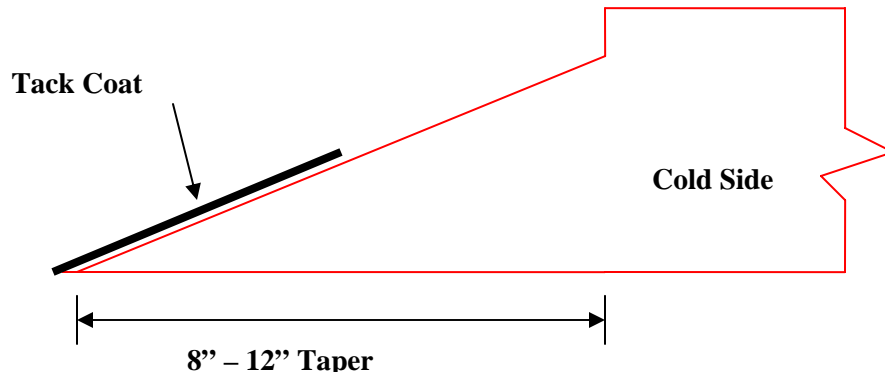
This project was shorter in overall paving lane length, did not have a center median area or any left or right turning lanes. Therefore, there was no need for a second paver and only a single paver was used. A Material Transfer Vehicle was not incorporated to the placement of this material. A 30 foot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

and shoulder, the exposed notched wedge joint was at the centerline of the roadway (Figure #5). 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 #6. This problem will need to be addressed on future trial or study projects incorporating the notched wedge joint method.



**Figure #5 – Project #98-98 Notched Wedge Joint at Centerline of Roadway**



**Figure #6 – Tack Coat on Lower Half of Wedge Diagram**

The two west bound lanes being paved remained closed to traffic through the course of the first nights 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 – Traffic on Open Joints:** The construction and use of the exposed joint as it was opened to traffic was filmed once again. 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 aggregated 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 #7).



**Figure #7 – Traffic Traversing the 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 on this project is as follows: All ConnDOT nuclear density measurements were taken after the hot side of the joint was paved. 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 180° 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 payment.

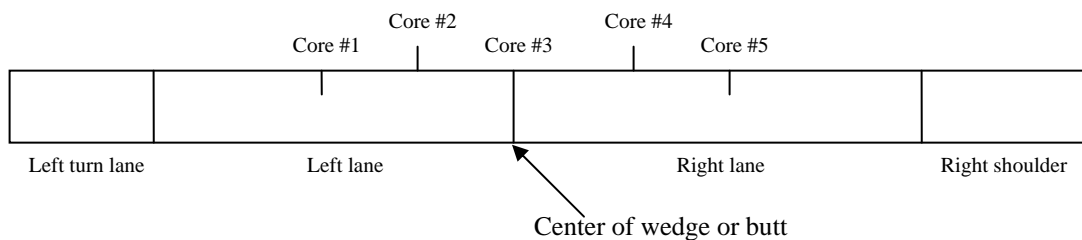
### **Field Evaluation Plan at Time of Construction**

CAP Lab personnel were onsite with the tools necessary for obtaining all data and samples pertinent to evaluating the longitudinal joint. This equipment included a drill with a 6 inch coring bit, generator, cooling water, distance measurement devices, digital camera 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.

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 would 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 #8, #9). 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 #9).



**Figure #8 – Sampling Plan – Cross-Sectional View**

○ = 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.

