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Cyclic Segregation

CONSTRUCTION-RELATED ASPHALT CONCRETE PAVEMENT TEMPERATURE DIFFERENTIALS AND THE CORRESPONDING DENSITY DIFFERENTIALS

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16. ABSTRACT

The detrimental effects of low compaction temperatures or aggregate segregation have been documented for at least forty years. Lower compaction temperatures are directly related to an increase in air void content, which decreases the strength of the pavement. Even with a perfect mix design, if the mix is not properly compacted in the field, the final product will not last for its intended length of time.

The goals of this study were to determine what kind of problem the Washington State Department of Transportation (WSDOT) experiences with hot-mix paving, whether temperature differentials or aggregate segregation or both, the possible causes of those problems, and what WSDOT can do to fix the problem. The study found that WSDOT experiences temperature differentials on many projects and to some extent aggregate segregation (typically in longitudinal streaks). The study also found that because many factors are involved with paving operations, no one single piece of equipment or operation will guarantee that temperature differentials will not occur, but that techniques can be utilized to offset the effects of the temperature differentials.

The study utilized a density profile procedure that provides a method of determining the effect of the temperature differentials in the finished product. It can locate potential areas of low density, test those areas, and provide results (via a nuclear asphalt content gauge) to determine the extent of the problem.

Density differentials are a primary concern in hot-mix paving. If temperature differentials exist, but the finished pavement has a uniform density of 93 percent or greater for dense-graded mixes, then the pavement should serve its intended purpose for its intended length of time. The density profile procedure does not guarantee a uniform mat density, but it can be used as a quality control tool to help attain a uniform density. This could be a major step in achieving a higher quality hot-mix product.

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This reported work resulted in four Master's theses at the University of Washington. These are: Steven Read (1996), Stephen Muench (1998), Travis Thompson (1999), and Kim Willoughby (2001). The student support for these theses came from WSDOT and the University of Washington Valle Scholarship Fund.

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INTRODUCTION

Large numbers of dense-graded asphalt concrete paving projects in the US and internationally have experienced a cyclic occurrence of low-density pavement areas, generally called “cyclic segregation” or “end-of-load segregation”, which prematurely fail by fatigue cracking, raveling, or both (Brock and Jakob, 1999). This problem led to the observation of hot-mix mat temperature differentials in Washington State, which can result in lower than desirable mix compaction. Pavement temperature differentials result from the concentrated placement of a cooler mass of hot-mix into the mat. This cooler mass is generally associated with the crust that can develop on the hot-mix during transport from the mixing plant to the paver. Placement of this cooler hot-mix can create pavement areas near or below cessation temperature, which tend to resist adequate compaction.

A 1995 Washington State Department of Transportation (WSDOT) examination of this issue was conducted by Read (1996) and the WSDOT Materials Laboratory. During that study, large temperature differentials were noted during night paving operations. Initial mat density checks indicated that these “cooler” areas exhibited less than desirable densities. Read noted that the cooler mass was the surface layer (or crust) that developed during hot-mix transport from the mixing plant to the job site. The cooler mass of hot-mix was typically near or below the cessation temperature and went through the paving machine without substantial remixing during end-dump operations. Read also noted that most of the WSDOT paving projects identified as having “cyclic segregation” occurred either during night paving operations or near the beginning or end of the normal paving season.

The work summarized in this report is an extension of the 1995 work, which identified the problem, and is based on an examination of approximately 60 WSDOT paving projects over three years (1998, 1999, and 2000). In each of the years this study was conducted, actual production paving projects were viewed and the majority of them were wearing course mixes. This research was done to determine (1) the existence and extent of mat temperature differentials, (2) what detrimental effects can be caused by temperature differentials, (3) how such mat effects can be mitigated, and (4) a test procedure to locate significant temperature and density differentials for quality control during paving. The ultimate goal of this study was to determine the extent and effect of the density differentials on the finished mat.

The goal of the 1998 study program was to determine if the areas of low density that were determined by locating temperature differentials in the mat were comprised of segregation of the mix components. An infrared camera (provided by Astec Industries) was used to identify cooler areas in the mat directly behind the paver, which were sampled along with normal-temperature pavement areas. These areas were tested for gradation, asphalt content, density (bulk, maximum theoretical, and nuclear), and temperature. The mat temperatures were taken with the infrared camera and temperature probes at mid-depth in the mat. The difference between the two showed that the temperature mid-depth is higher than the surface temperature, as expected, but the temperature differentials were identifiable by both methods. Gradation and asphalt content analyses showed no significant aggregate segregation within the cooler mat areas. The cooler mat areas had higher air voids than the surrounding pavement. Several studies indicate that higher air voids may cause premature failure when compared to the mat as a whole; however, it is early in the life of these pavements and the full extent of the potential distress (or performance) is uncertain. In March 2001, a visual survey of the majority of the 60 projects originally assessed for this study was performed. These results will be available by late-2001.

The 1999 study program took the previous studies a step further to determine if there were any patterns in temperature differential occurrence between (1) different transfer devices or other paving equipment and (2) laydown operations. Again, an infrared camera (purchased by WSDOT) was used to identify the cooler areas in the mat directly behind the paver. Since it was determined that the cooler areas were generally not experiencing aggregate segregation in Washington, the research team focused on data collection and observations of different transfer devices or other paving equipment and laydown operations. Project specific data was collected to determine the possible effects of different factors on temperature differentials. A nuclear density gauge was used to check the air void content in both the cooler areas and the normal-temperature pavement to determine any relationship between air void content and temperature differentials. A general relationship was found between increasing temperature differentials and increasing air voids.

Using the results from 1998 and 1999 activities, the 2000 study program evaluated a method of locating the temperature differentials and testing them for density differentials. The WSDOT infrared camera and a handheld infrared temperature gun were used to identify the cooler areas in the mat directly behind the paver. The handheld temperature gun was used to scan the mat directly behind the paver to determine the possibility of locating temperature differentials without the infrared camera. (The handheld temperature gun is inexpensive, especially when compared to the infrared camera, which costs approximately $50,000.) Again, project specific data was collected along with nuclear densities in a longitudinal “density profile” to determine the density range and density drop for each profile. The density range is the difference between the maximum and minimum density readings along the profile and the density drop is the difference between the average and minimum readings. The ultimate goal is to minimize the occurrence of large density differentials in the finished pavement. It was found that pavements that experienced large temperature differentials produced substantial density differentials.

WSDOT’s statistically based quality assurance (QA) specification for asphalt concrete uses random sampling for field control (nuclear density tests) and for obtaining samples for laboratory testing. Based on results to date, the temperature differentials and higher than desirable air voids in the compacted mat generally occur in a systematic matter. Thus, it is not a surprise that routine QA tests do not provide substantial insight into this construction-related issue.

Although temperature differentials can frequently occur on hot-mix construction projects, they may be minimized or eliminated by remixing, shorter haul distances, warmer environmental conditions, good rolling practices, etc. Examination of these factors was the major focus of the 1999 study program and a minor focus of the 2000 study program. WSDOT’s ability to view truck bed insulation and the tight/insulated tarping of loads during haul was rare. Thus, no conclusive evidence that the tarping of loads or truck bed insulation works to offset temperature differentials is offered; however, it must be noted that the opportunity to systematically study these effects was unavailable. During the 2000 paving season, the focus was to collect the “density profile” data to measure the effect of temperature differentials on the range of air voids found in the finished pavement and develop a quality control measure that can be used to improve paving operations.

The 1998 field data collection was performed by the University of Washington and WSDOT. All laboratory testing was performed by WSDOT at their central laboratory in Tumwater, Washington. The infrared camera was provided and operated by Astec Industries. The 1999 field data collection was done with the WSDOT purchased infrared camera, WSDOT project field personnel (density testing), WSDOT personnel from the Materials Laboratory, and the University of Washington. For the 2000 paving season, the field data collection was done with the WSDOT purchased infrared camera and WSDOT personnel from the Materials Laboratory.

BACKGROUND

Factors that affect mat density will be discussed in this report and include segregation, compaction, and the resulting increase in air voids and permeability of the hot-mix. Aggregate segregation and temperature differentials that result in insufficient compaction can result in high air voids and an increased permeability of the hot-mix.

Segregation

Hot-mix segregation has been identified as a significant problem since the mid-1980s. It was addressed by Bryant (1967) but began to receive additional attention after Brock (1986) noted segregation as a common and consistent problem. This section will examine existing segregation research and provide a background for the temperature differential analyses.

Based on several articles and reports (Kennedy, et al. (1987); Brown and Brownfield (1988); Williams, et al. (1996a, 1996b); Khedaywi and White (1996); AASHTO (1997)), a commonly accepted qualitative definition of aggregate segregation is "the non-uniform distribution of coarse and fine aggregate components within the asphalt mixture."

There are two basic types of aggregate segregation:

- *Coarse segregation*. Occurs when the gradation is shifted to include too much coarse aggregate and not enough fine aggregate. Coarse segregation is characterized by low asphalt content, low density (high air voids), rough surface texture, and accelerated rutting and fatigue failure (Williams, et al. (1996)). Typically, coarse segregation is considered the most prevalent and damaging type of segregation.
- *Fine segregation*. Occurs when gradation is shifted to include too much fine aggregate and not enough coarse aggregate. High asphalt content, low air voids, smooth surface texture, accelerated rutting, and better fatigue performance characterize fine segregation (Williams, et al. (1996)).

The term "segregation" by itself is usually taken to mean "coarse segregation."

High air voids, low asphalt content, and rough surface macrotexture are established symptoms of coarse segregation (Bryant (1967); Kandhal and Cross (1993); Williams (1996)). However, these symptoms are also common to other hot-mix paving problems such as poor mix design, mat tearing, and inadequate compaction (Brown (1984); Bell, et al. (1984); Hughes (1989)).

In addition to a qualitative definition, a quantitative definition is desirable since current state specifications dealing with segregation tend to be subjective. Of the 42 states Williams, et al. (1996) surveyed, 35 addressed segregation by either specification or training while seven did not. Of the responding states, only 11 indicated quantifiable definitions beyond a visual evaluation.

Another survey of 12 states done by Mahoney and Backus (1999) showed that construction-related problems vary from mix segregation to deviations from the mix design. Table 1 shows the percent of the states reporting their principal construction-related problems.

Table 1. Principal Construction-Related Problems

Problem	**Percent Reporting (Total of 12 States)**
Mix Segregation	73%
Less than Desirable Compaction	55%
Smoothness	55%
Poor Longitudinal Joints	45%
Deviations from Mix Design	27%
Variable Binder Content	0%

Note: Multiple problems could be listed in the questionnaire.

To quantify aggregate segregation, the percent passing a given sieve size as compared to the Job Mix Formula (JMF) is a reasonable indicator. Research to date indicates that hot-mix greater than or equal to 10% coarser than the JMF on the No. 8 or the No. 4 sieve is indicative of aggregate segregation.

Stroup-Gardiner and Brown (1998) have put forth a more comprehensive segregation definition: "Segregation is a lack of homogeneity in the hot-mix asphalt constituents of the in-place mat of such a magnitude that there is a reasonable expectation of accelerated pavement distress(es)." They point out that "constituents" should be interpreted to mean asphalt cement, aggregates, additives, and air voids. This would describe a range of segregation found in conventional dense-graded mixtures, stone mastic asphalt (SMA), open graded friction courses, large stone mixtures, as well as any other mixtures with unique proportioning or compositional factors.

Compaction

The difficulty of achieving adequate hot-mix compaction dates back to at least the 1950s. Laboratory experiments and evaluation of pavements have shown that insufficient compaction leads to an increase in air voids and permeability, which results in a decrease in pavement life. This section will examine existing research relating to compaction, percent air voids, and increased permeability to provide a background for the discussion of temperature differentials.

The decrease in achievable density has been directly linked to compaction temperatures (Parker (1959); Dickson, et al. (1970); Hadley, et al. (1971); Geller (1984); Kennedy, et al. (1984)). Parker (1959) performed a laboratory study that showed an increase in air void content and a decrease in stability with lower compaction temperatures. Compared to a sample compacted at

275°F, a sample compacted at a temperature of 200°F contained more than double the percent air voids and at 150°F, the air void content quadrupled. Stabilities performed on these samples typically show a decrease in stability with decreasing compaction temperature and the resulting increase in air voids. The study indicated that the majority of compaction should be accomplished before the temperature reaches 225°F and while the mix is still in a plastic state. Therefore, to achieve a uniform pavement, closer control of the temperatures in the field should occur. These findings are supported by Dickson, et al. (1970), Hadley, et al. (1971), Geller (1984), and Kennedy, et al. (1984).

Scherocman and Martenson (1984) identify typical problems that may occur during the paving process along with some possible causes. Of the problems listed, two that occur frequently along with the presence of temperature differentials are non-uniform mat texture and poor mix compaction. Some of the causes listed could possibly relate to the occurrence of temperature differentials and include mix segregation [aggregate], variation of mix temperature, and cold mix temperature. There are numerous other causes of these paving operation problems, but they may not be directly related to causing temperature differentials. From this, it can be seen that cooler than desirable temperatures and a variation in mix temperature (temperature differentials) can cause poor mix compaction and a non-uniform mat texture. A non-uniform mat texture typically leads to non-uniform densities and poor mix compaction, at least in the areas of cooler temperature. This decrease in density leads to a loss of fatigue life and serviceability of the pavement.

> "In terms of ultimate pavement durability, the air void content or density of the mix is probably the single most important characteristic of performance under traffic. If the air void content of the asphalt concrete material is adequate (less than 7%), the pavement structure should perform well under vehicular loading, even with minor variations in [the] mix design. If the level of density obtained during the compaction process is too low (too high an air void content), the mix will not be durable even with a "perfect" mix design and even without any other mat problems being present. If proper density can be and is obtained in the asphalt concrete material, the mixture will serve its intended purpose for many years." (Scherocman and Martenson (1984))

Kandhal et al. (1984) affirms these findings by saying that the percent compaction just after construction should be at least 92 percent of the maximum theoretical density to prevent premature distress in the pavement. A properly designed asphalt concrete mix will not be resistant to deformation and will not be durable unless it is properly compacted at the time of construction.

Air Voids and Permeability

Brown (1984) confirms that the lack of density during construction results in poor pavement performance and adds that the long-term deterioration is raveling and cracking. He cites that the purpose of compaction is to provide adequate percent air voids and shear strength, ensure that the pavement is essentially waterproof, and reduce oxidation of the asphalt binder. The permeability of the pavement influences the oxidation of the binder and the waterproof characteristics. A nonpermeable mat cannot be achieved without adequate compaction and if the percent air voids are 7 percent or less, the mix is essentially waterproof. Also, a laboratory study indicated that the permeability of an asphalt mixture essentially doubles for each one percent increase in air voids.

The permeability coefficient of an asphalt mixture can be estimated by the following equation (Arkansas Highway Transportation Department (1998)):

$$k = (1.38\times10^{-7})(3.92^{\%Va})(0.61^{\text{Lift Thickness}}) \qquad \text{(Equation 1)}$$

where:

%Va = Air Voids, expressed as a percentage

LT = Lift Thickness, in cm

A permeability coefficient of 10^{-4} cm/s has been selected as the break between high pavement permeability (10^{1} to 10^{-4} cm/s) and low pavement permeability (10^{-4} to 10^{-6} cm/s) in Arkansas. For example, a 2-inch (5.08 cm) lift thickness with 6 percent air voids compared to 10 percent air voids results in permeability coefficients of 4.1×10^{-5} cm/s and 9.6×10^{-3} cm/s, respectively. The same lift thickness produces a permeability of 1.6×10^{-4} cm/s at 7 percent air voids, which slightly exceeds the break between low permeability and high permeability. Using this equation as an estimate of the permeability of a particular mix for a given lift thickness, the permeability increases by almost 300 percent with every one percent increase in air voids. Figure 1 shows the increase in permeability with thinner lifts and with the increase of air voids.

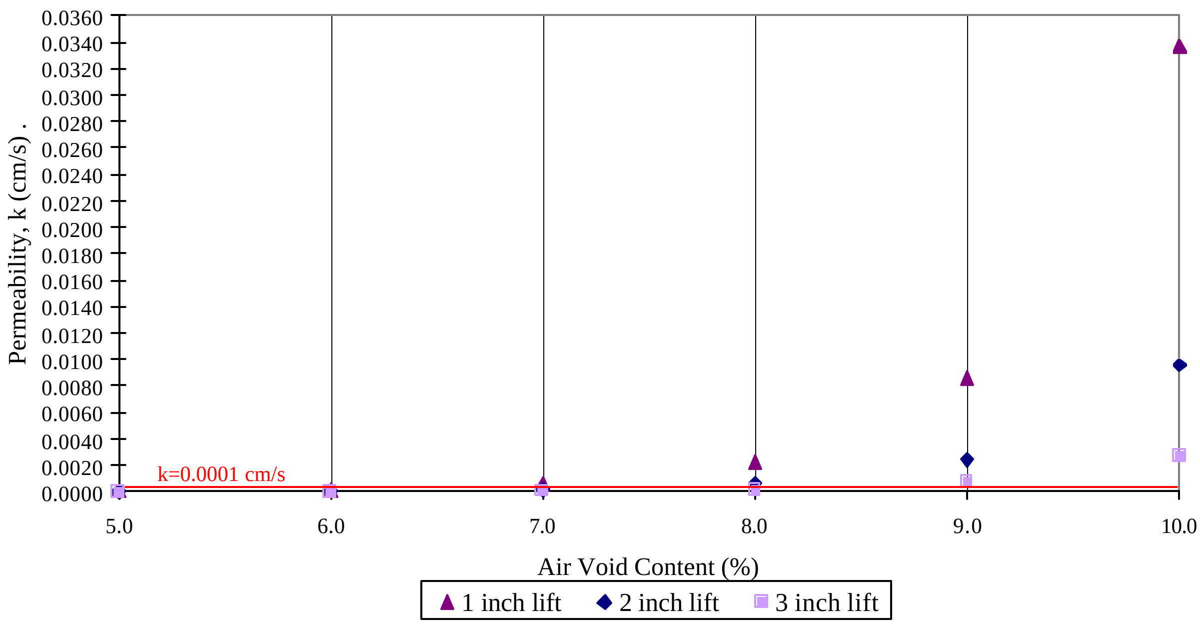


Figure 1. Permeability of Hot Mix for Differing Lift Thickness

NCHRP Project 9-11 Overview

Stroup-Gardiner and Brown (2000) performed a review of current technology and methods used to detect and measure segregation along with a field assessment. They labeled segregation in general as aggregate, temperature, and asphalt-aggregate segregation. Below are their definitions for no, low, medium, and high segregation. The study results are summarized in Table 2.

No segregation, assuming that proper mix design and compaction are attained:

- Acceptable air voids
- At least 90 percent of the anticipated mix stiffness
- An asphalt content within 0.3 percent of the Job Mix Formula
- No statistical difference in the percent passing any of the coarse sieve sizes

Low-level segregation:

- Mix stiffness of between about 70 and 90 percent of the non-segregated areas
- Increased air voids between about 0 and 4 percent
- If aggregate segregation is present,
  - At least one sieve size will be at least 5 percent coarser
  - A corresponding decrease in asphalt content between 0.30 and 0.75 percent

Medium-level segregation:

- Mix stiffness of between roughly 30 and 70 percent of the non-segregated areas
- Increase in air voids of between 2 and 6 percent
- If aggregate segregation is present,
  - At least two sieve sizes will be at least 10 percent coarser
  - A corresponding decrease in asphalt content between 0.75 and 1.30 percent

High-level segregation:

- Mix stiffness of less than 30 percent of the non-segregated areas
- Increase in air voids of more than 4 percent
- If aggregate segregation is present,
  - At least three sieve sizes will be at least 15 percent coarser
  - A corresponding decrease in asphalt content of greater than 1.30 percent
- Cores will tend to fall apart upon coring or cutting

Stroup-Gardiner and Brown performed an evaluation of the technology being used to detect and measure different types of segregation. Infrared technology, $ROSAN_V$ Surface Texture Measurements, and Rolling Nuclear Density Measurements were evaluated for their usefulness and ability to detect and/or measure aggregate segregation, asphalt-aggregate segregation, and temperature differentials.

Other methods considered were the Ground Penetrating Radar (GPR), Seismic Pavement Analyzers (SPA), and field permeability testing. GPR was not used because it was felt that this method would only have the ability to detect density changes. SPA's were not used mainly because the results are (1) pavement temperature dependent, (2) extensive laboratory testing would be required to correlate the change of properties with temperature, and (3) it is unknown what influence the underlying layers have on this equipment. Lastly, field permeability testing was not performed because these tests can only identify areas with high air voids. It was noted that the combined technologies of the GPR and Infrared Thermography complement each other very well. The GPR collects data in a longitudinal direction typically with multiple passes and the infrared technology produces a "map" of the entire pavement surface relating to temperatures.

The infrared technology works well to detect and measure levels of segregation, but cannot distinguish between aggregate segregation and temperature differentials exclusively. For the infrared camera to be used effectively, it must be used during laydown of the hot mix to determine any cooler areas prior to compaction. Stroup-Gardiner and Brown recommended that the infrared camera be used during construction to determine areas that have different material properties and exclude these areas from the normal random sampling plan for acceptance testing. ASTM D4788 *Standard Test Method for Detecting Delaminations in Bridge Decks Using Infrared Thermography* is used as a reference for testing with this type of equipment. Refer to Table 2 for the different levels of temperature differences during laydown.

The $ROSAN_V$ Surface Texture measurements can be used to detect and measure each level of aggregate segregation and asphalt-aggregate segregation because these both alter the surface texture of the pavement. The result is an estimate of the percentage of the longitudinal path with each level of segregation. The longitudinal paths were approximately 3, 6, and 9 feet from the shoulder and were approximately 10 inches in length. The ratios of the texture in segregated areas to that in non-segregated areas were set on the basis of statistically different key mixture properties – maximum size of aggregate, aggregate shape, and the gradation. It was assumed that the change in texture caused by segregation should be proportional, that is, the ratio of texture for a given level of segregation to that in the non-segregated areas should be consistent. Refer to Table 2 for texture ratios for each of the levels of segregation.

The Rolling Nuclear Density measurement was not found to be very useful for detecting and measuring all levels and types of segregation, but it is very useful for developing a longitudinal density profile that can then be used along with the infrared technology to identify a specific category of temperature differentials. It was found that there was a difference between the non-segregated areas in the outer longitudinal paths compared with the path down the middle of the lane, but there was no significant difference within a longitudinal path. The generally observed trend was a decrease in density with increasing levels of segregation, but this equipment had variable success in detecting aggregate segregation. Overall, the changes in density with the varying levels of segregation tend to be only statistically significantly different in the medium or high categories of segregation.

Laboratory testing was performed for each of these projects and the results were reported according to each level of segregation. The levels of segregation are reported according to temperature differentials seen during construction with the infrared camera and the surface texture ratios as measured by the $ROSAN_V$. The differences in the laboratory testing results by the level of segregation measure are also reported (Table 2). The testing included permeability, resilient and dynamic modulus at various temperatures, tensile strengths before and after moisture conditioning, triaxial testing to obtain Mohr-Coulomb failure criteria parameters, low temperature indirect tensile creep testing, and estimates of loss of life. Each of these tests was run with laboratory prepared samples.

The permeability of a specific mix increased with increasing levels of segregation. For fine segregated mixes, the permeability increased slightly and for coarse segregated mixes, the permeability increased noticeably.

Resilient and Dynamic Modulus testing was performed to assess the influence of segregation on mixture stiffness over a wide range of temperatures. A ratio of the stiffness for the segregated mixtures to that of the non-segregated mixture was used to estimate the percent loss of mix stiffness due to segregation.

The testing of tensile strengths showed that there was a slight decrease in strength when the samples were tested in the dry condition. However, the tensile strength of the samples when tested in the wet condition had significant reductions. Their hypothesis from this data is that even poor quality mixes can be fabricated more uniformly in the laboratory than during construction. It was only after the samples were conditioned did the influence of segregation become apparent.

It was found that there was a decrease in cohesion with decreasing asphalt contents and increasing levels of segregation. The angle of friction (Mohr-Coulomb criteria) was relatively constant for fine-graded mixes and decreased significantly with coarse-graded mixes. This indicates a loss of aggregate-to-aggregate contact between the larger particles. The octahedral shear stress is used to define the influence of the nine three-dimensional stresses at a specific point in the pavement and it decreases with increasing segregation.

The low temperature Indirect Tensile Creep was to be estimated by using analysis software, but the data produced very erratic results, especially for the coarse-graded mixes.

The Asphalt Institute's DAMA program was used to estimate the fatigue life based on the level of segregation. This program uses inputs of mean monthly high temperatures, key aggregate and asphalt properties, and pavement structure information. The assumption that segregation only occurred in one lift at a time was used. When segregation occurs in the wearing lift only, the life of only that lift is affected. When a high level of segregation is present in the wearing course, the failure mode is fatigue. High levels of segregation in the leveling course affect the wearing course and are noticed as rutting not fatigue. When low or medium levels of segregation are present in the leveling course, there is a loss of life in that lift, but typically doesn't affect the wearing lift. Rutting, as explained in Table 2, is not strongly influenced by segregation until a high level of segregation is reached.

When segregation leads to a loss of pavement life, localized maintenance strategies are typically not used within state agencies; pavements are overlaid or reconstructed. Therefore, Stroup-Gardiner and Brown suggest that payment for any lot with evidence of segregation should be paid on the basis of the segregated areas only because these areas control the life of the entire lot. If low levels of segregation are present within a lot, the pay factor should be 90 percent (consistent with a pay factor for a pavement with a 2 percent increase in air voids). Medium levels of segregation equate to a pay factor of 80 percent (consistent with pay factors for an increase in air voids of 4 percent) and lots with high levels of segregation should be removed and replaced.

Table 2. Summary of Specification Limits and Expected Corresponding Mixture Changes (Stroup-Gardiner and Brown (2000))

Mixture Property	Percent of Non-Segregated Mix Property by Level of Segregation			
	None	Low	Medium	High
Ranges of Temperature Differences, ^{o}C (^{o}F)	<10 (18)	10 (18) to 16 (28.8)	17 (30.6) to 21 (37.8)	>21 (37.8)
Surface Texture Ratios (segregated to non-segregated areas)	<1.16	1.16 to 1.56	1.56 to 2.09	>2.09
Changes in Mix Properties Expressed as a % of the Properties in the Non-Segregated Areas				
Permeability	Increased slightly	Increasing with level of coarse segregation		
Resilient Modulus[1], % of mixture stiffness compared to non-segregated areas	Little or slightly increasing stiffness	70 to 90%	50 to 70% (infrared[2]) 30 to 80% (laser[3])	<50% (infrared[2]) <30% (laser[3])
Dynamic Modulus, % of mixture stiffness compared to non-segregated areas	Little or slightly increasing stiffness	80 to 90%	70 to 80%	50 to 70%
Dry Tensile Strength	110%	90 to 100%	50 to 80%	30 to 50%
Wet Tensile Strength	80 to 90%	75%	50%	30%
Low Temperature Tensile Stress	No conclusions due to test method difficulties			
Loss of Fatigue Life when Segregation in Upper Lifts, %	Not estimated	38%	80%	99%
Rutting Potential	Not strongly influenced by gradation segregation until a high level of segregation is seen			
Difference in Values Between Segregated and Non-Segregated Areas				
Gradations Minimum number of sieve sizes that are a given % coarser	NA	1 sieve > 5%	2 sieves > 10%	3 sieves > 15%
Change in Air Voids, %	NA	2.5 to 4.5% (infrared[2]) 0 to 2.5% (laser[3])	4.5 to 6.5% (infrared[2]) 0 to 2.5% (laser[3])	>6.5% (infrared[2]) >4.0% (laser[3])
Change in Asphalt Content, %	NA	-0.3 to -0.75%	-0.75 to -1.3%	>1.3%

[1] Reflects results from testing both cores and laboratory-prepared samples

[2] Results expressed as a percentage of the corresponding level of segregation as measured by the temperature differences

[3] Results expressed as a percentage of the corresponding level of segregation as measured by the surface texture ratios

The following sections contain results of the studies performed by WSDOT and the University of Washington in 1998, 1999, and 2000 regarding temperature differentials. This work was done to expand knowledge on how temperature differentials were occurring and what could be done to minimize and/or measure their effects. The objective was to add additional insights into the complicated process involved in placing and compacting quality hot-mix asphalt concrete.

1998 FIELD SAMPLING AND TESTS

The field study of four WSDOT paving projects during the 1998 paving season was significantly influenced by Read's (1996) work during the 1995 paving season. Read found that large temperature differentials could occur to such an extent that the resulting compacted mat densities were lower than desirable. However, Read was able to produce only limited supporting field data. At the time, he was examining numerous factors that could be associated with the cyclic segregation issue, with the critical assumption that all cyclic segregation was due to aggregate segregation. Thus, the 1998 study program was used to place more emphasis on sampling and testing of the hot-mix during placement and compaction.

Sites were selected based on criteria that would allow adequate sampling opportunities and maximize temperature differential probability. These criteria were:

- Project size of greater than 5,000 tons of hot mix.
- Early or late season projects, night projects, projects with significant haul distances, or projects being done at locations where temperature differentials might be expected. Projects done under these conditions have been observed to have the most extensive construction related defects. The goal was to simply answer the question as to whether WSDOT paving projects experience significant temperature differentials and what, if any, effects occurred in the as-compacted mat.
- At least one project with a Material Transfer Vehicle (MTV) was viewed to examine its effect on temperature differentials.
- Projects using WSDOT Class A hot-mix (Class A mix was the most commonly used dense-graded WSDOT wearing course at that time).

Based on these criteria, four projects were chosen and are referred to as: I-5 (Blaine), SR 99 (Seattle), SR 2 (Spokane), and SR 195 (Colfax). Site locations are shown in Figure A1 in Appendix A, the field tests performed in Table A1, and the associated laboratory tests in Table A2.

A sampling plan was developed with the following goals in mind:

- Determine delivered mix temperatures and the associated temperature differentials (if any). Temperature probes placed in the mat at mid-depth and the ThermaCAM PM280 infrared camera provided by Astec Industries were used to obtain this information. The infrared camera was also used to determine mix surface temperatures in the truck bed, paver hopper, and behind the paver screed.
- Determine cooler and normal-temperature areas within the mat and associated mix characteristics. This involved identifying appropriate mat areas with the infrared camera, recording their temperature with a temperature probe at mid-layer depth (as a backup to the infrared camera), then obtaining loose-mix samples.

- Nuclear densities and cores were obtained following final compaction from paired normal- and cooler-temperature areas.
- Loose-mix samples were also taken from the same truckload of mix and paired together (one normal-temperature and one cooler area) to reduce variability when comparing cooler and normal-temperature mat areas.

1998 RESULTS

Results are presented in three subsections: mat temperatures; gradation and asphalt content; temperature differentials and air voids.

Mat Temperatures

The mat temperatures were measured directly behind the paving machine by use of a temperature probe and the infrared camera. The infrared camera located the cooler areas and the surface temperatures for both the normal and cool areas were recorded. The temperature probes were placed mid-depth in the normal and cool areas to verify the temperature differential between these areas. Only three of the four projects had sufficient data to compare the average temperatures in the "normal" and "cooler" portions of the mat (all temperatures reported were taken at the material sampling locations). As a reference, cessation temperature is assumed to be 175°F.

- I-5 (Blaine)
  - Average temperature "normal" areas = 276°F (temperature probe, n = 6) and 268°F (infrared camera, n = 4)
  - Average temperature "cooler" areas = 229°F (temperature probe, n = 6) and 219°F (infrared camera, n = 4)
  - Average temperature difference between the infrared camera and the temperature probe (located at mid-depth of freshly placed (uncompacted) overlay) = -9°F (temperature probe temperatures, on average, higher than infrared camera)
- SR 2 (Spokane)
  - Average temperature "normal" areas = 247°F (temperature probe, n = 4) and 241°F (infrared camera, n = 4)
  - Average temperature "cooler" areas = 203°F (temperature probe, n = 4) and 204°F (infrared camera, n = 4)
  - Average temperature difference between the infrared camera and the temperature probe (located at mid-depth of freshly placed (uncompacted) overlay) = -3°F (temperature probe temperatures, on average, higher than infrared camera)
- SR 195 (Colfax)
  - Average temperature "normal" area = 268°F (temperature probe, n = 2) and 255°F (infrared camera, n = 2)
  - Average temperature "cooler" area = 241°F (temperature probe, n = 2) and 238°F (infrared camera, n = 2)

- Average temperature difference between the infrared camera and the temperature probe (located at mid-depth of freshly placed (uncompacted) overlay) = -8°F (temperature probe temperatures, on average, higher than infrared camera)

Thus, the differences between the "normal" and "cooler" portions of the mats (via the temperature probes) were 47, 44, and 27°F, respectively. Also, the temperatures measured at mid-depth in the mat are higher than those measured with the infrared camera (surface temperature). The actual temperatures at the start of rolling were lower than those shown. This was especially true on SR 2 (night paving operation) and SR 195. On both of those projects, the roller operators were not diligent in keeping up with the laydown operation during the time the study team was present. That likely contributed to the high air voids reported.

Figure A3 shows the kinds of temperatures observed at one location for the I-5 (Blaine) test site (image from the infrared camera). To obtain that specific image, the camera was located on the back of the paving machine (the paved mat was approximately 12 feet wide).

Gradation and Asphalt Content

Gradation analysis did not reveal significant aggregate segregation (see Table A3). The results in Table A3 are based on averages of the samples taken from the mat directly behind the paving machine. Of 13 total paired mix samples, only two pairs exhibited greater than 10% difference in percent passing by weight for the No. 4 sieve; no paired samples showed greater than 10% difference on the No. 8 sieve (these values are generally accepted as the critical percent passing and associated sieves to best estimate the presence of aggregate segregation). Asphalt binder content results revealed no significant differences between the "normal" and "cooler" areas.

Temperature Differentials versus Air Voids

For all 13 paired mix samples and following final compaction, the cooler mat areas always exhibited higher air voids, and were typically four percent higher (see Table A4). Gradation and asphalt content analysis rule out significant aggregate segregation, which leaves temperature differentials as the probable cause. Previous studies had concentrated on aggregate segregation as the most likely cause for these isolated areas of high air voids. However, studies by Brown (1988), Cross and Brown (1993), Williams, et al. (1996), and Cross, et al. (1997) had difficulty consistently correlating visually identified distressed pavement areas with measured aggregate segregation. This study consistently identified high air void areas by locating the cooler portions of the mat. Previous research has already established that higher air voids can significantly reduce pavement life (Linden, et al. (1989), and Stroup-Gardiner and Brown (2000)).

Table A4 shows paired mat temperature differentials and air voids (for all pairs the higher air voids were associated with the lower temperature areas). Since the temperature probes and infrared image temperatures differed slightly, the results for each are shown in Figures A4 and A5, respectively.

After the completion of the 1998 work, Collins (1998), in conjunction with Astec Industries, performed an experiment with compaction temperatures and the Asphalt Pavement Analyzer

(APA). Collins took a particular type of mix at 300°F and compacted the sample in a vibratory compactor to 7 percent air voids. Using this sample to determine the pressure that was needed to achieve the 7 percent air voids, samples were then compacted at different temperatures (from 200 to 280°F at 20°F intervals) to determine the air void result for each sample. Then, using the APA, fatigue tests were run on each of the beams. Figure 2 shows that as the compaction temperature went down, the percent air voids increased and the cycles required to break the beam dropped significantly. Although this testing was performed on one specific type of mix in the laboratory, the results show that cooler areas in the mat can result in higher air voids and a drastically reduced pavement life. According to the fatigue test results, the mix compacted at 200°F would have approximately 10 percent of the life of the mix that was compacted at 300°F.

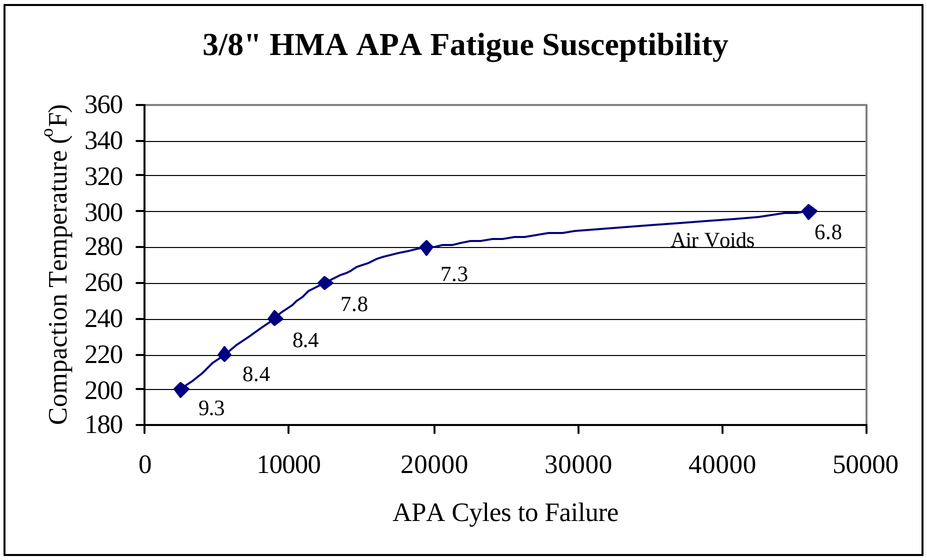


Figure 2. HMA samples tested in the APA to failure. (Collins (1998))

1998 CONCLUSIONS

While none of the four projects sampled during 1998 showed significant aggregate segregation, all four showed temperature differentials. Aggregate segregation is still a common and consistent problem in the hot-mix paving industry; however, when addressing what has previously been called "cyclic segregation" or "end-of-load segregation," temperature differentials resulting in lower than desirable densities should be considered as a possible cause along with aggregate segregation.

Temperature differentials are easily identified during construction by instruments such as the infrared camera. These mat areas, if they occur, generally do so at the beginning of each truckload of mix as it passes through the paver. However, these cooler portions in the mat do not always result in accelerated pavement distress. First, the temperature difference between a cool area and the surrounding mat may be minimized by shorter haul distances, a warmer environment, remixing equipment, and insulated or tarped trucks. However, these factors were not systematically observed during the 1998 paving season. Second, some MTVs or other remixing equipment/methods may eliminate or significantly reduce mat temperature differentials (on two of the four projects, MTV operations were observed but are not summarized for the 1998 data collection). Finally, despite substantial temperature differentials, good rolling and paver operation practices can minimize compaction deficiencies due to lower than desirable mat temperatures. Pneumatic rollers included in the paving train as the breakdown or intermediate roller tend to reduce the variability of the in-place densities, but because of the uncontrolled variables on each project, the 1998 data does not provide conclusive evidence. For instance, the project on SR 99 in Seattle had aggressive rollers with the breakdown roller consistently operating close to the paving machine. This project experienced the highest temperature differentials out of the four projects visited, but had the lowest difference in air voids between the cooler and normal temperature areas.

Specific Conclusions

1. *None of the four projects experienced significant aggregate segregation*. Gradation and asphalt content analyses of both normal-temperature and cooler mat areas showed no substantial aggregate segregation as defined by prior studies.

2. *All four projects experienced significant temperature differentials*. All four projects experienced placement of a significantly cooler portion of hot mix into the mat. Using the infrared camera, this cooler mass was verified as the surface layer (or crust) of the hot mix developed during transport from the mixing plant to the paver. The temperature differences between these cooler areas and the surrounding normal-temperature areas varied from 12 to 70^{o}F with an average of 38^{o}F (as determined by the infrared camera). Further, generalized conclusions about all WSDOT paving projects should not be made since these four projects were chosen for their higher temperature differential likelihood (i.e., the projects were sampled either early or late in the paving season, or were night paving jobs).

3. *Concentrated areas of significantly cooler hot-mix resulted in reduced compaction of these areas.* For all 13 paired samples, the cooler areas exhibited higher air voids than the normal-temperature areas. The difference in percent air voids within paired samples ranged from 1.6 to 7.8 percent with an average of 3.9 percent. Prior research has established that for dense-graded hot-mix, approximately a one-percent increase in air voids (above a baseline value of seven percent) results in a minimum 10 percent decrease in pavement life (Linden, et al. (1989)). Thus, these areas of higher air voids will likely suffer from accelerated pavement distress when compared to the mat as a whole.

