

**Application of Infrared Thermographic Imaging  
to Bituminous Concrete Pavements**

**Interim Report**

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| <b>16. Abstract</b><br><p>Recent research has shown that damage to hot mix paving mixtures (HMA) occurs during construction as a result of temperature differentials of the HMA mix during transport to and discharge from the paver. This phenomenon is called temperature differential damage (TDD). Researchers used a highly accurate infrared camera to evaluate this phenomenon. Temperature differentials were observed in the local HMA, and it was noted that areas of cool material did not consolidate properly during the placement process. Open segregated-appearing areas of pavement often resulted. Based upon the above research findings, it appears that the Department would benefit from the development of guidelines for reducing the occurrence of TDD by improved loading, trucking, handling, and placement methods and/or by employing new technology on HMA paving projects such as remixing pavers or remixing material transfer devices.</p> <p>In this investigation, difficult field conditions were imaged to obtain data on cold spots related to: cold-weather paving, night paving, cold-weather paving at night, paving equipment, paving bridge decks, and other seasonal paving situations.</p> <p>This interim report presents the results of the literature search and interim findings from the field investigation.</p> |                                                                |                                                                                                                                                                           |                                   |                  |
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## **Application of Infrared Thermographic Imaging to Bituminous Concrete Pavements**

### Background

Most of the pavement in Connecticut is constructed of hot mix asphalt (HMA). For successful placing and compaction of HMA, each step in the placement procedure must be accomplished within the proper temperature range. Thus, when the mix temperature varies in material placed, the compaction and thus the performance of the in-place pavement can also be expected to vary. Infrared thermometers have long been used to check surface temperatures, but small areas of low temperature can easily be missed. Infrared thermographic imaging is an alternative to thermometers that is available to give a continuous plot of surface temperatures. The infrared camera displays and records temperatures as colored images with a reference scale.

The research division of Connecticut Department of Transportation completed a study of temperature differential damage in HMA projects in autumn 1999. Thermal images were taken immediately after paver laydown and pairs of neighboring high-low temperature spots were selected. Nuclear measurements of the density after compaction were made in and near each recorded cool spot. Comparisons of the computed air voids for each pair (high and low temperature at the time of compaction) revealed differences in density as high as 8 percent. For a limited number of pairs, cores were also taken and the difference in air voids determined. The consistency of bituminous binder is influenced greatly by temperature; therefore, differences in the degree of compaction can be expected when the temperature varies.

Within the same study, frequently open textured areas were recorded as being cooler at the time of rolling. Observations over the years indicate that the open textured areas often perform poorly, frequently breaking up and developing into raveling at a much younger age than areas with tighter surface texture. Several other studies have shown that the problem is recognized throughout the United States. The infrared thermographic imager makes effective monitoring of temperature variations more possible than it was for earlier studies. If the causes of localized temperature differences can be determined, and techniques to reduce this differential developed, pavement life may be expected to increase.

### Study Objectives

The purpose of the investigation was to use infrared thermographic imaging to identify factors or conditions that contribute to the presence of cold spots in fresh paver-placed asphalt concrete, which affect compaction and lead to premature distress of the pavement. Data obtained from the project may be evaluated and used to provide contractors with tools to rectify the problem possibly before being required to use a material transfer device.

Temperature data was obtained using an infrared thermographic imaging camera, and related computer software, at paving sites in the field. Field conditions desirable for obtaining data on cold spots included:

- Cold weather paving
- Night paving
- Cold weather paving at night
- Seasonal paving – to rate severity/impact of temperature difference during summer and winter weather
- Paving equipment

- Bridge decks

An initial review of six to eight projects would be conducted to identify a variety of differences in the observations.

The Connecticut Department of Transportation would benefit through improved pavement performance. Better understanding of the relationship between placement conditions and mix temperatures would result in the development of improved placement procedures. Quantifying temperature differences based upon environmental conditions would assist DOT and industry personnel in the decision-making process related to paving operations during less-than-optimal conditions. Reduction in temperature differentials in the asphalt concrete mixture during the placement operation should reduce the number of irregularities and consequently, decrease the penalties conferred to contractors. The result would include improved durability and rideability of the finished pavement. Improved durability and rideability will ultimately benefit the motoring public by providing a smooth, longer lasting pavement.

## Literature Review

In recent years, a number of studies have been conducted that attempt to explain field observations of segregation in bituminous concrete pavements. This form of segregation has been referred to as “end-of-load”, “cyclic”, “systematic” or “spot” segregation. An attempt was made to identify, define, and measure this type of segregation through laboratory testing, field observations, and visual inspection. As part of a comprehensive NCHRP 9-11 study, Stroup-Gardiner and Brown (2000) defined segregation as:

“...a lack of homogeneity in the HMA constituents of the in-place mat of such a magnitude that there is a reasonable expectation of accelerated pavement distress(es). Constituents are interpreted to mean asphalt cement, aggregates, additives, and air voids.”

The primary focus of their study was to formulate procedures for identifying and measuring segregation (both gradation and temperature segregation) using various techniques. Each technique was also evaluated for its usefulness in detecting and assessing segregation and included a wide-range of nondestructive and destructive testing approaches. Infrared thermography was one of the approaches analyzed along with nuclear density tests, cores, portable seismic pavement analyzer, and ROSAN<sub>v</sub> surface texture measurement system. Pavement condition surveys from six states (including Connecticut) were presented with respect to gradation and temperature segregation and showed a decrease in life ranging from 5 to 12 years for pavements exhibiting segregation. Infrared thermography was reported as a viable method for doing the following:

- Surveying each lot for temperature differentials which indicated the level of segregation, and then allot consequent pay adjustments;



- Estimating the level and percentage of segregation in a specified area of pavement mat;
- Developing percent uniformity measurement for each lot potentially through use of an infrared sensor bar mounted behind paver screeds, and displayed on a monitor posted next to the paver operator.

The researchers reported that infrared thermography was not useful in identifying the type of segregation (gradation versus temperature). Additionally, staff at NCAT developed a spreadsheet analysis program that normalized data from thermal photographs and then created a histogram of temperatures that was used to compute the percent of level of segregation.

Another study was conducted in Michigan to classify levels of segregation on nineteen field sites, comparing one-minute nuclear density measurements and gradation tests on cores. The study did not attempt to identify the causes of segregation, but observed statistical patterns between gradation values and nuclear-measured density values for “segregated” and “non-segregated” portions of the mat. A sampling technique along with statistical methods was developed; however, the infrared thermographic camera was not used in the study.

Researchers in the state of Washington examined four WashDOT paving projects in 1998 for evidence of end-of-load segregation. Mostly dense-graded asphalt concrete mixes were monitored using the thermal infrared camera to identify the existence and extent of mat temperature differentials and related material properties. The sampling and testing of hot-mix during placement and compaction was the focus for the study, in terms of evaluating segregation. Early and late season projects, along with night projects, were evaluated for temperature differentials in the mat. Equipment and construction practices

were documented and in at least one project, a Material Transfer Vehicle (MTV) was used during paving operations. Samples were taken from the mat behind the paver screed and from the truck bed. Devices such as the nuclear gauge, non-nuclear gauge (PQI), and digital probe thermometer were used in addition to use of the thermal infrared camera and the extraction of cores. Density and percent air voids were determined and analyses using the Rice density test, gradation, and asphalt content were performed. Gradation and asphalt content analysis showed no significant aggregate segregation or difference in asphalt content within the cooler areas, although higher air voids were found in these areas. Temperature differentials for the four projects examined ranged between 7° and 39° C. It was reported that concentrated areas of significantly cooler material resulted in reduced compaction of these areas in the mat. The researchers also suggested that shorter haul times, insulated truck beds, warmer weather paving, improved rolling practices, and more frequent remixing of the HMA would help to greatly reduce or eliminate the occurrence of temperature differential damage.

John Henault (ConnDOT) completed a study on temperature differential damage for HMA projects in the fall of 1999. Thermal images were taken immediately after paver laydown and pairs of neighboring high and low temperature spots were selected. Nuclear measurements of the density after compaction were made on each spot. Comparisons of computed air voids for each pair (high and low temperature at time of compaction) revealed differences ranging up to 8%. For a limited number of pairs, cores were also taken and differences in air voids were determined. Since the viscosity of asphalt binder is directly related to temperature, differences in the degree of compaction can be expected when the temperature varies. It was also reported that open-textured

areas were frequently cooler at the time of rolling. Observations over the years have indicated that the open-textured areas often perform poorly, raveling at a much younger age than areas with less surface texture. Several other studies were found by Henault indicating that end-of-load segregation is recognized as an industry-wide problem. He confirmed that use of an infrared thermographic imager enabled more effective monitoring of localized temperature variations.

A similar study conducted by Washington State Department of Transportation was recently completed in Summer 2001. The study examined thermal segregation from many different angles. One factor identified by the report was the type of haul unit used to deliver the HMA to the job site. Of the different methods used to deliver HMA to the job-site, end dump haul units exhibited the greatest level of thermal segregation. In Connecticut, end dumps are the primary method used to convey HMA to the paving project. Additionally, the report proposed the concept of employing a density specification based upon the densities obtained in the mat where truck changes occurred. The rationale behind density testing at the truck changes was that these areas are the most prone to fail and even though they represent a small percentage of the surface area, failure of these areas generally will require the entire pavement to be replaced. The Washington State Department of Transportation report also showed that there was some correlation between warmer ambient temperatures and the temperature differentials that were observed. Higher ambient temperatures reduced the temperature differentials observed.

## Construction Data

For the CAP Lab project, construction data was selected from six paving sites ongoing in Connecticut. The placement of the wearing surface was monitored. Leveling courses were not monitored due to the wide variability in the placement thickness. The monitored projects included three (3) Connecticut DOT Class 1 (nominal maximum aggregate size of 12.5 mm) and two (2) of the projects were 12.5 mm Superpave mixes. Pavement for one site was placed in November 2000 and the remaining projects were placed in May through July 2001. HMA was produced at several different plants and limited sampling from truck beds was conducted at the plant for one project. Four (4) projects used material transfer devices (MTD) for HMA placement. On two of the projects, the Roadtec 2500 MTD was used. This is significant because of the large amount of material the MTD stores within it and the remixing of the material being delivered prior to discharging it to the paver. The MTDs used on the other two projects did not provide direct remixing of the material. The paver hopper inserts were equipped with remixing paddles but the paddles were not operated during the periods of observation. There was some indirect remixing of the HMA during the discharge into the MTD and the dumping of the material into the hopper of the paver.