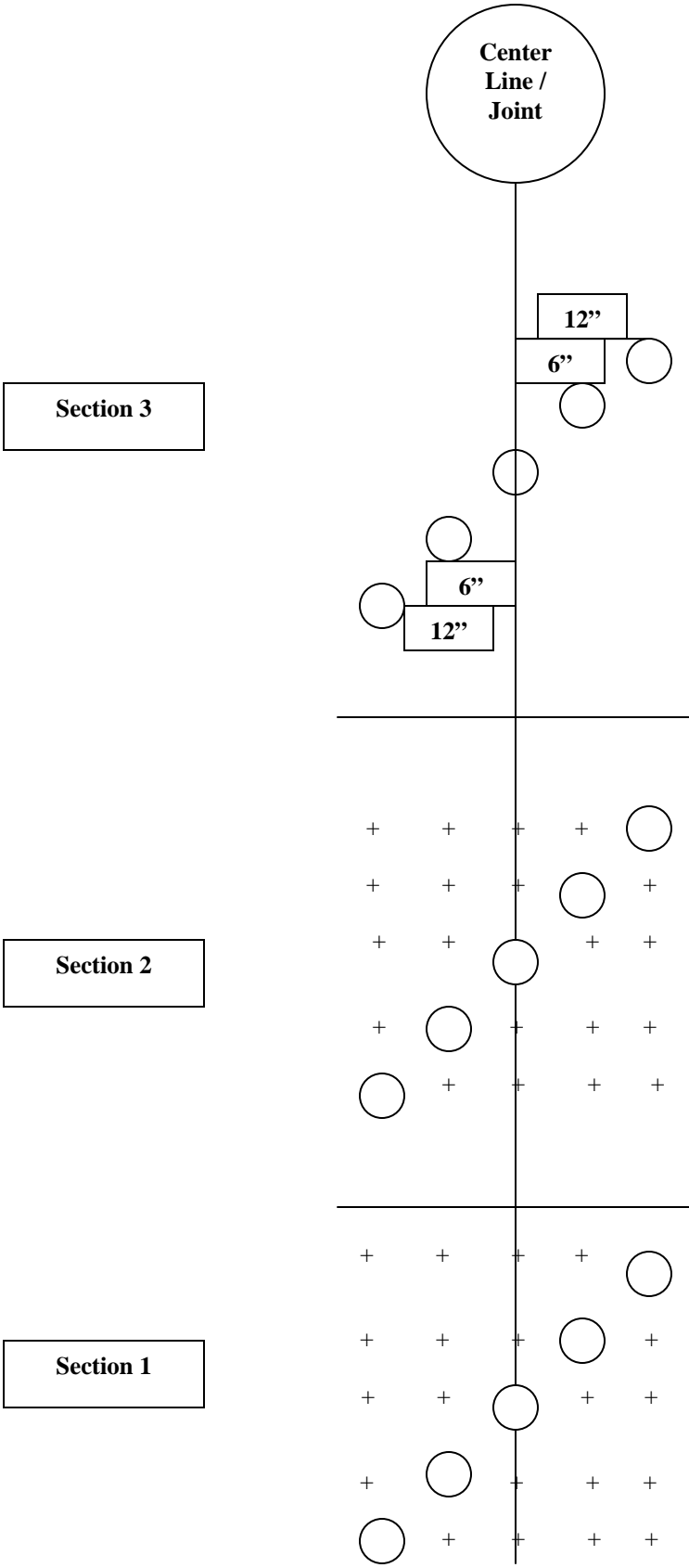


Figure #9 – Sampling Plan – Plan View



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 began collecting data. The distance of paving as well as quality 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. 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 project 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.

*Notched Wedge Correction Factors:* Connecticut Report No. CT-2242-F-05-5; *Correlation of Nuclear Density Readings with Cores Cut from Compacted Roadways (2)* 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 two projects. Project #171-326C there was only 4 random mat cores cut and on Project #98-98 there were no random mat cores cut. It was attempted to develop the correction with the few random mat cores that were cut however the attempt was unsuccessful. In future sections and projects, 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 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. 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 broken. 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. In both of the above stated projects the application of the correction factor resulted in an average error of 0.0% of maximum theoretical density which would be expected since all of the cores were used. With this in mind, the 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 #1**.

**Table #1 – Percent Density Error by Project Prior to Application of Correction Factor**

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

**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 #2.

**Table #2 - Nuclear Density Averages by Profile Location**

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

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<sup>th</sup> that of the nuclear density values. These averages are shown in Table #3.

**Table #3 – Core Density Averages by Profile Location**

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

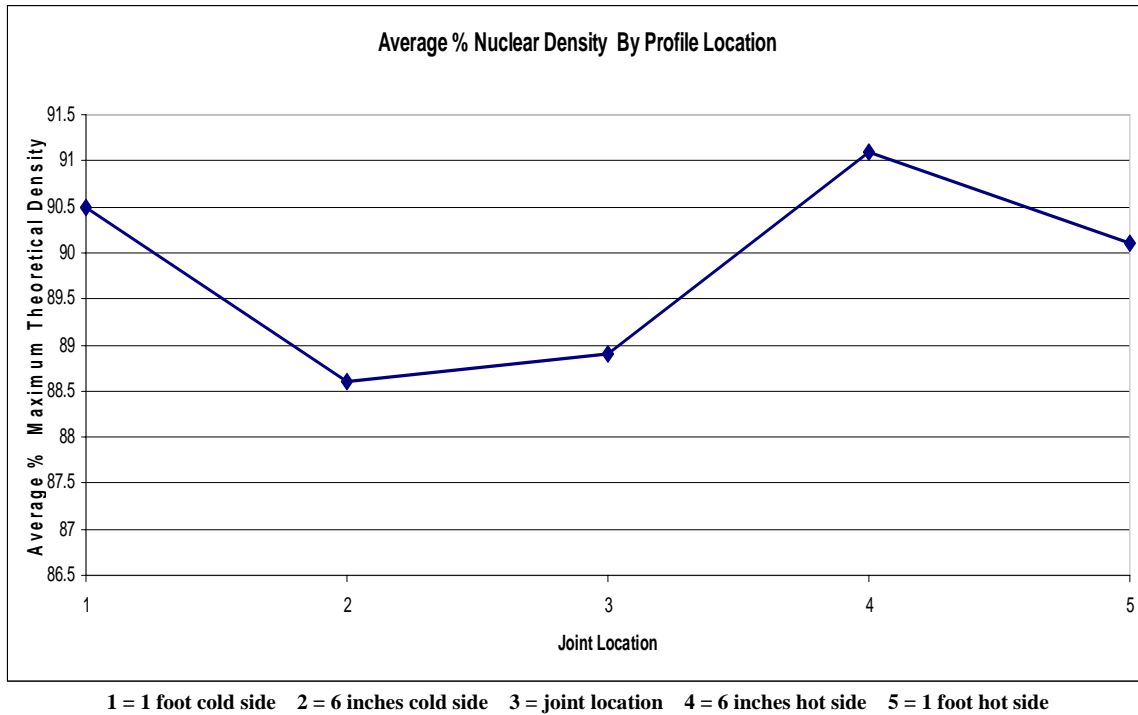
A = 1 foot cold side B = 6 inches cold side C = joint location D = 6 inches hot side E = 1 foot hot side