4. *Good construction practices may reduce temperature differential effects.* The observed cooler mat temperatures were always above the cessation temperature at laydown (however, in some cases, not by much). Typical normal mat temperatures ranged from 222^{o}F to over 300^{o}F while cooler area temperatures ranged from 184^{o}F to 262^{o}F. Thus, timely breakdown rolling and a proper compaction train should be able to adequately compact isolated cooler areas. For example, the SR 99 (Seattle) contractor used good laydown practices and therefore was able to minimize the difference in air voids to 2.8 percent despite one of the largest observed temperature differentials (70^{o}F) observed during the 1998 data collection. Conversely, compaction on the SR 195 (Colfax) project was substantially delayed resulting in breakdown rolling occurring near cessation temperature. Consequently, large air void

differences (5.0 and 7.8 percent) resulted from modest temperature differentials (12°F and 22°F).

5. *Temperature differentials are easily identified by infrared imaging*. This study and the earlier work of Brock and Jakob (1997) have consistently shown concentrated cooler mat areas are identifiable with an infrared-imaging camera.

1999 FIELD SAMPLING AND TESTS

During late 1998, WSDOT acquired an Inframetrics ThermaCAM™ PM290 infrared camera. One purpose of the camera was to examine a number of 1999 paving projects for temperature differentials and any associated as-placed mix problems (36 projects were examined). This study is an extension of the previous works done by Read (1996) and Muench (1998). The emphasis of the 1999 study was to attempt to determine various equipment and haul influences.

The types of projects that were examined include:
- Traditional paving projects with no special features with respect to temperature differentials
- Projects which use MTVs/MTDs
- Jobs which use windrows and windrow elevators
- Night paving projects
- Long hauls versus short hauls
- Hauling trucks with various types of tarps and fastening methods
- Other projects with innovative features that might reduce temperature differentials.

Projects were chosen so that a variety of MTVs/MTDs (including windrow elevators) would be viewed. Long hauls, night paving, and Superpave projects were included in the study to the extent possible.

The general procedure was to use the infrared camera to:
- Observe mix as it is being placed into the truck at the plant
- Observe the mix transition from the truck to the paver and into the mat
- Observe the temperature differences in the mat and locate points for nuclear density testing.

All associated data such as project tonnage, weather conditions, mix information, haul length, types of equipment on the job, rolling times for breakdown, intermediate, and final compaction, mat densities, etc., were recorded.

The objectives of the 1999 data collection were to determine:
- The influence of various types of MTVs/MTDs or other remixing equipment on temperature differentials
- Haul influence on temperature differentials in the hauling equipment and the mat
- Ambient air and surface temperature factors (if any)
- The influence of rolling patterns
- The connection between temperature differentials and density differentials
- Appropriate measures that help reduce temperature differentials or mitigate their effects.

1999 RESULTS

The results are presented in four subsections: a general overview of the 36 projects; influence of different factors on temperature differentials; the influence of factors on the change in air voids; and the influence of factors on the range in air voids.

Overview

There were 36 projects visited during the 1999 paving season (May to October). Table B1 in Appendix B has a comprehensive listing of project data. Below is a summary of the observations made concerning the projects.

- Classes of mix varied from WSDOT's typical dense-graded mix (Class A) to a Modified Class D (open-graded) and Stone Mastic Asphalt (SMA). Class A, B, E, and Superpave designated mixes are dense-graded mixes.
  - 21 projects – WSDOT Class A
  - 4 projects – WSDOT Class B
  - 5 projects – Superpave Class ½"
  - 3 projects – Superpave Class ¾"
  - 1 project – WSDOT Class E
  - 1 project – WSDOT Modified Class D
  - 1 project – Stone Mastic Asphalt (SMA)
- Mat temperatures were measured with the infrared camera directly behind the paving machine in the uncompacted mat and the typical mat temperatures varied from 230°F to 283°F with an overall average temperature of 251°F.
- Change in the mat temperatures or ΔT measured between the typical mat temperature and the cooler portion of the mat varied from 5°F to 69°F.
- Air temperatures ranged from 55°F to 104°F.
- Existing pavement surface temperatures ranged from 41°F to 140°F.
- The internal temperature of the hot-mix in the truck when dumping into the paving machine or MTV/MTD varied from 250°F to 320°F. This temperature was within 20°F of the hot-mix temperature at the plant during the loading of the trucks (most were within 10°F).
- The temperature of the exposed portion of the mix in the truck during the haul (the crust) varied from 130°F to 171°F. (These temperatures could not be directly recorded for tarped loads and were recorded as the "coolest" mix seen out of a belly dump or flowboy truck.)
  - These temperatures are below the recommended cessation temperature for compaction in all cases.
  - The thickness of the crust appeared to increase as the haul distance increased, although there was no physical measurement performed. The thickness was estimated visually from the infrared camera images.
- The haul distance (from the plant to the project site) varied from 1.3 to 35 miles and the haul times varied from 5 to 100 minutes. The haul times included the wait time until the vehicle was allowed to dump (in the case of trucks and pups, haul time included the wait time until the pup was allowed to dump).

A wide variety of projects were visited during the 1999 paving season and produced varied results. The influence of different factors on temperature differentials and percent air voids were difficult to determine for a specific factor because there were no controls on the types of equipment being used or how it was used for each project. Each factor was influenced by the types of equipment, weather conditions, mix type, plant temperatures, haul length, MTV/MTD type (if any), paving machine, and roller patterns used on the job. Therefore, the conclusions presented for specific factors affecting temperature differentials are uncertain, but the general trends are helpful for determining what types of equipment or conditions can reduce the occurrence of temperature differentials. All plots have regression lines plotted along with the calculated coefficient of determination (R^2). A low R^2 can confirm an expectation that there is no correlation between certain variables.

Temperature Differentials

The temperature differentials observed on these 36 projects include numerous factors that are interrelated and cannot be separated via this study. Temperature differentials are simply the difference between the highest and lowest temperatures seen on a project on the day visited. Figure 3 and Table 3 demonstrate that the largest temperature differential is 57.9°F (the white point has a temperature of 166.2°F and the temperature at the yellow point is 224.1°F). Since there are so many factors affecting the temperature differentials, a summary table (Table 4) shows the different factors the temperature differentials were plotted against, the R^2 for the specific graph, and any significant findings from the plot. Appendix B (Figures B2 through B8) illustrates the typical temperature differentials versus each of the factors for a more complete presentation of the results.

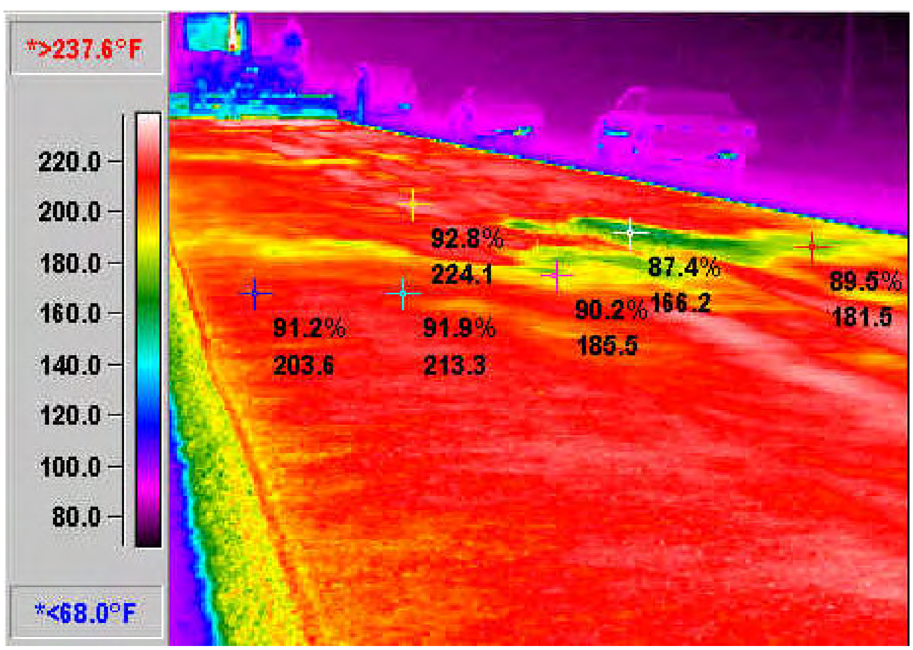


Figure 3. Example of Infrared Image with the Corresponding Densities and Temperatures.

Table 3. Breakdown of Figure 3 for Each Point Density and Corresponding Temperature.

Point Density/Temperature	Dark Blue	Light Blue	Yellow	Pink	White	Red
Temperature (^oF)	203.6	213.3	224.1	185.5	166.2	181.5
Maximum Theoretical Density (%)	91.2	91.9	92.8	90.2	87.4	89.5
Change in Temperature (^oF)	20.5	10.8	0.0	38.6	57.9	42.6
Change in Air Voids (%)	1.6	0.9	0.0	2.6	5.4	3.3

Table 4. Results and Significant Findings from the Temperature Differential Plots.

Mat DT versus:	**R^2**	**Significant Findings**
Air Temperature (Figure B2)	0.03	Air temp$\geq$85^{o}F: 40% with $\Delta T\geq 25^oF$, none above $\Delta T>35^oF$ Air temp<85^{o}F: 56% with $\Delta T\geq 25^oF$, 28% with $\Delta T>50^oF$
Pavement Surface Temperature (Figure B3)	0.01	
Mix Temperature at Plant (Figure B4)	0.05	When mix @ plant$\leq$260^{o}F, the $\Delta T\leq 20^oF$. When mix @ plant$\leq$275^{o}F, the $\Delta T\leq 65^oF$. When mix @ plant$\leq$320^{o}F, the $\Delta T\leq 80^oF$.
Haul Time (Figure B5)	0.11	In general, the longer the haul, the greater the ΔT. Haul time $\leq$20 min: 35% with $\Delta T\geq 25^oF$. Haul time >20 min: 70% with $\Delta T\geq 25^oF$.
Haul Time by Tarp Use (Figure B6)		Because of tarp type, no significant difference was noted.
Untarped	0.19	
Tarped	0.00	
Haul Time by Truck Type (Figure B7)		Belly dumps have a higher correlation value (R^2), but could be due to the fact that belly dumps are almost exclusively used with Windrow Elevators.
Trucks and Pups	0.08	
Belly Dumps	0.44	
Haul Time by MTV Use (Figure B8)		MC-30 used in two different capacities (with and without the paddles operating): 6 out of 7 projects had $\Delta T\geq 25^oF$.
End Dump	0.07	End Dumps: $\Delta T\geq 25^oF$ regardless of haul time.
Windrow Elevator	0.31	Slight correlation with the use of Windrow Elevators.
Shuttle Buggy	0.04	Shuttle Buggy: $\Delta T<25^oF$ regardless of haul time.

Range in Air Voids

The range in air voids was compared to numerous factors including the laydown, surface, and air temperature, haul time, breakdown rolling temperature, and mat temperature differentials. The air void ranges are calculated as the difference between the maximum and minimum readings for each set of transverse density readings on a project. The range in air voids is actually the variation in the air voids between the measured air voids in normal and cool temperature areas. If more than one set was taken on a job, the range in air voids is based on the average of all the transverse (or longitudinal) density sets. Referring to Figure 3 and Table 3, the range in air voids is 5.4 percent according to this definition (the difference in density between the yellow and white spots on the image). The temperature differential used in this section is the largest temperature differential seen at one set of transverse readings for each project (same temperature differential as in Figures B2 through B8). A summary table (Table 5) shows the different factors that the range in air voids were plotted against, the R^2 for the specific graph, and any significant findings from the plots.

Table 5. Results and Significant Findings from the Range in Air Void Plots.

Air Void Range versus:	$\mathbf{R^2}$	**Significant Findings**
Approximate Laydown Temperature (Figure B9)	0.02	
Pavement Surface Temperature (Figure B10)	0.01	Surface temp$\leq$75^{o}F: V_a average=2.65%, range 0.6-4.4 Surface temp>75^{o}F: V_a average=1.94%, range 0.3-3.5
Approximate Air Temperature (Figure B11)	0.02	Air temp$\geq$70^{o}F: 65% Air Void variation is 2% or less Air temp<70^{o}F: 40% Air Void variation is 2% or less
Haul Time (Figure B12)	0.04	In general, the longer the haul, the greater the variation (or range) of in-place air voids.
Approximate Breakdown Temperature (Figure B13)	0.06	In general, variation in V_a decreases as breakdown temp increases. Breakdown temp$\geq$265^{o}F: V_a variation is 2% or less
Mat Temperature Differential (Figure B14)	0.15	ΔT<25^{o}F: 87% have 2% or less variation in Air Voids ΔT$\geq$25^{o}F: 35% have 2% or less variation in Air Voids

Change in Air Voids

The change in percent air voids is the amount each individual point density changed from the high temperature's corresponding density on that specific density set. There may be more than one set of densities for each job (anywhere from one to three sets). The densities that were taken within approximately 12 inches of the edge were not considered because the outer edges of the mat typically have lower densities (higher air voids). Referring to Figure 3 and Table 3 once more, the point density and temperature on the left of the image would be excluded because it is within approximately 12 inches of the edge of the mat. Table 3 also shows the change in air voids for each of the point densities (the last column), which is the data used in the graphs in Appendix B.

Three different graphs were used: change in percent air voids versus temperature differentials, change in percent air voids versus approximate laydown temperatures, and change in percent air voids versus approximate breakdown temperatures. There are different variations on each of these graphs. For comparing temperature differentials and the change in percent air voids, the graphs are broken down into tarp use and MTV/MTD use. Approximate laydown temperature graphs are broken down into the influence of roller type and MTV/MTD use. Finally, the approximate breakdown temperatures focused on the inclusion of pneumatic rollers and MTV/MTD use. A summary table (Table 6) shows the different factors the change in air voids were plotted against, the R^2 for the specific graph, and any significant findings from the plots.

Table 6. Results and Significant Findings from the Change in Air Void Plots.

Change in Air Voids versus:	**R^2**	**Significant Findings**
Temperature Differential (Figure B15)	0.20	In general, the higher the ΔT, the larger change in V_a. $\Delta T<25^oF$: 90% have $\leq$ 2% change in V_a $\Delta T\geq 25^oF$: 65% have $\leq$ 2% change in V_a When $\Delta T<25^oF$, the V_a do not vary as much from the V_a in normal temperature areas as when the $\Delta T>25^oF$.
Temperature Differential by Tarp Use (Figure B16)		The correlation factors are similar, which suggests that tarps were not effective; however, tight tarps were not generally observed.
Untarped	0.13	
Tarped	0.15	
Temperature Differential by MTV Use (Figure B17)		
End Dump	0.36	End dump operations account for >50% of points outside a 2% change in V_a from normal temp areas.
Windrow Elevator	0.05	
Shuttle Buggy	0.03	
Approximate Laydown Temperature (Figure B18)	0.18	Laydown temp>265^{o}F: 100% of points within 2% of normal temp areas. Higher temps allow an increasing time to compact before mix reaches cessation temp.
Approximate Laydown Temperature by Roller Type (Figure B19)		Pneumatic rollers had 95% of its points within a change in air voids of 2%, steel rollers had only 78%.
Steel	0.27	$\Delta T\geq 25^oF$: average change in V_a of 2.4% (Table 7)
Pneumatic	0.03	$\Delta T\geq 25^oF$: average change in V_a of 0.7% (Table 7)
Approximate Laydown Temperature by MTV Use (Figure B20)		
End Dump	0.32	Weak correlation between increasing laydown temp and a decrease in the change in V_a compared to normal temp areas.
Windrow Elevator	0.11	
Shuttle Buggy	0.10	
Approximate Breakdown Temperature (Figure B21)	0.12	A 4% increase in the change of V_a over normal temp areas correspond to breakdown temps of <190^{o}F.
Approximate Breakdown Temperature by Roller Type (Figure B22)		
Steel	0.12	All points >4% air void change and <190^{o}F breakdown temp are steel wheel rollers.
Pneumatic	0.03	
Approximate Breakdown Temperature by MTV Type (Figure B23)		End dump operations have a moderate linear relationship between breakdown temp and V_a change.
End Dump	0.40	All points >4% air void change and <190^{o}F breakdown temp are steel wheel rollers with end dump operations.
Windrow Elevator	0.01	
Shuttle Buggy	0.07	

Table 7. Comparison of Density Differentials Between Steel Wheeled Rollers and Pneumatic Tired Rollers.

	For all ΔT		$\Delta T \geq 25^oF$	
	Temperature Differential (^oF)	Air Voids (%)	Temperature Differential (^oF)	Air Voids (%)
Pneumatic	D**T**	D**Va**	D**T**	D**Va**
Average	16.4	0.5	38.5	0.7
St. Dev.	18.1	1.1	11.4	1.3
No. of Samples	63	63	21	21
Steel Wheeled				
Average	14.4	0.9	41.2	2.4
St. Dev.	18.8	1.9	17.7	2.3
No. of Samples	136	136	34	34

1999 CONCLUSIONS

Listed below are general conclusions that were extracted from the 1999 paving season data.

- Large temperature differentials were observed under a variety of paving conditions
- In general, the higher the temperature differentials, the higher the as-compacted air voids associated with the cooler portions of the mat
- Temperature differentials generally decreased when the air temperature was greater than 85^{o}F
- Large temperature differentials occurred over a wide range of pavement surface temperatures
- Mat temperature differentials decreased when thick, tight tarps were used (limited data) – see Figure 4. (The mix at 194^{o}F is from the previous truck that did not have a tarp, the mix that is 253^{o}F and towards the back of the paver is from the tightly tarped truck.)
- Mat temperature differentials decreased when remixing occurred
  - End dump operations resulted in an average mat temperature differential of 56^{o}F, with a range between 32^{o}F and 69^{o}F (n=7). Figure B24 shows a typical infrared image with an end dump paving operation.
  - The Blaw-Knox MC-30 MTV (with and without the paddles in the paver hopper insert operating) resulted in an average mat temperature differential of 41^{o}F, with a range between 14^{o}F and 69^{o}F (n=7). If the paddles in the paver hopper are operating, the average temperature differential is 37^{o}F (range of 14^{o}F to 69^{o}F) and when the paddles are not operating, the average ΔT is 46^{o}F (range of 33^{o}F to 63^{o}F). Figure B25 and B26 show typical infrared images of a Blaw-Knox MC-30 MTV in the paving train, with and without the paddles in the paver hopper operating.
  - The Cedarapids MS-3 MTD resulted in an average mat temperature differential of 20^{o}F, with a range between 10^{o}F and 26^{o}F (n=3). Figure B27 shows a typical infrared image with a Cedarapids MS-3 MTD in the paving train.
  - All brands of windrow elevators were basically similar, so they were placed in one group. They resulted in an average mat temperature differential of 27^{o}F, with a range between

6°F and 45°F (n=13). Figure B28 shows a typical infrared image with a windrow elevator MTD in the paving train.
  - o The Roadtec Shuttle Buggy produced an average mat temperature differential of 10°F, with a range between 5°F and 16°F (n=5, the SMA project is not included here because of the variance in operations seen over the three days this project was visited). Figure B29 shows a typical infrared image with a Roadtec Shuttle Buggy MTV in the paving train.
- As-compacted air voids increased with truck haul time, when no transfer device was used, and when ΔT's were 25°F or greater
- As-compacted air voids decreased with mat temperatures greater than 265°F (limited data)

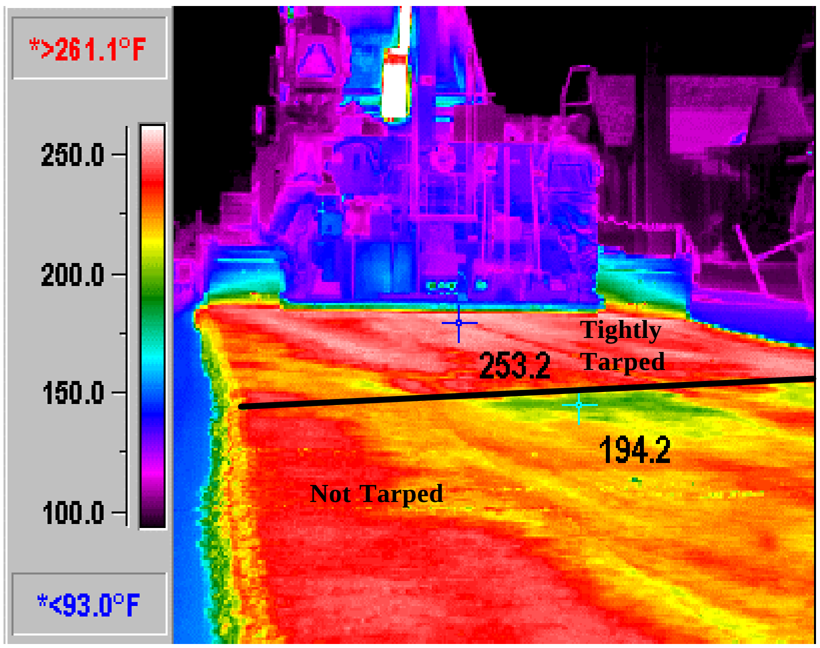


Figure 4. Infrared Image of a Tightly Tarped Truck Dumping into a Paver With No Transfer Device. (Temperatures are in °F.)

Specific Conclusions

Recall that the range in air voids is the difference between the maximum and minimum readings for a set of density readings. If there were more than one set of density readings on a particular job, all the sets were averaged. On the other hand, the change in air voids is the amount of change for each individual point density from the density that corresponded to the highest temperature in that set of readings.

1. *Mat temperature differentials*
- For mat temperature differentials less than 25°F, 87 percent have a 2 percent or less air void range compared to temperature differentials greater than or equal to 25°F, which only have 35 percent in the same category.
- For mat temperature differentials less than 25°F, 90 percent of the data has a change in air voids of less than 2 percent (the change in air voids ranged from –2 to +2 percent). Conversely, there were only 62 percent within that same range when the temperature differentials were 25°F or greater.

  - End dump operations account for over 50 percent of the data points outside the +/- 2 percent change in air voids.
- When temperature differentials are broken down into tarped trucks versus untarped trucks, there is no significant difference. This may be due to the type of tarps used.
- When the temperature differential is 25^{o}F or greater and pneumatic rollers were used as a breakdown or intermediate roller, an average change in air voids of 0.7 percent resulted. When steel wheeled rollers were used throughout the entire compaction train, a 2.4 percent change resulted. (Table 7)
  - A pneumatic roller as the breakdown or intermediate roller in the train resulted in 95 percent of the air voids within +/- 2 percent. The remaining 5 percent were all end dump operations. On the other hand, steel wheeled rollers produced only 78 percent in that same range.

2. *Air temperatures*

- Air temperatures have little effect on temperature differentials, but limited data shows that air temperatures above 85^{o}F have no temperature differentials over 35^{o}F and when they are below 85^{o}F, 56 percent of the projects had temperature differentials over 25^{o}F and 28 percent had temperature differentials greater than 50^{o}F.
  - If end dump operations are excluded from this data, air temperatures above 80^{o}F have no temperature differentials over 35^{o}F.
- Higher air temperatures could play a part in decreasing the range in air voids. For air temperatures greater than 70^{o}F, almost 70 percent have a range in air voids of less than 2 percent, and air temperatures less than 70^{o}F show that only 45 percent are in the same category.
  - Typically when the air temperature is above 70^{o}F, the surface temperature is greater than 100^{o}F (ranged from 95 to 140^{o}F, with an average surface temperature of 118^{o}F) and with air temperatures less than 70^{o}F, the surface temperature is cooler (ranged from 54 to 125^{o}F with an average surface temperature of 76^{o}F). According to Dickson, et al. (1970), the surface absorbs much more heat than the environment does, so with the surface temperature greater than the air temperature, it is more likely a combination of air and surface temperatures could affect the mat temperature differentials.

3. *Surface temperatures*

- Surface temperatures appear to have a limited effect on the observed mat temperature differentials.
  - Even when windrow elevators are separated from other types of operations (mix is laid out on the surface before it is picked up), the surface temperatures have little effect on temperature differentials. For windrow elevators, the two lowest temperature differentials, 6^{o}F and 18^{o}F, had the highest and lowest associated surface temperatures of 140^{o}F and 41^{o}F, respectively. Of the thirteen projects using windrow elevators, twelve of them were in Eastern Washington with an average surface temperature of 104^{o}F.
- The data shows that when the surface temperature is 85^{o}F or less, 59 percent of the data points have an air void range greater than 2 percent. Conversely, 41 percent of the data points have a 2 percent or greater air void range when the surface temperatures are greater than 85^{o}F.

4. *Breakdown temperatures*

- Breakdown temperatures of less than 190°F tended to produce a change in air voids of over 4 percent.
- All of the data points that have an increase in air voids above 4 percent and a breakdown temperature of less than 190°F correspond to end dump operations <u>and</u> the use of steel wheeled rollers, exclusively.
- For breakdown temperatures greater than or equal to 240°F, all data points except one (97 percent) are under an air void range of 2 percent.

5. *Laydown temperatures*

- Temperatures greater than 265°F during laydown resulted in all the air void changes to be within +/- 2 percent.
- The higher the laydown temperature in end dump operations, the smaller the change in percent air voids.

6. *Plant temperatures*

- Plant temperatures as the mix is loaded into the trucks versus mat temperature differentials have a low correlation, but the temperature differentials do tend to increase as the plant temperature increases.
  - If the plant temperature is 280°F or greater, the average temperature differential is 37°F, and below 280°F shows the average temperature differential decreases to 27°F.

7. *Haul times*

- Mix haul time does not appear to be a major factor in determining the range in air voids because of all the other job specific conditions, but there is a slight upward trend in the air void range with increasing haul time (excluding tarped loads).
- The effects of haul times on mat temperature differentials appear to show that the longer the hauls, the higher the temperature differentials, even though the correlation shows no evidence of this. This can probably be attributed to the use of remixing devices.
  - Only 35 percent of the projects with haul times less than 20 minutes have temperature differentials greater than 25°F as contrasted with over 70 percent when haul times are greater than 20 minutes.
  - There is a slight correlation between longer haul times and higher temperature differentials for trucks that do not use tarps.
  - Both the truck-pup combination (n=27) and the belly dumps (n=8) have approximately the same trend lines when the tightly tarped trucks are excluded.
  - The relationship of haul time and MTVs/MTDs varied depending on the type of remixing or transfer device.
    - End dump operations always resulted in high typical temperature differentials without regard to haul time ($\Delta T > 32°F$).
    - Just the opposite is true for the Roadtec Shuttle Buggy; no matter what the haul time, the typical mat temperature differential never exceeded 16°F (excluding the SMA project – different temperature differentials and operations each day visited).
    - Windrow elevator pickup machines have the strongest correlation between longer haul times and higher temperature differentials.

- The Blaw-Knox MC-30 was observed in two different operating modes (with and without the paddles running) and produced typical temperature differentials of greater than 25°F for six of the seven projects.

The overall goal from the 1999 data was to observe a wide variety of laydown operations and equipment to see how these factors affected the final compaction of the HMA. The 1999 data provided beneficial information, but changes to WSDOT specifications were not recommended due to numerous factors that affected mat temperature differentials and the resulting density differentials. This study was continued in 2000 to evaluate a test procedure's effectiveness at determining temperature differentials and the resulting density differentials.

2000 FIELD SAMPLING AND TESTS

The purpose of the study during the 2000 paving season was to evaluate a test method that uses temperature differentials to determine the location of a density profile on the compacted mat. Seventeen projects were visited during the 2000 paving season with typically three to four profiles conducted per project on uniform and non-uniform mat surface temperatures. Infrared imaging (digital and handheld infrared gun) was conducted to determine the temperature differentials in the mat.

These temperature differentials were used to locate where the density profiles should be performed. Density profiles are nuclear density readings taken every five feet in a 50 foot longitudinal direction. Two results are obtained from these density profiles, density range (maximum – minimum) and density drop (mean – minimum). The criteria used for examination of the paving projects were a density range of 6.0 pounds per cubic foot and a density drop of 3.0 pounds per cubic foot. This test method (with different density criteria) has been used by the Kansas DOT for the past ten years as an aggregate segregation detection system and the Texas DOT during the 2000 paving season (also to determine aggregate segregation effects) as a QA and QC requirement. Appendix D contains the current density profile test procedure.

The emphasis of the 2000 study was to determine if the density profile test procedure used by the Kansas DOT would work by determining the location through the existence of temperature differentials. The use of the method is different in that both Kansas and Texas are mainly concerned with aggregate segregation, so finding the test locations deviates from the Kansas DOT test method. Although the density profile locations were determined with the infrared camera during the 2000 study, another goal was to determine a relatively inexpensive way to detect the temperature differentials. This was successfully done with the handheld infrared temperature gun.

Much of the same data collected in 1999 was collected in 2000, such as MTV/MTD, equipment type, weather conditions, temperature differentials, mix information, and mat densities. The 17 projects visited in 2000 included production paving projects with no focus on specific project qualities.

2000 RESULTS

Results are presented in three subsections: overview of the 2000 paving season projects; density profiles; and temperature differentials.

Overview

There were 17 projects visited during the 2000 paving season. Table C1 in Appendix C includes a more complete listing of the projects. Class A, B, and Superpave designated mixes are dense-graded mixes.

- Classes of mix varied from WSDOT's typical dense-graded mix (Class A) to a Stone Mastic Asphalt (SMA).
  - 9 projects – WSDOT Class A
  - 2 projects – WSDOT Class B
  - 4 projects – Superpave Class ½"
  - 1 project – Superpave Class ¾"
  - 1 project – Stone Mastic Asphalt (SMA)

- Material transfer vehicles/devices used include:
  - 5 projects – Roadtec Shuttle Buggy
  - 4 projects – Blaw-Knox MC-30
    - 3 with the paddles in the paver hopper insert operating
    - 1 without the paddles in the paver hopper insert operating
  - 3 projects – Cedarapids MS-2 Windrow Elevator
  - 2 projects – No transfer device
  - 1 project each – Lincoln Windrow Elevator, CMI Corporation MTP-400, and CMI Corporation Windrow Elevator into a Blaw-Knox MC-30 (with the paddles operating)

- Typical mat temperature differentials:
  - 10 projects – less than a 25°F temperature differential
  - 7 projects – greater than or equal to 25°F temperature differential
  - Comparing this study season to previous seasons, the probable reason for the increase in projects with temperature differentials less than 25°F is the increase in the use of material transfer vehicles and greater awareness of temperature differentials.

Density Profiles

The density criterion that was used during the 2000 study program was a maximum density range of 6.0 lb/ft^3 and a maximum density drop of 3.0 lb/ft^3. The testing includes locating the area to be tested by either temperature differentials or visible aggregate segregation and taking a nuclear density test every five feet for a total of fifty feet. The density profile should be started approximately 10 feet behind the location of the temperature differential (or aggregate segregation) at the same offset as the deficiency in the pavement and continue through the deficiency. If the deficient area is located in the wheelpaths (what is typically described as a chevron, spot, or cyclic pattern), then the profile will not deviate from the chosen offset (Figure 5). If the deficient area is in a longitudinal streak, then the profile will be offset from each end of the streak by 2 feet (Figure 6). This is done to capture the density differential (between normal mat temperatures and low mat temperatures). See Appendix D for the current test method.

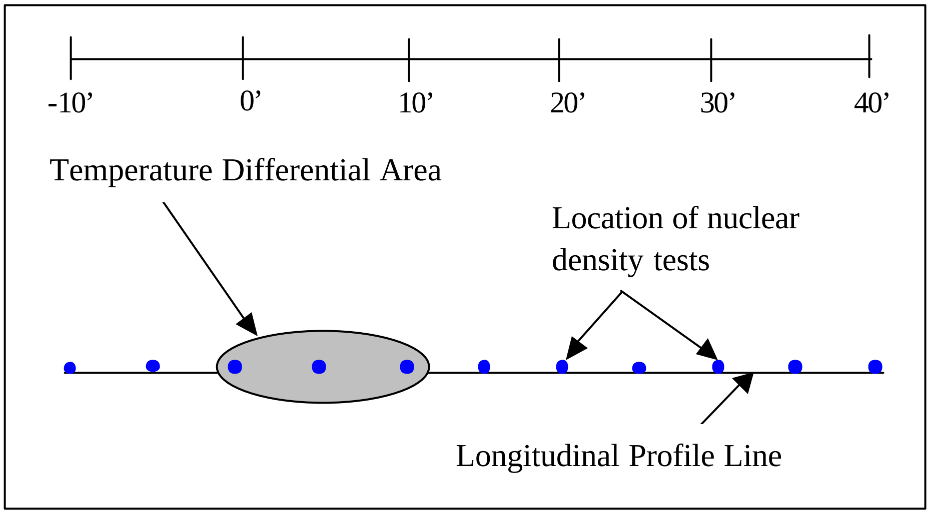


Figure 5. Location of Density Profile When Temperature Differential Occurs in a Cyclic Pattern, Chevron, or Spot.

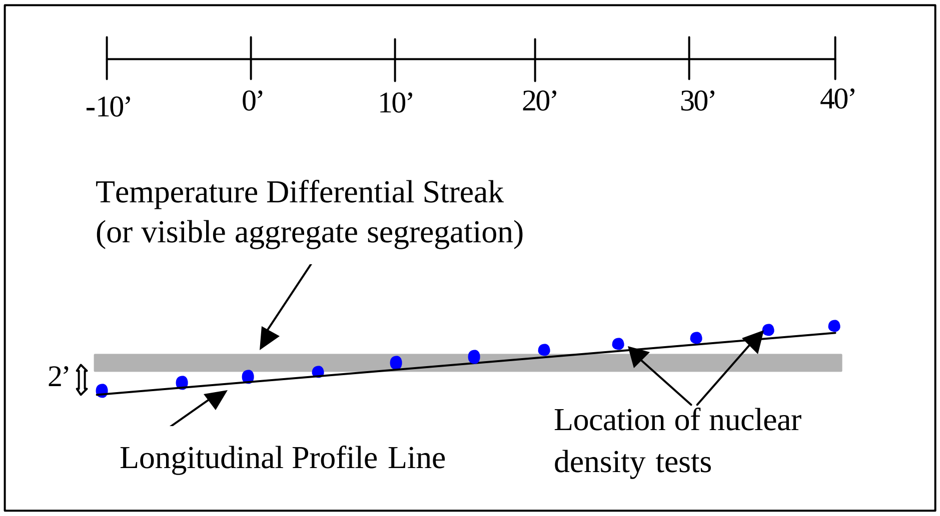


Figure 6. Location of Density Profile When Temperature Differential Occurs in a Longitudinal Streak.

The density profiles taken during the 2000 study did not deviate from the starting offset, even when longitudinal streaking was present. Offsetting the density profile to go through the streak at an angle was not discovered until after most of the testing was completed.

A total of 69 density profiles were taken on the 17 projects visited, with 28 profiles taken in areas with a temperature differential of 25^{o}F or greater and the remaining taken in areas with less than a 25^{o}F differential. In areas where the temperature differential was 25^{o}F or greater, 89 percent of the profiles failed to meet the criteria. Where temperature differentials were lower than 25^{o}F, 80 percent of the profiles passed the density criteria (Table 8). The 11 percent that passed when temperature differentials exceeded 25^{o}F and 20 percent that failed when temperature differentials were lower than 25^{o}F could be attributed to job specific conditions, equipment used, or roller operations. Table C2 shows the same information, but is broken down into the use of pneumatic or steel wheel rollers. Pneumatic rollers refer to a pneumatic roller used as either the breakdown or intermediate roller in the compaction train and steel wheel roller refers to the entire compaction train consisting of steel wheel rollers. The results are not significantly different than those reported in Table 8; however, it was observed that pneumatic rollers do reduce density differentials, especially when used as an aggressive breakdown roller (the mix is not allowed to cool prior to compaction because the breakdown roller is within 30 to 40 feet of the paver and is typically on the freshly placed mat within one minute).

Table 8. Percent Pass and Fail Density Criteria According to Temperature Differentials.

	$\Delta T \geq 25^oF$	$\Delta T < 25^oF$
Number of Profiles	28	41
Failed both density criteria	20	4
Passed both density criteria	3	33
Failed only high - low	3	2
Failed only mean - low	2	2
Percent passing	10.7	80.5
Percent failing	89.3	19.5

The 1999 data showed that pneumatic rollers tended to reduce the density differential seen in the compacted mat when compared to a roller train of all steel-wheeled rollers. Although the 2000 data shows the same general trend, the data in Table 9 shows that there is not a significant difference in the density ranges and drops by using a pneumatic tired roller. There was at least one case where the observations in the field showed that a pneumatic tired roller as an aggressive breakdown roller did offset the density differentials (see Contract 5871 in Appendix C for specific results).

Table 9. Comparison of Density Differentials Between Steel Wheeled Rollers and Pneumatic Tired Rollers.

	For All Data Points			For $\Delta T \geq 25^oF$		
	Density Range (pcf)	Density Drop (pcf)	ΔT (^oF)	Density Range (pcf)	Density Drop (pcf)	ΔT (^oF)
Pneumatic						
Average	6.2	3.5	21.2	7.4	4.2	27.2
St. Dev.	5.3	3.6	17.9	7.7	5.2	22.4
Count	34	34	34	14	14	14
Steel Wheeled						
Average	6.6	3.3	23.8	8.1	3.8	31.9
St. Dev.	3.0	1.7	17.4	2.4	1.3	13.8
Count	33	33	33	13	13	13

Figures 7 and 8 show the results of each profile with respect to the maximum density range and density drop, respectively. By examination of Figure 7, when the temperature differentials were less than 25^{o}F, the points fall below the criteria of 6 pounds per cubic foot (pcf) for the density range. Conversely, the density ranges exceeded 6 pcf when the temperature differentials exceeded 25^{o}F. Figure 8 shows the same type of results, except that instead of the density range, Figure 8 demonstrates the density drop (criteria of 3 pcf).

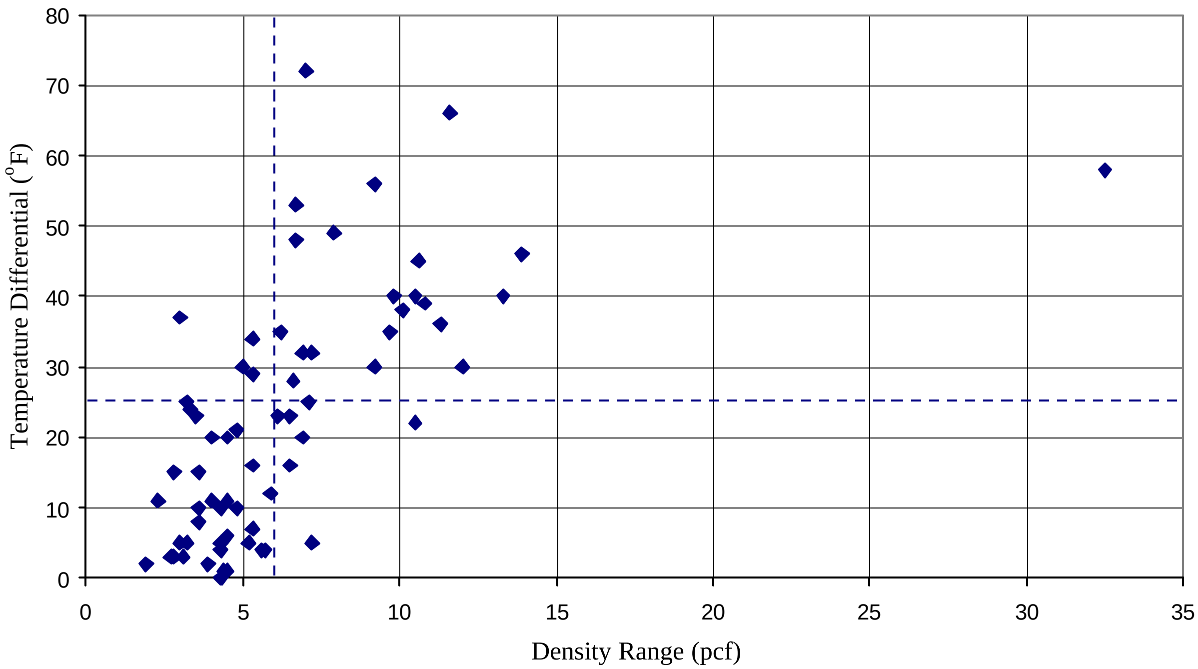


Figure 7. Density Range vs. Temperature Differential for Each Density Profile

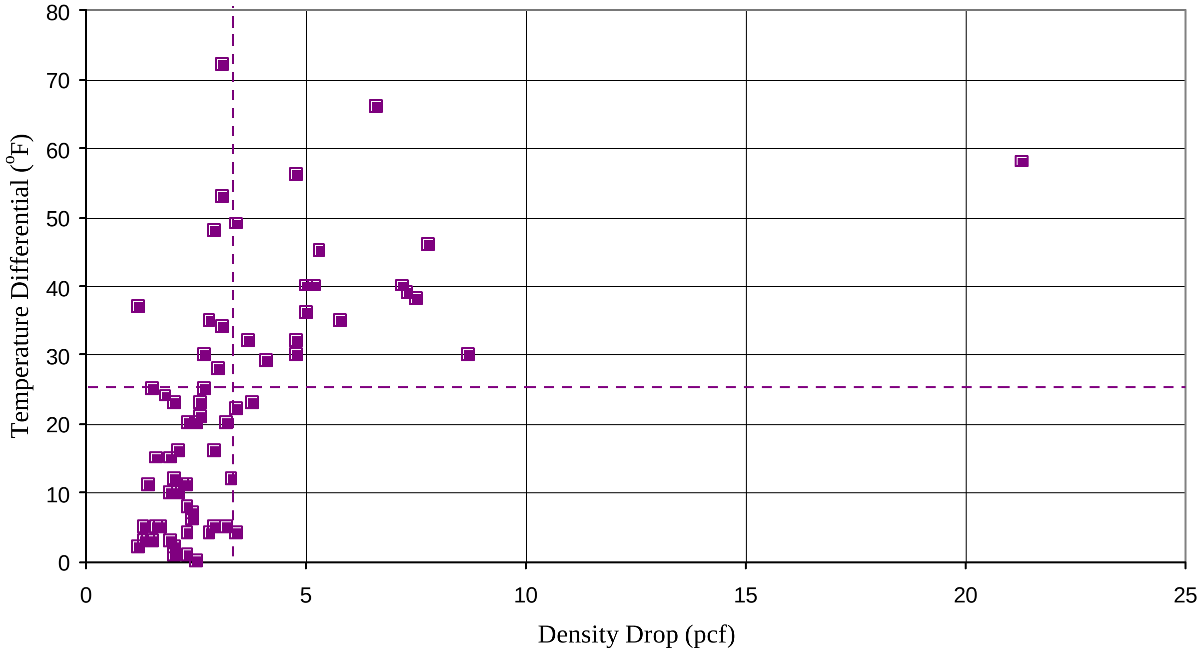


Figure 8. Density Drop vs. Temperature Differential for Each Density Profile

Figures 9 and 10 contain examples of density profile results. Figure 9 shows a density profile that passed both of the criteria, while Figure 10 contains a profile that failed the criteria. The profile in Figure 9 had a temperature differential of 2°F with a density range of 1.9 lb/ft^3 and a density drop of 1.2 lb/ft^3. Figure 10 contains a profile with a temperature differential of 66°F, a density range of 11.6 lb/ft^3, and a density drop of 6.6 lb/ft^3. Appendix C contains the density range, density drop, and graphs of each of the density profiles by contract number.