The procedure routinely consisted of gathering data and observations using the following tools:

- Visual observation,
- Infrared thermographic imaging camera and related computer software,
- Digital photographic imaging,
- Recording of image-specific site information (station locator, cold spot shape, etc.),
- Recording of exact location coordinates using GPS hand-held device for future monitoring,
- Entry of construction data into comprehensive ACCESS database.

Other tasks were performed occasionally in order to determine the impact of additional factors on the data presented. Examples of these tasks are as follows:

- Nuclear density testing of paved material,
- Material samples taken from loaded trucks at the plant,
- Material samples taken immediately behind paver by DOT officials,
- Recording of time between truck load changes,
- Infrared thermographic images taken from on top of roller and paver.
- Truck configurations
- Screed and spill locations

The ThermoCAM PM575 was used to capture thermal images of HMA mix while being discharged from the truck bed into the paver's hopper and while being placed to the mat, prior to compaction. Cool spots, or temperature differentials, in the uncompacted mat were marked for density tests (when possible) within each of the monitored test sections. GPS coordinates were also recorded for referencing at most of the cool spot locations. Thermal images were initially recorded during rolling operations as the mat was being compacted; however, issues related to safety limited the occurrence of capturing this vantage. Images were then processed and analyzed using the ThermoCAM Researcher 2000 software on a laboratory computer.

### **Preliminary Factors:**

The preliminary factors, as observed by the CAP Lab personnel, that may be considered as influential to the generation of cold spots in freshly-placed asphalt concrete pavements are outlined below. Further insight from the project's technical committee is anticipated in the near future.

- **General temperature placement issues** – including cold weather and night paving, and cold weather paving at night, differences in base and air temperature.

- **Inclement weather conditions** – effect of precipitation, placement of asphalt on wet surfaces, and rapid cooling of pavement material during truck loading into paver and/or prior to rolling or between roller passes. Observations during this conditions are difficult to the unpredictability of the weather combined with the uncertainty of whether or not paving will occur.
- **Equipment Issues** – e.g., frequency of folding hopper wings, auger movement and depth of material in augers, paver shadow, spacing between rollers, use of material transfer device (MTD), removal of spilled loose material, flow gate control.
- **Thickness Variation** – including thickness of lift (1.5” versus 2.0”) and leveling prior to overlays.
- **Truck Changes** – e.g., length of time between trucks, amount of material retained on pavement after truck pull out, amount of material in hopper, and loading delay incurred when paving under overpasses.
- **Segregation** – due to temperature or gradation.
- **Paving Material Characteristics** – such as virgin binder versus presence of RAP, and silo versus non-silo storage of mixture.

#### Monitored Site 1

Research was conducted at the first paving site for the study on I-395 Southbound between exit 83 and one mile north of exit 86 from November 8 through November 21, 2000. Conditions for the segments paved were as followed on the days of observation:

Table 1 - Placement Variables Observed on I-395 in Lisbon

| Date       | % RAP | Silo Used | Compacted Thickness | MTD Used |
|------------|-------|-----------|---------------------|----------|
| 11-8-2000  | 0     | No        | 1.5 Inches          | No       |
| 11-9-2000  | 0     | Yes       | 1.5 Inches          | No       |
| 11-13-2000 | 10%   | Yes       | 1.5 Inches          | No       |
| 11-15-2000 | 20%   | Yes       | 1.5 Inches          | Yes      |
| 11-16-2000 | 20%   | Yes       | 1.5 Inches          | Yes      |
| 11-18-2000 | 0     | No        | 1.5 Inches          | No       |
| 11-20-2000 | 0     | No        | 1.5 Inches          | No       |
| 11-21-2000 | 0     | No        | 2.0 Inches          | No       |

Some factors such as materials used and operational changes have been observed for their effects on the presence, extent, and visibility of cold spot areas. Cold spot areas in freshly paver-placed asphalt pavements may be indicative of poor performance later in the life of the pavement.

The materials used appeared to have little effect on the presence of cold spots. Since all sections, with or without the presence of RAP and with or without silo storage, showed some cold spots, it appears that the major cause of such spots may be in handling. Figure 1 shows the thermal images of cold spots in a Virgin, Silo placement and in the 10% RAP, Silo placement. Most cold spots were observed nearly across the entire width of the mat in a v-shaped pattern. This indicates cool material conveyed to the screed augers such that the augers continued to push the cool material outward from the center of the screed as the paver moved forward, thus creating the V-shaped cool spots.

Days that included paving from silo storage showed little difference from the days when no silo storage was employed. However, the use of silos may reduce loading delays between trucks. It was seen that on the start of days following cold and wet weather, the paver laid material faster than the plant was able to dry and heat the aggregate. Thus by the middle of a pass, the paver was forced to wait for each truck and the material in the hopper cooled more. Figure 2 shows images of cold spots in a Virgin, No Silo placement and in Virgin, Silo placement.

The thickness of the asphalt lift was altered on the last day of paving. The lift thickness was increased from 1.5 inches to 2.0 inches, and the mix was kept constant as Virgin, No Silo. The major difference in the two cases was the significantly decreased visibility of cold spots (visibly segregated patches) on the surface when the 2-inch lift

was paved. In the 1.5-inch section, cold spots were easily identified since they were visible to the human eye on the surface of the freshly placed pavement where the front of the paver had been stopped during truck changes. These cold spots were either barely or no longer visible to the human eye on the 2-inch lift; however, significant cold spots were visible in the thermal infrared images. Figure 3 illustrates the images of cold spots in both a 1.5-inch and 2.0-inch lift section. Cold spots observed in the 2.0-inch lift also were found to cover a smaller area than those observed in the 1.5-inch section.

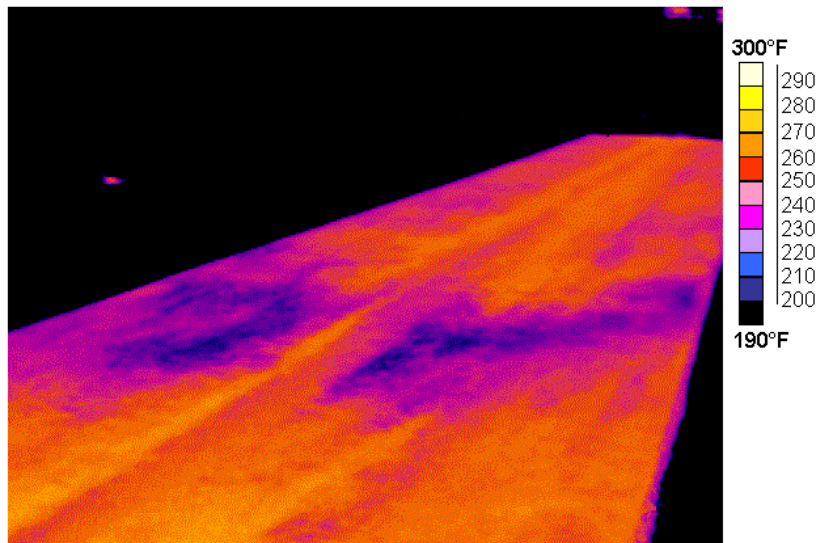
There were approximately 16 to 18 trucks hauling every day and the same amount of material in every truck, regardless of the capacity of the truck. The material in the semi trailers flared out to zero depth at one end, possibly leading to more cooling. Frequently, trucks pulling away from the paver spilled material on the pavement, as shown in two digital photographs presented in Figure 4. The spilled material was shoveled onto the shoulder or into the hopper, but on several occasions, it was left lying on the pavement in front of the paver. Cold spots were then recorded consistently in the spillage area after the paver had passed over the area containing the spillage (see Figure 5). When unloading a truck, the main flow of material is to the rear, but a lateral flow can occur through the triangular opening between the tailgate and the end of the truck bed sidewall. As this material was against the side wall of the haul unit during transit, it tends to be cooler. When the truck pulls out, a portion of this side pile falls to the conveyor. The corner of the bed of a new truck backing in can also knock some of the side pile into the conveyor and a cold spot tends to occur on that side.

For two days, a Roadtec 2500 MTD was used and as a result, the paver moved as much as 3,000 feet without stopping. Occasionally some material was spilled on the

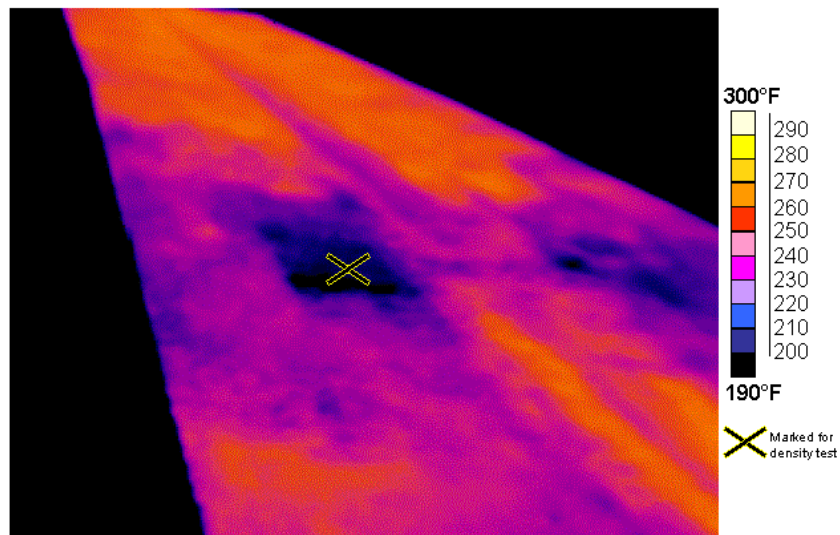


pavement as a truck pulled away from the MTD front hopper; however, as the paving train did not stop, it was impossible to shovel this material out of the paver path.

Surprisingly, thermal inspection revealed no cold spots as shown in Figure 6. The hopper that the trucks dumped into on the Roadtec MTD tended to spread any spilled material on the existing surface to a thickness of approximately the largest aggregate present in the HMA. The spreading out of the material by the Roadtec MTD combined with the speed of the paving train minimized uneven cooling of the HMA mat. These two factors, combined with the remixing of the HMA occurring within the Roadtec MTD greatly reduced or eliminated the appearance of cold spots altogether. Likewise, cold spots were not visible even when the operations were stopped for refueling of the paver or when waiting for additional material.