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.

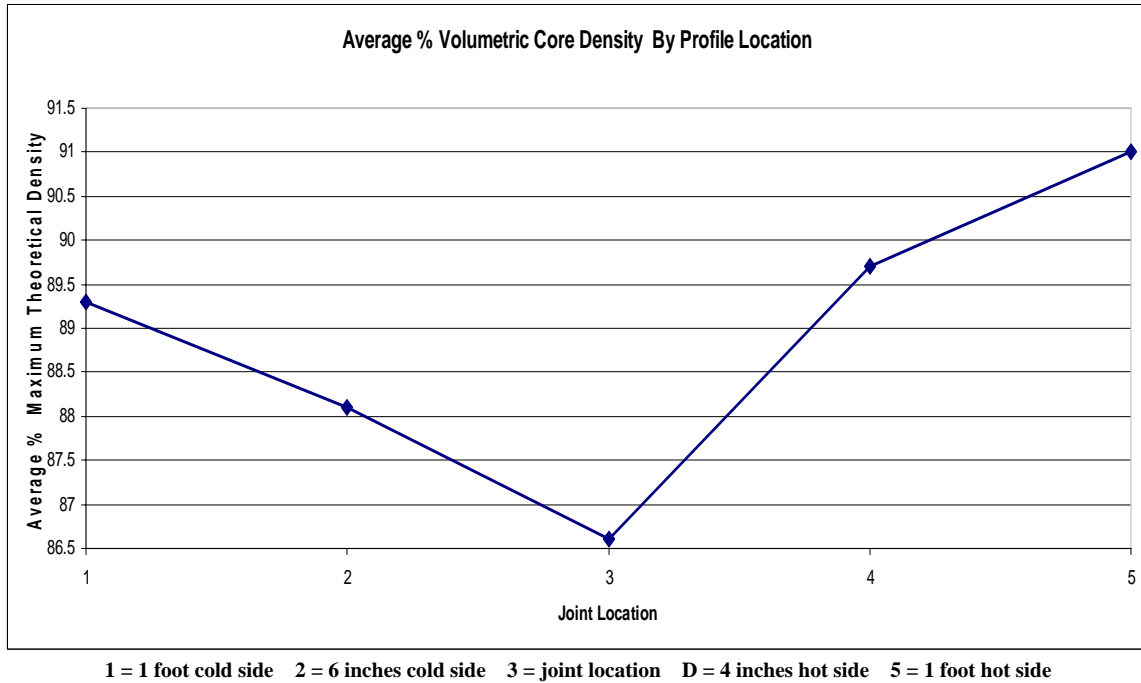
Figure #10 shows a plot of the average nuclear density behavior. The cold side of the joint overall appears to maintain lower density and more specifically the area of lowest density occurs from 6 inches on the cold side of the joint to the joint location itself. This may be due in part to less lateral 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 #11 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 #10 – Average % Nuclear Density by Profile Location**



**Figure #11 – Average % Volumetric Core Density by Profile Location**



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 ( $F_{crit}$ ) 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 #10 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  $F_{crit}$  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.  $F_{crit}$  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  $F_{crit}$  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.

## **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 for more attempts 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. That can be seen in the comparisons in the previous section in Tables 2 and 3 and figures 10 and 11. These indicate that the density measured 6 inches on the cold side of the joint was 1.6 percent less than 6 inches on the hot side when the volumetric density was compared and 2.5 percent less when comparing nuclear density averages. 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 seen in the above comparisons in Tables 2 and 3 and in Figures 10 and 11. There is an increase in average density from the joint location and 6 inches on the hot side of the joint.

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 a comparison of joint quality between the notched wedge joint and the traditionally used butt joint. This process is ongoing. The report for this comparison will be submitted as an interim report as part of this research.

## References

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## Appendix A – Analysis of Variance

### 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						
<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>		
C	35	3112.492	88.92834	8.01316		
D	35	3190.225	91.14928	3.713419		
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
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						
<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>		
D	35	3190.225	91.14928	3.713419		
E	35	3153.326	90.09504	2.603278		
ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	19.44986	1	19.44986	6.158237	0.015557	3.981896
Within Groups	214.7677	68	3.158349			
Total	234.2176	69				