Profile #1	Average
ΔT=2°F	Readings (pcf)
Average	134.6
Maximum	135.4
Minimum	133.5
	Ranges
Max-Min	1.9
Ave-Min	1.1

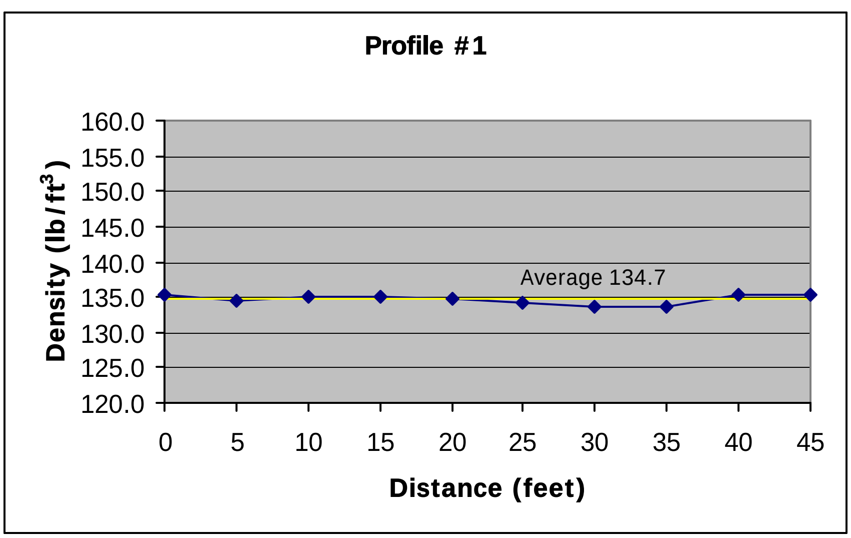


Figure 9. Passing Density Profile Example (Contract 5807).

Profile #1	Average
ΔT=66°F	Readings (pcf)
Average	128.5
Maximum	133.5
Minimum	121.9
	Ranges
Max-Min	11.6
Ave-Min	6.6

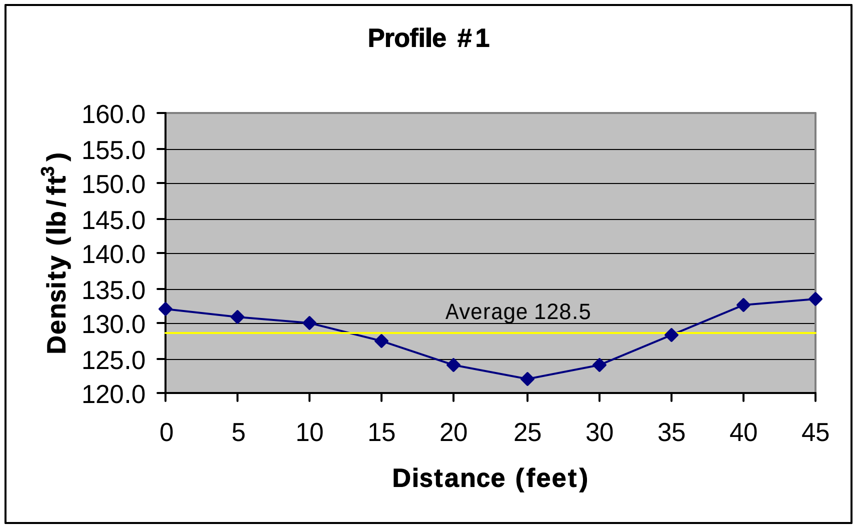


Figure 10. Failing Density Profile Example (Contract 5677).

Appendix C also contains each project's Quality Assurance (QA) nuclear density results along with the density profiles. The random tests taken for the Quality Assurance results typically show passing densities, which, according to WSDOT specifications, is above 91 percent of the maximum theoretical density (except for the SMA project, which has a minimum density requirement of 94 percent). From the random Quality Assurance tests, cooler areas that may exist in the mat are not adequately captured with the QA process. In fact, the highest percentage of failing QA testing results was 12.3 percent (see Table 10 for a summary of the 2000 projects). The random test results compared with the results from the density profiles show that the cooler temperature areas could easily be missed during QA testing. With density profiles as a quality control measure, these cooler temperature areas can be found (if they exist), tested to determine if they affect the density of the mat, then adjust the operations to reduce the detrimental effects.

Table 11 shows the results for each density profile performed as a percent of maximum theoretical density. (Note that the nuclear density gauge that was used to perform the density profiles was not calibrated to the project mix, but the correlation factor from the project nuclear density gauge was obtained along with the maximum theoretical density. The gauges were different models, but comparisons show that the correlation factors for both gauges on the same mix were nearly identical.) There were 47 of the 69 density profiles (68 percent) where at least the minimum density reading in the density profile was below the minimum density allowed for quality assurance (91 percent, except in the case of Contract 5882 (SMA)). Of the 69 density profiles, 10 (or 14 percent) had all of the readings below the minimum density allowed for quality assurance (see the maximum reading values in Table 8). This suggests that the density profile procedure not only captures the density differentials, but also the densities which fall below the in-place density specification.

A summary of the data presented in Table 11 by the density range (maximum – minimum) and density drop (average – minimum) criterion is shown in Table 12. The density range and drop criterion was varied according to what has been used in Texas and Kansas to evaluate how well the criterion worked for the 2000 study program. For the density range, the criterion was varied from 5 to 8 pcf and the density drop varied from 2 to 5 pcf. When a density profile exceeded the criterion of 6 pcf for the density range and 3 pcf for the density drop, the densities that were lower than the minimum allowed for QA totaled greater than 80 percent in both cases. This implies that the density profiles are identifying the variation in density and the minimum allowed densities greater than 80 percent of the time with this criterion.

Table 10. Overview of the 2000 Projects, Including Density Profiles and QA Data.

Contract	Job Density Average (QA)	% Below Minimum (QA)	Number of Profiles	Profiles With: DT ≥ 25°F / DT < 25°F	Average DT (°F)	Average Density Range (pcf)	Average Density Drop (pcf)	MTV Used	Pattern
5677	92.90	2.9	6	4	48	11.3	6.9	MC-30 (paddles not operating)	cyclic spots
				2	7	4.2	1.8		
5700	96.67	0.0	4	2	27	4.8	3.3	MC-30 (paddles operating)	random, cyclic (ΔT low)
				2	18	3.8	1.9		
5807	92.36	0.0	4	1	35	6.1	2.7	Shuttle Buggy	streaks, one-time occurrence
				3	5	3.4	2.0		
5816	92.10	12.3	1	0	-	-	-	MC-30 (paddles operating)	random spots, streaks
				1	23	6.1	3.8		
5823	92.81	0.7	4	2	32	7.0	4.2	Windrow Elevator	random spots, streaks
				2	8	3.8	1.8		
5827	92.98	3.3	5	3	40	9.2	4.5	Windrow Elevator/MC-30 (paddles operating)	cyclic spots, streaks
				2	7	2.7	1.5		
5831	93.09	1.0	3	1	58	32.4	21.2	Shuttle Buggy	streaks, one-time occurrence
				2	3	4.3	2.1		
5835	92.24	5.1	4	0	-	-	-	Windrow Elevator	streaks (ΔT low), visual segregation
				4	8	5.3	2.6		
5841	92.58	0.0	3	1	30	12.0	8.6	Windrow Elevator	random spots, streaks
				2	7	5.2	2.2		
5851	92.54	8.0	5	4	39	11.2	5.6	None	cyclic
				1	13	5.9	3.3		
5862	92.35	0.2	3	0	-	-	-	Shuttle Buggy	uniform, cooling from wind
				3	17	4.5	2.4		
5863	93.47	2.9	3	1	30	5.0	2.6	Shuttle Buggy	random spots @ beg., streaks
				2	11	4.1	2.2		
5871	93.53	3.0	4	4	53	5.8	2.6	None	cyclic
				0	-	-	-		
5879	93.03	3.7	4	0	-	-	-	CMI MTP-400	cyclic (ΔT low)
				4	22	5.3	2.4		
5882	95.19	10.6	5	0	-	-	-	Windrow Elevator	streaks (ΔT low)
				5	6	4.3	2.1		
5906	94.07	0.0	7	4	39	8.1	4.5	MC-30 (paddles operating, and not operating)	cyclic, random, streaks
				3	17	5.6	2.2		
5908	92.83	0.0	4	0	-	-	-	Shuttle Buggy	streaks (ΔT low)
				4	6	5.0	2.5		
Average	93.22			ΔT > 25°F	39	10.3	6.1		
				ΔT < 25°F	11	4.6	2.3		

Table 11. Density Profile Results Expressed as Percent of Maximum Theoretical Density.

Contract #	*Profile #*	*Density Profile (% of maximum theoretical density)*			*Maximum - Minimum (pcf)*	*Average - Minimum (pcf)*	*ΔT (°F)*	*Correlation Factor (3430)*	*Max. Theor. Density (pcf)*
		Average	*Maximum*	*Minimum*					
5906	1	91.01	92.13	90.19	3.0	1.3	5	1.0048	155.8
	2	91.42	92.39	90.16	3.5	2.0	23		
	3	91.70	93.10	89.71	5.3	3.1	34		
	4	85.92	90.45	83.71	10.5	3.4	22		
	5	87.35	90.16	85.58	7.1	2.7	25		
	6	89.78	92.61	86.68	9.2	4.8	56		
5906-2	1	94.91	97.20	90.13	10.8	7.3	39	1.0126	154.7
5871	1	93.65	95.95	91.87	6.7	2.9	48	0.9994	162.9
	2	93.61	94.69	92.85	3.0	1.2	37		
	3	93.33	95.52	91.41	6.7	3.1	53		
	4	93.25	95.68	91.38	7.0	3.1	70		
5908	1	90.96	92.66	89.85	4.3	1.7	5	1.0300	155.9
	2	91.49	92.99	89.26	5.7	3.4	4		
	3	90.54	92.46	88.96	5.3	2.4	7		
	4	90.25	91.67	88.70	4.5	2.4	6		
5879	1	91.71	93.10	90.03	4.8	2.6	21	1.0195	157.8
	2	91.02	93.55	89.35	6.5	2.6	23		
	3	91.71	94.04	89.80	6.6	3.0	18		
	4	92.27	93.26	91.13	3.3	1.8	24		
5882[1]	1	92.79	94.25	90.92	5.2	2.9	5	1.0500	162.2
	2	95.44	96.94	94.12	4.4	2.0	1		
	3	96.22	96.94	95.23	2.7	1.5	3		
	4	95.82	98.69	94.48	6.5	2.1	16		
	5	94.85	95.42	93.61	2.8	1.9	2		
5827	1	93.87	96.86	91.66	7.9	3.4	50	0.9998	152.1
	2	94.10	97.55	90.61	10.6	5.3	45		
	3	90.83	93.74	87.69	9.2	4.8	30		
	4	93.20	93.80	92.29	2.3	1.4	11		
	5	93.43	94.52	92.49	3.1	1.4	2		
5851	1	89.66	92.61	86.55	9.8	5.0	40	0.9987	161.6
	2	92.84	96.72	89.73	11.3	5.0	36		
	3	91.38	94.62	88.16	10.5	5.2	40		
	4	91.02	94.77	86.55	13.3	7.2	40		
	5	90.99	92.61	88.96	5.9	3.3	13		
5823	1	89.82	92.00	87.57	7.2	3.7	31	0.9820	158.4
	2	90.99	92.00	90.02	3.2	1.6	5		
	3	92.29	93.80	91.13	4.3	1.9	10		
	4	90.39	91.69	87.41	6.9	4.8	32		
5835	1	91.37	93.85	89.43	7.2	3.2	5	0.9891	160.2
	2	89.75	91.99	87.77	6.9	3.2	20		
	3	90.21	91.04	88.82	3.6	2.3	8		
	4	92.76	93.82	91.19	4.3	2.5	0		

[1] Contract 5882 is a SMA project. The minimum density is 94%.

Table 11 Continued. Density Profile Results Expressed as Percent of Maximum Theoretical Density.

Contract #	Profile #	Density Profile (% of maximum theoretical density) Average	Maximum	Minimum	Maximum - Minimum (pcf)	Average - Minimum (pcf)	ΔT (^oF)	Correlation Factor (3430)	Max. Theor. Density (pcf)
5677	1	85.95	89.28	81.55	11.6	6.6	66	1.0055	150.3
	2	86.51	88.24	81.52	10.1	7.5	38		
	3	89.80	91.02	88.94	3.1	1.3	3		
	4	88.72	91.32	84.83	9.7	5.8	35		
	5	86.72	90.82	81.52	13.9	7.8	46		
	6	90.97	92.89	89.68	4.8	1.9	10		
5862	1	89.79	91.02	88.23	4.5	2.5	20	0.9923	157.8
	2	92.66	93.73	91.50	3.6	1.9	15		
	3	93.32	94.80	91.50	5.3	2.9	16		
5807	1	88.78	89.27	88.01	1.9	1.2	2	1.0265	155.7
	2	90.00	90.98	88.15	4.3	2.8	4		
	3	88.41	90.65	86.60	6.2	2.8	35		
	4	87.12	88.34	85.71	4.0	2.2	10		
5863	1	94.61	96.17	92.84	5.0	2.7	30	1.0221	153.2
	2	91.80	92.77	90.40	3.6	2.1	10		
	3	93.87	95.34	92.34	4.5	2.3	11		
5831	1	92.78	94.91	91.28	5.6	2.3	4	1.0200	156.0
	2	90.69	91.93	89.38	3.9	2.0	2		
	3	84.82	92.13	70.91	32.5	21.3	58		
5841	1	88.97	91.51	87.65	5.9	2.0	12	1.0203	156.1
	2	89.19	91.38	83.53	12.0	8.7	30		
	3	87.34	88.76	85.85	4.5	2.3	1		
5700	1	94.89	95.70	93.87	2.8	1.6	15	1.0310	157.5
	2	93.22	94.33	91.74	4.0	2.3	20		
	3	92.46	93.58	91.48	3.2	1.5	25		
	4	94.98	95.74	92.30	5.3	4.1	29		
5816	1	91.01	92.50	88.60	6.1	3.8	23	0.9981	154.9

Table 12. Percent of Density Profiles with Varying Criteria for Density Range and Drop.

Density Range	Density Range Criterion			
	>5.0 pcf	>6.0 pcf	>7.0 pcf	>8.0 pcf
	78.9	82.8	94.4	100.0
Density Drop	Density Drop Criterion			
	>2.0 pcf	>3.0 pcf	>4.0 pcf	>5.0 pcf
	75.5	85.2	93.8	100.0

Table 13 shows the quality assurance test results for all 53 WSDOT projects evaluated in 1999 and 2000 for the day the project was visited grouped together by MTV/MTD. These results display the average along with the standard deviation for the QA density testing. In general, as the average density increases, the standard deviation also increases. Table 14 shows the quality assurance density test results for all 53 WSDOT projects evaluated in 1999 and 2000 for the day the project was visited grouped together by MTV/MTD. The number of projects are broken down into the typical temperature differential (ΔT) that the MTV/MTD produced routinely. The haul time, and average mat, air, and surface temperatures are also reported. The higher air and surface temperatures for the Windrow Elevators are due to jobs on the east side of the state, which has warmer summer temperatures. Even with these higher temperatures, there is not a significant difference in the average mat temperatures, haul times, or QA density results. The potential for temperature differentials increase with increasing haul time, so one might expect the standard deviations of the densities to increase, but the data does not show this type of trend – mainly because of the presence of remixing devices. Note that Tables 13 and 14 show the average and standard deviation of the QA densities over a number of projects. Since one project may have a higher average density than another within the same category of transfer device, the standard deviations of the densities are skewed. Appendix C contains the contract level data for each of the categories of transfer devices. In most cases, the contract standard deviations are lower than the average reported in Tables 13 and 14.

Table 13. Quality Assurance Densities by MTV Type (based on densities of each project).

Equipment	Number of Projects	Number of Tests	Average	Standard Deviation
No MTV	9	1405	93.19	1.56
Blaw-Knox MC-30	11			
Paddles operating	7	1295	93.43	1.77
Paddles not operating	4	790	93.98	1.94
Roadtec Shuttle Buggy	11	2430	92.82	1.25
Cedarapids MS-3	2	480	93.42	1.27
Windrow Elevator	18			
Cedarapids MS-2	12	2735	93.34	1.48
Other Windrow Elevator	6	1420	92.86	1.39
CMI MTP-400	1	425	93.03	1.25
Windrow Elevator/MC-30	1	485	92.98	1.37

Table 14. Quality Assurance Density Testing and Specific Project Information on the Day Visited.

	Number of Projects with Typical ΔT[1]			QA Densities[2]			Average[1]			
				Number		Standard	Haul	Temperatures (°F)		
Equipment	<25°F	>25°F	Total	of Tests	Average	Deviation	Time (min)	Mat	Air	Surface
No MTV	0	9	9	1405	93.19	1.56	13	257	69	98
Blaw-Knox MC-30	3	9	11							
Paddles operating	3	4		1295	93.43	1.77	18	260	63	84
Paddles not operating	0	4		790	93.98	1.94	8	253	66	77
Roadtec Shuttle Buggy	10	1	11	2430	92.82	1.25	36	251	64	81
Cedarapids MS-3	1	1	2	480	93.42	1.27	24	253	58	75
Windrow Elevator	13	5	18							
Cedarapids MS-2	9	3		2735	93.34	1.48	22	243	79	104
Other Windrow Elevator	4	2		1420	92.86	1.39	28	260	83	108
CMI MTP-400	1	0	1	425	93.03	1.25	12	240	63	65
Windrow Elevator/MC-30	1	0	1	485	92.98	1.37	15	250	55	60

1 Typical ΔT and data collected on the day the project was visited with the infrared camera.
2 QA Densities are the nuclear density readings taken for the entire day on the same day the project was visited.

As noted above, density profiles are performed at locations that include temperature differentials greater than or equal to 25°F or visible aggregate segregation. The 2000 study focused on locating density profiles with temperature differentials, but some temperature differentials also appeared to contain aggregate segregation. No gradation or asphalt content testing was performed in these areas. Most of the areas that appeared to have aggregate segregation occurred in longitudinal streaks. Figures 11 and 12 show an infrared image of the longitudinal streaks and a photograph, respectively. These longitudinal streaks usually appear down the middle of the paved lane or on either side of the middle of the lane, separated by approximately three to four feet. The infrared image (Figure 11) shows a project that had two streaks (one on each side of the middle of the lane) and the photo (Figure 12) shows a streak down the middle (and a slight streak towards the inner edge of the pavement). Typically, the streaks that form on either side of the middle of the lane were observed on projects that had a windrow elevator in operation. The streaks on either side of the middle of the lane were also observed with other types of equipment, but the temperature differentials were not as great. The streaks that formed at the middle of the lane did so in a variety of different situations and no pattern could be detected. These streaks are noticeable directly behind the paving machine and can still be observed after the final rolling is complete. Observations in the field and the fact that the paving contractor could typically reduce or eliminate these streaks show that paver adjustments (such as flow and/or auger speed and height) could be a possible solution.

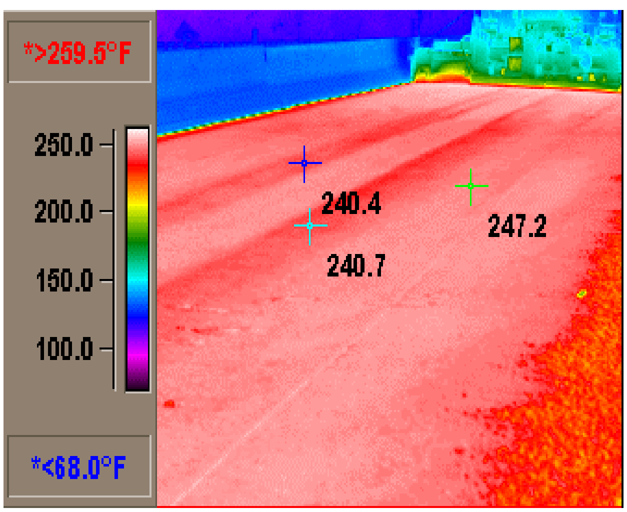


Figure 11. Infrared Image of Longitudinal Streak.

Figure 12. Photo of Longitudinal Streak.

Temperature differentials (greater than 25°F) that occur as spots or chevrons are shown in Figures 13 and 14 as an infrared image and a photograph, respectively. Figure 14 was taken approximately a year and a half after paving and illustrates the effect temperature differentials can have on inadequate compaction. (The lift thickness was 3.6 inches, which is why the low-density areas are so close to each other.)

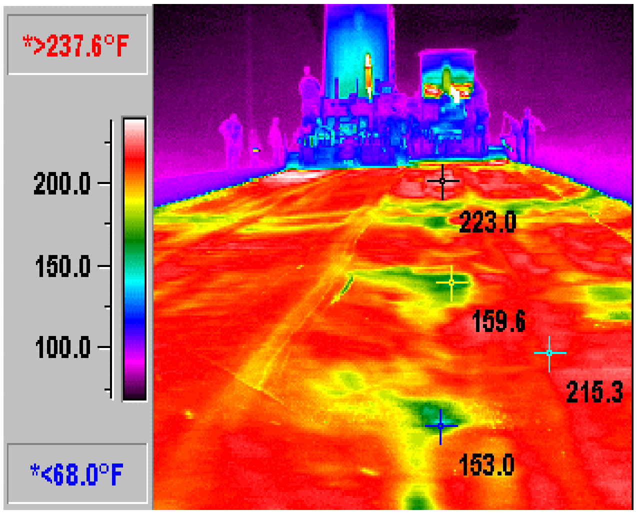


Figure 13. Infrared Image of Spots.


Figure 14. Photo of Low Density Spots.

Temperature Differentials

This study season, when compared to the 1999 season, had an increase in projects with temperature differentials less than 25°F. The probable reason for this is the increase in the use of MTV/MTD's and a greater awareness of temperature differentials. The typical temperature differentials reported for the 2000 study are the temperature differentials produced routinely by the type of equipment on the job that day the project was visited (Table 14 shows a breakdown of each equipment's typical temperature differentials).

This study was conducted by locating any temperature differentials over 25°F, even if they were not typical of that project, and evaluating these areas for density differentials. There is no correlation between these projects according to equipment type and this indicates that no one type of material transfer vehicle/device or other equipment eliminates temperature differentials completely. From the 1999 study program and confirmed in the 2000 study program, there are certain material transfer vehicles/devices that can minimize temperature differentials (Table 14), but there is not a proven device that will work just because it is on the job – proper operation is critical.

The temperature criterion of 25°F was set after reviewing the 1999 data. The density profile data collected in 2000 has shown that when the temperature differential is greater than or equal to 25°F, almost 90 percent fail the density criteria. When the temperature differential is less than 25°F, approximately 80 percent pass the density criteria. The other 10 and 20 percent, respectively, could possibly be attributed to job specific conditions, varying or inadequate roller patterns, or equipment usage (refer to Table 8).

The temperature differential that corresponds to each density profile is the difference between the high and low temperatures in that specific density profile. The lowest mat temperature typically relates to the cool area of mix and the highest temperature is typically the highest temperature seen along the offset where the density profile was taken. Figure 15 shows the lowest mat temperature compared to the density range seen in the density profile. Although the R^2 value is low (0.24), there is a noticeable downward trend. Logically, this is showing that the lower the temperature becomes, the higher the range of densities will be and the lower the mat temperature, the less time that exists to compact that part of the mat. Figure 16 shows the density range compared with the high temperature along the profile. It shows that the high temperature doesn't have much control over the range in densities. This suggests that the compliance or failure of the density profile depends on the low mat temperature and the corresponding temperature differential. (Appendix C contains Figures C1 and C2 for the low and high temperature compared with the density drop, which shows the same trends as Figures 15 and 16, respectively.)

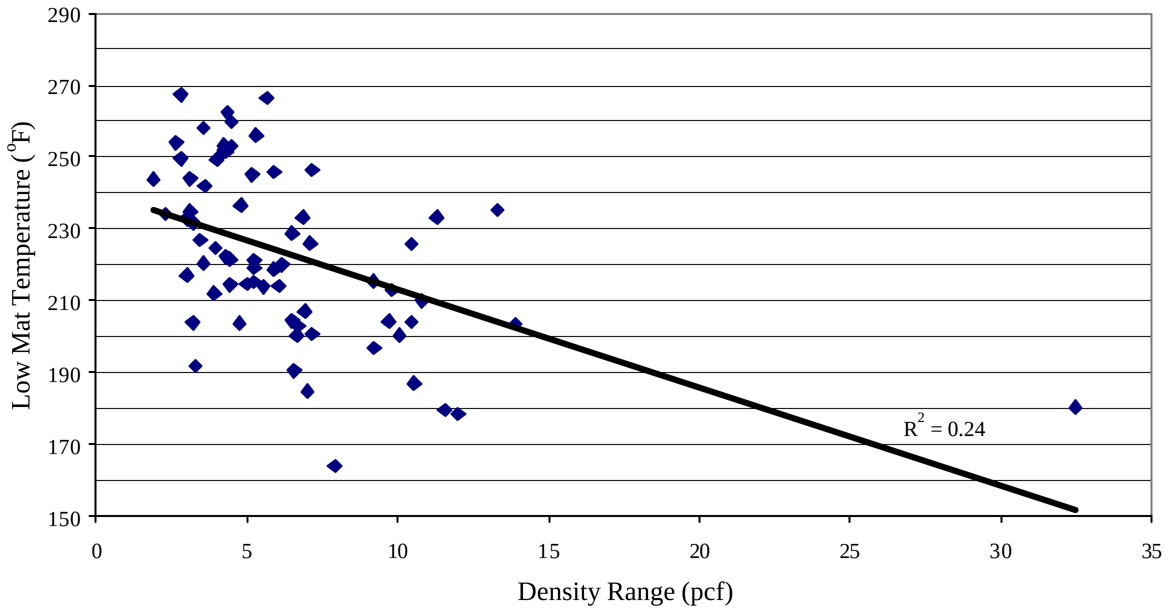


Figure 15. Density Range vs. Low Mat Temperature

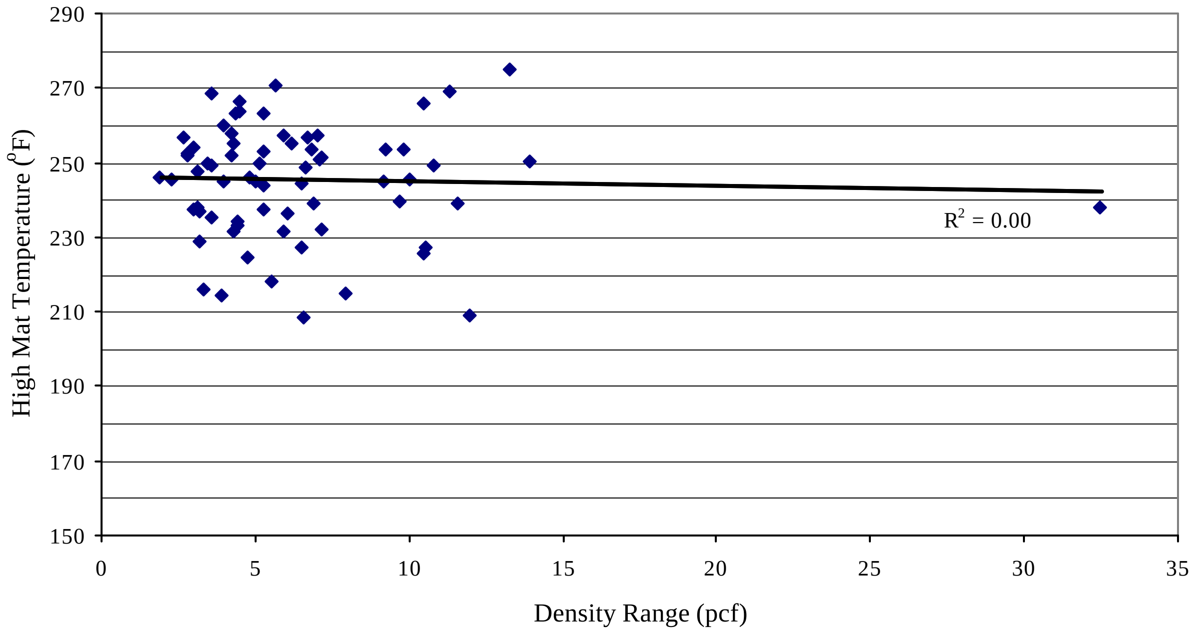


Figure 16. Density Range vs. High Mat Temperature

By using temperature differentials to locate where the density profiles are conducted, some of the guesswork has been removed from the test method. The infrared camera gives an image of the mat, but the infrared temperature gun can also locate a cooler area and the density profile can pinpoint the location of a lower density area. Since temperature differentials can determine the location of coarse aggregate segregation because the segregated mat is typically more open than the rest of the mat and cools quicker, temperature differentials are a logical way to locate any problem areas in the mat and test for low density. If areas of aggregate segregation pass the temperature differential profile, then visual identification is used to identify the area to be tested.

There is a possibility of a relatively new procedure being able to take density profiles at the end of each day's production with relative ease. This technology is the Ground Penetrating Radar (GPR) and although the GPR is not new, the ability to measure pavement density is new. The GPR would allow for density profile collection at high speeds and could cover the entire mat area instead of select locations. The development of this procedure is being performed in Finland. This method would give a continuous profile over the paved section, typically in 5 longitudinal profiles across the paved area (Saarenketo and Roimela (1998)).

2000 CONCLUSIONS

Listed below are the significant conclusions from the 2000 paving season. These are not recommendations or suggested specifications, but trends observed from the data collection process and subsequent review.

- In general, the occurrence of temperature differentials decreased when compared to the 1999 data. This is most likely because more transfer devices are being used, the increased awareness that temperature differentials exist, and their potential impacts.
- The higher the temperature differentials, the higher the in-place air voids associated with the cooler portions of the mat.
  - Exceptions to this may be aggressive rolling or the incorporation of a pneumatic roller in the compaction train as the breakdown or intermediate roller. These factors <u>may</u> be able to offset <u>some</u> of the effects of temperature differentials.
- Normal Quality Assurance testing typically does not capture the occurrence or severity of these cool "pockets" of mix because of the relatively low number of random tests per 400-ton lot. See Table 10 for a summary of QA density averages, the percent below the minimum percent passing for QA testing, and the density profile averages by contract.
- Temperature differentials (ΔT) ranged from a low of 0^oF to a high of 72^oF.
  - When the temperature differential was below 25^oF, the average ΔT was 10.5^oF.
  - When the temperature differential was 25^oF or higher, the average ΔT was 40.7^oF.
- The density range and drop for each profile show that the lower the temperature in the cool spot, the higher the range (or drop) in density. (Figures 15 and C1)
- Temperature differentials decreased when remixing occurred. (Remixing refers to the hot-mix being remixed either in the paver or other equipment such as a MTV/MTD before it is placed.)
- The density profile test method can determine the effects of temperature differentials and if used as a quality control item, can assist the contractor in minimizing the occurrence of density differentials in the mat. (See Table 10 and the profiles taken in an area with ΔT less than 25^oF.)

Specific Conclusions

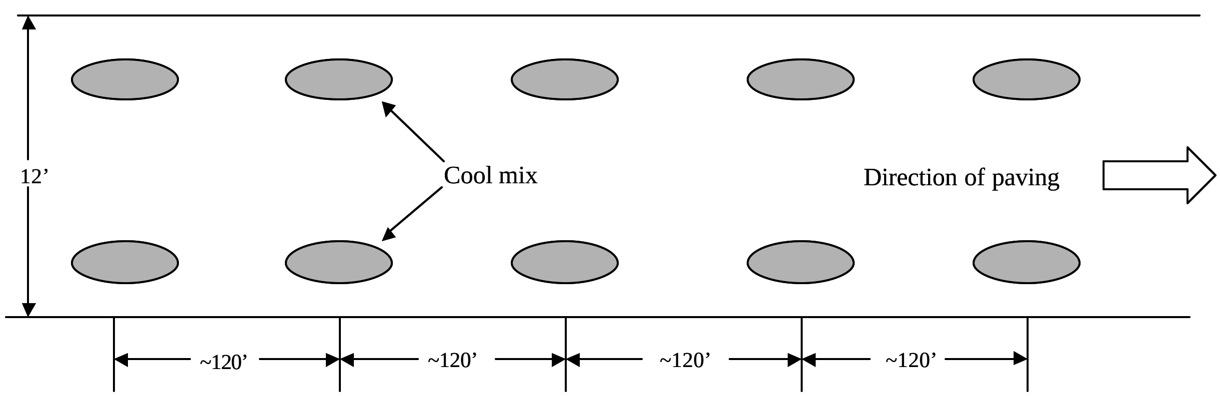
1. *Temperature differentials are a construction related problem.* Temperature differentials can lead to significant density differentials in the finished mat. They not only address the differences in the mat due to temperature, but can also locate aggregate segregation, which can also lead to density differentials. Over 40 percent of the jobs observed during the 2000 construction season had temperature differentials 25^oF or greater. The need to minimize the effects of temperature differentials is readily apparent if a 15 year overlay life is to be achieved.

2. *Ultimately, large density differentials need to be avoided.* Large density differentials cause areas in the mat that are susceptible to premature failure in the form of raveling, cracking, and the possibility of increased oxidation of the asphalt binder and stripping. A decrease in density of just 3 pounds per cubic foot results in an approximate increase in air voids of 2 percent. For every 2 percent increase in air voids, the permeability of the hot-mix can increase significantly (Equation 1).

3. *Random sampling used for the Quality Assurance program does not capture these low density areas.* The density differentials typically occur in a systematic pattern and samples taken randomly (typically 5 per 400 ton lot) cannot capture the extent of the problem. (See Figures 17 through 19.)

- A worst-case scenario is an end dump operation where the cool areas of mix are located approximately every 120 feet and can result in a possibility of 25 or more low density locations per 400-ton lot (Figure 17). Also, these cool pockets of mix can cover up to 50 percent of the mat (Figure 19).
- Longitudinal streaking can also be a problem. Although it is not nearly as obvious or severe as the cool pockets, these low density streaks can cover up to 180 feet of the mat over a 400-ton lot (Figure 18).
- Best-case scenario is the event where there are very few or no observations of cool pockets of mix or streaks. Not taking into account paving joints at the beginning and end of the day, this is possible to achieve.
- A review of WSDOT pavements show that, depending on the thickness of the lift placed, these areas of low density can range anywhere from approximately 40 feet to 120 feet apart.

4. *Density profiles are a systematic procedure to determine if density differentials are present.* Temperature differentials or visual inspection is used to locate where a density profile is performed. Profiles can be used as a control method to improve the quality of the finished product. Along with the possibility of new technology to collect this data (GPR), this could be a relatively quick method to check for quality of the finished mat.



For a 400-ton lot (assuming 12’ lane and 0.15’ overlay), there would approximately 0.61 miles covered. These areas of cool mix typically occur every 120’ or so for an end dump operation, leaving over 25 locations of cool mix per 400-ton lot.

Figure 17. Areas of Cool Mix Affect Over 25 Locations Per 400-ton Lot.

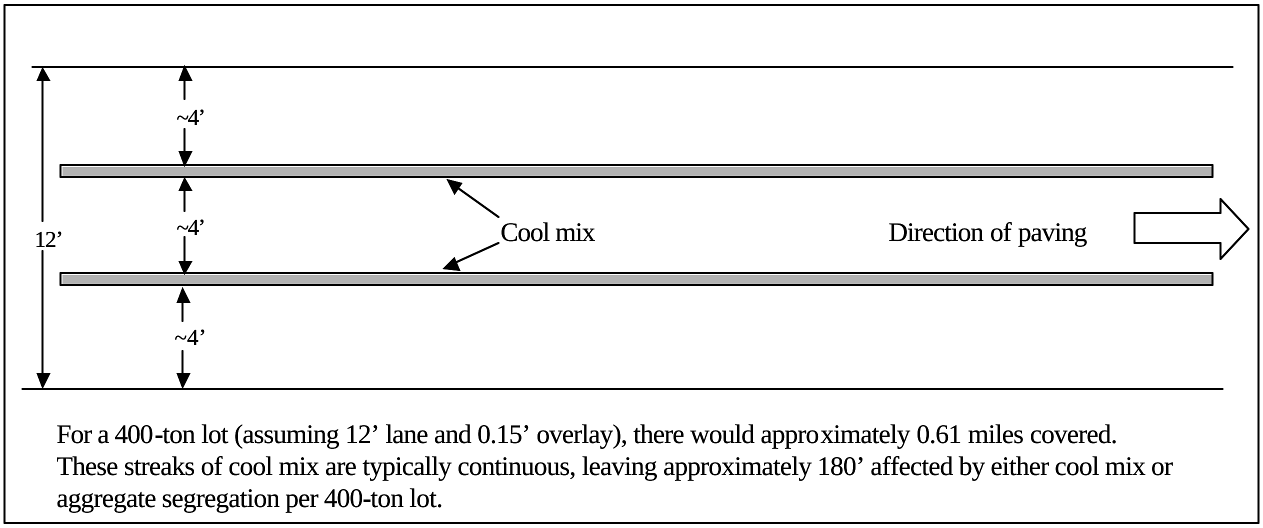


Figure 18. Longitudinal Streaks of Cool Mix or Aggregate Segregation Affect Approximately 180 Feet in a 400-ton Lot.