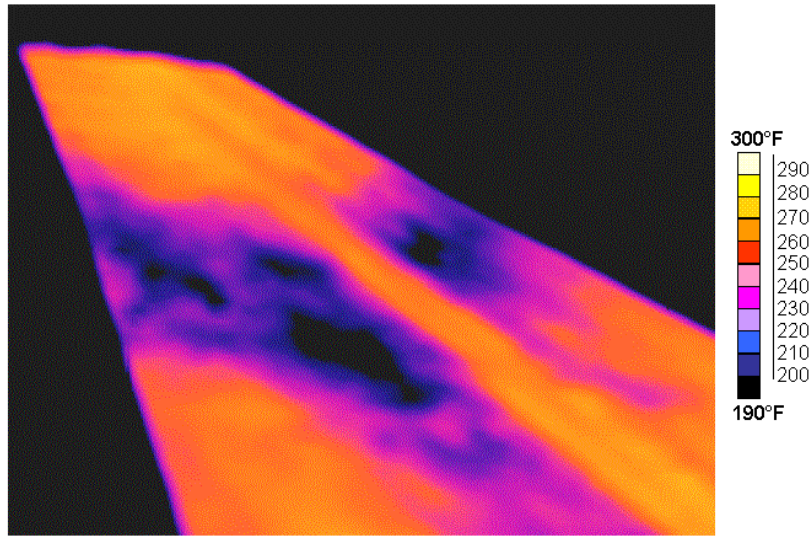


**Virgin, Silo – V-shaped Cold Spots**

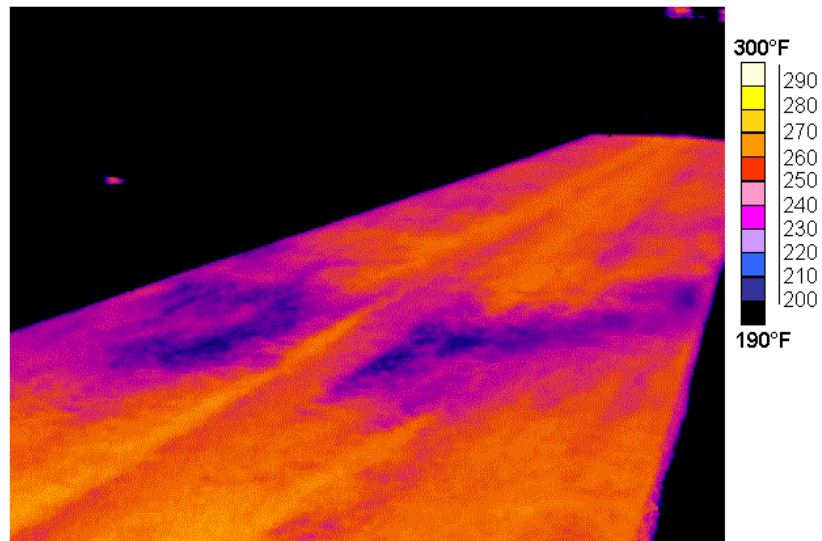


**10% RAP, Silo – V-shaped Cold Spots**

**Figure 1: Effect of Mixture Type, Virgin versus RAP, Shown in Thermal Images of Cold Spots in Paved Section I-395.**

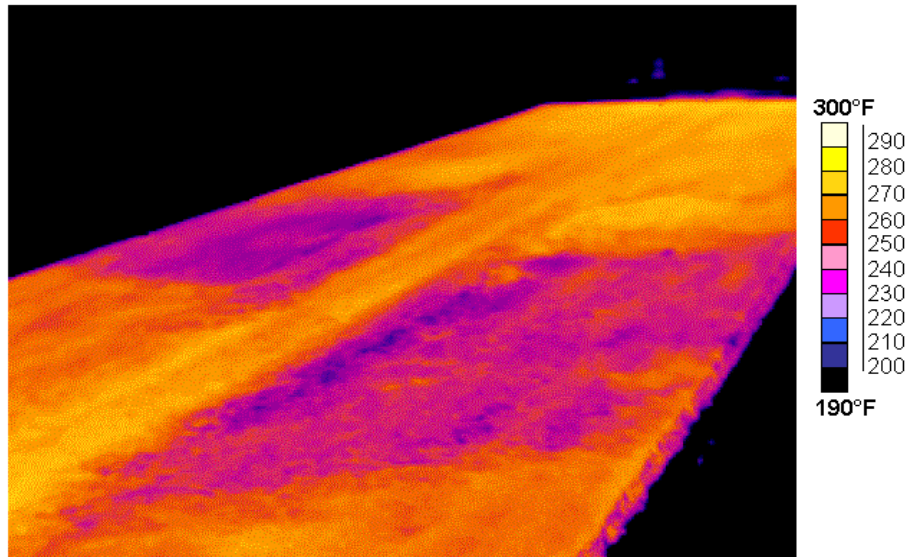


**Virgin, Non-Silo – V-shaped Cold Spots**

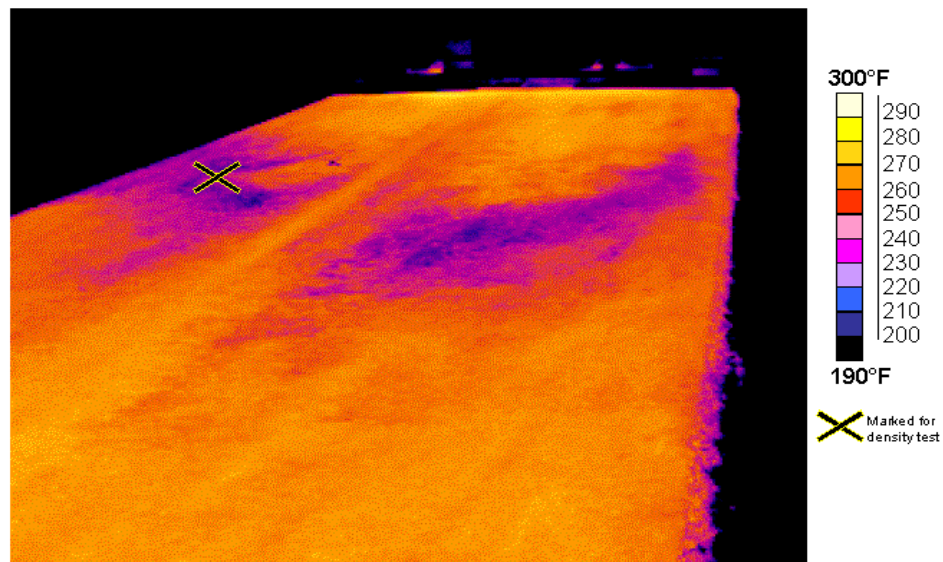


**Virgin, Silo – V-shaped Cold Spots**

**Figure 2: Effect of Material Storage, Silo versus No Silo, Shown in Thermal Images of Cold Spots in Paved Section I-395.**



**1.5-inch Virgin, Non-Silo – Cold Spots Both Sides of Lane**



**2.0-inch Virgin, Non-Silo – Smaller V-shaped Cold Spots**

**Figure 3: Effect of Mat Thickness, 1.5 versus 2.0 inch, Shown in Thermal Images of Cold Spots in Paved Section I-395.**





**Spillage of Material in Front of Paver and Out of Hopper Bed**



**Figure 4: Two Examples of Material Spillage in Front of Paver on I-395.**



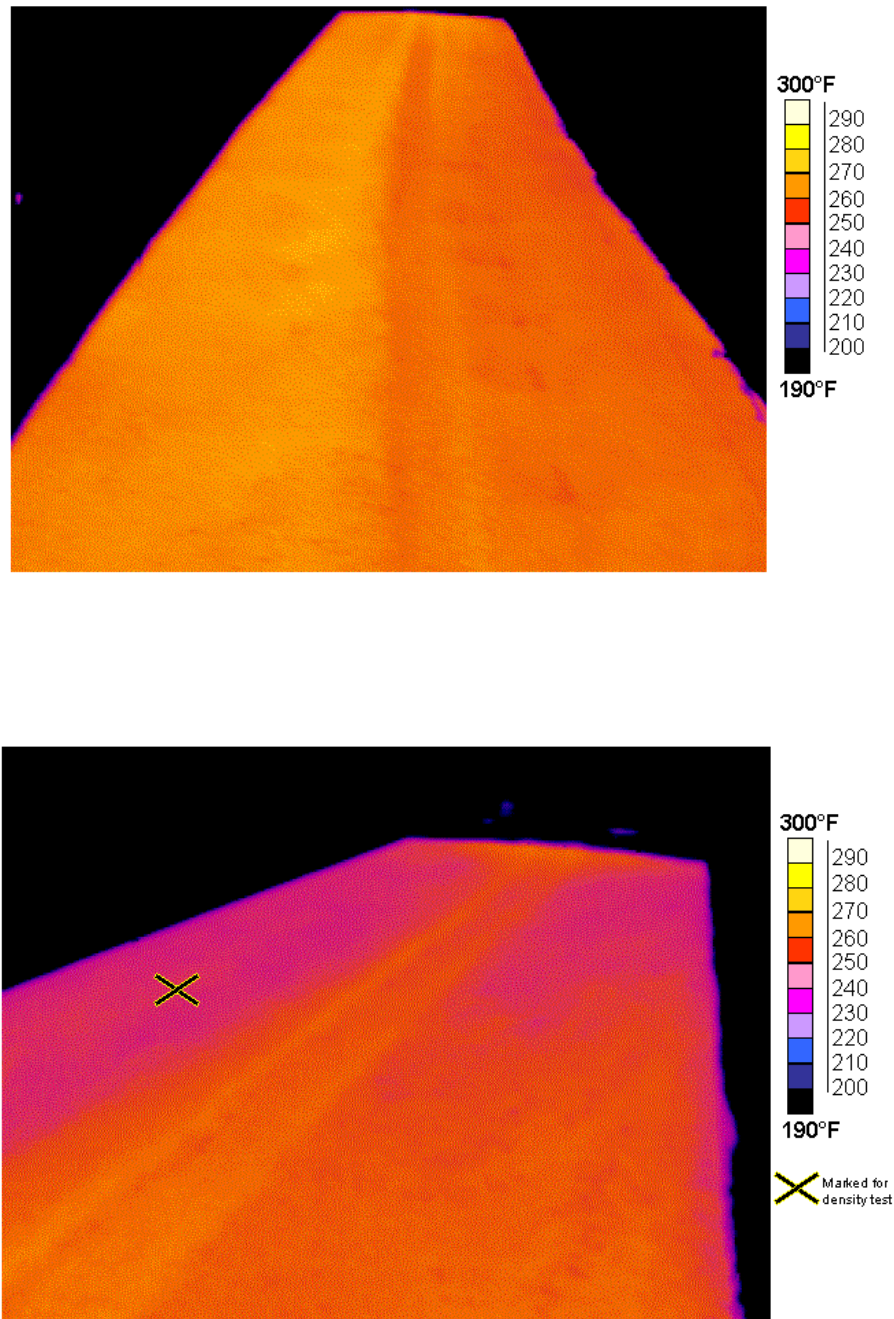


**Virgin, Silo, 1.5" Lift Thickness – Open Texture in Compacted Mat Corresponding to Cold Spot**



**10% RAP, Silo, 1.5" Lift Thickness – Open Texture in Compacted Mat Corresponding to Cold Spot**

**Figure 5: Two Examples Where Cold Spots, Found with Infrared Thermal Camera, Are Visible on Surface of Pavement on Site Section I-395.**



**Figure 6: Effect of Material Transfer Device - Mat Shows No Evidence of Cold Spots in Thermal Images for Paved Section I-395 (20% RAP, Silo, 1.5" Lift Thickness).**

In cold weather paving, the time available for compaction is limited by rapid cooling of the mat. It may be suggested that roller operators should be alert to the formation of cold rolling cracks. Cold rolling cracks were formed when roller spacing was not tight enough and the mat cooled too much before the rolling process had been completed. These cracks were sometimes observed even on the day when the material transfer device was in operation and when the 2.0-inch mat was paved (see Figure 7). It appears that rolling these cracks out completely is very difficult, and they may later become the initiators of active surface cracks. The number of rollers needed may increase when paving in cold weather. For example, if three rollers are adequate on a 50°F day, it may require four rollers on a 40°F day because faster cooling decreases time for compaction.