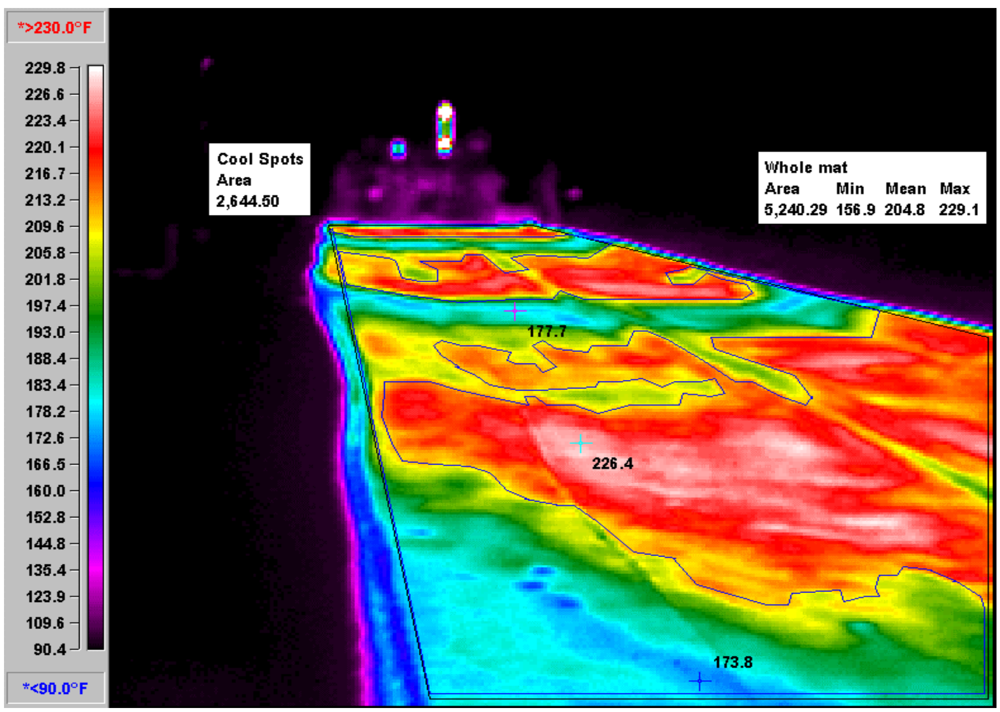


Figure 19. Worst-case scenario – cool mix consumes approximately half of the mat.

SUMMARY AND CONCLUSIONS

Below is a summary of the all the data collected over the three construction seasons in Washington State. It includes observations of the research team in the field and compiled data from the past three years.

1. Temperature differentials are a concern in hot-mix paving. They can cause concentrated areas of lower density hot-mix which are susceptible to premature failure by cracking or raveling. These areas of low density are also more susceptible to water intrusion due to increased permeability and more prone to oxidation of the binder.

2. Over the past three construction seasons, the research team has seen temperature differentials range from 0^oF up to 80^oF. Depending on the normal mat temperature, the higher temperature differentials can result in concentrated cooler areas below the cessation temperature directly behind the paver (before any compaction has taken place).

3. The 1999 work showed that the main factor in the appearance of temperature differentials was the crust that formed in the haul vehicle that was not remixed prior to placement. There was a slight correlation between haul time and larger temperature differentials, but large temperature differentials were seen even when the haul time was less than 5 minutes (without remixing).

4. Normally, WSDOT does not experience significant amounts of aggregate segregation. Testing during the 1998 construction season has shown that these cooler areas in the mat do not suffer from aggregate segregation as classified by Williams, et al. (1996) and others. There have been occurrences of aggregate segregation, but this typically occurs along with the longitudinal streaks.

5. Temperature and density differentials can be a significant issue on paving projects. More than half of all the projects (28 out of 53) visited in 1999 and 2000 had temperature differentials that exceeded 25^oF.

6. End dump operations usually cause cyclic patterns of large spots of lower density mix that are typically located in the wheelpaths but can be found in the middle of the lane or across the entire paved lane.

7. Windrow elevator operations are the most prevalent cause of longitudinal streaking behind the paver, but streaking is not exclusive to windrow elevator operations. Paver operation can also cause streaking.

8. Material transfer devices and vehicles can reduce the magnitude of temperature differentials, but every device that was observed, if operated incorrectly, caused temperature differentials greater than 25^oF.

9. Timely compaction and the use of pneumatic rollers <u>may</u> be able to offset <u>some</u> of the effects of temperature differentials.

10. For every three pounds per cubic foot the density decreases, the percent air voids increase approximately two percent (Table 15). Just a two percent increase in air voids can lead to a significant increase in permeability.

Table 15. The Percent Change in Air Voids with a Density Decrease of 3 and 6 pcf.

Percent of Mean MTD Density [1]	Air Voids of Mix at Mean Density	Air Voids of Mix at Mean Density – 3 pcf	Air Voids of Mix at Mean Density – 6 pcf
95%	5.0%	7.0%	9.0%
94%	6.0%	8.0%	10.0%
93% [2]	7.0%	9.0%	11.0%
92%	8.0%	10.0%	12.0%
91%	9.0%	11.0%	13.0%

[1] Assume Maximum Theoretical Density (MTD) of 155 pcf (pounds per cubic foot).
[2] Long term WSDOT average density of 93.08%

11. The Quality Assurance program that WSDOT uses for paving projects does not capture the significance of low density areas on the finished pavement and these low density areas can significantly affect the performance and life of the pavement.

13. The density profile procedure can locate potential areas of low density (whether due to temperature differentials or aggregate segregation), test those areas, and provide results (via a nuclear asphalt content gauge) to determine the extent of the problem on any job.

Conclusions

The detrimental effects caused by low compaction temperatures or aggregate segregation date back at least forty years. Several articles and reports (Parker (1959); Dickson, et al. (1970); Hadley, et al. (1971); Geller (1984); and Kennedy, et al. (1984)) confirm that lower compaction temperatures are directly related to an increase in air void content. The air void content is probably the most important characteristic of hot-mix performance under traffic. Even with a perfect mix design, if the mix is not properly compacted in the field, the final product will not last for its intended length of time.

Temperature differentials do not cover the entire mat (worst-case scenario is approximately fifty percent), but even when cracking, raveling, or potholes develop on just a portion of the roadway, maintenance and eventually rehabilitation is needed earlier than expected. The cost savings are difficult to estimate, but WSDOT paves approximately 1.5 million tons of HMA per construction season at an average cost of $30 per ton. If reducing density differentials produced a 20 percent increase in pavement life, this improvement would amount to about $9 million in savings per year.

The goals of this study were to determine what kind of mat problem WSDOT experiences (temperature differentials or aggregate segregation, or both), the probable causes, and how to fix the problem. It was found that WSDOT experiences temperature differentials on many projects and to some extent aggregate segregation (typically in longitudinal streaks). It was observed that there are numerous factors involved with the paving operations, so that no one single piece of equipment or operation will guarantee that temperature differentials will not occur, but there are equipment and techniques that can be utilized to offset the occurrence and effects of temperature differentials. Finally, the density profile procedure provides a method of determining the effect of the temperature differentials in the finished product.

Density differentials are a primary concern in hot-mix paving. If temperature differentials exist, but the finished pavement has a uniform density of 93 percent or greater (air voids of 7 percent or less) for dense-graded mixes, then the pavement should serve its intended purpose for its intended length of time. The density profile procedure does not guarantee a uniform mat density, but it can be used as a quality control tool to help attain a uniform density. This could be a major step in achieving a higher quality hot-mix product.

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APPENDIX A

Summary of 1998 Project Data

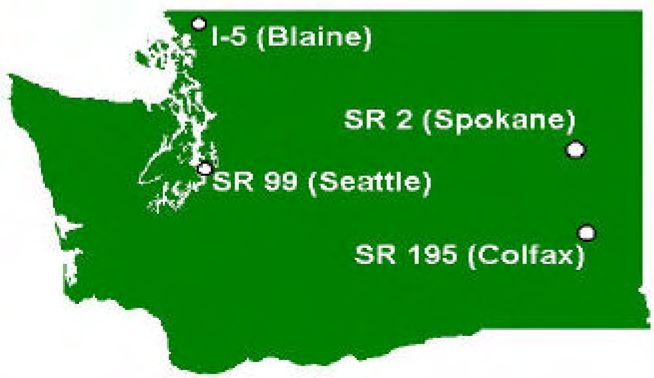


Figure A1. Site Locations

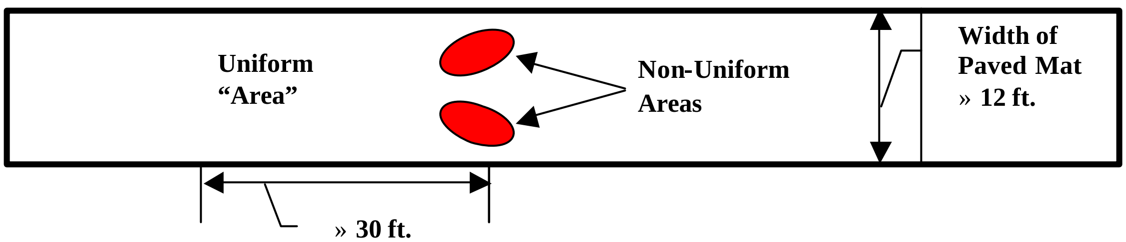


Figure A2. Sampling Location Detailed Schematic

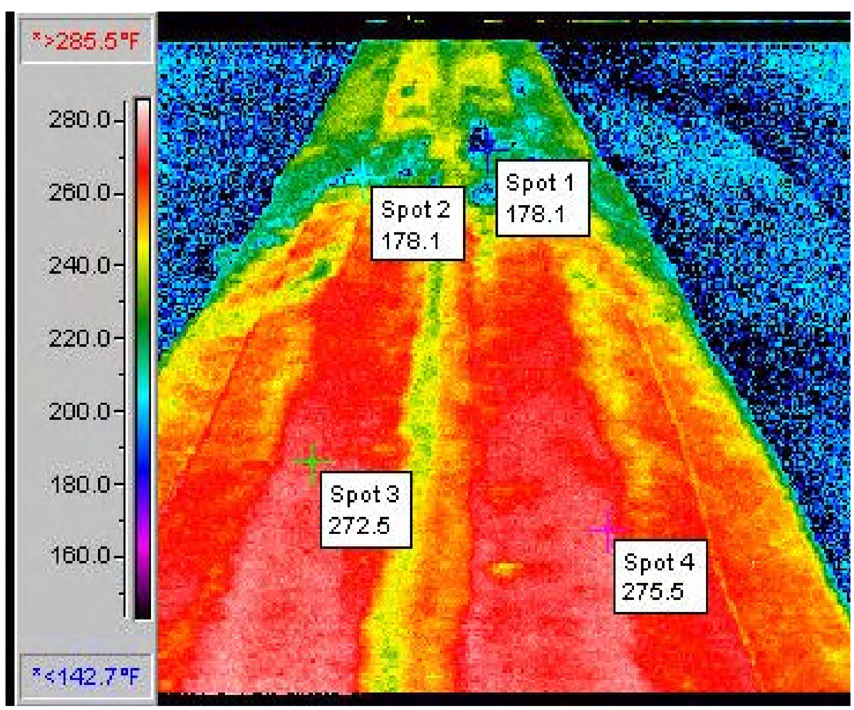


Figure A3. Infrared Image of I-5 (Blaine) 1998 Paving Project with Truck End Dumping
(Note: Temperatures are in °F)

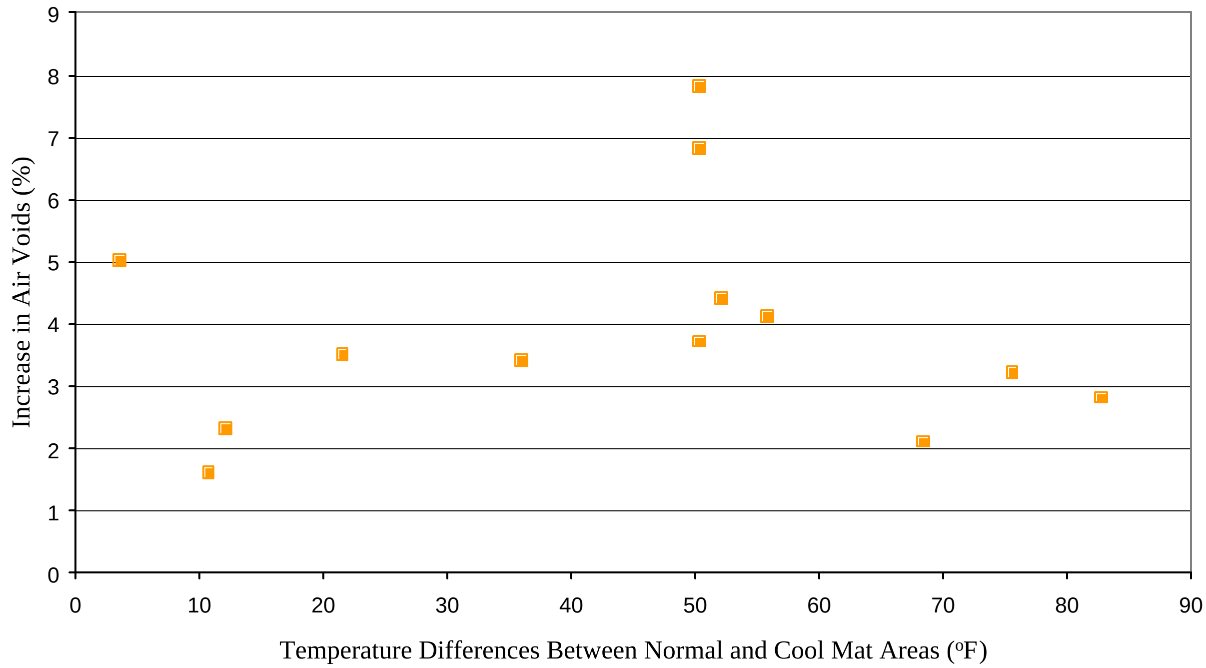


Figure A4. Probe Measured Temperature Differentials vs. Increase in Air Voids

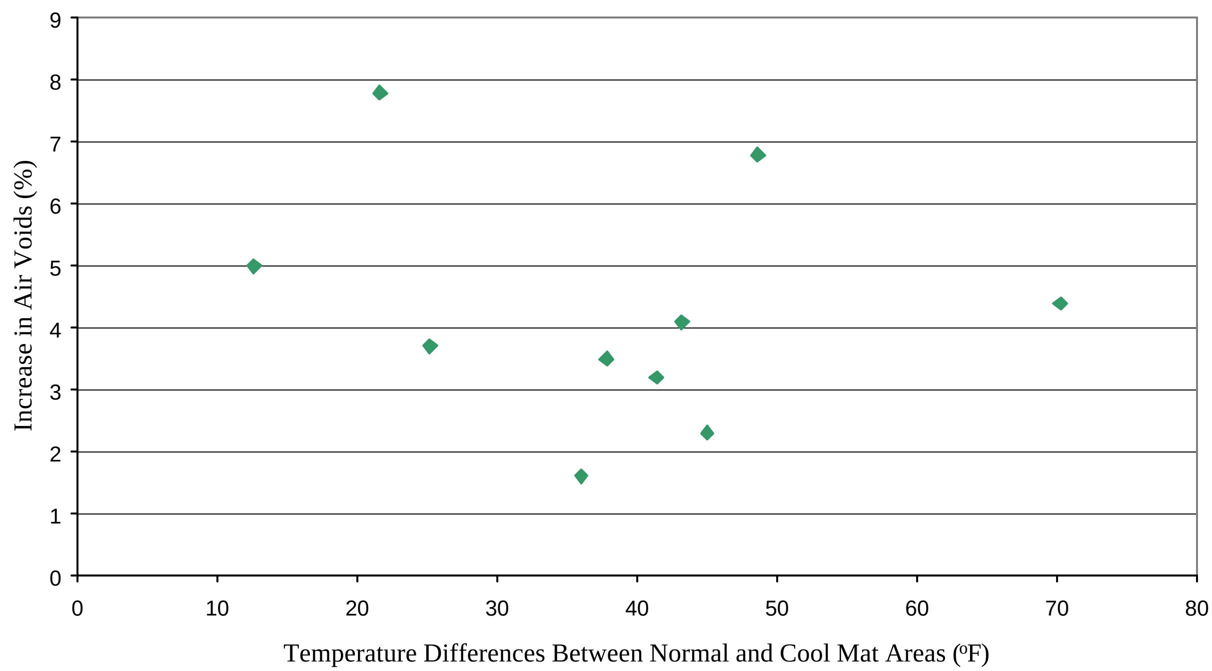


Figure A5. Infrared Measured Temperature Differentials vs. Increase in Air Voids

Table A1. Field Tests

Test	Test ID	Material Condition	Test Location	Material Temperature Condition
Temperature Probe	None	Loose	Truck, Opposite corners/middle	N/A
			Behind Screed	Cool Spot
				Normal-Temp. Area
Non-Nuclear Density (PQI)	None	Fully Compacted	Behind Screed	Cool Spot
				Normal-Temp. Area
Nuclear Density	WSDOT 715	Fully Compacted	Behind Screed	Cool Spot
				Normal-Temp. Area

(1) Nuclear density gauges were calibrated by project specific cores per WSDOT standard procedures.
(2) Non-nuclear density gauge used at same points as the nuclear gauge on two of the four projects and not calibrated.

Table A2. Laboratory Tests

Test	Test ID	Material Condition	Sampling Location	Material Temperature Condition
Gradation and AC Content	AASHTO T11, T27	Loose	Truck, Opposite corners and middle	N/A
			Behind Screed	Cool Spot
				Normal-Temp. Area
		Core	Behind Screed	Cool Spot
				Normal-Temp. Area
Rice Density	AASHTO T209	Core	Behind Screed	Cool Spot
				Normal-Temp. Area
		Loose	Behind Screed	Cool Spot
				Normal-Temp. Area
Density, Percent Air Voids	WSDOT 704, AASHTO T166	Core	Behind Screed	Cool Spot
				Normal-Temp. Area

Table A3. Gradation and Asphalt Content Summary

Project	Sample ID	Gradation (% Passing by Weight)								Asphalt Content (%)
		¾" (19.0 mm)	½" (12.5 mm)	3/8" (9.5 mm)	No.4 (4.75 mm)	No.8 (2.36 mm)	No.10 (2.00 mm)	No.40 (0.425 mm)	No.200 (0.075 mm)	
I-5 Blaine	Normal	100.0	95.9	82.1	50.6	33.0	29.7	13.6	5.5	4.8
	Cool	100.0	96.0	80.4	45.9	30.1	27.3	12.4	5.2	4.5
	Diff	0.0	-0.1	1.7	4.7	2.9	2.4	1.1	0.3	0.3
SR 99 Seattle	Normal	100.0	98.0	86.0	61.0	42.0	38.0	17.0	6.6	5.0
	Cool	100.0	98.0	86.0	59.5	40.5	36.5	16.0	6.3	5.1
	Diff	0.0	0.0	0.0	1.5	1.5	1.5	1.0	0.3	-0.1
SR 2 Spokane	Normal	100.0	96.0	80.8	52.8	34.8	31.0	13.5	6.5	5.5
	Cool	100.0	97.8	80.8	50.8	34.0	30.8	13.3	6.2	5.5
	Diff	0.0	-1.8	0.0	2.0	0.8	0.2	0.2	0.3	0.0
SR 195 Colfax	Normal	100.0	93.5	76.0	50.5	35.0	31.5	14.0	5.9	5.1
	Cool	100.0	92.3	76.7	50.0	34.7	30.7	13.7	5.8	5.1
	Diff	0.0	1.2	-0.7	0.5	0.3	0.8	0.3	0.1	0.0

(1) In Column 2, "Normal" is the average gradation for all "normal" temperature samples. "Cool" is the average gradation for all "cool" temperature samples. "Diff" represents the differences between the two averages.
(2) WSDOT's 1998 Standard Specifications for Road, Bridge, and Municipal Construction does not include the 4.75 and 2.36-mm sieves but were included due to prior research that showed they were important in determining aggregate segregation.
(3) Asphalt content is based on percent by weight of total mix.

Table A4. Temperature and Percent Air Void Differences

Project	Paired Samples	Temperature Difference (°C)		Increase in Air Voids (%)
		Probe	Infrared Camera	
I-5 (Blaine)	3N/4C	28	27	6.8
	5N/6C	29	39	4.4
	7N/8C	31	24	4.1
	10N/11C	12	21	3.5
	12C/13N	38	-	2.1
	14N/15C	20	-	3.4
SR 99 (Seattle)	2N/3C	46	-	2.8
SR 2 (Spokane)	1C/2N	28	14	3.7
	3C/4N	22	25	2.3
	5C/6N	42	23	3.2
	7C/8N	6	20	1.6
SR 195 (Colfax)	2N/3C	2	7	5.0
	4C/5N	28	12	7.8
Averages		26	21	3.9

(1) For the paired samples, the numbers represent a specific location. "N" represents a normal temperature area of the mat and "C" represents a cooler portion. The paired samples are from a single truckload of hot-mix. The order of N and C is not important since they simply represent the order of sampling.
(2) Temperature difference = N – C (for all cases the normal area mat temperatures were higher than the cooler mat areas)
(3) Increase in Air Voids = C – N (for all cases the air voids in the cooler areas were higher than the normal areas) The air voids were determined using densities from calibrated WSDOT nuclear density gauges along with Rice densities from loose box samples taken from the mat. The one exception to this was SR 99 whereby core bulk density data was used in lieu of nuclear densities (nuclear densities not available at the sampled locations).

APPENDIX B

Summary of 1999 Project Data

Table B1. Comprehensive Project Data Spreadsheet.

1	2	3	4	5	6	7	8	9	10	11	12	13
Contract Number	State Route	Day or Night	Air Temp (F)	Surface Temp (F)	Class	Binder	Layer Depth (mm)	Plant Temp	Haul Time	Haul Dist	Truck Type	Tarp Info
5544	211	Day	85	110	D modified	PG 64-34	45	265	30	18	Belly Dumps	no tarps
5054	405	Night	65	75	A	PG 58-22	45	268	40	12	Belly Dumps	no tarps
5345	101	Day	60	75	A	PG 58-22	45	280	40	20	Trucks and Pups	loosely tarped
5497	2	Day	80	110	A	PG 64-34	45	275	11	5	Belly Dumps	no tarps
5519	395	Day	70	85	A	PG 64-34	45	275	15	11	Belly Dumps	no tarps
5544	2	Day	65	70	12.5mm Superpave	PG 64-34	45	265	9.5	7	Belly Dumps	no tarps
5545	2	Day	80	125	A	PG 58-34	45	265	30	15	Trucks and Pups	no tarps
5554	174	Day	60	68	A	PG 58-34	45	-	105	35	Trucks and Pups	tight tarps
5562	530	Day	70	107	B	PG 64-22	45	317	16	9	Trucks and Pups	no tarps
5576	2	Day	65	95	A	PG 58-34	45	295	17	9	Trucks and Pups	no tarps
5581	82	Day	104	140	19mm Superpave	PG 70-28	60	310	5	1	Belly Dumps	no tarps
5586	171	Day	65	41	A	PG 64-34	45	275	13.5	6	Trucks and Pups	no tarps
5592	160	Day	65	74	A	PG 58-22	45	275	30	17	Trucks and Pups	loosely tarped
5598	24	Day	80	102	A	PG 64-28	52	252	9.5	7	Trucks and Pups	no tarps
5605	17	Day	60	72	A	PG 58-34	45	290	18	5	Trucks and Pups	no tarps
5606	195	Day	65	125	A	PG 64-28	52	280	10	6	Flowboys	no tarps
5609	395	Day	60	95	B	PG 58-34	45	296	25	12	Trucks and Pups	no tarps
5614	6	Day	75	120	A	PG 58-22	45	270	75	29	Trucks and Pups	one tarped
5626	524	Night	55	65	SMA	PG 64-34	45	300	40	18	Trucks and Pups	no tarps
5627	17	Day	102	140	19mm Superpave	PG 64-28	90	278	22	16	Trucks and Pups	no tarps
5628	90	Day	65	85	E	PG 64-28	105	270	12	8	Trucks and Pups	no tarps
5632	7	Day	60	65	A	PG 58-22	45	283	40	23	Trucks and Pups	loosely tarped
5642	203	Day	56	70	A	PG 64-22	45	288	30	18	Trucks and Pups	loosely tarped
5645	99	Day	60	75	12.5mm Superpave	PG 64-22	45	300	6	3	Trucks	no tarps
5647	507	Night	75	95	A	PG 58-22	60	315	30	20	Trucks and Pups	loosely tarped
5654	18	Night	55	65	12.5mm Superpave	PG 64-22	45	315	40	18	Trucks and Pups	loosely tarped
5657	20	Day	80	120	B	PG 58-22	45	-	10	5	Trucks and Pups	no tarps
5659	395	Day	95	137	12.5mm Superpave	PG 70-28	45	-	10	4	Belly Dumps	no tarps
5663	82	Day	80	115	19mm Superpave	PG 70-28	60	278	18	5	Belly Dumps	no tarps
5664	397	Day	85	120	A	PG 70-28	45	325	26	17	Trucks and Pups	no tarps
5665	525	Night	60	65	A	PG 58-22	45	295	55	15	Trucks and Pups	no tarps
5666	12	Day	55	63	12.5mm Superpave	PG 58-22	40	278	30	20	Trucks and Pups	loosely tarped
5673	101	Day	65	85	A	PG 58-22	45	298	26	6	Trucks and Pups	loosely tarped
5673	101	Day	65	85	A	PG 58-22	45	298	26	6	Trucks and Pups	loosely tarped
5675	90	Day	80	100	A	PG 70-28	45	260	10	6	Trucks and Pups	no tarps
5679	20	Day	55	54	B	PG 58-34	45	301	20	14	Trucks and Pups	no tarps
5701	14	Day	65	90	A	PG 64-22	45	302	23	16	Trucks and Pups	loosely tarped

NOTES

5 Surface Temp measured in front of paver prior to laydown with handheld gun

9 Plant Temp is temperature of mix measured with the infrared camera as the mix is loaded into the trucks

10 Haul Time is measured from the time the truck receives the mix at the plant to the time when it unloads at the job

13 Loosely tarped trucks have tarps attached at front and back of bed only, tight tarps are attached over the perimeter of the entire box

Table B1 Comprehensive Project Data Spreadsheet Continued.

1	14	15	16	17	18	19
Contract Number	MTV Used	Paving Machine	Typical Mat Temp (F)	Placement Temp (F)	Breakdown Temp (F)	Breakdown Roller Type
5544	Cedarapids MS-2 Windrow Elevator	Blaw Knox PF-500	265	265	250	Dynapac CC-501
5054	Barber Greene BG MTV 650 Windrow Elevator	Barber Greene BG-265B	245	245	240	Hyster Hypac C-778-A
5345	Blaw Knox MC-30	CAT AP-1055 B	265	275	260	CAT CB-634-C
5497	Cedarapids MS-2 Windrow Elevator	Blaw Knox PF-5510	245	-	-	IR DD-130
5519	Ko-Cal Windrow Elevator	Blaw Knox PF-200	245	-	-	Dynapac CC-501
5544	Cedarapids MS-2 Windrow Elevator	Blaw Knox PF-200	230	255	245	Dynapac CC-501
5545	Roadtec Shuttle Buggy SB-2500	Blaw Knox PF-500	225	240	230	IR DD-110
5554	Blaw Knox MC-30	Blaw Knox PF-5510	255	-	-	Dynapac CC-501
5562	None	Blaw Knox PF-5510	260	280	270	Sakai Pneumatic
5576	Roadtec Shuttle Buggy SB-2500	CAT AP-1055 B	258	275	260	Sakai Pneumatic
5581	Lincoln 660H Windrow Elevator	Blaw Knox PF-3200	283	295	290	IR DD-130
5586	Ko-Cal + Windrow maker Windrow Elevator	Blaw Knox PF-510	245	-	-	IR DD-110
5592	None	Blaw Knox PF-5510, and PF-500	238	225	210	IR DD-130
5598	Cedarapids MS-2 Windrow Elevator	Blaw Knox PF-510	235	250	240	CAT CB 534 B
5605	Blaw Knox MC-30	Blaw Knox PF-510	234	245	223	IR DD-110
5606	None	Cedarapids CR-561	238	255	-	Dynapac CC-501
5609	Cedarapids MS-3	Cedarapids CR-461	250	260	212	Dynapac CC-501
5614	None	CAT AP-1055 B	255	260	250	Dynapac CC-501
5626	Roadtec Shuttle Buggy SB-2500	Blaw Knox PF-300	270	270	265	Bomag BW-202-AD
5627	Cedarapids MS-2 Windrow Elevator	Blaw Knox PF-3200	253	280	230	Dynapac CC-501
5628	Cedarapids MS-2 Windrow Elevator	Blaw Knox PF-3200	233	255	200	Dynapac CC-501
5632	Blaw Knox MC-30	CAT AP-1055 B	245	250	230	Dynapac CC-501
5642	None	Barber Greene BG-245C	255	245	235	Hypac C778A
5645	Roadtec Shuttle Buggy SB-2500 B	CAT AP-1055 B	254	275	255	Dynapac CC-501
5647	Blaw Knox MC-30	CAT AP-1055 B	270	290	265	CAT CB 534 C
5654	Roadtec Shuttle Buggy SB-2500	CAT AP-1055 B	263	300	265	Dynapac CC-522
5657	None	Blaw Knox PF-510	250	250	230	Hyster Hypac C-266-B
5659	Cedarapids MS-2 Windrow Elevator	Blaw Knox PF-5510	245	260	260	IR DD-130
5663	Cedarapids MS-2 Windrow Elevator	Blaw Knox PF-3200	255	260	255	Dynapac CC-501
5664	Barber Greene BG MTV 650 Windrow Elevator	Blaw Know PF-510	275	290	265	Dynapac CC-522
5665	None	Blaw Knox PF-5510 and PF-410	273	270	210	IR DD-110
5666	Roadtec Shuttle Buggy SB-2500 B	Blaw Knox PF-500	237	245	240	IR DD-110
5673	Blaw Knox MC-30	CAT AP-1055 B	256	280	250	Dynapac CC-501
5673	None	Blaw Know PF-4410	256	280	250	Dynapac CC-501
5675	Cedarapids MS-2 Windrow Elevator	Blaw Knox PF-5510	236	257	230	Dynapac CC-501
5679	Cedarapids MS-3	Cedarapids Greyhound CR-461	255	290	290	Dynapac CC-50
5701	Blaw Knox MC-30	Blaw Knox PF-3200	265	270	255	CAT CB 634 C

NOTES

16 Typical mat temperature measured with infrared camera
17, 18, 20, 22 Placement, breakdown, intermediate, and finish temps measured with handheld temperature gun

Table B1. Comprehensive Project Data Spreadsheet Continued.

1	20	21	22	23	24	25	26	27
Contract Number	Intermediate Temp (F)	Intermediate Roller Type	Finish Temp (F)	Finish Roller Type	Mat Description From Field Notes	Delta T Max (F)	Delta Air Voids	Range in Air Voids (%)
5544	230	None	210	Hypac	Fairly uniform with some streaks	15	no densities	no densities
5054	-	None	210	Dynapac CC-501	Some isolated cool spots	36	3.6	3.7
5345	220	IR CR-80/Cat CB-534-C	150	Hyster	Slowly reaching uniform	40	1.4	2.6
5497	-	Dynapac CC-501	-	Hypac C-778-A	Uniform	8	-0.4	1.9
5519	-	Hyster Hypac	-	Hyster Hypac	Streaks	21	-0.3	1.1
5544	200	Ferguson SP -1118, Hyster	160	Hyster Hypac	Some streaking, one cool spot	19	0.1	0.6
5545	200	Bros AR 6000 Pneumatic	38	IR DA-50	Uniform	12	0.1	1.2
5554	-	None	-	IR DD-50	Non-Uniform	42	2.8	2.4
5562	250	IR DD-110	200	Hyster C-625-B	Typical end load cool spots	80	1.3	1.5
5576	235	Dynapac CC-501, Cat CB-334-C	-	Hyster C-776-B	Very Uniform	12	0.1	0.6
5581	230	Cat PS-300B	215	IR DD-110	Very Uniform	15	0.7	1.1
5586	-	IR DD-110	-	IR DD-70	Uniform	20	0.9	1.9
5592	180	IR DD-110	-	IR DD-24	Non uniform	66	4.9	4.4
5598	200	IR DA-48	-	Tampo RS 166A	Fairly Uniform mat	10	0.7	0.8
5605	183	IR DD-110	-	IR DD-40	Mostly Uniform	40	3.7	3.7
5606	-	Dynapac CC-501	-	Dynapac CC-501	Mostly Uniform	50	-1.2	3.1
5609	196	Hypac C-7728-B	-	Tampo RS-166-A	Uniform	25	0.4	1.6
5614	210	Sakai Pneumatic	-	Hyster	Non-uniform	61	2.8	2.1
5626	210	IR DD-110 HF	180	Dynapac CC-50	Uniform	10	no densities	no densities
5627	225	IR DD-130, IR PT-125R Pneumatic	175	IR DD-110	Some cool (20 degrees) areas	35	-0.8	3.1
5628	175	IR DD-130	-	Not Recorded	Mostly Uniform	20	0.3	0.3
5632	215	Dynapac Pneumatic CP-30	200	Dynapac	Cool spots similar to end dumps	71	1.2	1.2
5642	-	None	210	Dynapac CC-501	Typical end dump pattern	55	4.5	3.4
5645	-	None	160	Hyster C-350-AD	Uniform	10	0.9	2.9
5647	260	Sakai Pneumatic	170	Dynapac CC-522	Non pattern cool spots	66	0.6	1.8
5654	190	Dynapac CC-222	165	Hypac C-766-B	Uniform	10	0.8	1.9
5657	175	Dynapac CC-42	145	Hyster C-330A	Cool Spots from end dumps	55	1.9	3.5
5659	205	Dynapac CC-510	-	Hypac C-778-A	Fairly Uniform	15	0.0	1.3
5663	205	IR DD-130	180	IR DD-130	Mostly Uniform	25	-0.4	3.4
5664	240	Hyster/Dynapac Pneumatic	160	Hyster C-766-A	Pattern like end dumps smaller dT	29	-1.5	1.9
5665	-	None	120	IR DD-110	Typical end dump pattern	77	2.5	4.1
5666	208	Dynapac CC-501/Sakai Pneumatic	140	IR DD-110	Uniform	10	0.0	2.0
5673	215	Sakai 15500 Pneumatic	-	Cat CB-534-C	Uniform when MTD used, else not	14	3.2	3.5
5673	215	Sakai 15500 Pneumatic	140	Cat CB-534-C	End Dump Pattern	43	1.7	1.7
5675	210	IR DD-110	-	IR DD-130	Fairly uniform	20	1.6	2.0
5679	-	None	170	Hypac C-778-B	Cyclic twenty degree pattern	40	-1.1	1.6
5701	215	IR PT-125-R Pneumatic	185	IR DD-130	Spots, only about dT=10	30	-0.9	3.3

NOTES

25 Delta T Max is the difference in temperature between the hot and cool temperatures at the density locations via the infrared camera

26 Delta Air Voids is the percent air voids at the cool temperature spot minus the percent air voids at the high temperature spot at the density location

27 Range in Air Voids is the average difference in air voids from the low % air voids and the high % air voids at the density locations for each project. A project may have one to five different density locations, and the range reported is the average of the locations.

The information that follows is broken into two separate sections: temperature differentials and air void differences.

Temperature Differentials

The temperature differentials observed on these 36 projects surveyed in 1999 include numerous factors that are interrelated. This helps to explain the variation seen in Figures B2 through B8. These figures illustrate the typical temperature differentials seen on each project compared to various factors. The densities were taken in a transverse profile in most cases, with some densities taken longitudinally. The reason for densities taken in longitudinal directions was because the cooler areas covered the entire width of the mat thus preventing comparisons with warmer material.

It is assumed that the day the team visited the job is representative of the entire paving job. Nuclear density readings were taken where the team observed typical mat conditions. Therefore, the temperature differential data used in these figures are the largest temperature differentials at the same location as where the densities were taken. Temperatures were taken from the infrared images and the difference between the highest and lowest temperatures were used. Referring to Figure 3 and Table 3 in the report, the temperature differential would be 57.9°F according to this definition. Each density location has a corresponding temperature and typically the higher the temperature, the lower the air void content (Figure 3, Table 3). The infrared camera operator determined the location where the densities were performed along with the specific offsets for each density test. Note is made that the infrared camera records the surface temperatures of the hot-mix. The temperatures at mid-depth were typically 10 to 15 degrees higher than the recorded temperature of the camera, but the temperature differentials between two areas were basically constant. Figure B1 shows the relationship between the recorded camera temperature and the probe temperature (mid-depth).

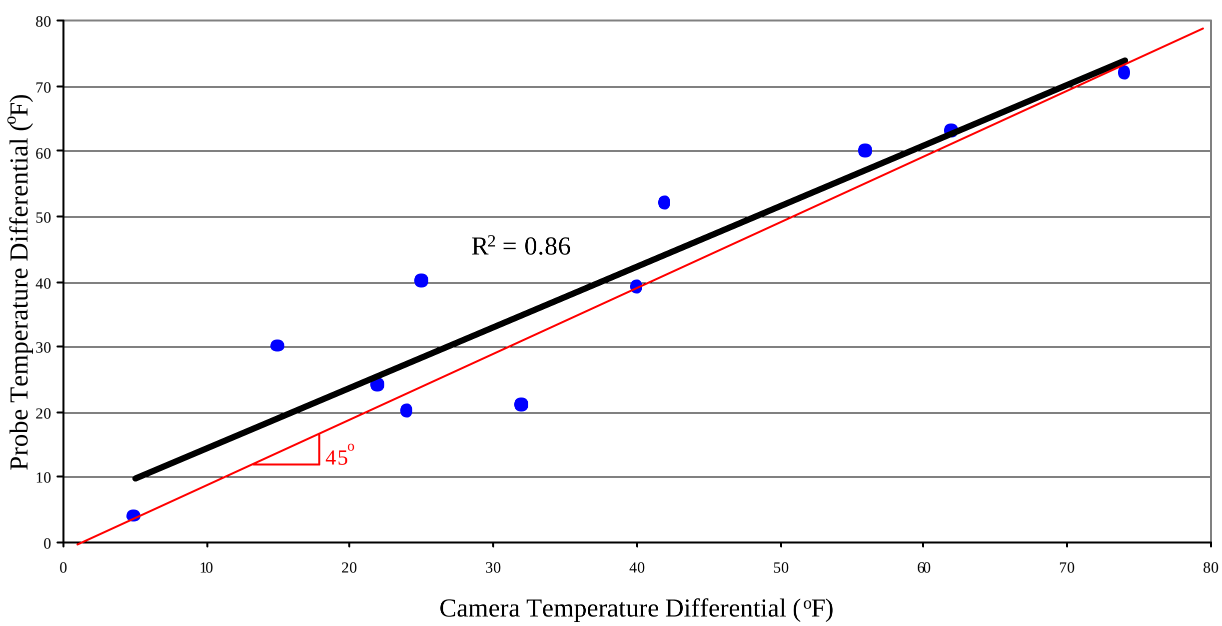


Figure B1. Camera vs. Probe Measured Temperature Differentials

In Figure B2, the air temperature is plotted against the mat temperature differential observed on each project. A regression of the data results in a very low coefficient of determination (R^2). Although the data points are limited (n=5), it appears to show a slight trend when air temperatures are 85°F or greater. For air temperatures of 85°F or over, there are only 2 of the 5 projects that have a temperature differential over 25°F and none of the projects had temperature differentials greater than 35°F. For air temperatures below 85°F, temperature differentials of 25°F or greater were observed on 56 percent of the projects and 28 percent had temperature differentials over 50°F.

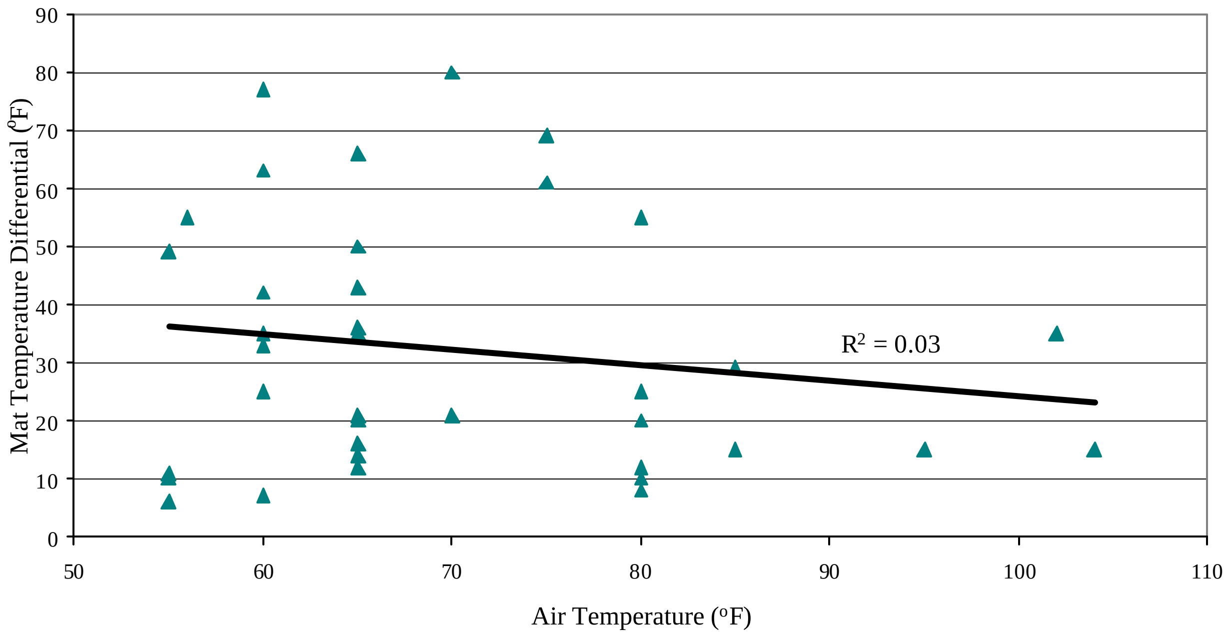


Figure B2. Air Temperature vs. Mat Temperature Differential

Figure B3 shows the relationship between the existing surface temperature and the mat temperature differential. Figure B4 plots the plant mix temperature versus the mat temperature differential. Although the graphs do not show any significant relationship between each of the two factors, higher temperature differentials are seen as the mix temperature at the plant increases. There is a maximum temperature differential of 20°F when the temperature of the hot-mix at the plant is 260°F, is 65°F with a temperature of 275°F at the plant, and is 80°F when the hot-mix temperature is 320°F at the plant, but this could have more to do with haul time (which is shown in Figure B5).