Nuclear density tests were taken through a few cool spots at some locations. The typical mat temperature was approximately 265°F and the maximum temperature differential was typically around 70°F. The distribution of temperature differential with change in density is shown in Figure 8. Figure 9 indicates the change in average density with temperature differential through the cool spot. The figures indicate that as the temperature differential increases, there is a drop in density. This drop in density can be explained by the cooler HMA's resistance to compaction. Cool spots typically started 1.5 feet to either side of the paver pass centerline and extended forward towards the edges of the paver pass. These tend to be cyclic when the haul units dumped directly into the paver hopper.



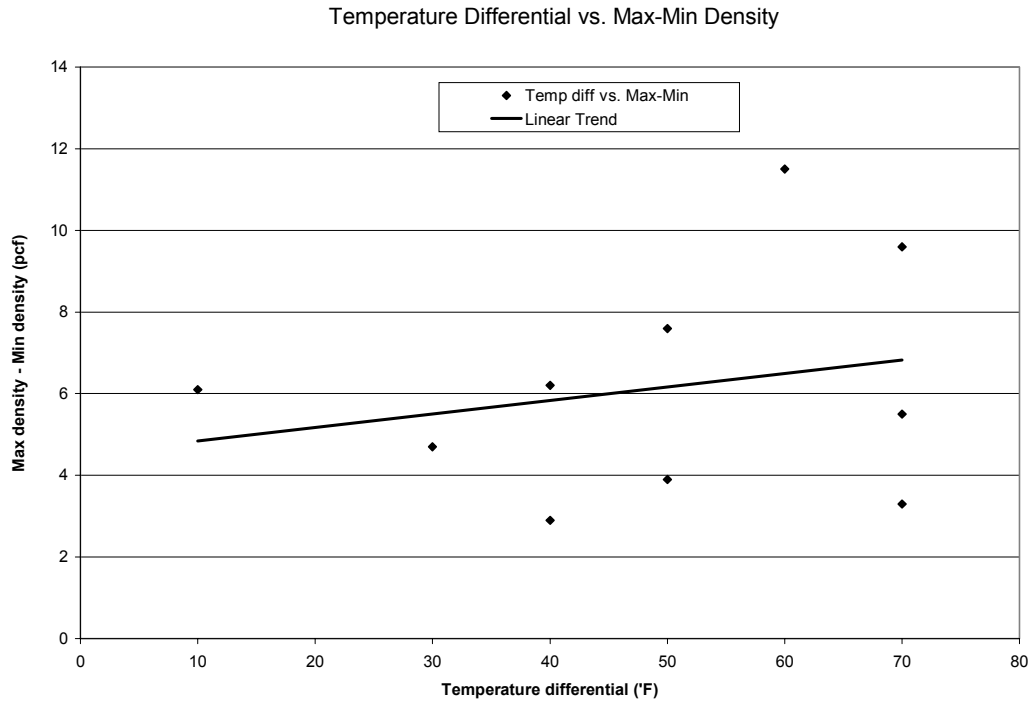


**1.5-inch 20% RAP, Silo, Material Transfer Device Used – Cold Rolling Cracks**

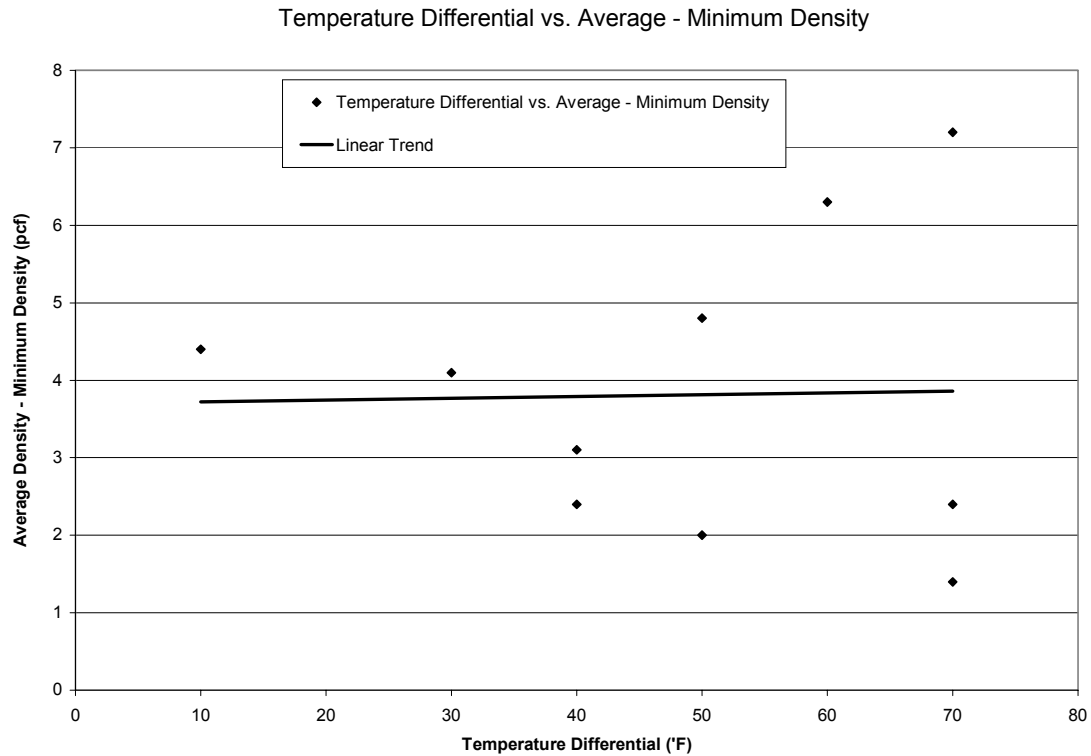


**2.0-inch Virgin, No Silo – Cold Rolling Cracks**

**Figure 7: Effect of Roller Spacing – Cold Rolling Cracks Evident When Rollers Were Not Spaced Tightly.**



**Figure 8. Distribution of Temperature Differential with Maximum Change in Density.**



**Figure 9. Distribution of Temperature Differential with Average Change in Density.**

## Monitored Site 2

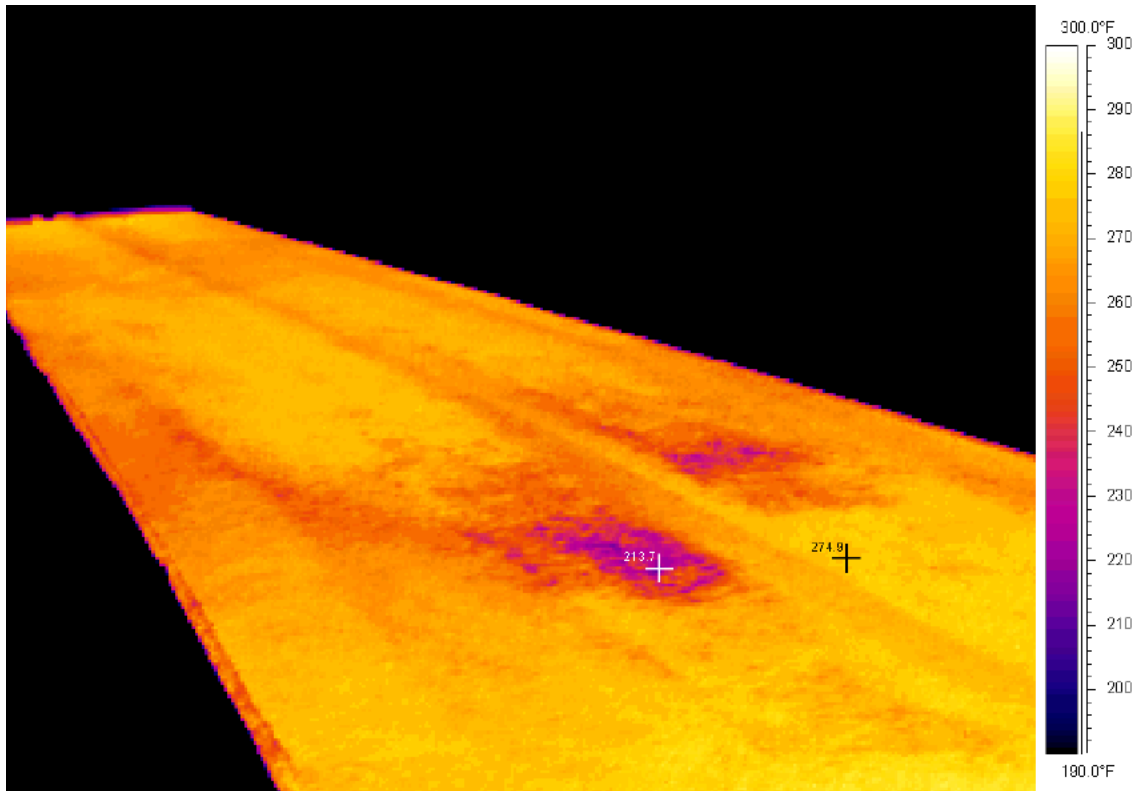
The second site selected for monitoring was a resurfacing project located on Route 178 between Routes 185 and 189. Route 178 is a two-lane undivided state route, functionally classified as a minor arterial and was completed under State Contract 171-293C. The pavement was placed around May 1, 2001 and the haul time was approximately 15 minutes for a distance of 10 miles. The weather conditions were sunny with an ambient air temperature of 88°F. A batch plant was used to produce 2000 tons of Connecticut DOT Class 1 mix (PG 64-28 binder) wearing course placed at 50-mm (2.0-inch) depth. Typical mix temperatures were recorded in the truck beds at approximately 280°F and typically three drops of material were loaded per truck.