The haul time compared to the observed mat temperature differential is shown in Figure B5. The general trend is the longer the haul times, the higher the temperature differentials; however, the linear relationship is weak. This can probably be attributed to the use of MTVs/MTDs or remixing devices. The projects with haul times under 20 minutes have fewer temperature differentials over 25°F (35 percent) than those projects with haul times over 20 minutes (70 percent).

The next three figures show different plot variations of haul time versus mat temperature differential. Figure B6 breaks down the data between trucks that were tarped and those that were not. All of the tarped trucks except one had the type of tarp that is not tied down on the sides and made of non-insulated material. The figure shows that there is no correlation between mat temperature differentials and the haul time for tarped loads (a “positive” finding) and a slight correlation with untarped loads.

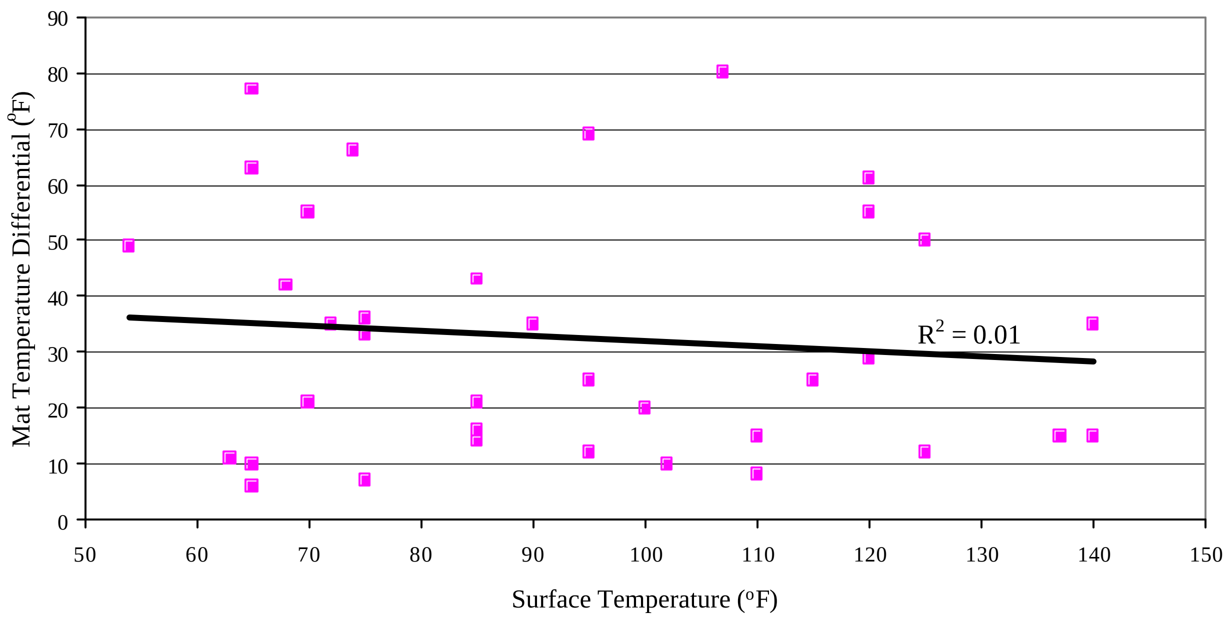


Figure B3. Existing Pavement Surface Temperature vs. Mat Temperature Differential

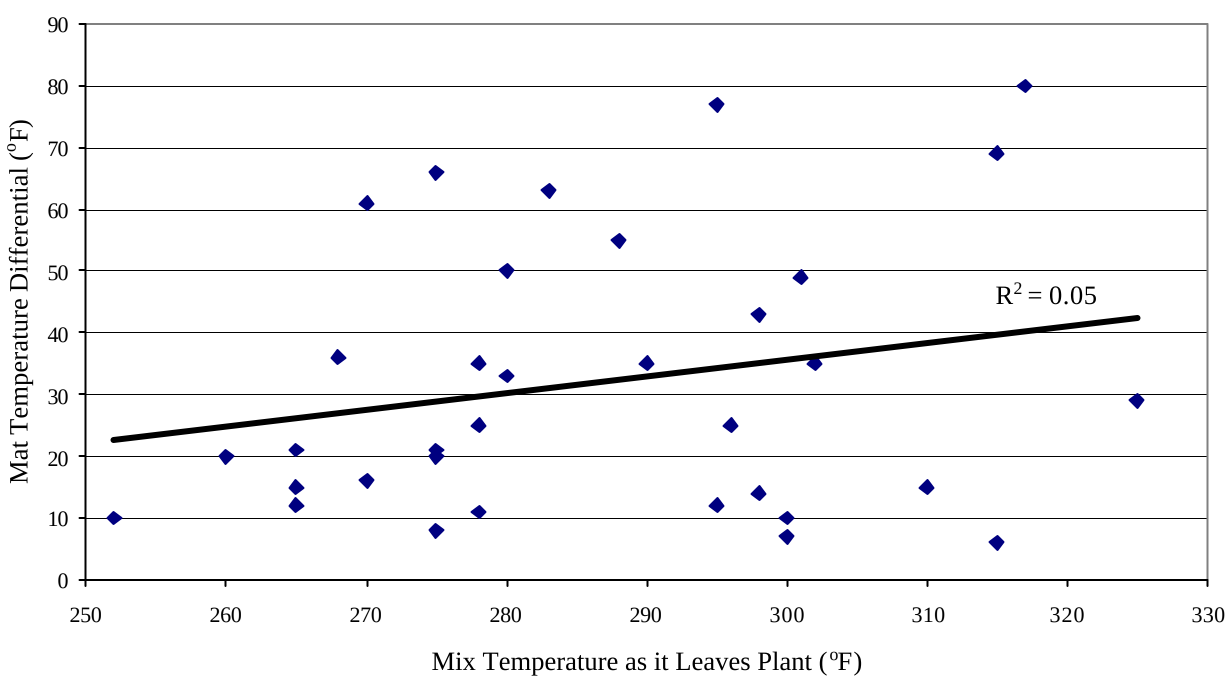


Figure B4. Mix Temperature at Plant vs. Mat Temperature Differential

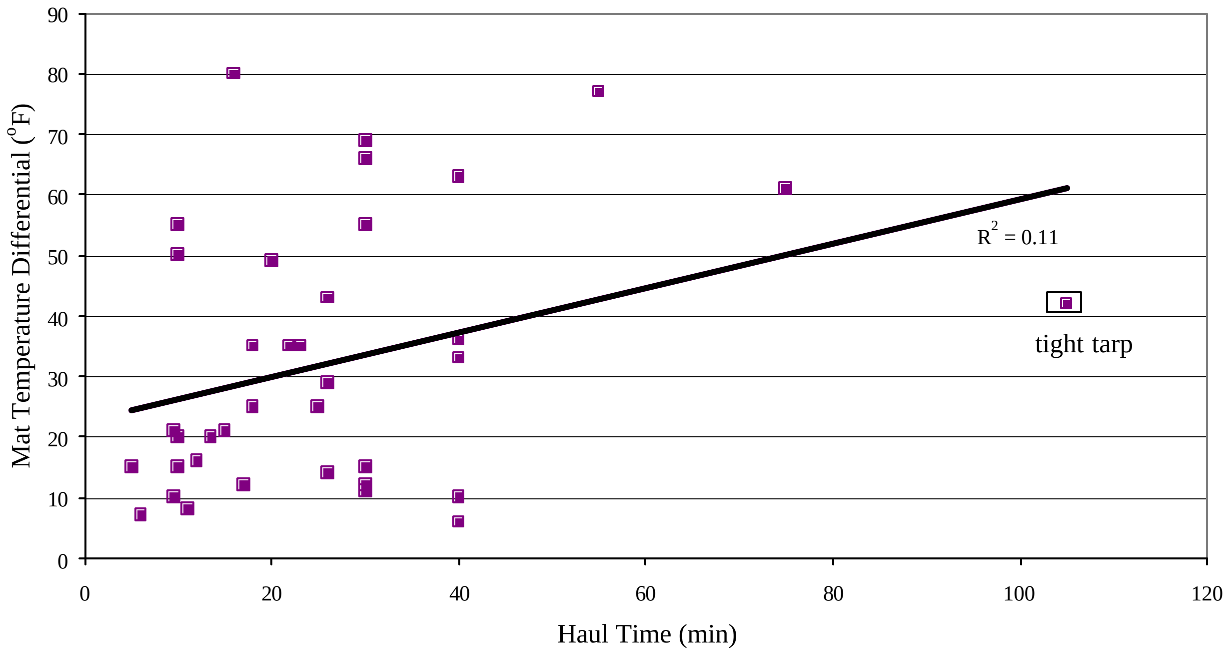


Figure B5. Haul Time vs. Mat Temperature Differential

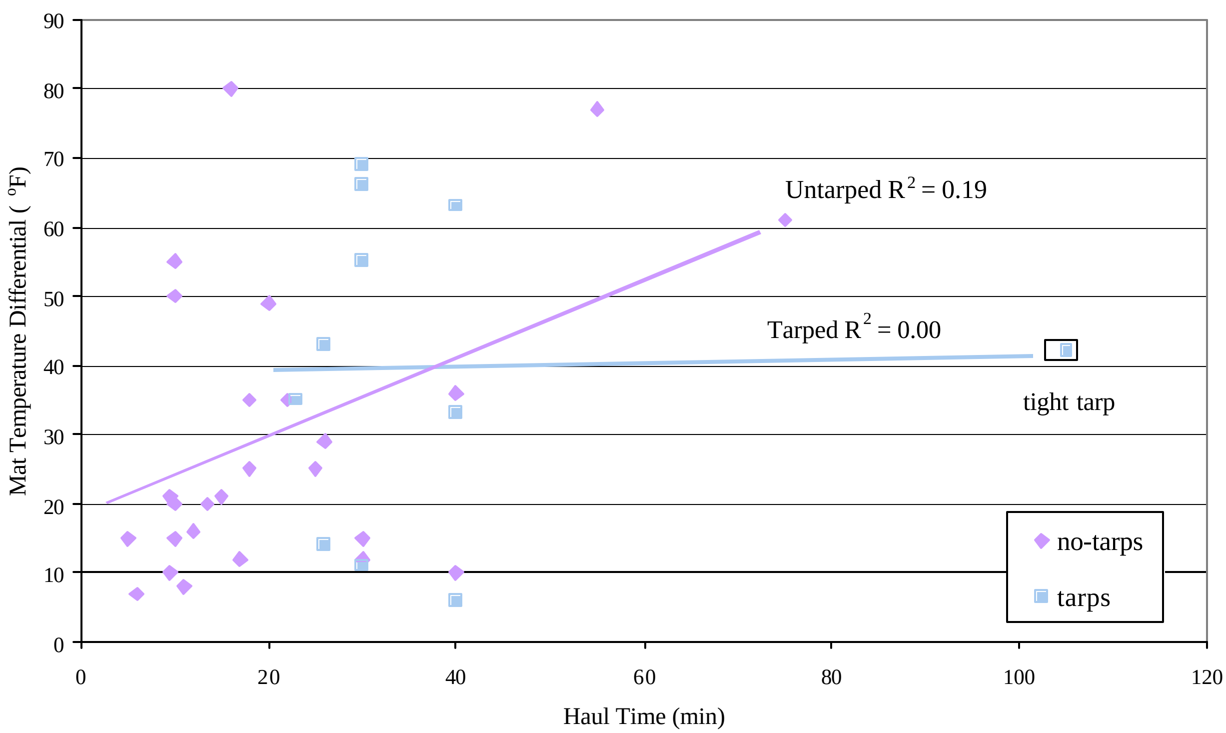


Figure B6. Haul Time By Tarp Use vs. Mat Temperature Differential

Figure B7 distinguishes between the conventional truck and pup combinations and belly dump trucks. From the graph, it appears that truck types have little effect on the relationship between the haul time and mat temperature differential, but the belly dumps have a higher linear relationship than the truck-pup combinations (R^2 of 0.44 and 0.08, respectively).

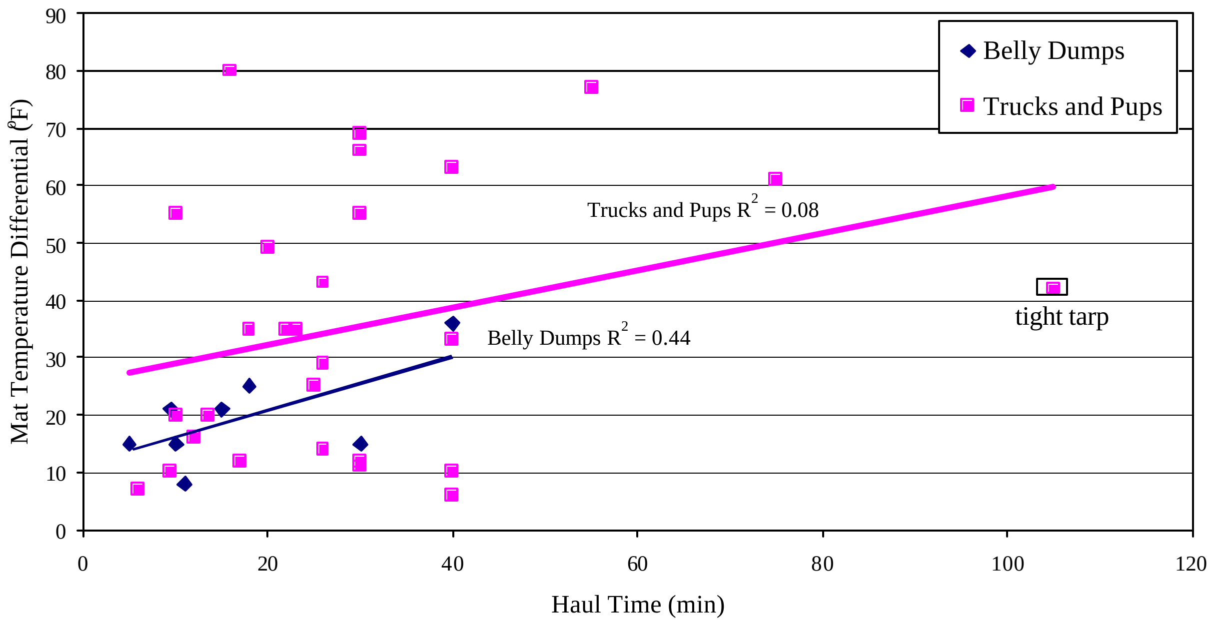


Figure B7. Haul Time by Truck Use vs. Mat Temperature Differential

Figure B8 shows that the use of different MTVs/MTDs can influence the relationship between the haul time and the temperature differential. For instance, projects that had an end-dump operation resulted in high temperature differentials regardless of haul time and just the opposite was true for the Roadtec Shuttle Buggy. There seems to be a slight correlation between the haul time and mat temperature differentials for windrow elevator transfer devices ($R^2 = 0.31$). During data collection, it was observed that the Blaw-Knox MC-30 was used in two different capacities, with the paddles in the paver hopper insert operating and without the paddles operating. These two conditions appear to produce differing mat temperature differentials, but there were only four and three data points, respectively. Six of the seven MC-30 projects produced temperature differentials of 25°F and greater.

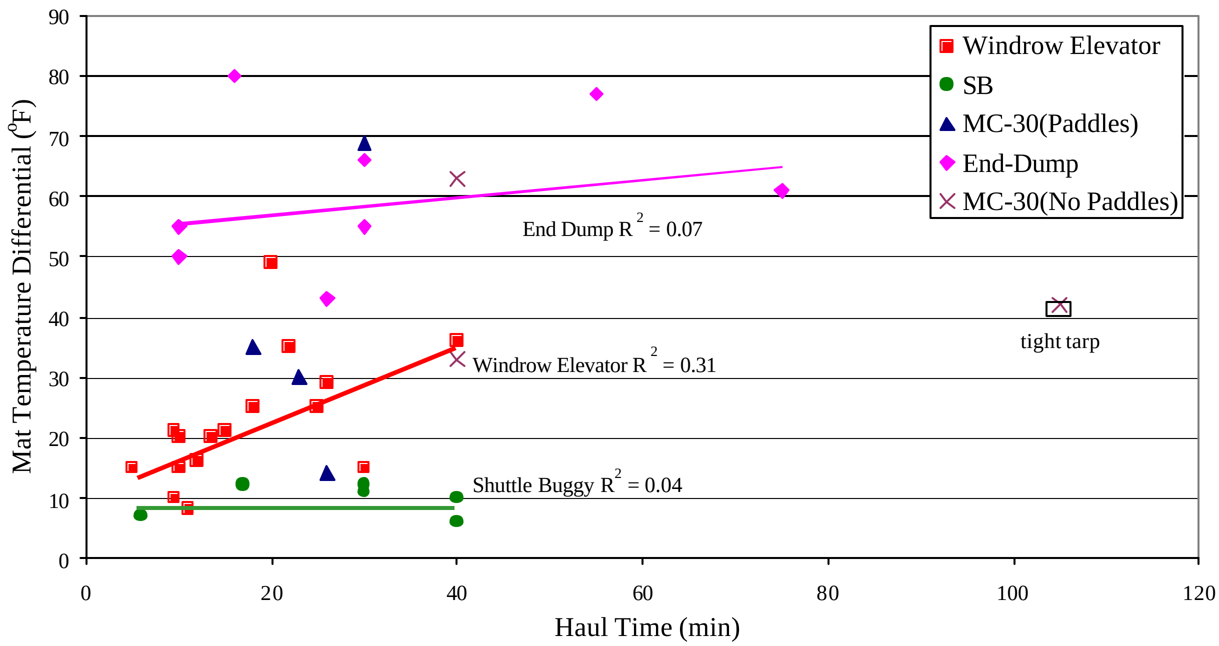


Figure B8. Haul Time Separated by MTV Used vs. Mat Temperature Differential

Air Void Differences

The range in air voids were compared to numerous factors that included the laydown, surface, and air temperature, haul time, breakdown rolling temperature, and mat temperature differentials. The air void ranges are calculated as the difference between the maximum and minimum readings for each set of transverse density readings on a project. If more than one set was taken on a job, the range in air voids is based on the average of all the transverse (or longitudinal) density sets. Referring to Figure 3 and Table 2, the range in air voids is 5.4 percent according to this definition (the difference in density between the yellow and white spots on the image). The temperature differential used in this section is the largest temperature differential observed at one set of transverse readings for each project (same temperature differential as in Figures B2 through B8).

Figures B9 through B14 show the air void range plotted against the laydown temperature, surface temperature, air temperature, haul time, breakdown rolling temperature, and temperature differentials, respectively. Each of these plots had an R^2 value of less than 0.15.

Figure B9 shows the laydown temperature versus the air void range. No significant trend is observed, which means that the temperature at laydown is not a significant factor in predicting the range in air voids.

The air void range versus the surface temperature, Figure B10, shows a slight decreasing trend with higher surface temperatures. When surface temperatures are 75°F or less, the average range in air voids is 2.7 percent with the range in air voids varying from 0.6 to 4.4 percent. Surface temperatures greater than 75°F vary from 0.3 to 3.5 percent and have an average air void range of 1.9 percent.

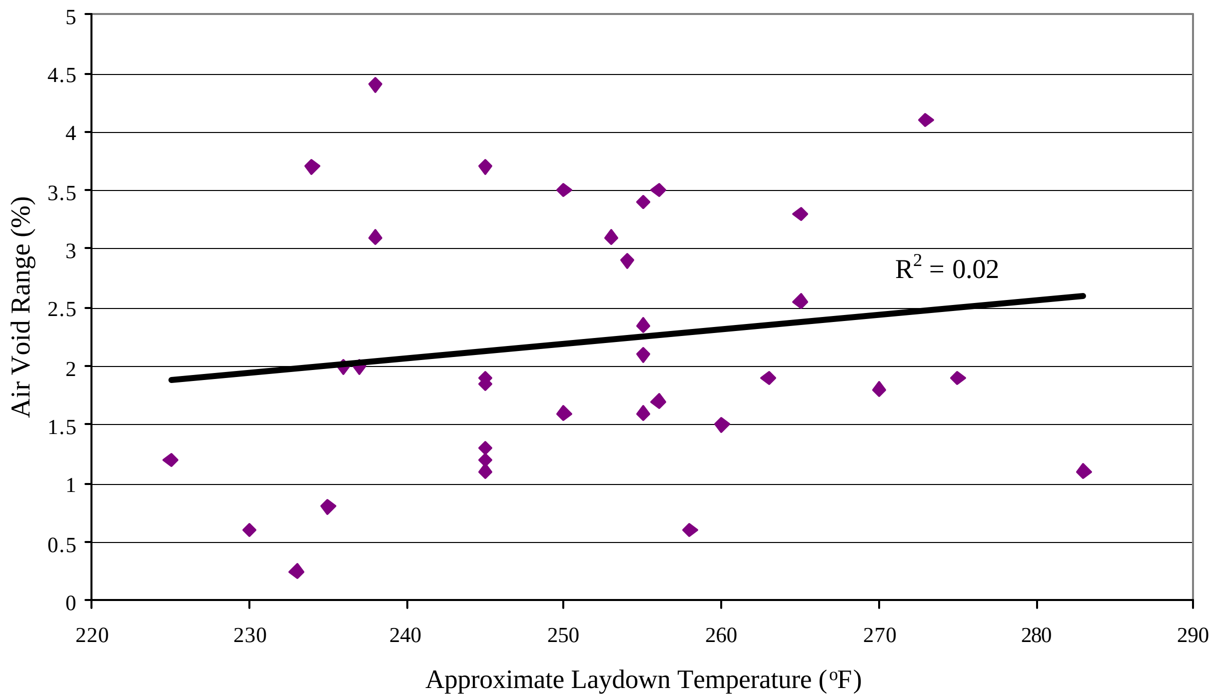


Figure B9. Approximate Laydown Temperature vs. Air Void Range

Figure B11 (air void range versus approximate air temperature) shows a difference in the data above and below 70°F. When the air temperatures are 70°F or greater, almost 65 percent of the values have a range in air voids of less than 2 percent. Conversely, when the air temperature is less than 70°F, only 40 percent of the projects have a range in air voids of less than 2 percent.

Figure B12 shows the haul time plotted against the range in air voids. One project had all trucks tightly tarped and another job had one truck tightly tarped. If these projects that had tight tarps are removed from the plot, there is a slight upward trend in the data between a greater range in air voids and longer haul times.

Figure B13 shows the air void range versus the approximate breakdown temperature (as recorded with a handheld infrared temperature gun). Although the trend line has a low R^2 value, it shows that the air void range decreases as the breakdown temperature increases. Also, when the breakdown temperature is approximately 265°F or greater, the range in air voids are all below 2 percent (limited data, n=5).

Figure B14 shows the range in air voids compared to the temperature differentials. There is a weak linear trend between these two factors, but for temperature differentials below 25°F, 87 percent of the air void ranges are at 2 percent or less. Conversely, with temperature differentials greater than or equal to 25^{o}F, only 35 percent of the data points are below the 2 percent range in air voids.

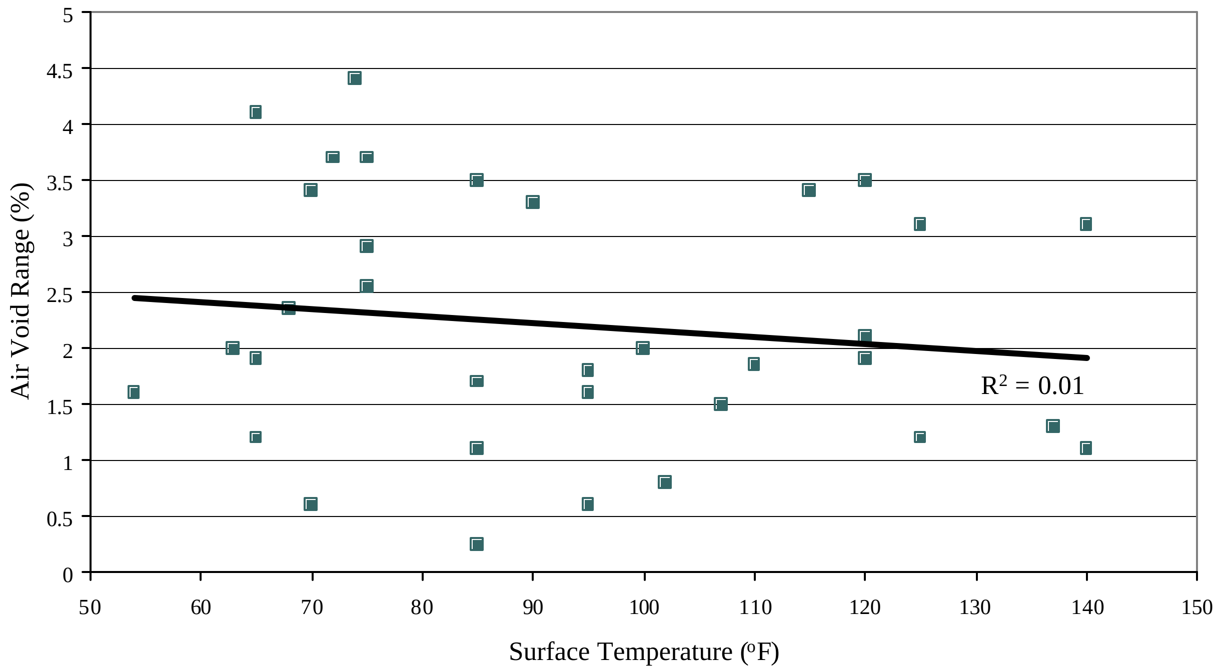


Figure B10. Existing Pavement Surface Temperature vs. Air Void Range

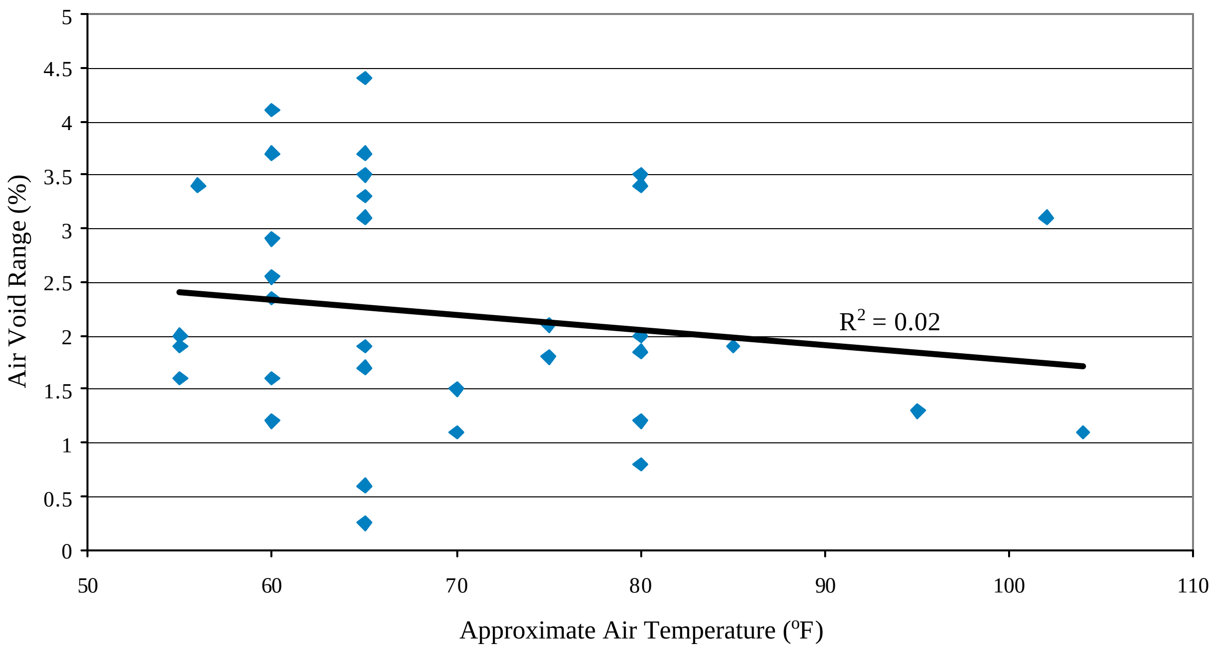


Figure B11. Approximate Air Temperature vs. Air Void Range

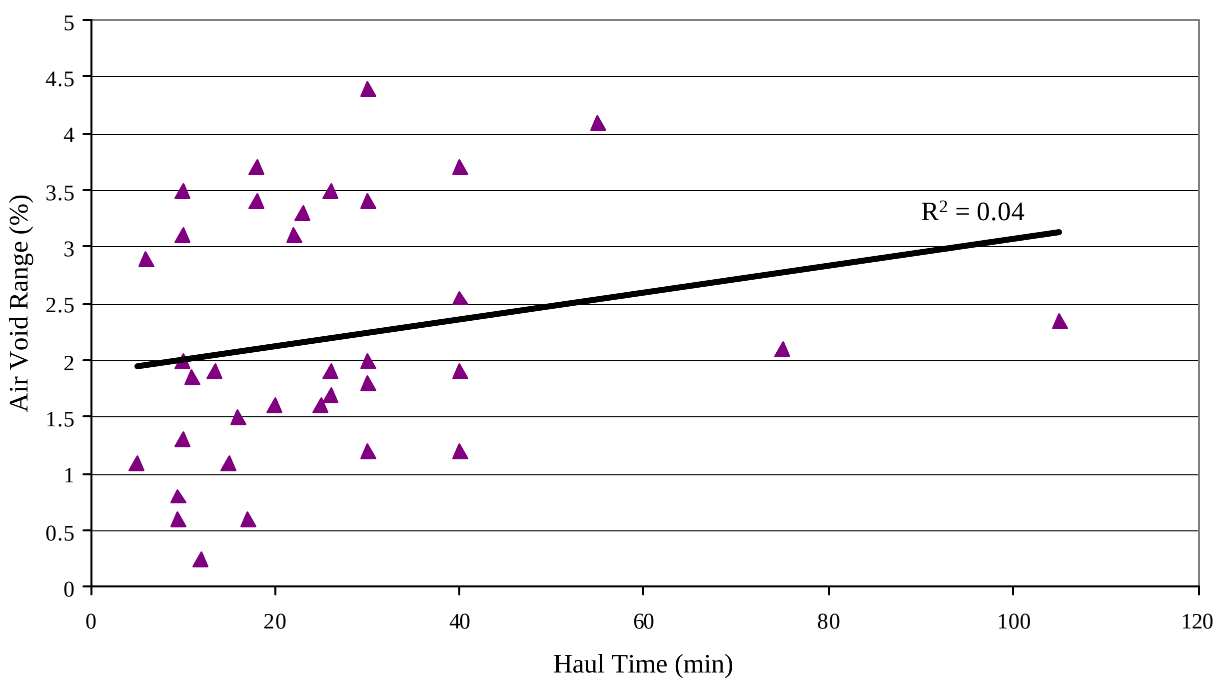


Figure B12. Haul Time vs. Air Void Range

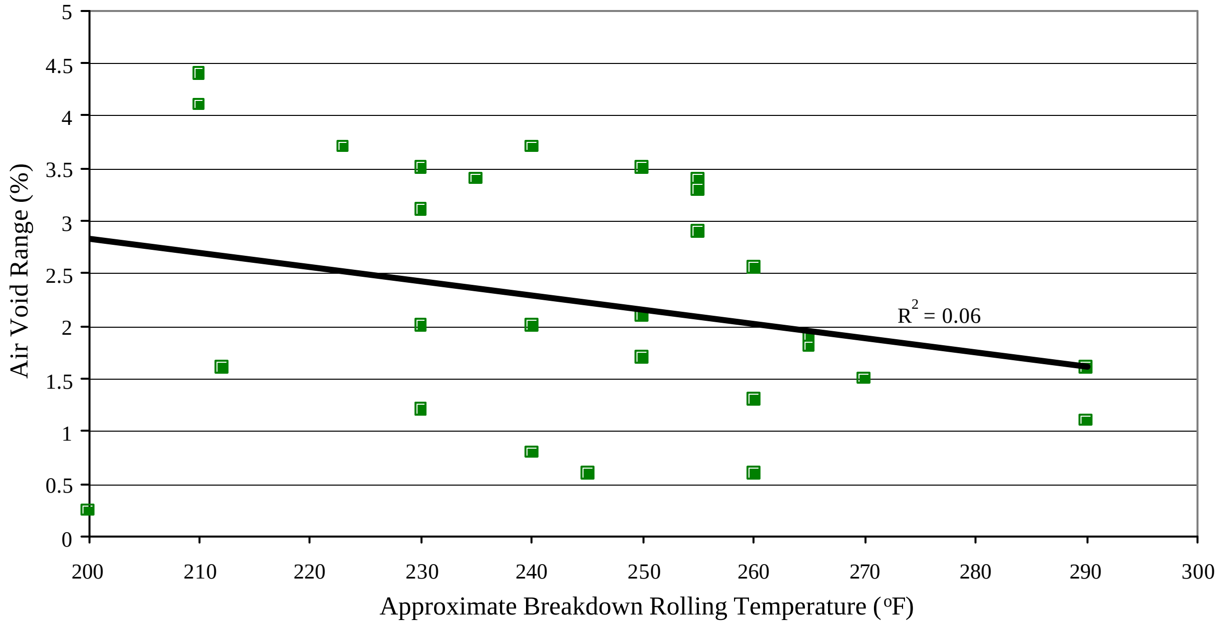


Figure B13. Approximate Breakdown Rolling Temperature vs. Air Void Range

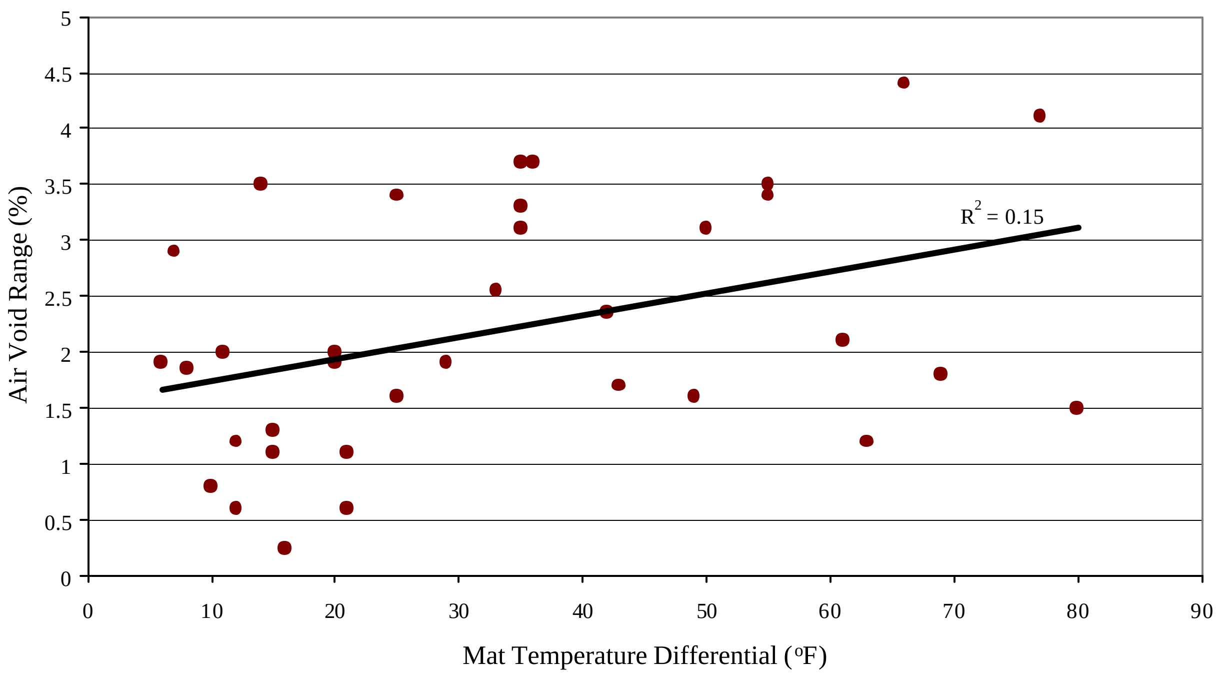


Figure B14. Mat Temperature Differential vs. Air Void Range

The change in percent air voids is the amount each individual point density changed from the high temperature density for that specific density set. There may be more than one set of densities for each job (anywhere from one to three sets). The densities that were taken within approximately 12 inches of the edge were not considered. Table 3 also shows the change in air voids for each of the point densities, which is the data used in the following graphs.

Three different graphs were used: change in percent air voids versus temperature differentials, change in percent air voids versus approximate laydown temperatures, and change in percent air voids versus approximate breakdown temperatures. There are a few different variations on each of these graphs. For the temperature differential plot, the graph is broken down into tarp use and MTV/MTD use. The approximate laydown temperatures examined the influence of roller type and MTV/MTD use. Finally, the approximate breakdown temperatures focused on the inclusion of pneumatic rollers and MTV/MTD use.

Figures B15 through B17 relate to the change in air voids compared to the temperature differential. Recall, the high temperature and corresponding density for each density set (excluding the densities taken within the outer 12 inches of the mat) is the zero point, or what each of the other readings in that set are compared against. Typically, the highest temperature of a density set corresponds to the highest density (or lowest air void content).

Figure B15 shows the change in air voids versus the temperature differential for all data points. There is a weak linear relationship between higher temperature differentials and a larger change in air voids. Note that the majority (90 percent) of the points with a temperature differential of less than 25^{o}F fall within a change of air voids of only 2 percent (only 62 percent fall within the same range when the temperature differentials are greater than 25^{o}F). This means that with varying temperatures, as long as the temperature differential is less than 25^{o}F, the air voids do not vary much from the air voids in the normal temperature areas.