The paving contractor used a Cedar Rapids Grayhound CR551 paving machine and loosely-tarped tri-axle dump trucks carried the material from the mix plant. There was no remixing of any kind implemented. An Ingersoll-Rand DD110 breakdown vibratory roller was used along with an 18-ton Hypac 50 C340CW finishing roller. A simple truck configuration study was conducted both days on site to determine pivot height, pivot-to-lip distance, pull-out height of lip, and pull-out spillage. There was a considerable amount of material spilled in front of the paver after each load was discharged into the hopper, as seen in Figure 10. Additional material was spilled on the existing surface when the haul units shook the beds and cleaned out the tailgates after discharging their loads into the paver.



**Figure 10. Material Spilled By Truck Pull-Out After Discharge into Paver.**

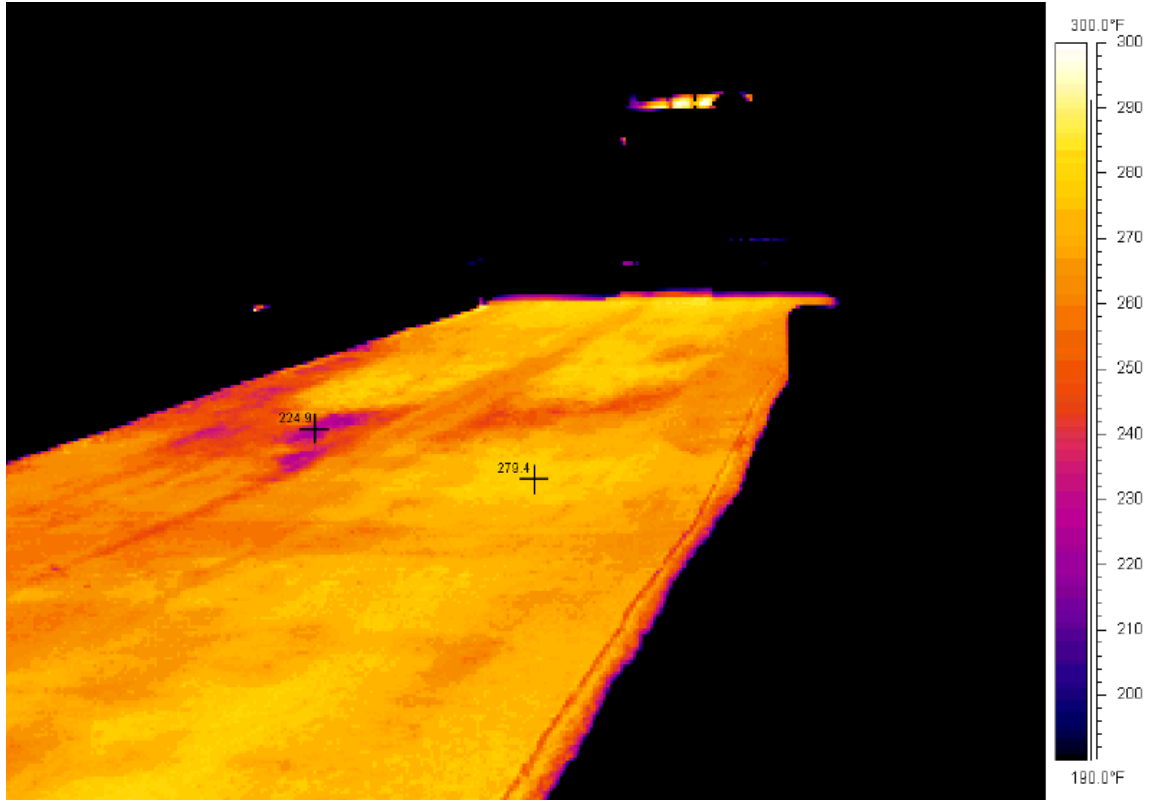
The existing mat surface temperature, prior to placement of wearing course, was recorded to be 124°F. Temperature differentials in the freshly placed pavement were observed with the thermographic camera as being typically in the outer portions of the lane. The typical mat temperature after placement, but before breakdown compaction, was recorded as 270°F. However, the maximum temperature differential was observed to be as high as 80°F. Figure 11 shows a temperature differential of approximately 60°F in the uncompacted mat.



**Figure 11. Temperature Differential in Mat Prior to Compaction on Rt. 178.**

The cool spots observed in mats on Route 178 were typically not cyclic; however, they appeared to occur in conjunction with spilled material in front of the paver. The image shown in Figure 12 illustrates a temperature differential of approximately 55°F with a weak v-shaped cool spot.

A nuclear gauge was not available; therefore, no compaction data for determining the change in air voids or range of air voids was gathered. However, visual inspection showed areas of open-textured mat, such as that seen in Figure 13, that were observed as cool spots in the same location using the infrared thermographic camera.



**Figure 12. Temperature Differential in Mat Prior to Compaction on Rt. 178**





**Figure 13. Open-textured Mat Observed Prior to Compaction.**

### Monitored Site 3

The next site selected for monitoring was a resurfacing project (172-327G) on June 19, 2001, located on Route 66 in Windham. The sunny day had an ambient air temperature of 83°F and the existing pavement surface temperature during the daytime hours was recorded at 120°F. Loosely-tarped tri-axle dump trucks were discharged into a CAT AP-1055B paving machine. A 10-ton Hyster 350 breakdown roller was used for initial compaction, followed by a Hyster 766 15-ton vibratory finish roller.

A compacted thickness of 1.5 inches of Connecticut DOT Class 1 (PG 64-28) mix was placed as a wearing course. There was no remixing of any kind used in this project. The 1000 tons of material was produced at a batch plant approximately 25 miles away

and had a 30-minute haul time. The typical temperature of the HMA recorded while unloading from the haul units was 310°F.

The typical mat temperature prior to compaction was 290°F. Cyclic cool spots were observed typically in the middle of the lane and a maximum temperature differential of approximately 60°F was documented. Spilled material was often left on the existing pavement in front of the paver. Delays between haul units arriving at the site permitted excessive cooling of this spilled-loose material, making it more difficult to compact once it was covered by fresh HMA since the effective heat transfer between the two materials was not attained. Figure 14 shows the typical cold spot configurations observed at this location. The cool spots were not nearly as large as were observed at other projects. This was most likely the result of the ambient air temperature being warmer than on the other projects that had much more expansive cold spots.

Figure 15 shows an image taken after a long delay between truckloads of material being delivered to the site. The image has the paver moving away in the image and the black region at the bottom of the image shows that the pavement placed before the delay was cooler than 190°F. The delay was approximately 50 minutes and the resulting temperature difference was almost 90°F.

There was some difficulty acquiring data at this project due to its location in downtown Willimantic and the urban nature of the traffic patterns. Nuclear density readings were not obtained at this site.



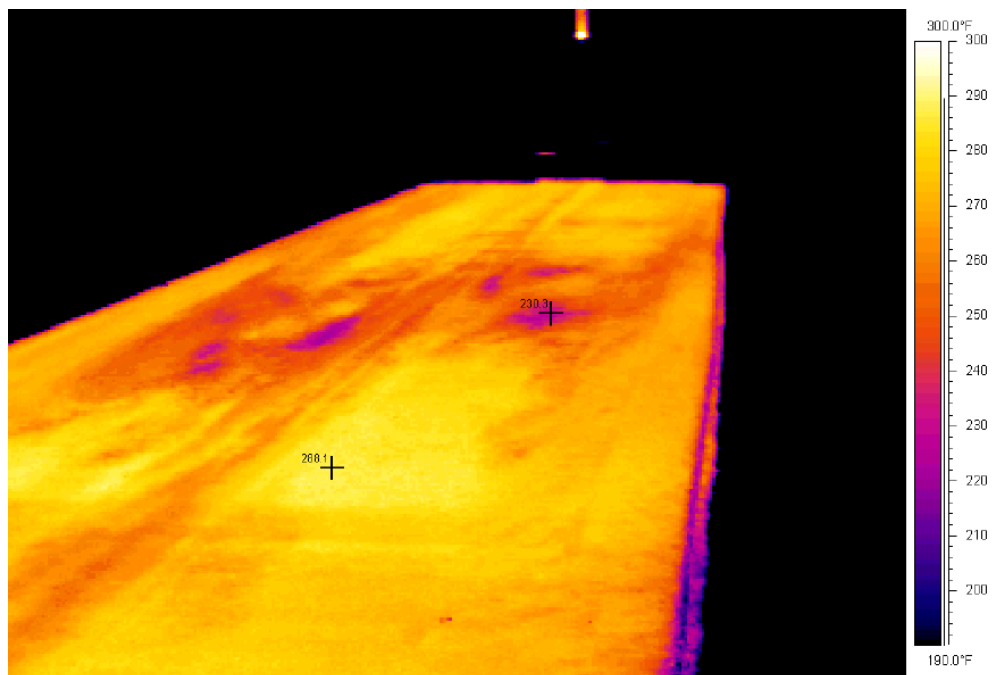
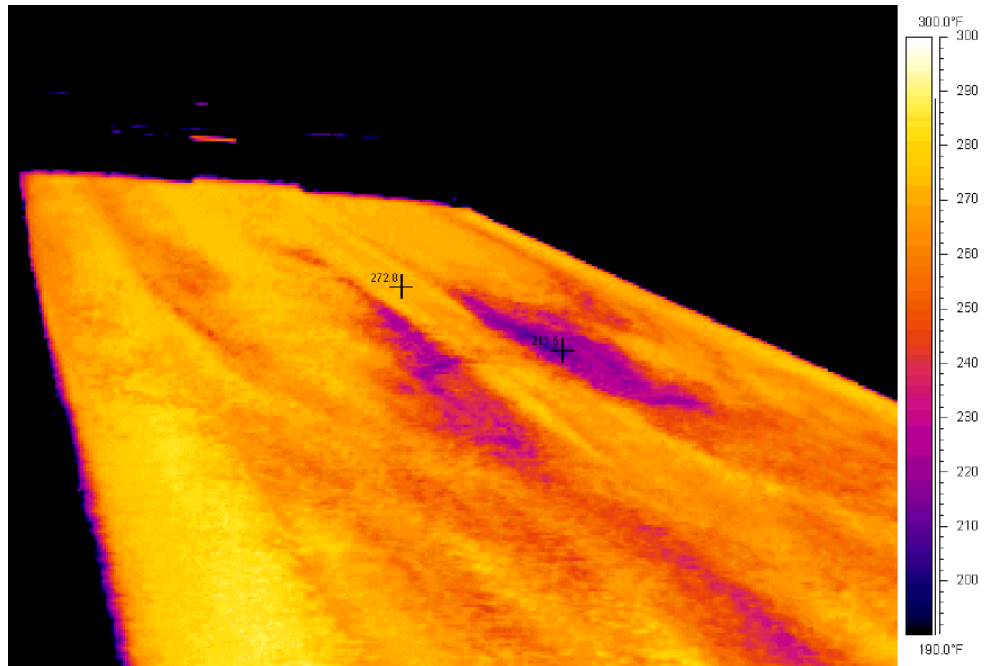