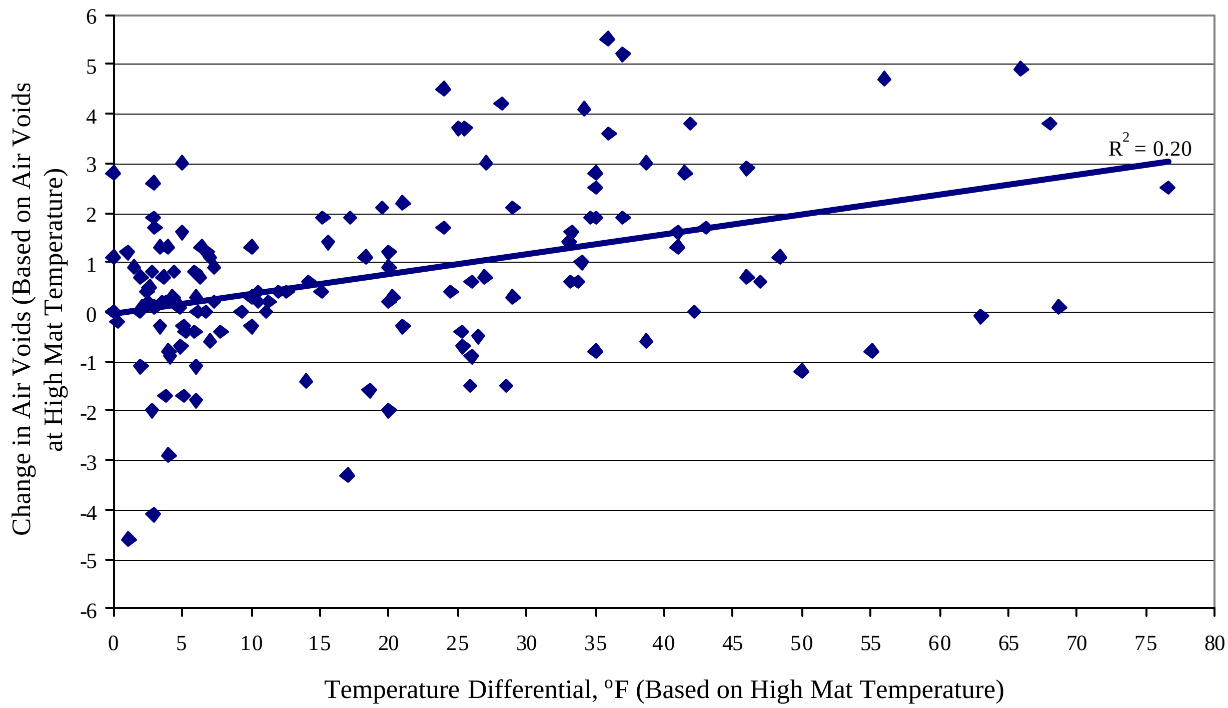


Figure B15. Temperature Differential vs. Change in Air Voids

Figure B16 shows the same data that is in Figure B15, but broken down by the use of tarps. The same relationship applies here: the higher the temperature differentials, the higher the change in air voids. It is noted that the majority of the tarps used are not securely fastened on the sides of the trucks.

Figure B17 has this data separated into the different types of MTV/MTDs used on the projects. The end dump operations showed a weak correlation between higher air voids and higher temperature differentials. Additionally, the end dump projects account for more than half of the data points that are outside of the +/- 2 percent change in air voids.

Figures B18 through B20 deal with the change in air voids versus the approximate laydown temperature. Figure B18 includes all data points and has a very slight linear relationship. This figure shows that all the data points were within the +/- 2 percent change in air voids for laydown temperatures above 265°F. The higher laydown temperature allows for an increased time to compact the HMA before any part of the mat (cool or normal area) reaches cessation temperature.

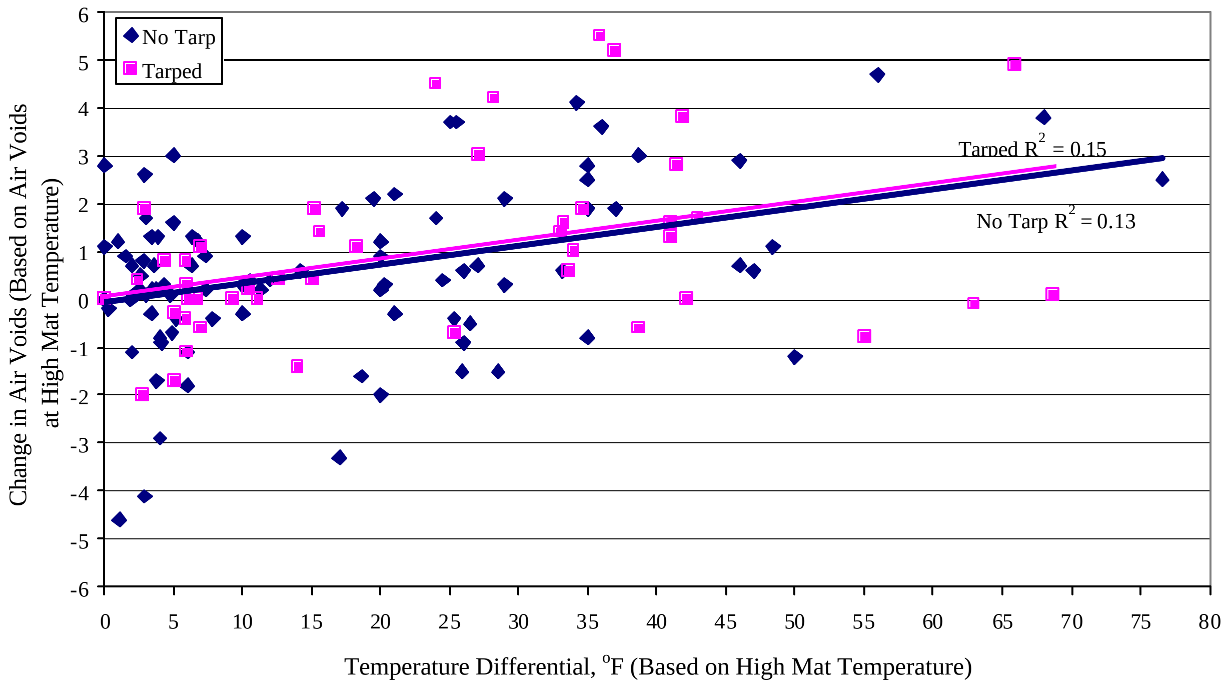


Figure B16. Temperature Differential by Tarp Use vs. Change in Air Voids

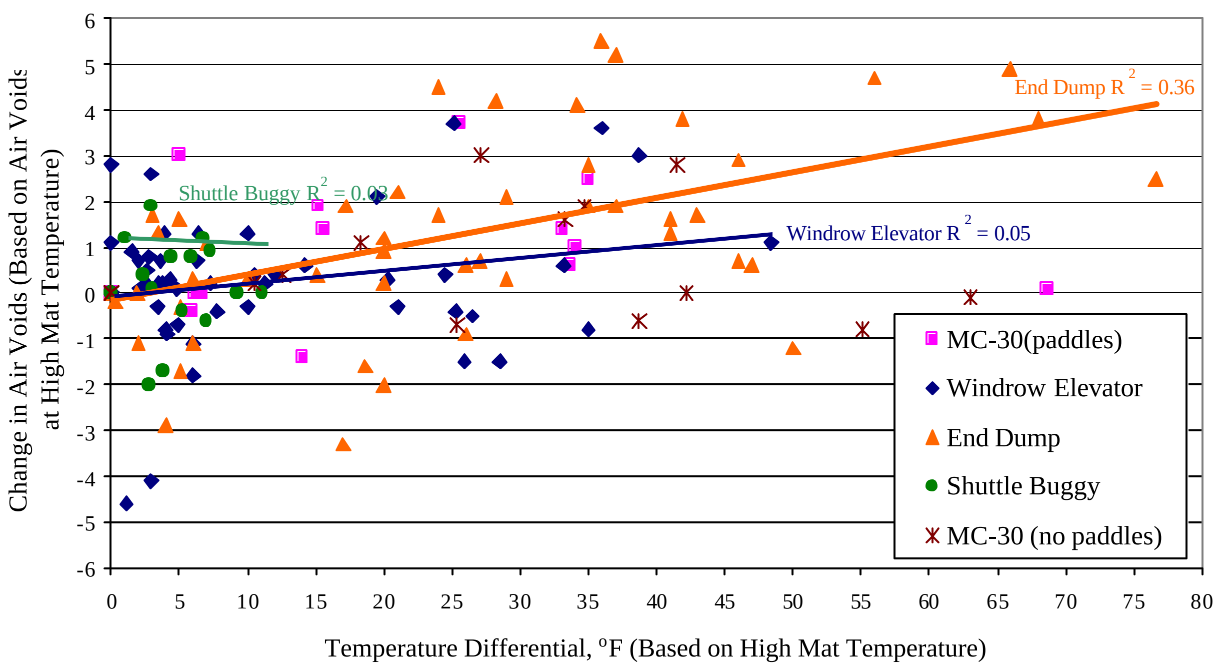


Figure B17. Temperature Differential by MTV Type vs. Change in Air Voids

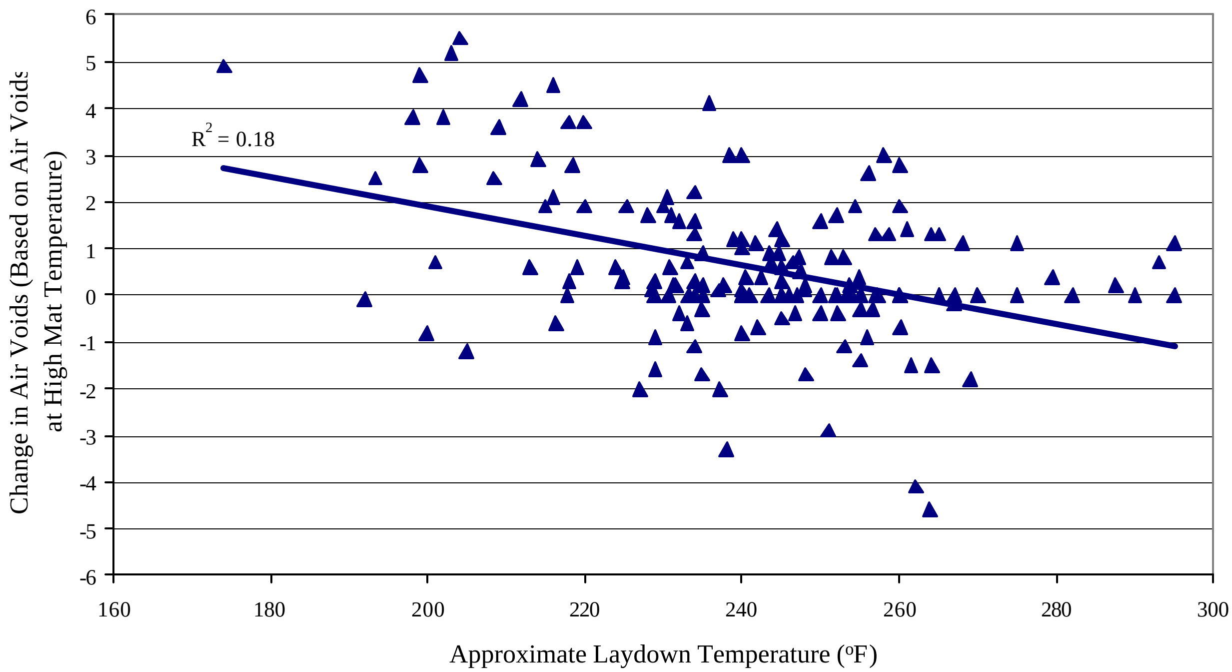


Figure B18. Approximate Laydown Temperature vs. Change in Air Voids

Figure B19 separates this data into projects that used a pneumatic roller anywhere in the roller operation versus projects that used all steel wheel rollers. The steel wheel rollers have a weak linear relationship with the laydown temperature whereas the pneumatic rollers have no relationship with laydown temperature. The pneumatic rollers tended to produce a change in air voids of +/- 2 percent (all but three data points), while the steel wheel projects only had 78 percent fall within that same range. Additionally, when the temperature differential was 25°F or greater, the pneumatic rollers produced a change in air voids of 0.7 +/- 1.3, while the steel wheel rollers had a change in air voids of 2.4 +/- 2.3 (Table 7).

Figure B20 then divides this data into MTV/MTD use. The most noticeable trend is the end dump operation, which shows a weak correlation between the increase of the laydown temperature and the decrease in the change in air voids.

The last three figures (B21 through B23) in this section compare the change in air voids to the approximate breakdown temperatures. The breakdown temperatures were taken with a handheld infrared gun and correspond to the first touch of the roller to a location on the mat.

Figure B21 shows that the percent air voids that register a 4 percent increase all correspond to breakdown temperatures that were below 190°F. Besides this observation, there seems to be no linear trend.

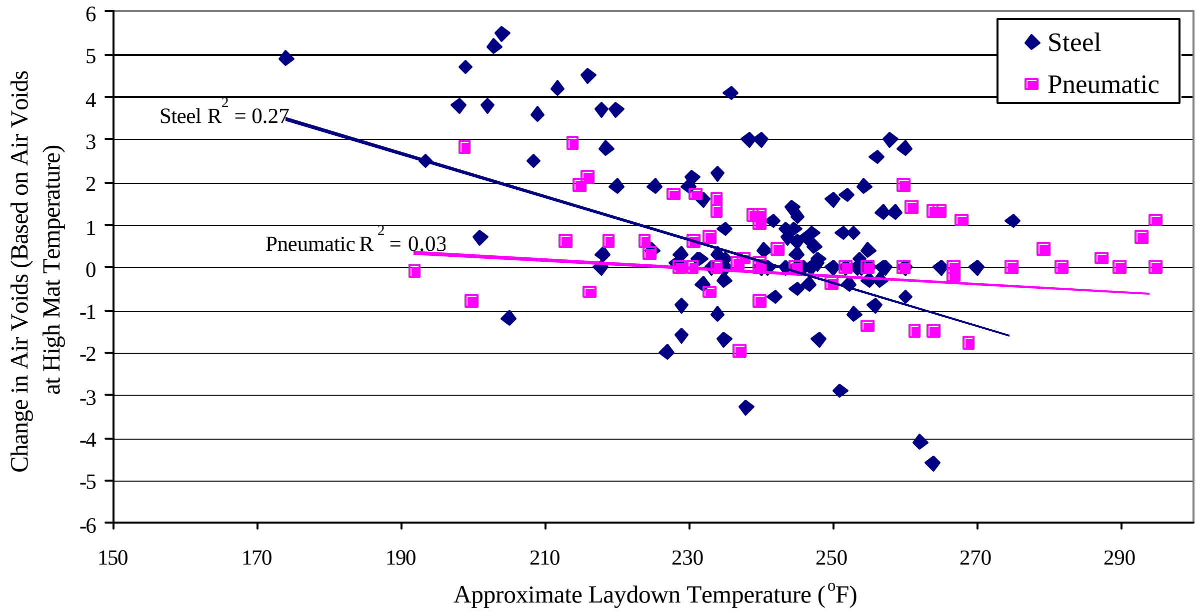


Figure B19. Approximate Laydown Temperature (by Roller) vs. Change in Air Voids

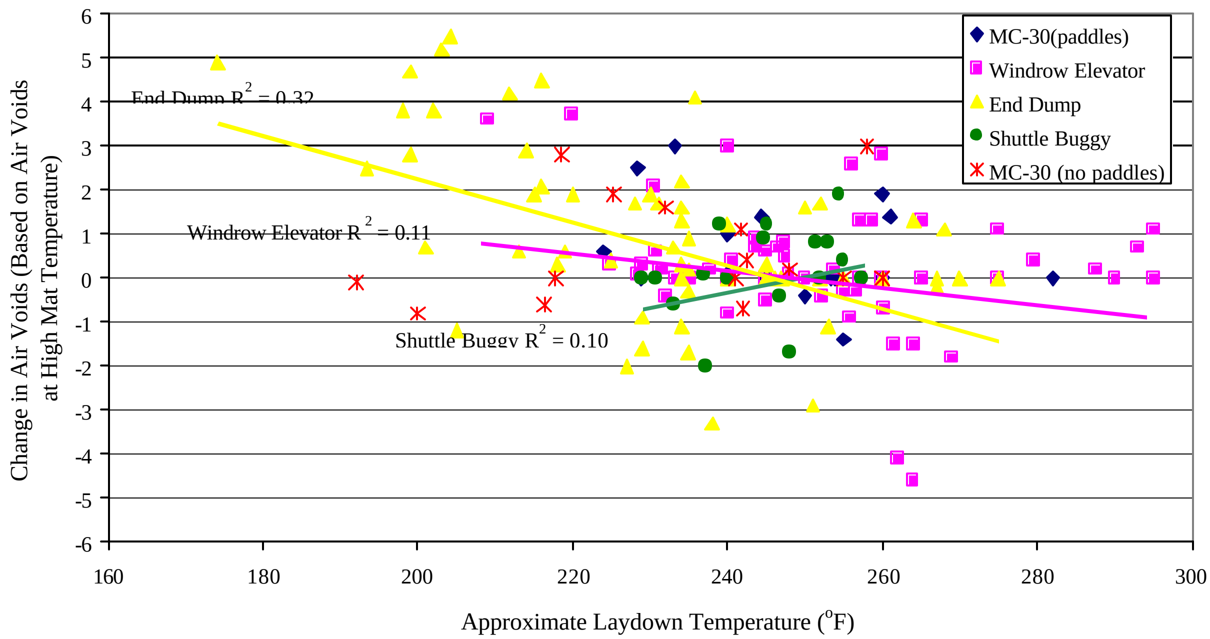


Figure B20. Approximate Laydown Temperature (by MTV Type) vs. Change in Air Voids

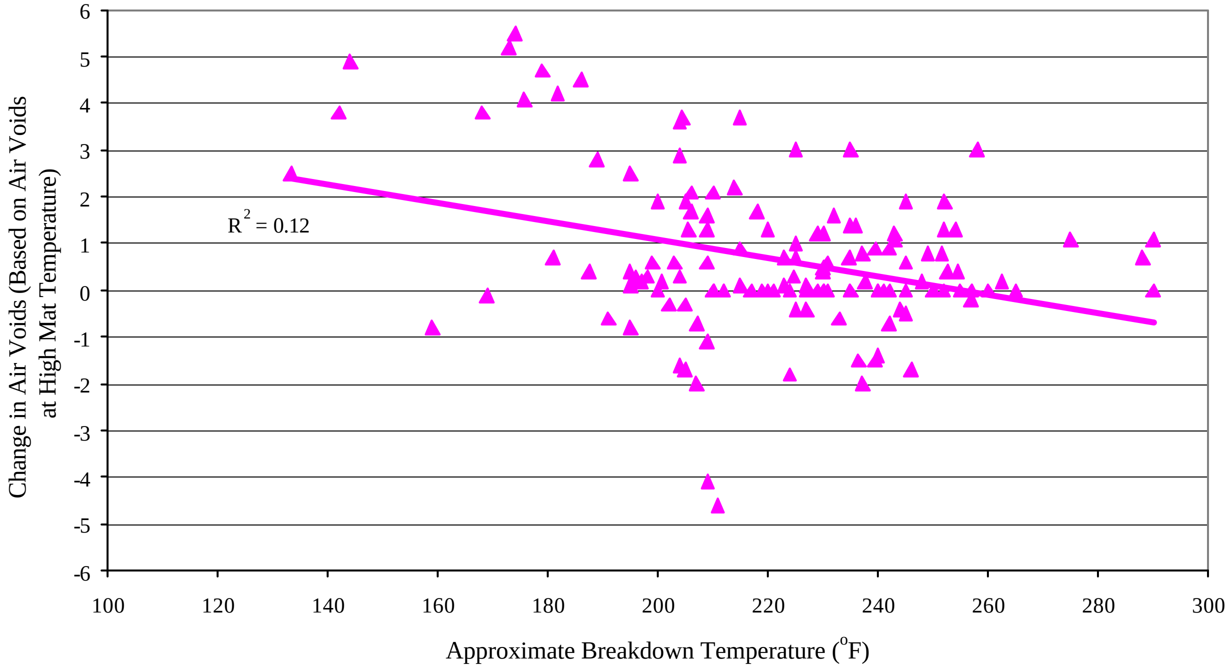


Figure B21. Approximate Breakdown Temperature vs. Change in Air Voids

Figure B22 shows the breakdown of pneumatic and steel wheel rollers. Each of these show a different trend, but the pneumatic roller tends to keep the change in air voids down to +/- 2 percent (except 3 points). Also of notice is the percent air voids with a 4 percent increase and breakdown temperatures below 190°F are all steel wheel rollers.

Lastly, Figure B23 shows the change in air voids compared to the breakdown temperature, separated into MTV/MTD use. The end dump operation, once again, shows a moderate linear correlation between decreasing breakdown temperatures and increasing changes in air voids. The same data points that are below 190°F and have a 4 percent increase in air voids happen to be all end dump operations.

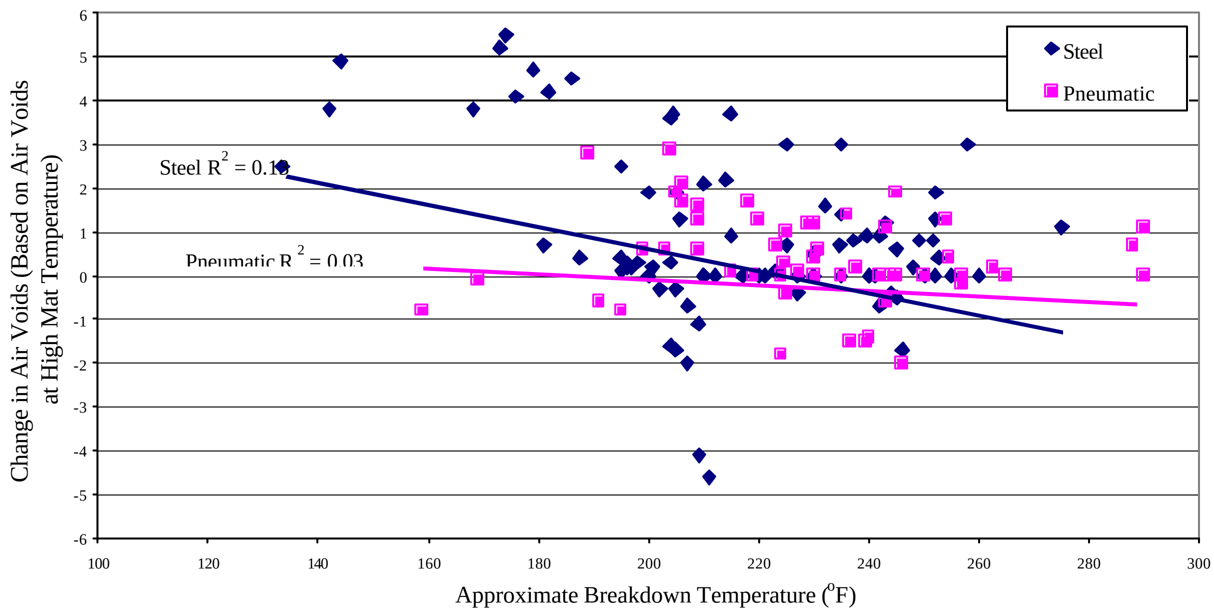


Figure B22. Approximate Breakdown Temperature (by Roller Used) vs. Change in Air Voids

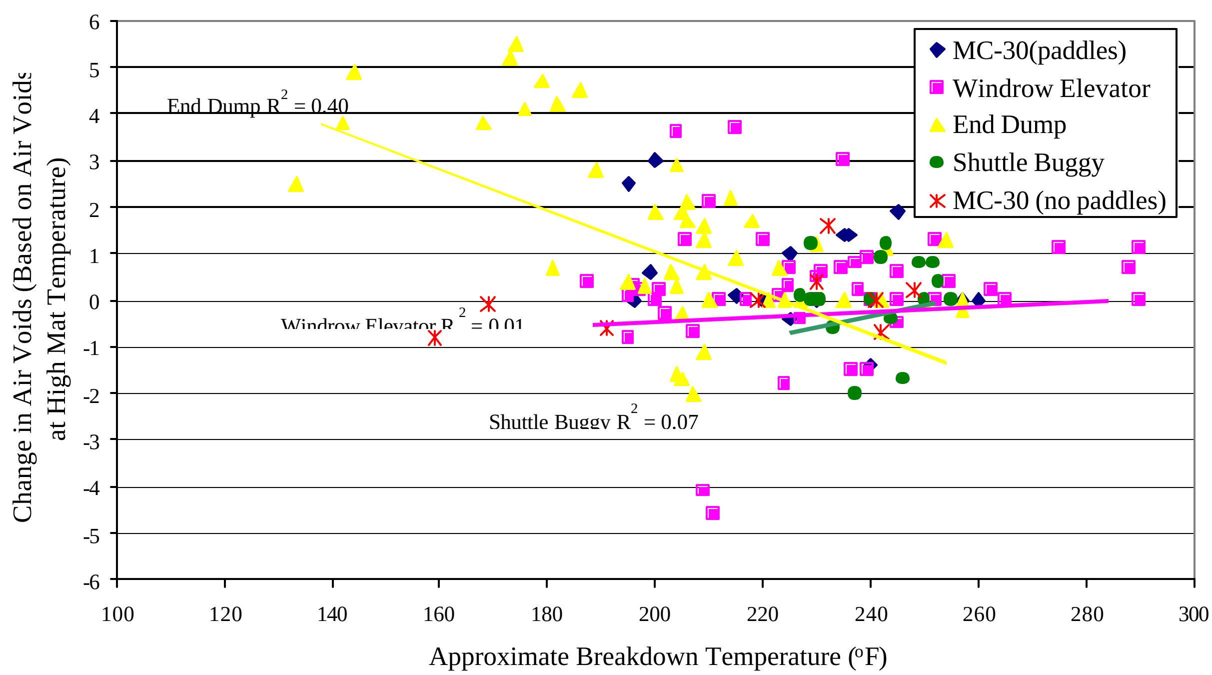


Figure B23. Approximate Breakdown Temperature (by MTV Use) vs. Change in Air Voids

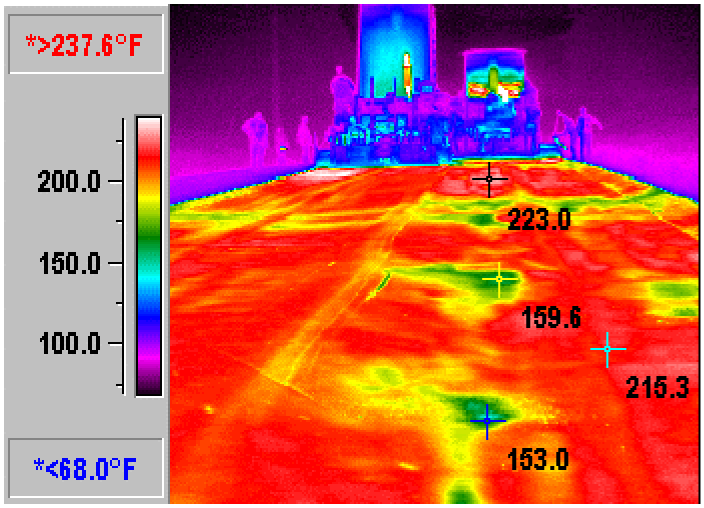


Figure B24. Typical End dump operation.

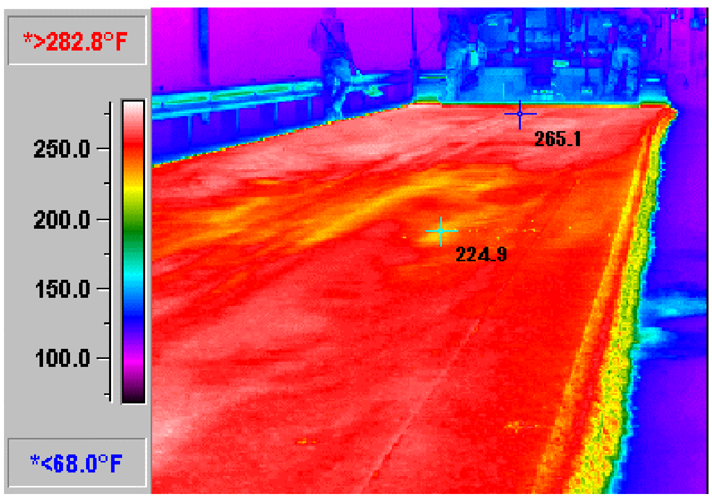


Figure B25. Typical Blaw-Knox MC-30 with the paddles in the paver hopper operating.

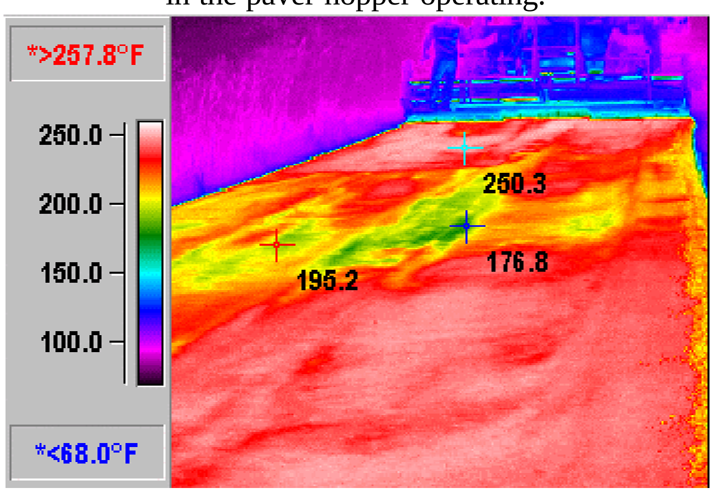


Figure B26. Typical Blaw-Knox MC-30 without the paddles in the paver hopper operating.

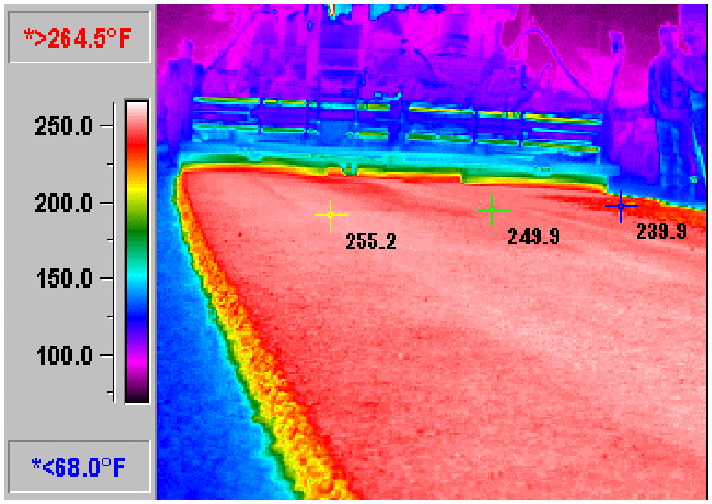


Figure B27. Typical Cedarapids MS-3 paving operation.

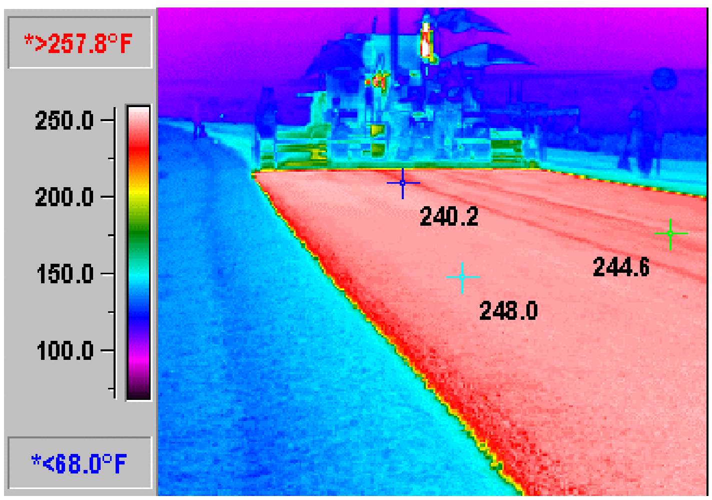


Figure B28. Typical Windrow Elevator operation.

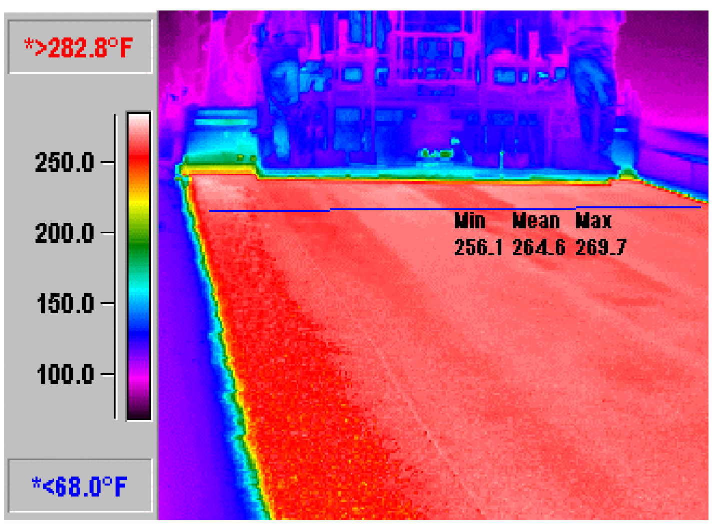


Figure B29. Typical Roadtec Shuttle Buggy operation.

APPENDIX C

Summary of 2000 Project Data

Table C1. Comprehensive Project Data Sheet.

1	2	3	4	5	6	7	8	9
Contract Number	***Profile Number***	***SR***	***Project MP***		***Test Date***	***Mix Type***	***Thickness***	***Segregation***
			Begin	***End***				
5906	1	90	55.52	67.31	9/20/00	12.5 mm	0.20'	2 streaks left and right of middle
5906	2	90			9/20/00	12.5 mm	0.20'	2 streaks left and right of middle
5906	3	90			9/20/00	12.5 mm	0.20'	2 streaks left and right of middle
5906	4	90			9/20/00	12.5 mm	0.20'	2 streaks left and right of middle
5906	5	90			9/20/00	12.5 mm	0.20'	2 streaks left and right of middle
5906	6	90			9/20/00	12.5 mm	0.20'	2 streaks left and right of middle
5906	1	90			9/28/00	12.5 mm	0.20'	streak down middle of paved lane
5871	1	12	1.72	4.97	9/15/00	A	0.15'	none
5871	2	12			9/15/00	A	0.15'	none
5871	3	12			9/15/00	A	0.15'	none
5871	4	12			9/15/00	A	0.15'	none
5908	1	547	0.00	5.83	9/13/00	B	0.15'	none
5908	2	547			9/13/00	B	0.15'	none
5908	3	547			9/13/00	B	0.15'	none
5908	4	547			9/13/00	B	0.15'	none
5879	1	3	36.61	44.07	8/28/00	A	0.15'	none
5879	2	3			8/28/00	A	0.15'	none
5879	3	3			8/28/00	A	0.15'	none
5879	4	3			8/28/00	A	0.15'	none
5882	1	90	220.80	231.76	8/21/00	SMA	0.15'	at back of paver, roller able to take it out
5882	2	90			8/21/00	SMA	0.15'	streaks left and right of middle
5882	3	90			8/21/00	SMA	0.15'	streaks left and right of middle
5882	4	90			8/21/00	SMA	0.15'	streaks left and right of middle
5882	5	90			8/21/00	SMA	0.15'	streaks left and right of middle
5827	1	5	70.90	85.51	8/17/00	A	0.15'	none
5827	2	5			8/17/00	A	0.15'	none
5827	3	5			8/17/00	A	0.15'	none
5827	4	5			8/17/00	A	0.15'	none
5827	5	5			8/17/00	A	0.15'	none
5851	1	97	61.27	70.00	8/10/00	12.5 mm	0.15'	none
5851	2	97			8/10/00	12.5 mm	0.15'	none
5851	3	97			8/10/00	12.5 mm	0.15'	none
5851	4	97			8/10/00	12.5 mm	0.15'	none
5851	5	97			8/10/00	12.5 mm	0.15'	none
5823	1	12	314.00	332.16	8/9/00	19.0 mm	0.25'	spots
5823	2	12			8/9/00	19.0 mm	0.25'	spots
5823	3	12			8/9/00	19.0 mm	0.25'	none
5823	4	12			8/9/00	19.0 mm	0.25'	none
5835	1	12	335.19	342.40	8/8/00	A	0.25'	streaks
5835	2	12			8/8/00	A	0.25'	left wheelpath and center
5835	3	12			8/8/00	A	0.25'	left wheelpath and center
5835	4	12			8/8/00	A	0.25'	streaks

Table C1. Comprehensive Project Data Sheet Continued.

1 ***Contract Number***	10 ***Station/MP***	11 ***Lane Direction***	12 ***Lane***	13 ***Offset***	14 ***Rice Value***	15 ***Correlation Factor***	16 ***Profile Comments***
5906	303+00	WB	2	5'6"	155.8	1.0048	between 2 streaks
5906	300+40	WB	2	10'2"	155.8	1.0048	
5906	297+40	WB	2	11'	155.8	1.0048	
5906	294+00	WB	2	7'3"	155.8	1.0048	in left streak
5906	292+80	WB	2	4'7"	155.8	1.0048	in right streak
5906	290+35	WB	2	3'3"	155.8	1.0048	paver stop and go
5906	300+40	EB	1	5'1"	154.7	1.0126	
5871	9+960	WB	2	6'8"	162.9	0.9994	
5871	9+810	WB	2	6'	162.9	0.9994	
5871	9+640	WB	2	4'	162.9	0.9994	paver stop and go
5871	9+640	WB	2	5'5"	162.9	0.9994	paver stop and go
5908	5+350	SB	1	11'	155.9	1.0300	
5908	5+260	SB	1	7'	155.9	1.0300	
5908	5+040	SB	1	5'	155.9	1.0300	
5908	4+945	SB	1	8'3"	155.9	1.0300	
5879	61+390	SB	1	4'	157.8	1.0195	
5879	61+335	SB	1	5'3"	157.8	1.0195	
5879	61+250	SB	1	3'6"	157.8	1.0195	
5879	60+970	SB	1	7'	157.8	1.0195	
5882	362+360	WB	2	6'	162.2	1.0500	in between fat spots
5882	362+270	WB	2	3'	162.2	1.0500	
5882	362+170	WB	2	6'	162.2	1.0500	
5882	362+130	WB	2	8'	162.2	1.0500	
5882	362+100	WB	2	7'	162.2	1.0500	
5827	77.7	NB	1	4'6"	152.1	0.9998	
5827	77.85	NB	1	6'	152.1	0.9998	
5827	77.97	NB	1	8'6"	152.1	0.9998	
5827	78.1	NB	1	5'	152.1	0.9998	
5827	78.23	NB	1	5'8"	152.1	0.9998	
5851	510+280	NB	2	4'3"	161.6	0.9987	
5851	510+330	NB	2	9'	161.6	0.9987	left wheelpath
5851	510+370	NB	2	5'3"	161.6	0.9987	
5851	510+415	NB	2	8'	161.6	0.9987	left wheelpath
5851	510+425	NB	2	6'	161.6	0.9987	
5823	505+950	EB	2	13'6"	158.4	0.9820	R wheelpath, coarse agg. pocket
5823	505+990	EB	2	5'7"	158.4	0.9820	
5823	506+028	EB	2	8'6"	158.4	0.9820	
5823	506+060	EB	2	6'3"	158.4	0.9820	
5835	12+650	WB	1	6'10"	160.2	0.9891	
5835	12+665	WB	1	13'	160.2	0.9891	in streak
5835	12+450	WB	1	9'2"	160.2	0.9891	
5835	12+320	WB	1	10'10"	160.2	0.9891	

Table C1. Comprehensive Project Data Sheet Continued.

1 ***Contract Number***	17 ***MTV/MTD***	18 ***Paver***
5906	Blaw-Knox MC-30	Blaw-Knox PF-5510
5906	Blaw-Knox MC-30	Blaw-Knox PF-5510
5906	Blaw-Knox MC-30	Blaw-Knox PF-5510
5906	Blaw-Knox MC-30	Blaw-Knox PF-5510
5906	Blaw-Knox MC-30	Blaw-Knox PF-5510
5906	Blaw-Knox MC-30	Blaw-Knox PF-5510
5906	Blaw-Knox MC-30 paddles not operating	Blaw-Knox PF-5510
5871	none	Barber-Greene BG 245B
5871	none	Barber-Greene BG 245B
5871	none	Barber-Greene BG 245B
5871	none	Barber-Greene BG 245B
5908	Roadtec Shuttle Buggy SB2500	Blaw-Knox PF-5510
5908	Roadtec Shuttle Buggy SB2500	Blaw-Knox PF-5510
5908	Roadtec Shuttle Buggy SB2500	Blaw-Knox PF-5510
5908	Roadtec Shuttle Buggy SB2500	Blaw-Knox PF-5510
5879	CMI Corp. MTP-400	Blaw-Knox PF-5510
5879	CMI Corp. MTP-400	Blaw-Knox PF-5510
5879	CMI Corp. MTP-400	Blaw-Knox PF-5510
5879	CMI Corp. MTP-400	Blaw-Knox PF-5510
5882	Cedarapids MS-2	Blaw-Knox PF-5510
5882	Cedarapids MS-2	Blaw-Knox PF-5510
5882	Cedarapids MS-2	Blaw-Knox PF-5510
5882	Cedarapids MS-2	Blaw-Knox PF-5510
5882	Cedarapids MS-2	Blaw-Knox PF-5510
5827	CMI Corp. Windrow Elevator into a Blaw-Knox MC-30	Blaw-Knox PF-220
5827	CMI Corp. Windrow Elevator into a Blaw-Knox MC-30	Blaw-Knox PF-220
5827	CMI Corp. Windrow Elevator into a Blaw-Knox MC-30	Blaw-Knox PF-220
5827	CMI Corp. Windrow Elevator into a Blaw-Knox MC-30	Blaw-Knox PF-220
5827	CMI Corp. Windrow Elevator into a Blaw-Knox MC-30	Blaw-Knox PF-220
5851	none	Blaw-Knox PF-5510
5851	none	Blaw-Knox PF-5510
5851	none	Blaw-Knox PF-5510
5851	none	Blaw-Knox PF-5510
5851	none	Blaw-Knox PF-5510
5823	Cedarapids MS-2	Caterpillar AP-1055B
5823	Cedarapids MS-2	Caterpillar AP-1055B
5823	Cedarapids MS-2	Caterpillar AP-1055B
5823	Cedarapids MS-2	Caterpillar AP-1055B
5835	Lincoln 660H Windrow Elevator	Blaw-Knox PF-5510
5835	Lincoln 660H Windrow Elevator	Blaw-Knox PF-5510
5835	Lincoln 660H Windrow Elevator	Blaw-Knox PF-5510
5835	Lincoln 660H Windrow Elevator	Blaw-Knox PF-5510

Table C1. Comprehensive Project Data Sheet Continued.