Figure 14 – Typical Cold Spot configuration observed on Route 66 in Windham

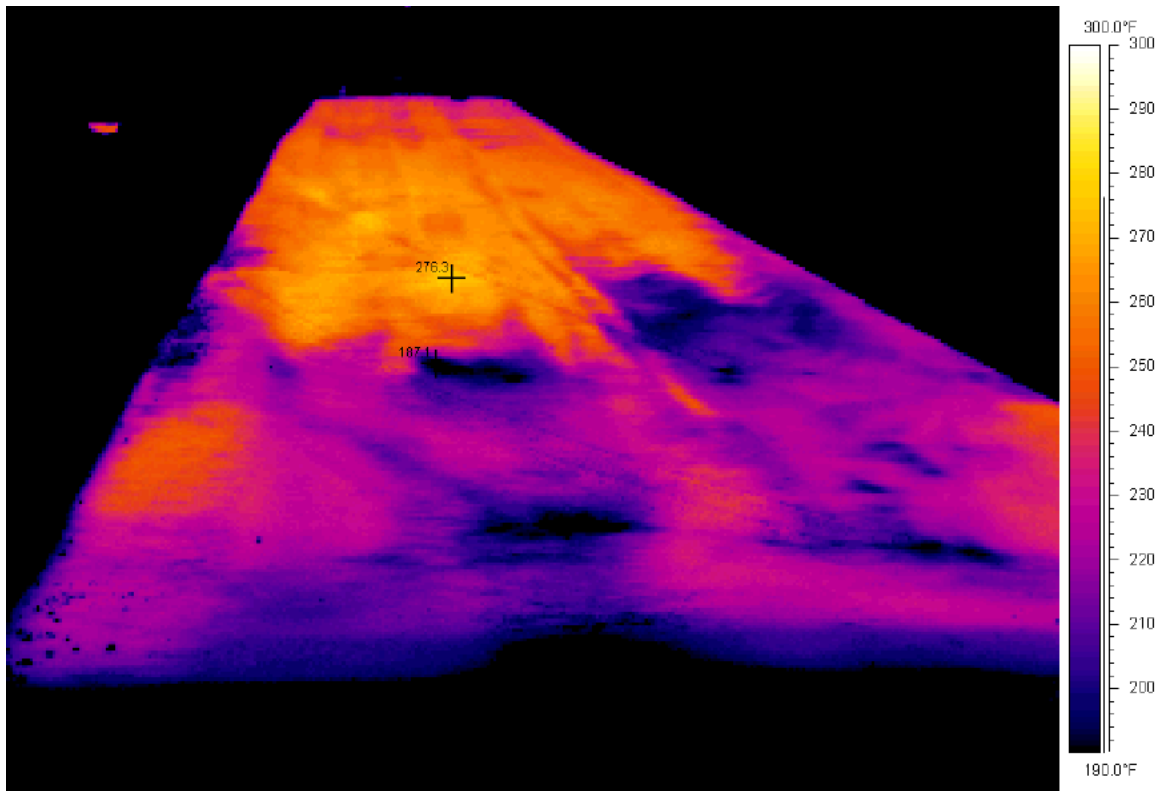


Figure 15 – Image showing effect of approximately 50 minute delay between truck loads of material being delivered to the site – Route 66 in Windham.  
(The paver is moving away in this image)

#### Monitored Site 4

The fourth site monitored was a resurfacing project of Route 2 in Stonington, completed under State Contract 137-137. The pavement operation was observed during daytime hours on June 29, 2001 and the haul time was approximately 15 minutes for a distance of 10 miles. The weather conditions were partly sunny with an ambient air temperature of 70°F. A drum plant was used to produce a virgin Superpave 12.5 mm mix (PG 64-28 binder), placed at 50-mm (2.0-inch) depth. Mix temperature was recorded in the truck beds at 310°F and typically three drops of material were placed in each truck.

The Paving Contractor used a Blaw-Knox PF-200B paving machine and loosely-tarped tri-axle dump trucks carried the material from the mix plant to the site. Remixing of material was accomplished by the utilization of a Roadtec 2500 material transfer device (MTD). An Ingersoll-Rand DD-110HF vibratory roller was used for breakdown compaction along with a vibratory Hyster finishing roller.

Infrared images indicated that the existing mat surface temperature, prior to placement of wearing course, was recorded to be 100°F. Temperature differentials in the freshly placed pavement were not observed with the thermographic camera. It appeared that the lack of material spillage and the advantage of remixing provided by using the material transfer vehicle virtually eliminated the presence of temperature differentials. Figure 16 shows the typical thermographic profile observed at this project.

Compaction data was not obtained for this particular site.

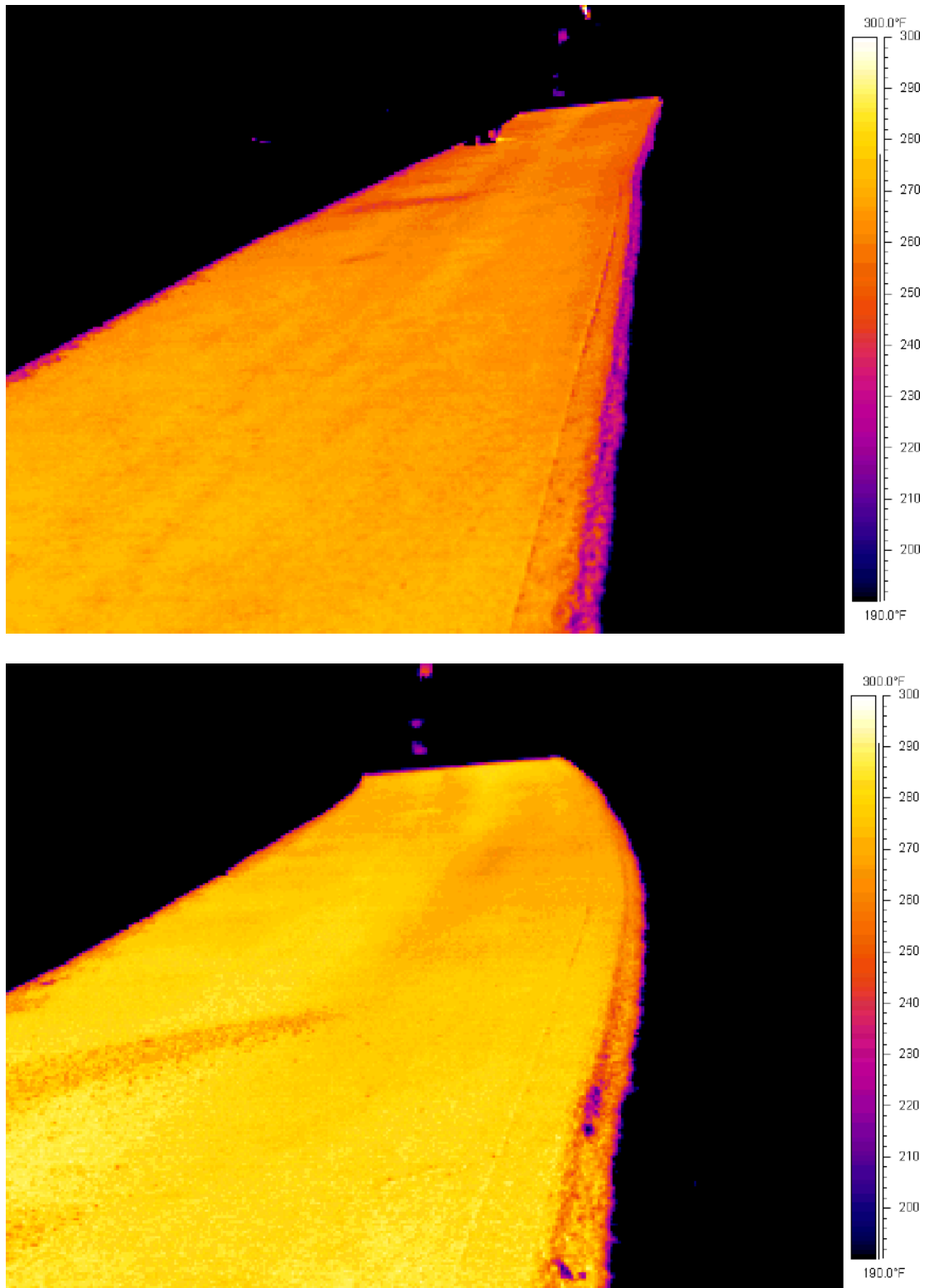


Figure 16 – Typical Thermographic Images from Route 2 in Stonington where a re-mixing MTD was used.

### Monitored Site 5

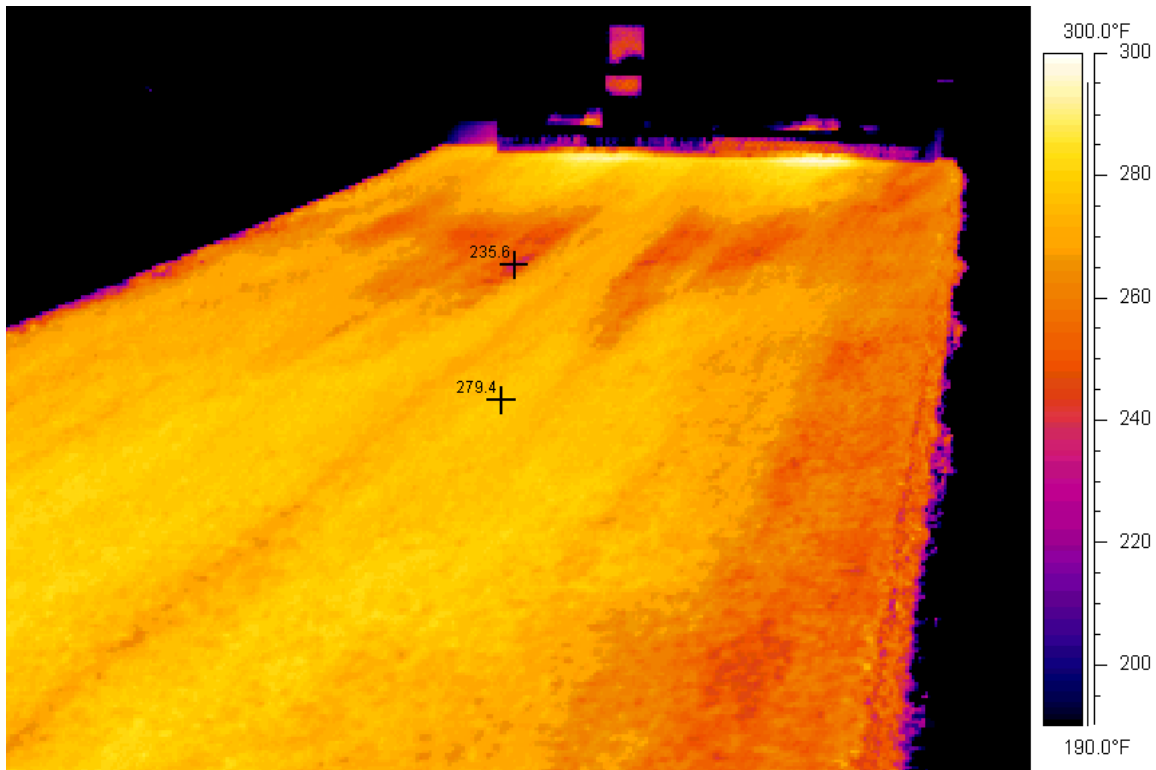
The resurfacing project of Route 8 in Torrington was the next site monitored for the study and was completed under State Contract 174-295. This pavement was placed at night on July 5, 2001 which gave the opportunity to record temperature differentials and observe nighttime construction operations. The haul time was approximately 15 minutes for a distance of 10 miles. The weather conditions were cloudy with an ambient air temperature of 70°F. A batch plant was used to produce Superpave 12.5 mm mix (PG 64-28 binder), placed at depth of 2 inches (50 mm). Typical mix temperatures recorded in the truck beds were approximately 310°F.

The paving contractor used a Blaw-Knox PF 3200 paving machine with a Blaw-Knox MC330 MTD and loosely-tarped tri-axle dump trucks (loaded with three drops) brought material from the mix plant to the site. The MTD did not remix the material prior to dumping it into the paver hopper insert. The re-mixers on the hopper insert were not utilized. One 12-ton Ingersoll-Rand DD-90HF vibratory roller was used for breakdown compaction and another for intermediate rolling and finishing.

Infrared images indicated that the existing mat surface temperature, prior to placement of wearing course, was recorded to be 85°F. Temperature differentials in the freshly placed pavement were not observed to be as severe as in the paving sites where a material transfer vehicle was not used. Trucks dumping into a MTD tend to spill less material since there is no concern for maintaining some material in that hopper unlike when trucks dump directly into the paver hopper. By allowing the MTD hopper to empty completely, all of the material in the haul unit can be easily delivered to the MTD hopper. And when the haul unit leaves the MTD hopper there is little to no material remaining

that can then fall on to the paver conveyor. It also appeared the speed of the paving train did not allow any material that did spill to cool substantially before it was incorporated into the mat. The action of the indirect remixing provided by this MTD also helped to reduce the presence of temperature differentials as well as decreasing the severity; however, it did not eliminate them entirely. An additional factor affecting how much cooling the material could experience before placement was the short haul distance. Figure 14 shows a typical image containing temperature differentials observed during the placement of the material. As can be seen in Figure 14, the presence of cool spots was greatly reduced, but unlike the re-mixing MTDs the cool spots were still visible.

Compaction data was obtained for this particular site using a Campbell nuclear density gauge. The theoretical maximum density for this project was cited as 165.1 pcf. However, tests showed that in some locations the designed level of compaction was not reached. In one case, the in-place density was observed to be only 75% of the maximum theoretical density for that material. This material was also observed to still be soft enough to show foot prints when the surface temperature of the compacted mat was around 95°F.



**Figure 17, Area of Cooler Material Behind the Paver using a MTD that does not Re-mix the Material.**

#### Monitored Site 6

The sixth site monitored was the resurfacing of Route 195 in Mansfield, Connecticut. These observations were made on July 10 and 11, 2001. The wearing surface for this project was to have a compacted thickness of 1.5 inches. The paver both days was a Blaw Knox PF200B. On July 10<sup>th</sup> a Blaw Knox MTD was used while on July 11<sup>th</sup> the MTD was not used. The haul time was approximately 30 minutes for a distance of about 25 miles. Two rollers were used both days. Due to a technical problem, some of the data and images acquired during these two days has been lost.

On July 10<sup>th</sup> the weather was sunny with an ambient air temperature of 85°F and a base temperature of 110°F. The MTD in use on this day did not directly re-mix the



material and the paver hopper insert did not remix the material either. As was similar with the other project using a Blaw Knox MTD the cold spots observed did not appear as large as the projects not using a MTD. The temperature differentials within an area were also not as great. On this day, the largest temperature differential observed was 40°F. Figure 18 shows a thermographic image of a typical cooler area on the mat observed on the day the MTD was in use.

On July 11<sup>th</sup> the weather was again sunny with an ambient air temperature of 85°F and a base temperature of 120°F. The Blaw Knox MTD was not in use for this day of paving. Without the MTD, the cold spots were considerably larger and the temperature differentials were greater. Unfortunately, these images have been lost. This project demonstrated the advantages of MTDs for reducing cold spots.

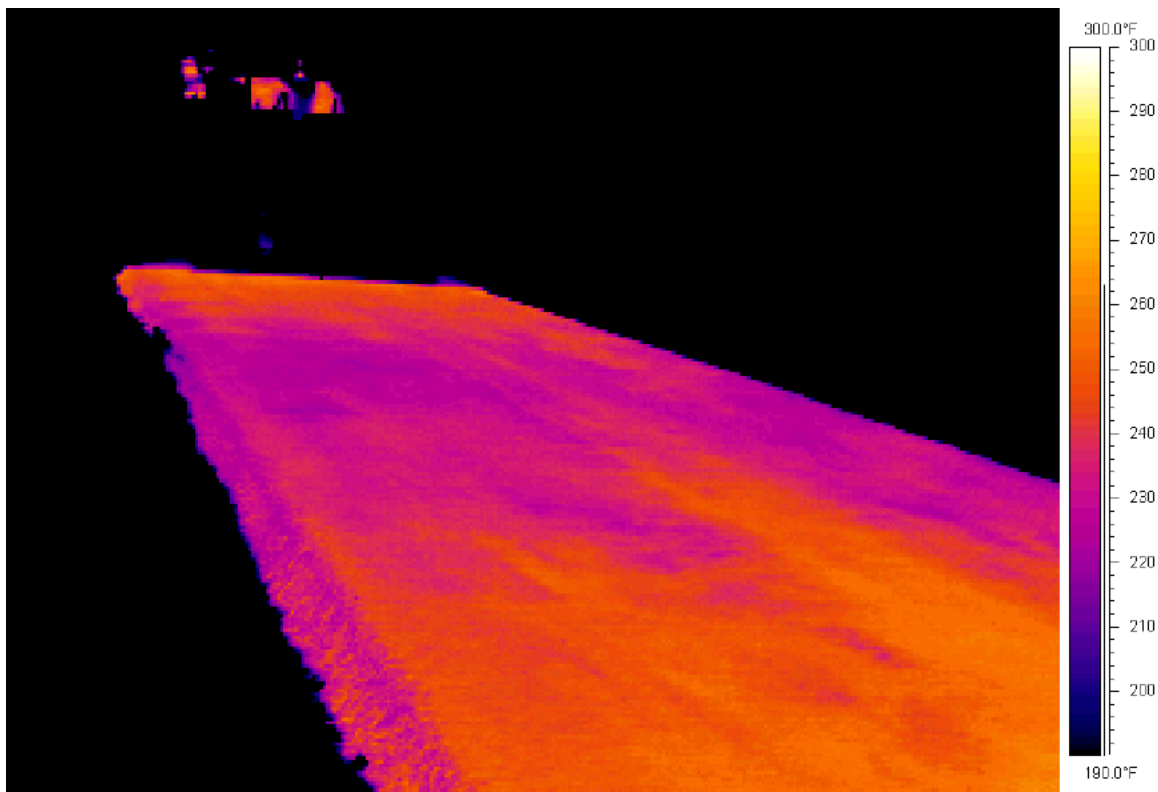


Figure 18 – Typical Thermographic Image of Paving on Route 195 with a MTD

### Truck Configuration Study

Most cold spots occurred in the 25 to 30 feet immediately after the screed position during a truck change. There are several ways that the truck/paver configuration can contribute to the formation of these cold spots. Spills of material like those seen in Figure 4 are typically caused by the lip of the dump bed dragging material off of the hopper edge or folding the hopper wings. The spill seen in Figure 10 is typical of those caused by raising the bed to remove any material remaining in the bed after pulling out from the paver. The paver screed tends to spread such spills in the direction of paving (Figure 11). Lowering the bed before the truck pulls out so that the lip is clear of the buildup on the front edge of the hopper and cleaning the bed somewhere off the roadway would eliminate such spills and resulting cold spots.

V shaped cold spots seen in Figure 1, 2 and 3 are quite common. The angles of the cold spots indicate that the screed auger was transporting cold material laterally as the paver moved forward. The source of the cooler material is the perimeter of the paver hopper. When a truck pulls away from the paver without disturbing the material on the hopper edge, the next truck can push the material into the conveyor. If there has been a delay between the trucks, the material on the edge has cooled. This material must then pass up the conveyor and drop to the auger making the spot start several feet after the truck backed in. The typical truck bed pivot point is approximately 42 inches above the pavement. The distance and height difference between the pivot and lip differs from truck to truck. For nearly all trucks, waiting to raise the bed until the lip is inside the hopper will eliminate the cold spot. Occasionally, the angled cold spot occurs only on

one side of center only. Truck beds are some 18 inches narrower than the hopper. The cold material on either side of the hopper is significantly higher than that on the forward edge and a tailgate lip high enough to clear the edge pile can, if the truck is near to one side, it may knock material into only one side of the conveyor, thus sending cool material to only one auger.

As usually the spacing of cool spots is some multiple of a truckload length of pavement, truck changes must contribute to formation. Can spills and knockdown of cool material into the conveyor be prevented by timing of the raising and lowering of the truck bed so that material left on the edges of the hopper is not disturbed?

#### Observations, Comments and General Discussion

Most of the observed cold spots occurred 25 to 30 feet after the position where the paver screed stopped for a truck change when there was no re-mixing MTD. Rarely were cold spots observed during the middle of the load. This would indicate that truck changes are a major contributor to the formation of the cold spots. There appeared to be two ways in which the trucks pulling away from the paver caused cold spots to appear.