1	2	3	4	5	6	7	8	9
Contract	***Profile***		***Project MP***		***Test***			
Number	***Number***	***SR***	***Begin***	***End***	***Date***	***Mix Type***	***Thickness***	***Segregation***
5677	1	12			8/1/00	12.5 mm	0.15'	center of lane
5677	2	12	118.00	134.00	8/1/00	12.5 mm	0.15'	center of lane and right wheelpath
5677	3	12			8/1/00	12.5 mm	0.15'	center of lane
5677	4	12			8/1/00	12.5 mm	0.15'	center of lane
5677	5	12			8/1/00	12.5 mm	0.15'	center of lane
5677	6	12			8/1/00	12.5 mm	0.15'	center of lane
5862	1	14	114.06	134.29	7/27/00	A	0.15'	none
5862	2	14			7/27/00	A	0.15'	none
5862	3	14			7/27/00	A	0.15'	none
5807	1	542	21.41	30.92	7/19/00	B	0.11'	none
5807	2	542			7/19/00	B	0.11'	one patch
5807	3	542			7/19/00	B	0.11'	none
5807	4	542			7/19/00	B	0.11'	none
5863	1	5	95.10	99.15	7/18/00	A	0.12'	none
5863	2	5			7/18/00	A	0.12'	none
5863	3	5			7/18/00	A	0.12'	none
5831	1	2/97	117.15	119.17	7/12/00	A	0.15'	none
5831	2	2/97			7/12/00	A	0.15'	streak
5831	3	2/97			7/12/00	A	0.15'	mix on roadway
5841	1	27	75.66	83.10	6/28/00	12.5 mm	0.15'	none
5841	2	27			6/28/00	12.5 mm	0.15'	yes
5841	3	27			6/28/00	12.5 mm	0.15'	none
5700	1	101	249.00	252.00	6/26/00	A	0.17'	none
5700	2	101			6/26/00	A	0.17'	none
5700	3	101			6/26/00	A	0.17'	streak from reading 3 to 5
5700	4	101			6/26/00	A	0.17'	none
5816	1	500	8.37	20.37	6/20/00	A	0.15'	none

Table C1. Comprehensive Project Data Sheet Continued.

1 ***Contract Number***	10 ***Station/MP***	11 ***Lane Direction***	12 ***Lane***	13 ***Offset***	14 ***Rice Value***	15 ***Correlation Factor***	16 ***Profile Comments***
5677	133.8	WB	1	6'5"	150.3	1.0055	left wheelpath
5677	133.74	WB	1	4'	150.3	1.0055	right wheelpath
5677	133.69	WB	1	5'	150.3	1.0055	
5677	133.63	WB	1	7'6"	150.3	1.0055	left wheelpath
5677	133.57	WB	1	3'7"	150.3	1.0055	right wheelpath
5677	133.55	WB	1	5'5"	150.3	1.0055	
5862	130.6	WB	1	4'10"	157.8	0.9923	
5862	131	WB	1	8'8"	157.8	0.9923	middle of paved lane
5862	131.4	WB	1	12'5"	157.8	0.9923	
5807	19+175	NB	1	4'	155.7	1.0265	
5807	19+420	NB	1	9'6"	155.7	1.0265	
5807	19+915	NB	1	7'5"	155.7	1.0265	
5807	19+980	NB	1	5'6"	155.7	1.0265	
5863	bridge @Exit 95	NB	2	3'6"	153.2	1.0221	
5863	153+450	NB	2	6'6"	153.2	1.0221	center of lane
5863	153+600	NB	2	9'	153.2	1.0221	
5831	18+10	EB	1	7'	156.0	1.0200	from joint (21' total width)
5831	18+35	EB	1	4'6"	156.0	1.0200	from joint (21' total width)
5831	18+60	EB	1	8'6"	156.0	1.0200	from joint (21' total width)
5841	82.7	SB	1	4'6"	156.1	1.0203	
5841	before 46th Ave.	SB	1	8'6"	156.1	1.0203	before finish roller, 2-3 hrs back
5841	82.1	SB	1	6'6"	156.1	1.0203	before finish, 2-3 hrs back, b/n streaks
5700	252.5 (40' from bridge)	WB	1	7'	157.5	1.0310	from inside
5700	4+575	WB	1	5'	157.5	1.0310	from inside
5700	4+600	WB	1	4'6"	157.5	1.0310	from inside
5700	251.99	WB	1	10'	157.5	1.0310	from inside
5816	19.2	EB	1	4'6"	154.9	0.9981	

Table C1. Comprehensive Project Data Sheet Continued.

1 ***Contract Number***	17 ***MTV/MTD***	18 ***Paver***
5677	Blaw-Knox MC-30 paddles not operating	Caterpillar AP-1055B
5677	Blaw-Knox MC-30 paddles not operating	Caterpillar AP-1055B
5677	Blaw-Knox MC-30 paddles not operating	Caterpillar AP-1055B
5677	Blaw-Knox MC-30 paddles not operating	Caterpillar AP-1055B
5677	Blaw-Knox MC-30 paddles not operating	Caterpillar AP-1055B
5677	Blaw-Knox MC-30 paddles not operating	Caterpillar AP-1055B
5862	Roadtec Shuttle Buggy SB2500	Blaw-Knox PF-5510
5862	Roadtec Shuttle Buggy SB2500	Blaw-Knox PF-5510
5862	Roadtec Shuttle Buggy SB2500	Blaw-Knox PF-5510
5807	Roadtec Shuttle Buggy SB2500	Blaw-Knox PF-5510
5807	Roadtec Shuttle Buggy SB2500	Blaw-Knox PF-5510
5807	Roadtec Shuttle Buggy SB2500	Blaw-Knox PF-5510
5807	Roadtec Shuttle Buggy SB2500	Blaw-Knox PF-5510
5863	Roadtec Shuttle Buggy SB2500	Roadtec RP-230
5863	Roadtec Shuttle Buggy SB2500	Roadtec RP-230
5863	Roadtec Shuttle Buggy SB2500	Roadtec RP-230
5831	Roadtec Shuttle Buggy SB2500	Blaw-Knox PF-5510
5831	Roadtec Shuttle Buggy SB2500	Blaw-Knox PF-5510
5831	Roadtec Shuttle Buggy SB2500	Blaw-Knox PF-5510
5841	Cedarapids MS-2	Blaw-Knox PF-5510
5841	Cedarapids MS-2	Blaw-Knox PF-5510
5841	Cedarapids MS-2	Blaw-Knox PF-5510
5700	Blaw-Knox MC-30	Caterpillar AP-1055B
5700	Blaw-Knox MC-30	Caterpillar AP-1055B
5700	Blaw-Knox MC-30	Caterpillar AP-1055B
5700	Blaw-Knox MC-30	Caterpillar AP-1055B
5816	Blaw-Knox MC-30	Blaw-Knox PF-3200

Table C2. Percent pass and fail density criteria according to temperature differentials and the use of pneumatic or steel wheeled rollers.

	ΔT ≥ 25°F		ΔT < 25°F	
	Pneumatic	Steel	Pneumatic	Steel
Number of Profiles	15	13	21	20
Failed both density criteria	9	11	3	1
Passed both density criteria	3	0	18	15
Failed only high - low	2	1	0	2
Failed only mean - low	1	1	0	2
Percent passing	20.0	0.0	85.7	75.0
Percent failing	80.0	100.0	14.3	25.0

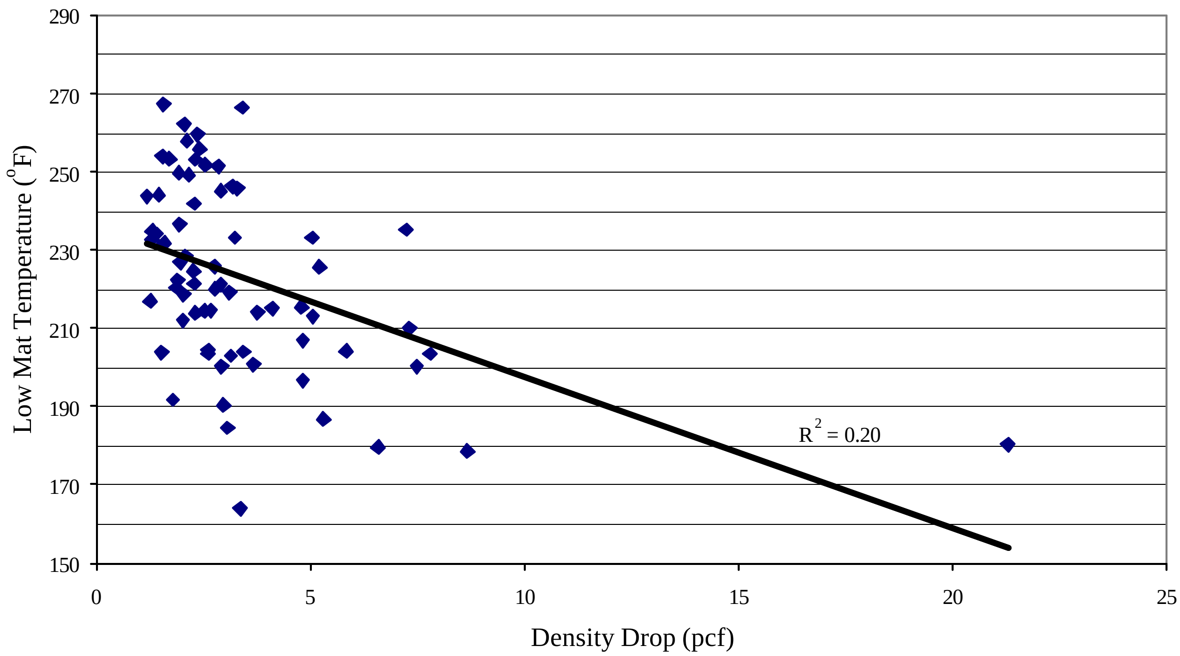


Figure C1. Density Drop vs. Low Mat Temperature

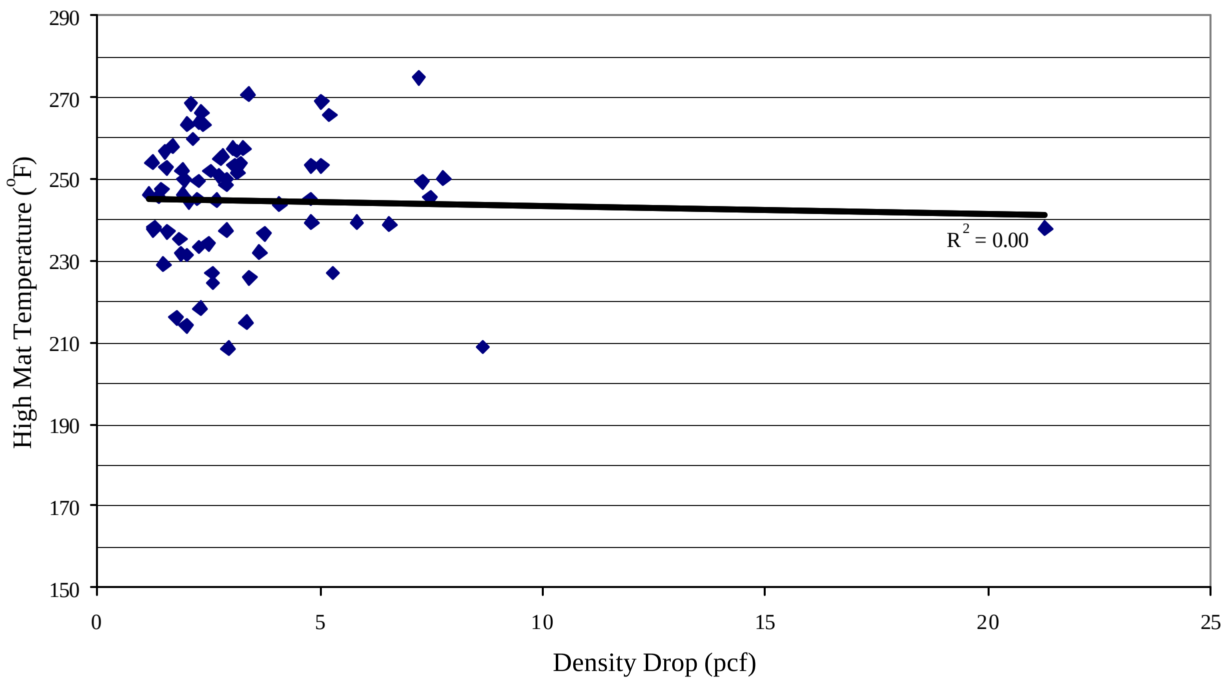


Figure C2. Density Drop vs. High Mat Temperature

Table C3. Contract 5677 QA Density Results.

Date Paved	Mix Design	Lot #	Random tests 1	2	3	4	5	Average	Standard Deviation	Lot Pay Factor	Tonnage	Lot Bonus
7/26/2000	G9420	1	92.90	93.10	91.70	94.40	94.40	93.30	1.14	1.05	400	268.00
7/26/2000	G9420	2	94.10	92.70	91.30	92.10	95.90	93.22	1.81	1.03	400	160.80
7/31/2000	G9420	3	91.20	96.10	93.20	93.80	93.00	93.46	1.77	1.04	400	214.40
7/31/2000	G9420	4	92.80	91.90	92.00	92.40	93.40	92.50	0.62	1.05	400	268.00
7/31/2000	G9420	5	93.40	92.80	94.40	93.10	92.80	93.30	0.66	1.05	400	268.00
7/31/2000	G9420	6	92.90	91.90	92.40	92.80	91.70	92.34	0.53	1.05	400	268.00
7/31/2000	G9420	7	91.80	94.30	92.50	93.40	93.40	93.08	0.96	1.05	400	268.00
7/31/2000	G9420	8	92.30	94.80	93.30	91.10	92.00	92.70	1.41	1.03	400	160.80
7/31/2000	G9420	9	90.70	91.20	90.60	91.20	93.00	91.34	0.97	0.92	400	-428.80
7/31/2000	G9420	10	93.30	93.30	91.70	93.20	95.00	93.30	1.17	1.05	400	268.00
8/1/2000	G9420	11	93.50	90.80	92.50	92.70	91.30	92.16	1.09	1.02	400	107.20
8/1/2000	G9420	12	95.90	92.50	91.10	94.00	92.00	93.10	1.89	1.03	400	160.80
8/1/2000	G9420	13	91.00	91.30	91.40	91.60	91.10	91.28	0.24	1.03	400	160.80
8/1/2000	G9420	14	91.00	92.70	91.40	92.30	92.90	92.06	0.83	1.04	400	214.40
8/1/2000	G9420	15	91.60	90.80	93.50	91.10	91.40	91.68	1.06	0.98	361	-96.75
8/1/2000	G9420	16	91.60	92.00	91.00	93.50	91.20	91.86	0.99	1.01	400	53.60
8/1/2000	G9420	17	91.40	93.50	92.50	91.60	94.00	92.60	1.14	1.04	400	214.40
8/1/2000	G9420	18	91.00	93.90	93.90	91.40	93.10	92.66	1.38	1.03	400	160.80
8/1/2000	G9420	19	95.20	94.40	93.40	92.90	94.50	94.08	0.92	1.05	231	154.77
8/2/2000	G9420	20	92.50	93.10	91.50	93.40	91.60	92.42	0.86	1.04	400	214.40
8/2/2000	G9420	21	93.60	93.60	93.10	92.30	91.90	92.90	0.77	1.05	400	268.00
8/2/2000	G9420	22	93.10	89.00	92.90	92.50	94.20	92.34	1.97	0.98	400	-107.20
8/2/2000	G9420	23	90.40	91.50	93.40	91.70	91.70	91.74	1.07	0.98	400	-107.20
8/2/2000	G9420	24	91.30	91.30	94.20	91.40	88.40	91.32	2.05	0.87	400	-696.80
8/2/2000	G9420	25	93.40	94.10	91.70	92.10	94.00	93.06	1.10	1.05	144	96.48
8/2/2000	G9420	26	91.30	91.60	91.00	91.90	90.10	91.18	0.69	0.90	400	-536.00
8/2/2000	G9420	27	90.90	91.30	91.60	91.90	91.80	91.50	0.41	1.03	400	160.80
8/2/2000	G9420	28	91.70	92.70	92.10	91.50	91.10	91.82	0.61	1.04	400	214.40
8/2/2000	G9420	29	91.20	94.00	94.00	91.30	91.00	92.30	1.56	1.00	130	0.00
8/7/2000	G9420A	1	94.70	94.20	93.70	93.90	93.90	94.08	0.39	1.05	400	268.00
8/7/2000	G9420A	2	92.70	95.60	95.90	93.70	93.30	94.24	1.43	1.05	400	268.00
8/7/2000	G9420A	3	92.90	92.30	95.30	95.90	95.80	94.44	1.71	1.05	400	268.00
8/7/2000	G9420A	4	96.10	96.90	92.40	93.40	95.40	94.84	1.88	1.05	400	268.00
8/7/2000	G9420A	5	91.90	96.70	93.90	92.10	94.90	93.90	2.00	1.04	400	214.40
8/7/2000	G9420A	6	94.50	94.30	93.80	92.70	94.40	93.94	0.74	1.05	400	268.00
8/7/2000	G9420A	7	93.00	91.80	91.50	92.30	92.70	92.26	0.62	1.05	400	268.00
8/7/2000	G9420A	8	92.20	93.50	92.70	92.80	93.00	92.84	0.47	1.05	400	268.00
8/7/2000	G9420A	9	94.70	92.60	92.90	91.40	91.80	92.68	1.28	1.04	400	214.40
8/7/2000	G9420A	10	94.00	93.30	92.10	94.30	93.70	93.48	0.86	1.05	400	268.00
8/7/2000	G9420A	11	94.00	92.90	93.40	91.10	92.00	92.68	1.15	1.04	400	214.40
8/7/2000	G9420A	12	92.60	93.50	91.90	91.90	92.40	92.46	0.66	1.05	455	304.85
8/7/2000	G9420A	13	93.20	94.60	93.10	91.80	94.50	93.44	1.15	1.05	400	268.00
8/7/2000	G9420A	14	95.60	92.50	94.00	94.60	95.40	94.42	1.25	1.05	400	268.00
8/7/2000	G9420A	15	93.00	93.80	95.50	93.10	92.20	93.52	1.24	1.05	400	268.00
8/7/2000	G9420A	16	92.80	94.40	94.00	93.70	93.90	93.76	0.59	1.05	400	268.00
8/7/2000	G9420A	17	92.70	93.40	92.30	91.90	94.00	92.86	0.84	1.05	400	268.00
8/7/2000	G9420A	18	93.20	92.70	93.70	93.20	91.90	92.94	0.68	1.05	400	268.00
8/7/2000	G9420A	19	91.80	93.90	93.60	94.80	91.90	93.20	1.31	1.05	400	268.00

Table C3 Contract 5677 QA Density Results Continued.

Date Paved	Mix Design	Lot #	Random tests 1	2	3	4	5	Average	Standard Deviation	Lot Pay Factor	Tonnage	Lot Bonus
8/7/2000	G9420A	20	91.60	95.10	91.40	93.20	94.60	93.18	1.69	1.04	400	214.40
8/7/2000	G9420A	21	91.40	94.50	93.60	91.70	93.80	93.00	1.37	1.04	400	214.40
8/7/2000	G9420A	22	94.70	93.80	92.50	95.40	90.90	93.46	1.80	1.04	400	214.40
8/7/2000	G9420A	23	93.50	93.30	92.10	91.50	92.40	92.56	0.84	1.05	400	268.00
8/7/2000	G9420A	24	91.30	92.70	92.00	92.00	92.50	92.10	0.54	1.05	150	100.50
8/7/2000	G9420A	25	95.10	92.10	96.70	91.30	92.50	93.54	2.27	1.03	400	160.80
8/7/2000	G9420A	26	92.40	94.20	93.10	94.10	93.60	93.48	0.75	1.05	400	268.00
8/7/2000	G9420A	27	92.00	94.00	94.70	94.60	92.20	93.50	1.31	1.05	400	268.00
8/7/2000	G9420A	28	93.30	94.10	93.20	93.10	92.70	93.28	0.51	1.05	400	268.00
8/7/2000	G9420A	29	92.50	92.50	92.80	94.20	92.50	92.90	0.74	1.05	400	268.00
8/7/2000	G9420A	30	94.40	93.00	93.20	93.80	92.50	93.38	0.74	1.05	411	275.37
Totals								**92.90**	**1.36**	**1.032**	**22682**	**9840.02**

$33.50/tonne 12.5 mm Superpave MTV: Blaw-Knox MC-30 (paddles not operating)

Profile #1	Average
ΔT=66°F	Readings (pcf)
Average	128.5
Maximum	133.5
Minimum	121.9
	Ranges
Max-Min	11.6
Ave-Min	6.6

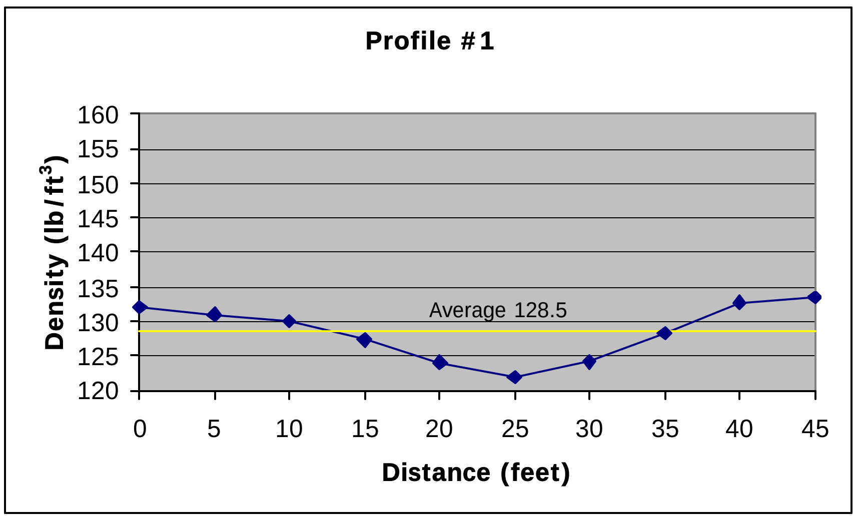


Figure C3-a. Contract 5677 Density Profile #1.

Profile #2	Average
$\Delta T = 45^{o}F$	Readings (pcf)
Average	129.4
Maximum	131.9
Minimum	121.9
	Ranges
Max-Min	10.0
Ave-Min	7.5

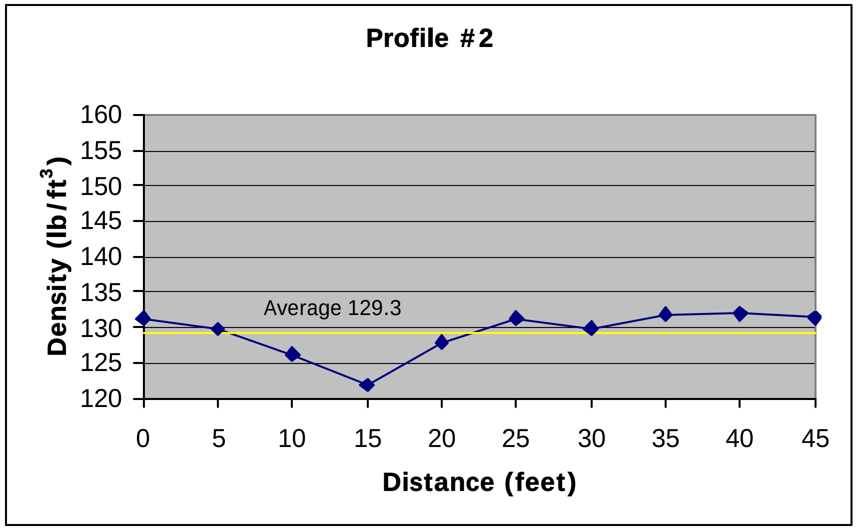


Figure C3-b. Contract 5677 Density Profile #2.

Profile #3	Average
$\Delta T = 3^{o}F$	Readings (pcf)
Average	134.2
Maximum	136.1
Minimum	132.5
	Ranges
Max-Min	3.6
Ave-Min	1.7

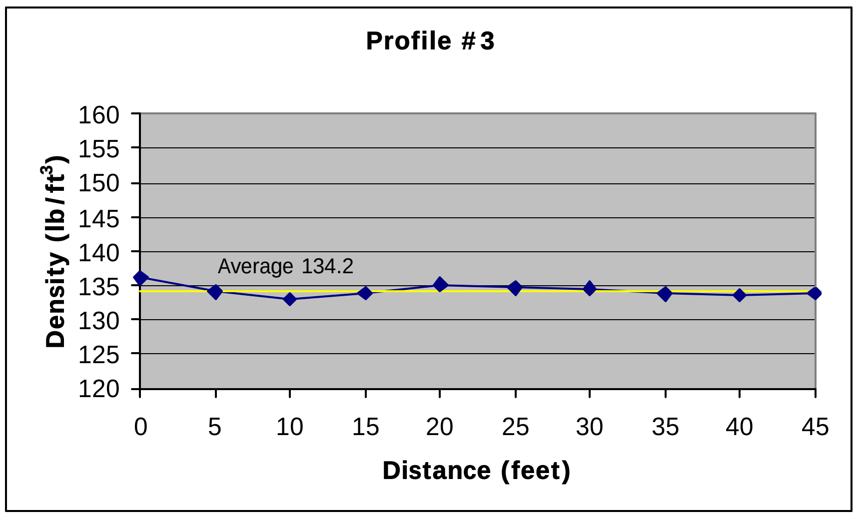


Figure C3-c. Contract 5677 Density Profile #3.

Profile #4	Average
$\Delta T = 35^{o}F$	Readings (pcf)
Average	132.6
Maximum	136.5
Minimum	126.8
	Ranges
Max-Min	9.7
Ave-Min	5.8

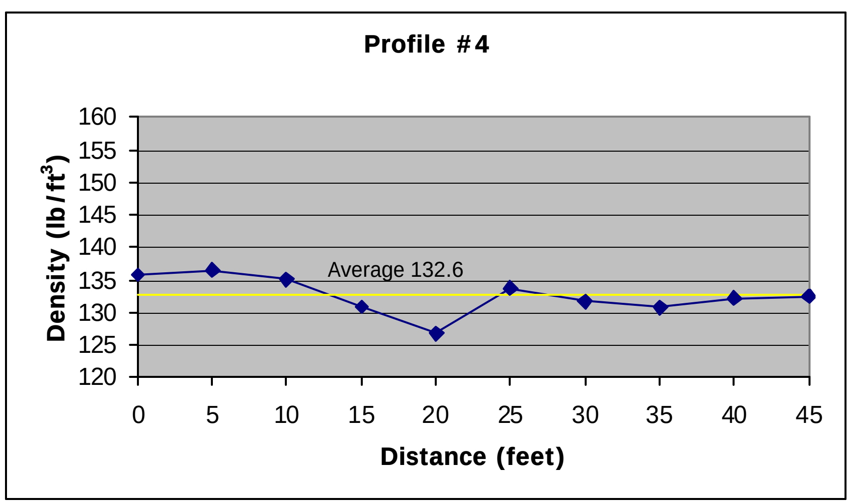


Figure C3-d. Contract 5677 Density Profile #4.

Profile #5	Average
ΔT=46°F	Readings (pcf)
Average	129.6
Maximum	135.8
Minimum	121.9
	Ranges
Max-Min	13.9
Ave-Min	7.7

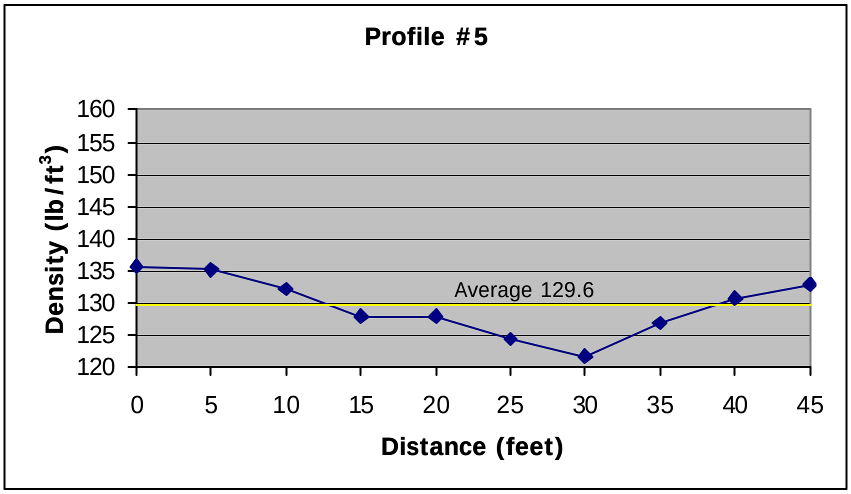


Figure C3-e. Contract 5677 Density Profile #5.

Profile #6	Average
ΔT=10°F	Readings (pcf)
Average	136.0
Maximum	138.9
Minimum	134.1
	Ranges
Max-Min	4.8
Ave-Min	1.9

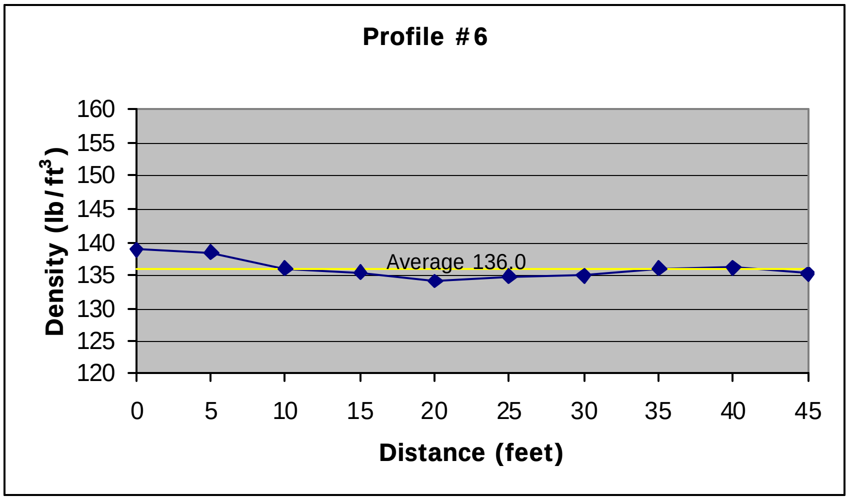


Figure C3-f. Contract 5677 Density Profile #6.

Table C4. Contract 5700 QA Density Results.

Date Paved	Mix Design	Lot #	Random Tests 1	2	3	4	5	Average	Standard Deviation	Lot Pay Factor	Tonnage	Lot Bonus
6/26/2000	G9323	1	96.60	96.10	97.40	92.70	93.00	95.16	2.16	1.05	400	350.24
6/26/2000	G9323	2	95.70	96.20	96.70	94.60	95.60	95.76	0.78	1.05	400	350.24
6/26/2000	G9323	3	97.10	96.50	99.50	96.60	97.30	97.40	1.22	1.05	400	350.24
6/26/2000	G9323	4	97.60	95.10	96.10	95.80	96.40	96.20	0.92	1.05	321	281.07
6/27/2000	G9323	5	96.70	98.80	95.50	97.50	95.10	96.72	1.50	1.05	400	350.24
6/27/2000	G9323	6	99.00	97.00	99.30	95.00	97.80	97.62	1.73	1.05	400	350.24
6/27/2000	G9323	7	95.40	96.80	98.00	97.30	98.40	97.18	1.17	1.05	400	350.24
6/27/2000	G9323	8	96.70	98.80	96.00	95.20	96.50	96.64	1.34	1.05	288	252.17
6/28/2000	G9323	9	97.50	96.30	92.30	96.40	97.50	96.00	2.15	1.05	400	350.24
6/28/2000	G9323	10	95.90	96.10	95.30	95.00	94.70	95.40	0.59	1.05	400	350.24
6/28/2000	G9323	11	98.30	95.50	95.80	96.60	96.30	96.50	1.09	1.05	400	350.24
6/28/2000	G9323	12	97.30	97.80	94.80	98.50	95.20	96.72	1.63	1.05	400	350.24
6/28/2000	G9323	13	97.10	97.00	97.80	96.50	98.20	97.32	0.68	1.05	400	350.24
6/28/2000	G9323	14	91.60	97.70	94.70	92.50	96.90	94.68	2.66	1.04	325	227.66
6/30/2000	G9323	15	92.40	96.80	96.20	96.30	97.90	95.92	2.08	1.05	400	350.24
6/30/2000	G9323	16	98.80	97.90	99.00	99.40	97.10	98.44	0.93	1.05	400	350.24
6/30/2000	G9323	17	96.30	98.80	97.20	99.80	99.20	98.26	1.46	1.05	400	350.24
6/30/2000	G9323	18	97.50	98.60	99.00	98.20	99.40	98.54	0.73	1.05	400	350.24
6/30/2000	G9323	19	96.20	96.00	95.50	95.50	98.40	96.32	1.20	1.05	257	225.03
6/30/2000	G9323	20	93.10	95.70	97.20	99.00	98.50	96.70	2.38	1.05	186	162.86
Totals								**96.67**	**1.73**	**1.050**	**7377**	**6402.39**

$43.78/tonne Class A MTV: Blaw-Knox MC-30

Profile #1 ΔT=15°F	Average Readings (pcf)
Average	145.0
Maximum	146.2
Minimum	143.4
	Ranges
Max-Min	2.8
Ave-Min	1.6

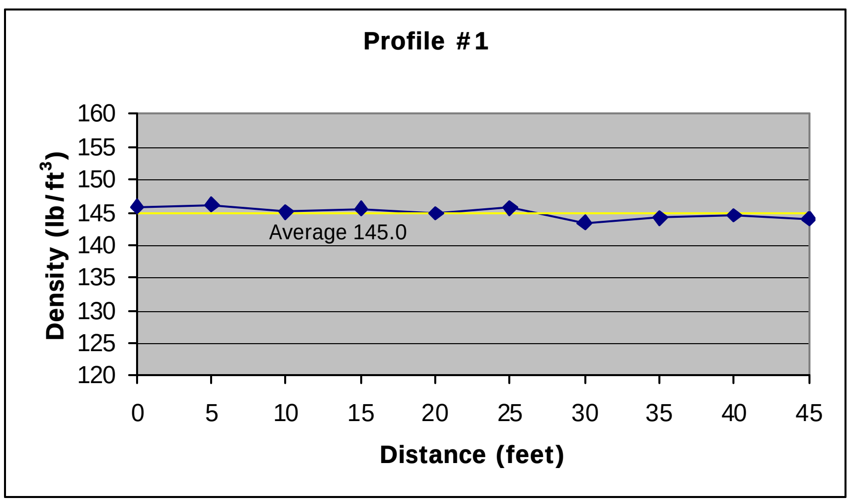


Figure C4-a. Contract 5700 Density Profile #1.

Profile #2	Average
ΔT=20°F	Readings (pcf)
Average	142.4
Maximum	144.9
Minimum	140.2
	Ranges
Max-Min	4.7
Ave-Min	2.2

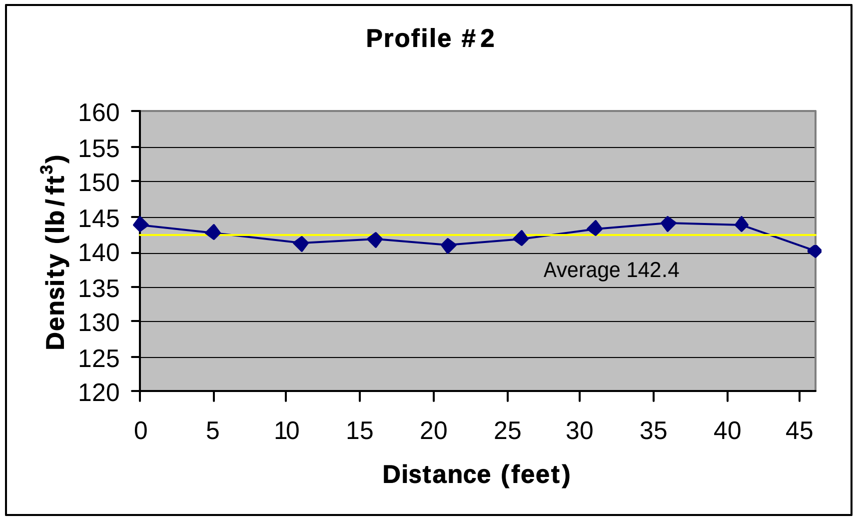


Figure C4-b. Contract 5700 Density Profile #2.

Profile #3	Average
ΔT=25°F	Readings (pcf)
Average	141.2
Maximum	143.0
Minimum	138.8
	Ranges
Max-Min	4.2
Ave-Min	2.4

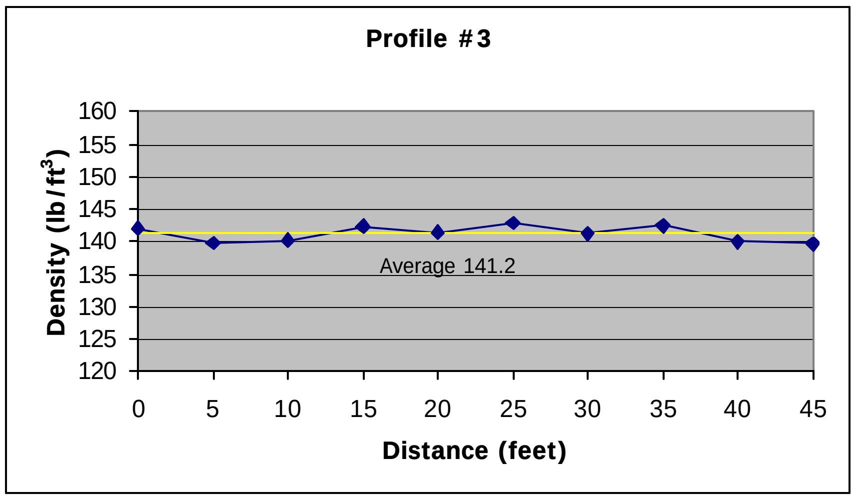


Figure C4-c. Contract 5700 Density Profile #3.

Profile #4	Average
ΔT=29°F	Readings (pcf)
Average	145.1
Maximum	146.3
Minimum	141.0
	Ranges
Max-Min	5.3
Ave-Min	4.1

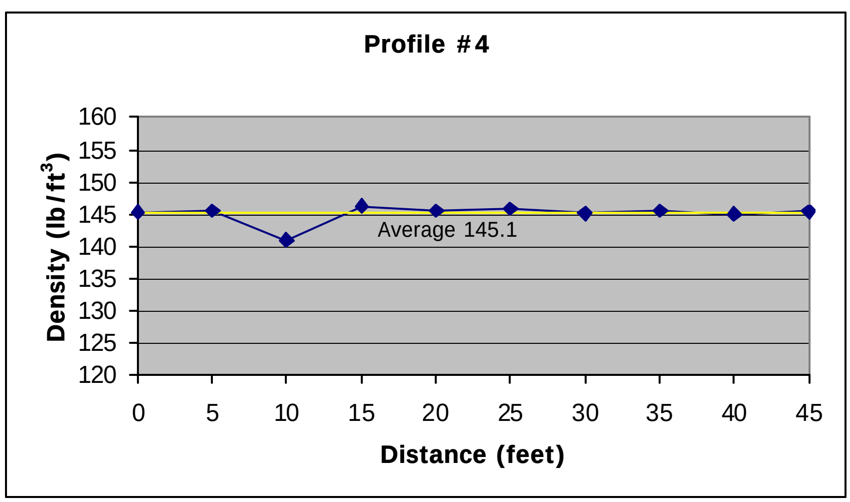


Figure C4-d. Contract 5700 Density Profile #4.