Figure 10 shows a spill of loose HMA onto the existing pavement caused from the haul unit cleaning the loose material from its bed by raising the dump body after pulling away from the paver. If there is a delay between trucks and this material is allowed to stay on the existing surface, this material is already cooler than desired and will continue to cool before the paver spreads fresh hot material over it. Cooler weather conditions exacerbate this problem as well as having extended waiting periods for materials to arrive at the paving site. Figure 11 shows a cold spot that corresponds to the location of spilled

material on the existing surface from the raising of the truck bed to remove loose material. Figures 1, 2 and 3 are examples of V-shaped cold spots. The shape of the cold spots indicates that cold material was being moved out laterally by the auger screed as the paver moved forward. The cold material for this type of cold spot would be the paver hopper. When a truck pulls away from the paver hopper without disturbing the material on the edge of the hopper, the next truck backing into the paver hopper will more than likely knock a portion of this material down onto the paver's conveyor. Since the material on the edge of the paver hopper has been exposed to the ambient air temperature for an extended period of time, its temperature will be significantly lower than desired. Occasionally, the angled cold spot occurs on one side of the mat. This can be explained by the new truck backing into the paver, off center, knocking cooler material onto only one of the paver's conveyors, thus sending material to only one of the screed augers and the cold spot occurs only on one side.

Almost all truck changes produce a distinct area of cooler material. This is caused by the fact that the material around the perimeter of the haul unit tends to cool faster than the core of the material in the haul unit. The formation of the cold spots is easily explained by the fact that the last HMA out of a haul unit will tend to be cooler than the material coming out of the middle of the haul unit. The first HMA being dumped into the paver hopper coming from the next haul unit will tend to be cooler. This combined with the last HMA out of the previous haul unit will tend to create a large mass of cooler material which is then spread by the paver.

The occurrence of cool spots in the mat immediately after placement tends to create areas with lower densities. These areas of lower density will tend to show distress

first due to accelerated aging of the asphalt binder due to increased air voids as well as increased water permeability. Depending upon the temperature differential and surface area of the cold spot, these spots may even be visible to the naked eye after compaction has been completed. Eliminating these areas completely is not possible without the use of re-mixing MTDs. The use of re-mixing MTDs is not practical for all paving jobs so determining the primary causes of thermal segregation should lead to ways to reduce thermal segregation.

Observations of pavement being placed on bridge decks were not made. Most of the paving projects observed did not have any bridge decks or if they did, they were not being resurfaced during the mainline paving operations.

An issue that became clear during the field observations was the number of variables that could affect the pavement's thermal profile. Isolating these variables is important for determining their importance. During the 2002 paving season, paving projects that will allow the isolation of certain variables will be monitored. This will include both day and night projects. A baseline temperature differential will be established by monitoring 10 "average projects" for a minimum of three days. "Average projects" will be defined as projects with average times, average paving equipment and average paving conditions. Thermal images will be taken for each truck change to allow the development of the average temperature differential observed for "average projects". This baseline temperature differential will then be applied to other projects to determine how non-average conditions are affecting the pavement's thermal profile.

Cooler areas typically exhibit a more open texture before and after compaction. This open texture may be created as the paver screed encounters cooler material, the

screed tends to drag and stretch the cooler material. Since the material is somewhat stiffer the fines are unable to work their way into the voids as would occur in a warmer material. If the roller could compact the cooler areas to the density of the warmer areas, there would tend to be a slight depression in the finished surface which has not been observed. Changes in the rolling pattern can not overcome this condition. The only correction for this is to have a uniform material temperature at the paver screed.

### Recommendations

Some preliminary suggestions may be made regarding improvements for paving procedures in cold weather. Additionally, temperature variations found in cold weather paving should be compared to those found in warm weather paving job.

- Reduce or eliminate loose material dropped in front of paver by departing trucks. Requiring trucks to clean out at a designated area not in the paving area would help to greatly reduce this spilled material. Any loose material that is spilled in the paving area should be shoveled up and discarded since cold spots (colder than surrounding material by 40° to 60° F) often appeared in the spillage area after the paver passed over the spillage area.
- Recommend further exploration of under what conditions a material transfer vehicle would be desirable.
- Using the thermal imaging camera, investigate differences between trucks with heated bodies (when available) versus trucks without heated bodies. This could be especially important during cold weather operations.
- Attempt to correlate the effect that the length of time as well as ambient air temperature has on spilled material left on the existing pavement.

Cores from three projects are proposed to be taken during the 2002 construction season. This will allow for density testing to be performed and compared with the nuclear density values. The cores will also provide an insight as to if the open textured surface translates into higher air voids throughout the pavement layer. The gradation of the pavement will

also be compared to the job mix formula for the material being placed to determine if there is any gradation segregation occurring. During the second phase of this project, emphasis will be placed upon obtaining as many nuclear densities as possible. This will add in the development of the estimates of density drop relative to the temperature differentials observed. Additional recommendations can be expected after more intensive testing of material taken from the paving sites and various conditions.

## References

Mahoney, J., Pierce, L., Uhlmeier, J., Moore, R., Muench, S., Read, S., and H. Jakob. “Identification and Assessment of Construction-Related Asphalt Concrete Pavement Temperature Differentials”, Presented to Transportation Research Board, 2000.

Stroup-Gardiner, M., and E.R. Brown. “Segregation in Hot-Mix Asphalt Pavements”, NCHRP Report 441, National Research Council, 2000.

Chang, C., Wolff, T., and G. Baladi. “Detecting Segregation in Bituminous Pavements and Relating Its Effects to Condition”, Presented to Transportation Research Board, 2000.

Henault, J. “Development of Guidelines for Reduction of Temperature Differential Damage (TDD) for Hot Mix Asphalt Pavement Projects in Connecticut”, Construction Report No. 2222-1-99-5, Connecticut Department of Transportation, November 1999.

Willoughby, K. A., Mahoney, J., Pierce, L. M., Uhlmeier, J. S., Anderson, K., Read, S., Muench, S., Thompson, T. and R. Moore. “Construction-Related Asphalt Concrete Pavement Temperature Differentials and Corresponding Density Differentials”, Report Number WA-RD 476.1, Washington State Transportation Center, June 2001.



## Appendix A – ACCESS Construction Database

### General Information Form Used in the ACCESS Construction Database

|                                        |                                           |                                  |                                                     |
|----------------------------------------|-------------------------------------------|----------------------------------|-----------------------------------------------------|
| Location                               | <input type="text" value="66"/>           | Base Temperature (F):            | <input type="text" value="130"/>                    |
| Date:                                  | <input type="text" value="6/19/2001"/>    | Air Temperature (F):             | <input type="text" value="85"/>                     |
| Weather:                               | <input type="text" value="Sunny"/>        | Project ID:                      | <input type="text"/>                                |
| <b>Equipment</b>                       |                                           |                                  |                                                     |
| Type of Paver used:                    | <input type="text" value="Cat AP-1055B"/> | <input type="checkbox"/> mtd     |                                                     |
| Number of rollers:                     | <input type="text" value="2"/>            | Type of MTD:                     | <input type="text"/>                                |
| <b>Material Data</b>                   |                                           |                                  |                                                     |
| Mixture Type:                          | <input type="text" value="Virgin"/>       | Percent RAP:                     | <input type="text" value="0%"/>                     |
| <input type="checkbox"/> Silo          | Lift Thickness (inch):                    | <input type="text" value="2.0"/> | Lift Type: <input type="text" value="Surface Top"/> |
| Average Compacted Lift Thickness (in): |                                           | <input type="text" value="1.5"/> |                                                     |

## Thermal Image Information Form in the ACCESS Construction Database

|                                          |                                                                     |                                                                     |                                                 |
|------------------------------------------|---------------------------------------------------------------------|---------------------------------------------------------------------|-------------------------------------------------|
| Image ID:                                | <input type="text" value="119"/>                                    | Image Location:                                                     | <input type="text" value="Thermal Images\6-1"/> |
| Date:                                    | <input type="text" value="6/19/2001"/>                              | <input type="checkbox"/> GPS taken                                  | Lane: <input type="text" value="Middle"/>       |
| Station Coordinates:                     | <input type="text" value="ST #2, Pt 3"/>                            | Cold Spot Location:                                                 | <input type="text" value="Center of lane"/>     |
| Temperature in Colder Area:              | <input type="text" value="214"/>                                    | Degrees of Differential Between Cold Spot and Surrounding Material: | <input type="text" value="60 F"/>               |
| Description of Thermal Image:            | <input type="text"/>                                                |                                                                     |                                                 |
| <input type="checkbox"/> Sampled HMA     | <input checked="" type="checkbox"/> Visibility of Cold Spots to Eye | <input type="checkbox"/> Hopper Wings Folded                        |                                                 |
| <input type="checkbox"/> Sampled binder  | <input type="checkbox"/> Compaction Data                            | <input checked="" type="checkbox"/> Spilled Material                |                                                 |
|                                          | <input checked="" type="checkbox"/> Truck Change                    |                                                                     |                                                 |
|                                          | <input type="button" value="Lab Data"/>                             |                                                                     |                                                 |
| Construction Equipment_Materials         |                                                                     |                                                                     |                                                 |
| <input type="checkbox"/> Equipment Image | Equipment Image Location: <input type="text"/>                      |                                                                     |                                                 |
| Description of Equipment Image:          | <input type="text"/>                                                |                                                                     |                                                 |
| GPS Coordinates:                         |                                                                     |                                                                     |                                                 |
| Latitude:                                | <input type="text" value="41.710758574"/>                           |                                                                     |                                                 |
| Longitude:                               | <input type="text" value="-72.205682267"/>                          |                                                                     |                                                 |

## Gradation and Density Form in the ACCESS Construction Database

|                        |                      |
|------------------------|----------------------|
| Station<br>Coordinates | <input type="text"/> |
| Sample<br>Location:    | <input type="text"/> |
| Gradation Data:        | <input type="text"/> |
| Nuclear density Data:  | <input type="text"/> |
| Data<br>Description:   | <input type="text"/> |

## Long Term Performance Form for the ACCESS Construction Database

|                                     |                      |                                              |
|-------------------------------------|----------------------|----------------------------------------------|
| GPS coordinates                     | <input type="text"/> | <input type="checkbox"/> Digital Image taken |
| Time after construction             | <input type="text"/> | Digital Image: <input type="text"/>          |
| Original thermal image              | <input type="text"/> | <input type="checkbox"/> Visual segregation  |
| <input type="checkbox"/> Sand patch |                      |                                              |
| Description:                        | <input type="text"/> |                                              |
| <input type="checkbox"/> Core taken |                      |                                              |
| Date core taken:                    | <input type="text"/> |                                              |