Table C5. Contract 5807 QA Density Results.

Date Paved	Mix Design	Lot #	Random Tests 1	2	3	4	5	Average	Standard Deviation	Lot Pay Factor	Tonnage	Lot Bonus
7/18/2000	9481a	1	94.00	91.30	92.80	91.40	91.60	92.22	1.16	1.02	400	112.00
7/18/2000	9481a	2	91.80	93.80	92.90	92.20	91.70	92.48	0.88	1.05	400	280.00
7/18/2000	9481a	3	91.30	92.80	92.50	92.10	91.80	92.10	0.59	1.05	400	280.00
7/19/2000	9481a	4	92.10	92.70	92.90	91.60	93.70	92.60	0.80	1.05	400	280.00
7/19/2000	9481a	5	92.90	93.10	91.80	91.60	92.30	92.34	0.66	1.05	260	182.00
7/19/2000	9481a	6	92.50	91.50	91.70	93.80	92.80	92.46	0.92	1.04	400	224.00
7/20/2000	9481a	7	91.90	93.80	91.90	91.90	93.00	92.50	0.87	1.05	288	201.60
7/20/2000	9481a	8	91.10	92.10	92.10	92.00	92.30	91.92	0.47	1.05	400	280.00
7/20/2000	9481a	9	91.90	91.50	92.60	93.20	91.50	92.14	0.74	1.04	400	224.00
7/24/2000	9481a	10	91.60	92.10	92.60	93.30	93.20	92.56	0.72	1.05	346	242.20
7/24/2000	9481a	11	92.60	91.20	92.40	93.40	93.40	92.60	0.91	1.05	400	280.00
Totals								**92.36**	**0.77**	**1.046**	**4094**	**2585.80**

$35.00/tonne Class B MTV: Roadtec Shuttle Buggy SB-2500

Profile #1	Average
$\Delta T = 2^oF$	Readings (pcf)
Average	134.6
Maximum	135.4
Minimum	133.5
	Ranges
Max-Min	1.9
Ave-Min	1.1

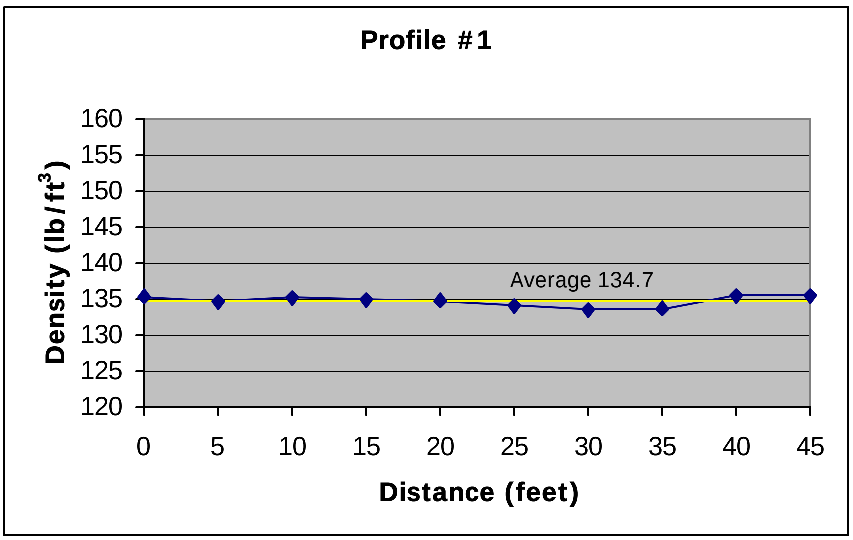


Figure C5-a. Contract 5807 Density Profile #1.

Profile #2	Average
ΔT=4°F	Readings (pcf)
Average	136.5
Maximum	138.0
Minimum	133.7
	Ranges
Max-Min	4.3
Ave-Min	2.8

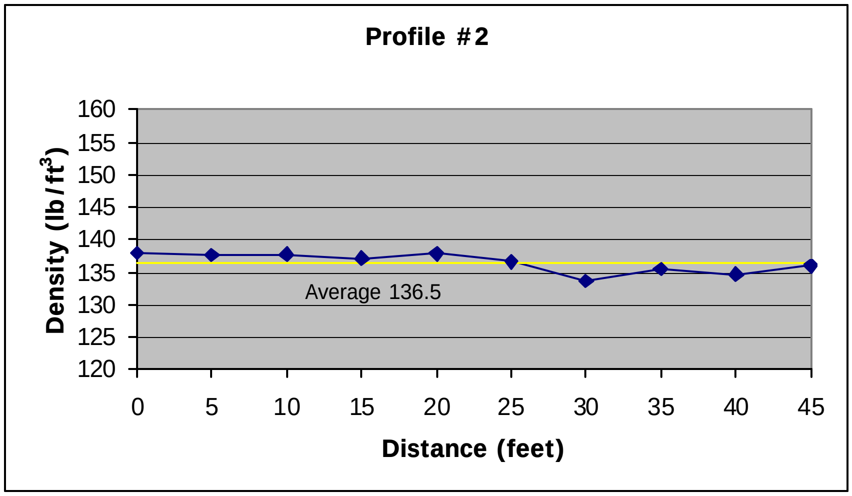


Figure C5-b. Contract 5807 Density Profile #2.

Profile #3	Average
ΔT=25°F+	Readings (pcf)
Average	134.1
Maximum	137.5
Minimum	131.4
	Ranges
Max-Min	6.1
Ave-Min	2.7

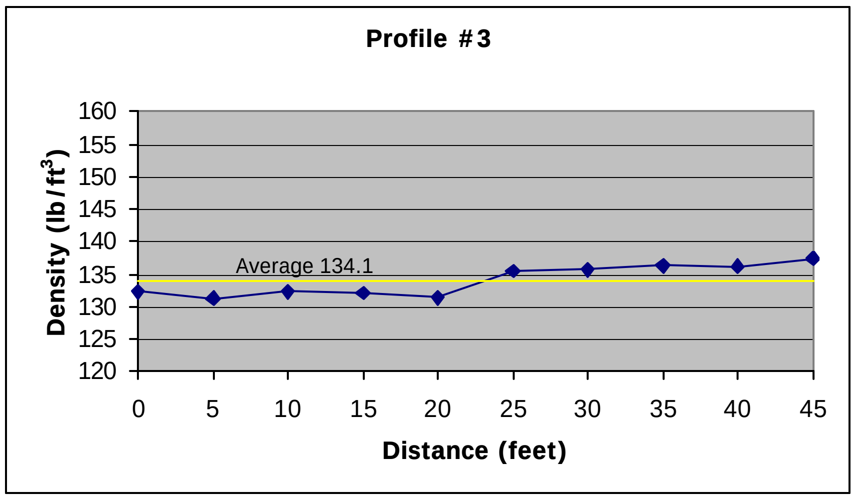


Figure C5-c. Contract 5807 Density Profile #3.

Profile #4	Average
ΔT=10°F	Readings (pcf)
Average	132.2
Maximum	134.0
Minimum	130.0
	Ranges
Max-Min	4.0
Ave-Min	2.2

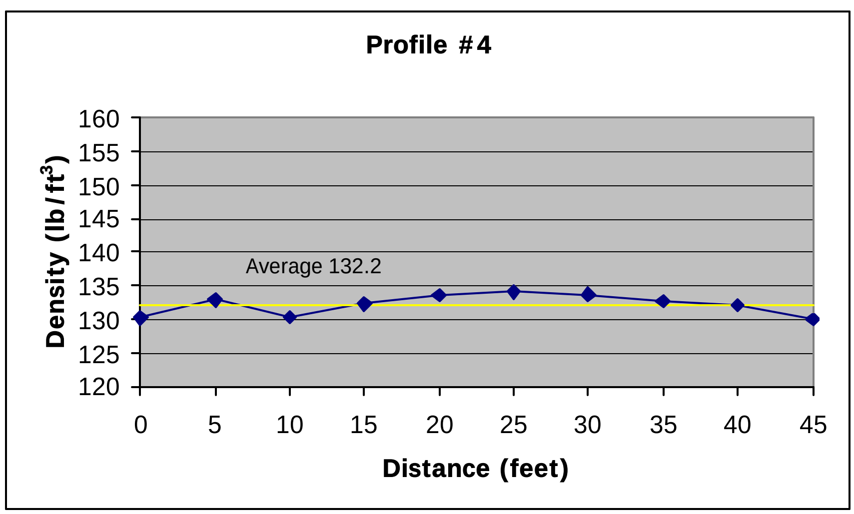


Figure C5-d. Contract 5807 Density Profile #4.

Table C6. Contract 5816 QA Density Results.

Date Paved	Mix Design	Lot #	Random Tests 1	2	3	4	5	Average	Standard Deviation	Lot Pay Factor	Tonnage	Lot Bonus
5/30/2000	G9464	1	90.70	93.90	93.50	92.70	92.40	92.64	1.24	1.04	400	243.20
5/31/2000	G9464	2	90.90	90.90	91.60	91.40	93.40	91.64	1.03	0.97	400	-182.40
5/31/2000	G9464	3	94.20	94.30	93.40	91.70	93.50	93.42	1.04	1.05	400	304.00
5/31/2000	G9464	4	93.10	92.00	95.30	90.40	92.80	92.72	1.78	1.02	400	121.60
6/1/2000	G9464	5	90.50	93.70	91.30	93.20	92.50	92.24	1.33	1.01	400	60.80
6/1/2000	G9464	6	92.60	91.00	92.80	91.90	91.20	91.90	0.81	1.03	400	182.40
6/1/2000	G9464	7	93.40	90.80	92.10	92.00	91.20	91.90	1.00	1.01	400	60.80
6/2/2000	G9464	8	91.30	91.00	92.60	93.50	92.30	92.14	1.01	1.03	400	182.40
6/2/2000	G9464	9	91.80	91.20	92.40	91.90	92.60	91.98	0.55	1.05	400	304.00
6/2/2000	G9464	10	92.30	91.40	93.00	92.30	91.80	92.16	0.60	1.05	400	304.00
6/5/2000	G9464	11	91.40	90.10	93.50	92.70	91.30	91.80	1.32	0.97	400	-182.40
6/5/2000	G9464	12	92.70	92.10	91.60	92.80	92.10	92.26	0.49	1.05	400	304.00
6/5/2000	G9464	13	91.10	91.90	91.60	93.70	92.10	92.08	0.98	1.03	400	182.40
6/5/2000	G9464	14	93.60	92.30	92.60	92.00	91.40	92.38	0.81	1.05	400	304.00
6/6/2000	G9464	15	93.70	91.10	91.30	92.20	90.80	91.82	1.17	0.99	400	-60.80
6/6/2000	G9464	16	91.90	90.70	91.30	91.50	90.60	91.20	0.55	0.92	400	-486.40
6/8/2000	G9464	17	91.60	92.00	91.60	90.80	91.10	91.42	0.47	1.01	400	60.80
6/8/2000	G9464	18	91.20	92.00	91.30	91.60	90.30	91.28	0.63	0.94	400	-364.80
6/8/2000	G9464	19	90.30	91.10	91.80	92.10	90.30	91.12	0.83	0.86	400	-851.20
6/8/2000	G9464	20	90.80	91.30	91.20	92.90	92.40	91.72	0.89	1.00	221	0.00
6/9/2000	G9464	21	89.60	91.50	92.40	92.50	90.90	91.38	1.19	0.91	400	-547.20
6/9/2000	G9464	22	91.60	91.10	92.20	91.80	92.40	91.82	0.51	1.04	220	133.76
6/15/2000	G9464	23	92.30	91.90	89.60	92.20	92.30	91.66	1.16	0.96	400	-243.20
6/15/2000	G9464	24	92.10	93.40	92.00	91.70	93.60	92.56	0.87	1.05	400	304.00
6/15/2000	G9464	25	92.90	91.70	91.70	89.60	91.70	91.52	1.19	0.94	400	-364.80
6/15/2000	G9464	26	92.40	91.50	90.60	92.10	92.10	91.74	0.72	1.02	230	69.92
6/16/2000	G9464	27	92.80	91.30	91.40	92.10	91.00	91.72	0.73	1.02	400	121.60
6/16/2000	G9464	28	93.60	93.70	93.80	92.50	92.20	93.16	0.75	1.05	400	304.00
6/16/2000	G9464	29	93.30	91.60	92.90	92.90	91.10	92.36	0.95	1.04	230	139.84
6/17/2000	G9464	30	93.20	91.30	94.10	93.40	92.90	92.98	1.04	1.05	400	304.00
6/17/2000	G9464	31	95.00	92.80	92.90	91.40	91.90	92.80	1.38	1.04	380	231.04
6/17/2000	G9464	32	92.10	92.50	92.50	92.30	90.60	92.00	0.80	1.03	200	91.20
6/19/2000	G9464	33	91.70	92.20	91.90	92.10	92.80	92.14	0.42	1.05	400	304.00
6/20/2000	G9464	34	92.80	91.90	92.40	90.60	91.50	91.84	0.85	1.02	400	121.60
6/20/2000	G9464	35	92.30	91.20	92.80	91.50	92.30	92.02	0.65	1.04	400	243.20
6/20/2000	G9464	36	92.30	93.10	91.80	92.90	93.30	92.68	0.62	1.05	400	304.00
6/21/2000	G9464	37	92.90	92.70	93.00	90.90	93.10	92.52	0.92	1.04	400	243.20
6/21/2000	G9464	38	93.70	94.40	90.20	93.50	91.50	92.66	1.75	1.01	400	60.80
6/21/2000	G9464	39	92.30	91.50	93.40	95.10	91.10	92.68	1.61	1.02	400	121.60
Totals								**92.10**	**1.05**	**1.012**	**14681**	**2428.96**

$38.00/tonne Class A MTV: Blaw-Knox MC-30

Profile #1	Average
ΔT=23°F	Readings (pcf)
Average	141.3
Maximum	143.6
Minimum	137.5
	Ranges
Max-Min	6.1
Ave-Min	3.8

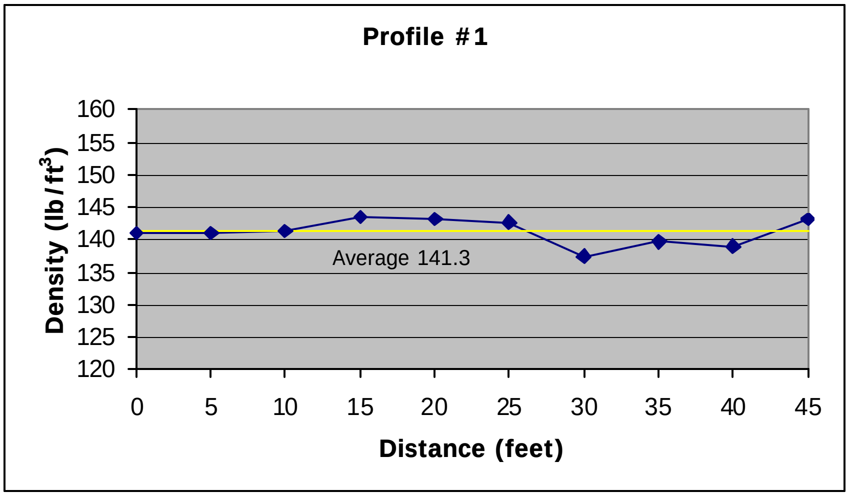


Figure C6-a. Contract 5816 Density Profile #1.

Table C7. Contract 5823 QA Density Results.

Date Paved	Mix Design	Lot #	Random Tests 1	2	3	4	5	Average	Standard Deviation	Lot Pay Factor	Tonnage	Lot Bonus
8/9/2000	G9549	1	95.50	95.20	94.60	93.50	94.30	94.62	0.79	1.05	402	229.14
8/9/2000	G9549	2	95.60	95.70	95.60	93.50	95.90	95.26	0.99	1.05	402	229.14
8/9/2000	G9549	3	94.10	94.60	95.50	93.50	94.20	94.38	0.74	1.05	402	229.14
8/9/2000	G9549	4	93.50	94.30	93.50	94.40	93.50	93.84	0.47	1.05	402	229.14
8/9/2000	G9549	5	93.20	96.60	93.60	94.50	96.60	94.90	1.62	1.05	311	177.27
8/10/2000	G9549	6	91.30	91.70	91.70	92.80	92.40	91.98	0.61	1.04	400	182.40
8/10/2000	G9549	7	92.60	91.80	91.60	94.30	93.10	92.68	1.09	1.04	338	154.13
8/11/2000	G9549	8	92.40	92.10	93.60	95.60	94.00	93.54	1.40	1.05	398	226.86
8/11/2000	G9549	9	93.10	95.00	93.30	93.80	93.30	93.70	0.77	1.05	398	226.86
8/11/2000	G9549	10	93.90	93.50	93.70	95.30	93.10	93.90	0.84	1.05	234	133.38
8/14/2000	G9549	11	93.20	93.60	91.70	92.10	93.80	92.88	0.93	1.05	400	228.00
8/14/2000	G9549	12	93.10	93.20	91.80	95.40	93.50	93.40	1.29	1.05	398	226.86
8/14/2000	G9549	13	92.10	93.80	93.70	91.80	92.20	92.72	0.95	1.05	398	226.86
8/14/2000	G9549	14	94.20	92.00	92.50	93.60	93.00	93.06	0.87	1.05	400	228.00
8/14/2000	G9549	15	93.00	92.30	92.70	92.90	92.40	92.66	0.30	1.05	259	147.63
8/15/2000	G9549	16	92.80	90.90	94.80	95.10	94.00	93.52	1.71	1.04	402	183.31
8/15/2000	G9549	17	92.20	92.90	92.70	92.60	91.40	92.36	0.59	1.05	402	229.14
8/15/2000	G9549	18	95.30	93.00	94.10	91.00	91.90	93.06	1.71	1.03	402	137.48
8/15/2000	G9549	19	93.40	91.80	92.40	93.20	92.10	92.58	0.69	1.05	307	174.99
8/16/2000	G9549	20	92.80	93.60	91.50	91.80	91.40	92.22	0.95	1.04	402	183.31
8/16/2000	G9549	21	95.20	93.50	92.90	92.20	91.20	93.00	1.50	1.04	402	183.31
8/16/2000	G9549	22	93.40	91.80	93.30	92.30	91.00	92.36	1.02	1.04	402	183.31
8/16/2000	G9549	23	92.20	92.70	93.10	91.00	91.40	92.08	0.88	1.03	402	137.48
8/16/2000	G9549	24	93.60	91.80	92.00	92.10	93.30	92.56	0.83	1.05	454	258.78
8/17/2000	G9549	25	91.50	93.90	90.80	92.70	95.00	92.78	1.71	1.02	402	91.66
8/17/2000	G9549	26	94.00	92.20	92.50	94.00	92.40	93.02	0.90	1.05	402	229.14
8/17/2000	G9549	27	93.20	92.80	92.80	91.70	92.90	92.68	0.57	1.05	402	229.14
8/17/2000	G9549	28	92.10	91.50	92.30	93.60	94.50	92.80	1.22	1.04	402	183.31
8/17/2000	G9549	29	91.60	91.10	91.90	92.90	92.60	92.02	0.73	1.04	278	126.77
8/18/2000	G9549	30	93.00	93.40	91.80	93.90	94.40	93.30	0.99	1.05	402	229.14
8/18/2000	G9549	31	93.70	91.30	94.70	91.70	93.60	93.00	1.44	1.04	402	183.31
8/18/2000	G9549	32	91.70	91.20	91.10	93.00	94.20	92.24	1.33	1.01	402	45.83
8/18/2000	G9549	33	93.40	91.70	92.20	91.50	91.70	92.10	0.77	1.04	292	133.15
8/21/2000	G9549	34	91.00	91.20	91.50	91.80	91.80	91.46	0.36	1.04	402	183.31
8/21/2000	G9549	35	92.70	91.10	92.00	91.70	92.60	92.02	0.66	1.04	402	183.31
8/21/2000	G9549	36	93.00	93.00	92.50	93.00	91.00	92.50	0.87	1.05	402	229.14
8/21/2000	G9549	37	91.20	92.90	91.80	93.60	93.20	92.54	1.00	1.04	402	183.31
8/21/2000	G9549	38	94.10	92.70	92.80	91.20	92.40	92.64	1.04	1.04	402	183.31
8/21/2000	G9549	39	93.20	92.50	93.60	92.10	92.30	92.74	0.63	1.05	141	80.37
8/22/2000	G9549	40	91.80	92.00	91.20	91.50	93.10	91.92	0.73	1.03	402	137.48
8/22/2000	G9549	41	91.60	91.30	93.10	93.30	93.80	92.62	1.10	1.04	402	183.31
8/22/2000	G9549	42	92.30	91.70	94.00	92.50	91.60	92.42	0.96	1.04	402	183.31
8/22/2000	G9549	43	91.80	91.50	91.50	92.50	93.20	92.10	0.74	1.04	402	183.31
8/22/2000	G9549	44	94.60	93.00	93.40	94.20	92.50	93.54	0.86	1.05	402	229.14
8/22/2000	G9549	45	92.70	92.20	92.90	92.40	92.60	92.56	0.27	1.05	172	98.04
8/23/2000	G9549	46	92.70	93.30	92.10	93.40	93.50	93.00	0.59	1.05	402	229.14
8/23/2000	G9549	47	93.40	92.90	93.10	92.50	92.40	92.86	0.42	1.05	402	229.14
8/23/2000	G9549	48	91.90	93.20	92.20	91.90	92.60	92.36	0.55	1.05	400	228.00
8/23/2000	G9549	49	92.70	92.00	93.10	93.60	93.50	92.98	0.65	1.05	128	72.96

Table C7 Contract 5823 QA Density Results Continued.

Date Paved	Mix Design	Lot #	Random Tests 1	2	3	4	5	Average	Standard Deviation	Lot Pay Factor	Tonnage	Lot Bonus
8/24/2000	G9549	50	93.70	92.80	91.40	92.30	94.00	92.84	1.05	1.05	402	229.14
8/24/2000	G9549	51	92.20	91.10	91.10	91.40	91.70	91.50	0.46	1.02	400	91.20
8/24/2000	G9549	52	91.40	92.30	91.20	91.10	91.20	91.44	0.49	1.01	442	50.39
8/25/2000	G9549	53	92.40	91.70	92.20	92.90	91.80	92.20	0.48	1.05	334	190.38
8/28/2000	G9549	54	92.30	92.40	93.60	91.60	91.20	92.22	0.92	1.04	319	145.46
Totals								**92.81**	**1.17**	**1.043**	**20063**	**9720.52**

$28.50/tonne Class 19.0 mm Superpave MTV: Cedarapids MS-2 (windrow pick-up machine)

Profile #1	Average
ΔT=31°F	Readings (pcf)
Average	144.9
Maximum	148.4
Minimum	141.3
	Ranges
Max-Min	7.1
Ave-Min	3.6

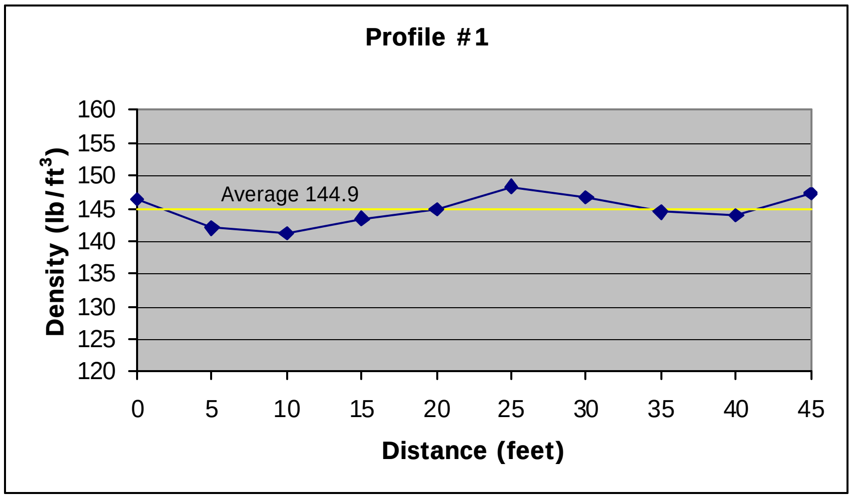


Figure C7-a. Contract 5823 Density Profile #1.

Profile #2	Average
ΔT=5°F	Readings (pcf)
Average	146.8
Maximum	148.4
Minimum	145.2
	Ranges
Max-Min	3.2
Ave-Min	1.6

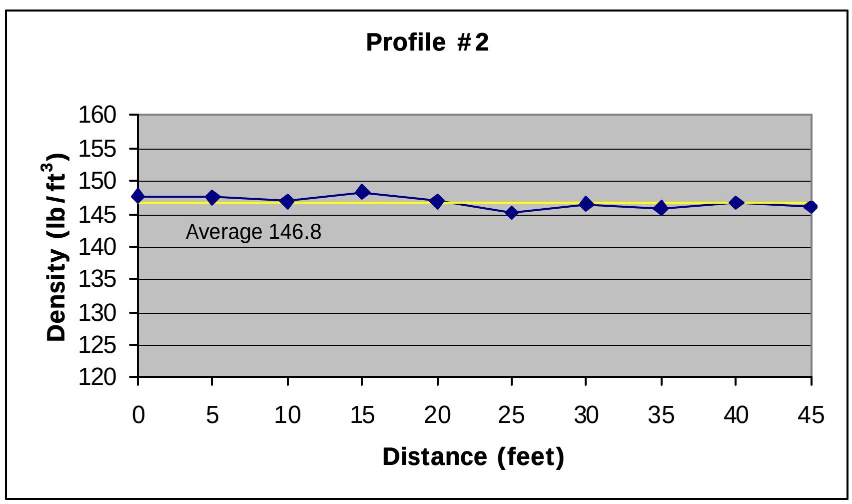


Figure C7-b. Contract 5823 Density Profile #2.

Profile #3	Average
ΔT=10°F	Readings (pcf)
Average	148.9
Maximum	151.3
Minimum	147.0
	Ranges
Max-Min	4.3
Ave-Min	1.9

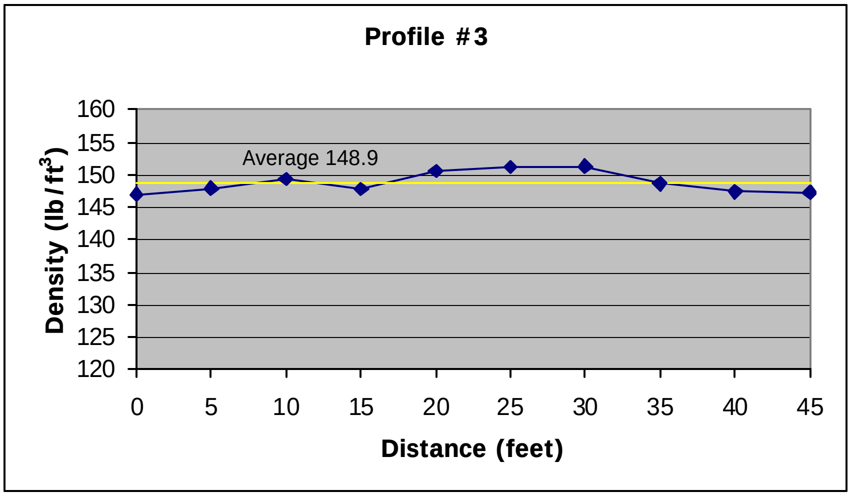


Figure C7-c. Contract 5823 Density Profile #3.

Profile #4	Average
ΔT=32°F	Readings (pcf)
Average	145.8
Maximum	147.9
Minimum	141.0
	Ranges
Max-Min	6.9
Ave-Min	4.8

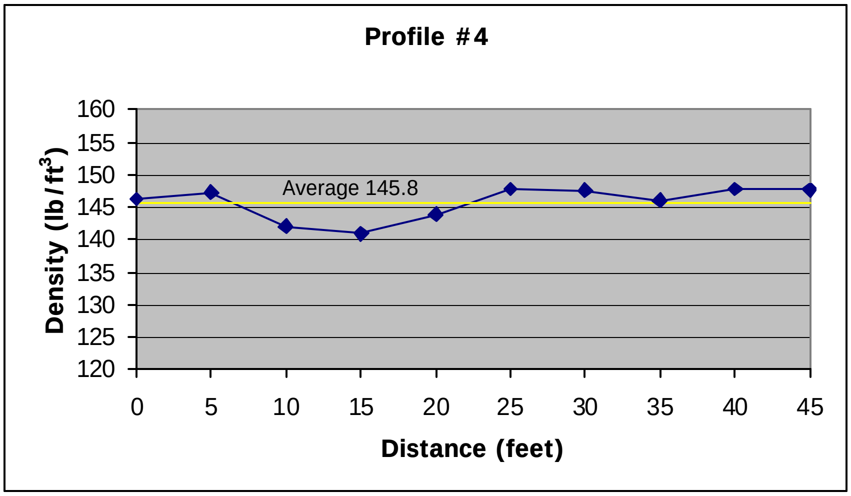


Figure C7-d. Contract 5823 Density Profile #4.

Table C8. Contract 5827 QA Density Results.

Date Paved	Mix Design	Lot #	Random Tests 1	2	3	4	5	Average	Standard Deviation	Lot Pay Factor	Tonnage	Lot Bonus
8/7/2000	G9596	1	91.00	92.30	93.50	91.30	92.50	92.12	1.00	1.03	391	136.07
8/8/2000	G9596	3	95.30	92.20	92.90	88.70	91.60	92.14	2.38	0.95	400	-232.00
8/8/2000	G9596	4	92.30	94.90	91.60	91.70	91.60	92.42	1.42	1.02	400	92.80
8/9/2000	G9596	5	90.80	90.60	91.90	91.70	90.10	91.02	0.76	0.83	321	-633.01
8/9/2000	G9596	6	92.50	91.30	91.00	91.40	89.80	91.20	0.97	0.88	400	-556.80
8/9/2000	G9596	7	92.00	95.80	95.70	91.40	95.50	94.08	2.19	1.04	321	148.94
8/9/2000	G9596	8	91.70	91.00	92.80	92.50	92.30	92.06	0.72	1.04	191	88.62
8/10/2000	G9596	9	95.10	92.30	93.70	93.40	92.90	93.48	1.05	1.05	400	232.00
8/10/2000	G9596	10	91.00	93.40	91.80	91.00	94.60	92.36	1.59	1.01	400	46.40
8/10/2000	G9596	11	94.10	93.00	91.70	91.90	92.40	92.62	0.97	1.04	376	174.46
8/11/2000	G9596	12	92.80	92.30	92.10	91.80	92.60	92.32	0.40	1.05	224	129.92
8/11/2000	G9596	13	91.90	92.30	91.90	93.00	92.00	92.22	0.47	1.05	113	65.54
8/14/2000	G9596	14	91.90	94.10	92.90	92.80	91.00	92.54	1.16	1.04	400	185.60
8/14/2000	G9596	15	93.70	92.90	93.10	94.80	93.00	93.50	0.79	1.05	445	258.10
8/15/2000	G9596	16	91.60	93.00	92.20	93.40	95.10	93.06	1.34	1.04	400	185.60
8/15/2000	G9596	17	95.40	93.30	93.90	94.10	92.70	93.88	1.01	1.05	400	232.00
8/15/2000	G9596	18	94.10	95.00	93.60	92.00	91.50	93.24	1.46	1.04	400	185.60
8/15/2000	G9596	19	93.40	93.20	94.60	93.40	93.20	93.56	0.59	1.05	153	88.74
8/16/2000	G9596	20	94.40	95.50	92.90	94.50	92.20	93.90	1.33	1.05	400	232.00
8/16/2000	G9596	21	93.50	94.50	93.20	92.50	93.50	93.44	0.72	1.05	400	232.00
8/16/2000	G9596	22	92.90	94.50	95.30	95.40	91.90	94.00	1.54	1.05	446	258.68
8/17/2000	G9596	23	93.30	93.40	92.60	92.70	93.60	93.12	0.44	1.05	400	232.00
8/17/2000	G9596	24	94.20	93.70	93.00	92.20	92.20	93.06	0.89	1.05	354	205.32
8/21/2000	G9596	25	95.00	92.00	93.50	95.20	93.50	93.84	1.30	1.05	400	232.00
8/21/2000	G9596	26	94.90	93.10	95.10	94.80	93.60	94.30	0.89	1.05	420	243.60
8/22/2000	G9596	27	94.80	93.00	93.00	93.20	95.30	93.86	1.10	1.05	400	232.00
8/22/2000	G9596	28	93.50	92.90	93.50	92.00	91.50	92.68	0.90	1.05	400	232.00
8/22/2000	G9596	29	95.20	93.90	91.60	93.10	94.10	93.58	1.34	1.05	369	214.02
8/23/2000	G9596	30	91.30	94.00	93.60	93.40	93.10	93.08	1.05	1.05	400	232.00
8/23/2000	G9596	31	93.80	95.10	92.40	91.00	92.70	93.00	1.54	1.04	395	183.28
8/23/2000	G9596	32	92.50	93.30	91.70	92.80	94.00	92.86	0.86	1.05	477	276.66
8/24/2000	G9596	33	91.60	93.80	91.30	92.10	92.40	92.24	0.97	1.04	400	185.60
8/24/2000	G9596	34	95.00	93.30	93.00	93.50	93.60	93.68	0.77	1.05	400	232.00
8/24/2000	G9596	35	93.10	92.80	91.20	94.70	94.20	93.20	1.36	1.04	388	180.03
8/24/2000	G9596	36	94.40	93.90	93.90	92.20	94.10	93.70	0.86	1.05	331	191.98
8/25/2000	G9596	37	92.90	93.60	94.80	95.70	93.30	94.06	1.16	1.05	306	177.48
8/25/2000	G9596	38	91.50	93.60	92.90	93.40	92.90	92.86	0.82	1.05	308	178.64
8/28/2000	G9596	39	93.90	93.80	94.80	94.10	93.40	94.00	0.51	1.05	400	232.00
8/28/2000	G9596	40	92.60	91.30	93.20	93.40	91.10	92.32	1.07	1.03	400	139.20
8/28/2000	G9596	41	92.20	92.20	92.30	94.60	93.20	92.90	1.04	1.05	109	63.22
8/29/2000	G9596	42	94.90	95.30	93.10	94.60	94.20	94.42	0.84	1.05	400	232.00
8/29/2000	G9596	43	92.80	91.30	91.30	92.20	91.50	91.82	0.66	1.03	400	139.20
8/29/2000	G9596	44	94.80	92.10	94.10	92.90	92.50	93.28	1.13	1.05	458	265.64
8/30/2000	G9596	45	94.00	94.10	93.30	93.90	93.00	93.66	0.48	1.05	400	232.00
8/30/2000	G9596	46	92.90	91.90	94.10	93.30	91.90	92.82	0.94	1.05	236	136.88
9/5/2000	G9596	47	93.00	92.50	91.00	92.20	91.00	91.94	0.90	1.02	312	72.38
9/5/2000	G9596	48	91.40	93.80	92.00	94.50	92.10	92.76	1.32	1.04	312	144.77
9/6/2000	G9596	49	92.80	95.50	95.10	93.30	93.80	94.10	1.16	1.05	400	232.00
9/6/2000	G9596	50	92.60	92.00	94.20	91.60	94.80	93.04	1.40	1.04	400	185.60

Table C8 Contract 5827 QA Density Results Continued.

Date Paved	Mix Design	Lot #	Random Tests 1	2	3	4	5	Average	Standard Deviation	Lot Pay Factor	Tonnage	Lot Bonus
9/6/2000	G9596	51	94.50	91.60	94.70	93.70	93.10	93.52	1.25	1.05	344	199.52
9/11/2000	G9596	52	94.20	95.90	92.60	92.70	95.00	94.08	1.44	1.05	400	232.00
9/11/2000	G9596	53	95.90	94.50	95.10	92.50	93.80	94.36	1.30	1.05	400	232.00
9/11/2000	G9596	54	92.80	91.00	91.00	93.10	92.90	92.16	1.06	1.03	280	97.44
9/12/2000	G9596	55	91.10	93.70	94.00	91.30	91.20	92.26	1.46	1.01	400	46.40
9/12/2000	G9596	56	93.80	92.60	95.80	91.80	94.30	93.66	1.55	1.05	400	232.00
9/12/2000	G9596	57	94.20	92.90	92.70	93.10	91.10	92.80	1.11	1.04	400	185.60
9/12/2000	G9596	58	93.30	92.40	91.70	91.40	92.90	92.34	0.80	1.05	217	125.86
9/13/2000	G9596	59	93.50	93.90	93.60	92.90	93.10	93.40	0.40	1.05	400	232.00
9/13/2000	G9596	60	94.70	94.90	95.00	94.10	93.40	94.42	0.67	1.05	400	232.00
9/13/2000	G9596	61	92.70	93.00	94.90	94.80	95.80	94.24	1.33	1.05	83	48.14
9/14/2000	G9596	62	94.10	92.80	95.00	91.90	93.10	93.38	1.20	1.05	400	232.00
9/14/2000	G9596	63	92.70	93.80	95.10	93.10	91.40	93.22	1.37	1.04	452	209.73
9/15/2000	G9596	64	92.30	94.30	93.90	93.40	92.30	93.24	0.92	1.05	111	64.38
9/25/2000	G9596	65	92.10	94.50	91.10	89.70	90.40	91.56	1.87	0.90	134	-155.44
9/25/2000	G9596	66	93.40	92.10	91.00	85.20	88.60	90.06	3.24	0.00	229	-2656.40
9/25/2000	G9596	67	88.80	93.70	91.00	89.70	90.10	90.66	1.87	0.77	241	-642.99
9/26/2000	G9596	68	92.10	90.30	89.90	92.30	91.20	91.16	1.06	0.87	196	-295.57
9/26/2000	G9596	69	95.90	94.60	93.80	93.10	90.10	93.50	2.17	1.03	235	81.78
9/26/2000	G9596	70	94.80	94.80	93.40	92.30	91.10	93.28	1.61	1.04	174	80.74
9/27/2000	G9596	71	94.90	91.10	92.00	92.70	92.20	92.58	1.42	1.03	302	105.10
9/27/2000	G9596	72	95.40	94.10	94.80	93.00	93.80	94.22	0.92	1.05	231	133.98
9/27/2000	G9596	73	94.40	95.90	91.40	93.10	95.20	94.00	1.79	1.05	169	98.02
9/28/2000	G9596	74	92.30	95.10	93.30	91.60	91.30	92.72	1.54	1.03	340	118.32
9/28/2000	G9596	75	91.90	91.50	91.90	91.10	92.50	91.78	0.52	1.04	342	158.69
10/2/2000	G9596	76	91.10	91.50	92.90	92.20	91.60	91.86	0.70	1.03	392	136.42
10/2/2000	G9596	77	92.60	92.50	91.00	91.20	91.30	91.72	0.77	1.01	161	18.68
10/3/2000	G9596	78	92.30	91.00	93.70	91.30	91.10	91.88	1.14	1.00	286	0.00
10/4/2000	G9596	79	92.60	93.10	94.30	91.80	92.10	92.78	0.98	1.05	334	193.72
10/4/2000	G9596	80	93.20	92.40	94.30	93.30	91.40	92.92	1.08	1.05	272	157.76
10/5/2000	G9596	81	92.60	91.70	91.90	93.10	92.50	92.36	0.56	1.05	388	225.04
10/5/2000	G9596	82	93.10	92.60	91.30	92.50	93.00	92.50	0.72	1.05	439	254.62
9/21/2000	G9534	500	95.10	93.50	95.20	92.90	93.20	93.98	1.09	1.05	400	232.00
9/21/2000	G9534	501	92.30	94.40	93.50	91.60	94.60	93.28	1.31	1.05	400	232.00
9/21/2000	G9534	502	94.80	92.60	92.90	93.60	93.20	93.42	0.86	1.05	337	195.46
9/22/2000	G9534	505	93.10	90.70	93.20	92.60	93.10	92.54	1.05	1.04	331	153.58
9/22/2000	G9534	506	92.50	93.80	93.90	92.30	92.70	93.04	0.75	1.05	314	182.12
9/25/2000	G9534	507	93.60	94.50	94.20	93.60	95.00	94.18	0.60	1.05	314	182.12
9/25/2000	G9534	508	91.50	92.70	94.30	92.60	94.60	93.14	1.29	1.04	399	185.14
9/25/2000	G9534	509	93.90	94.30	91.50	92.90	93.50	93.22	1.09	1.05	399	231.42
9/25/2000	G9534	510	92.90	93.10	93.90	92.80	94.50	93.44	0.73	1.05	178	103.24
9/26/2000	G9534	511	94.40	94.70	92.80	93.40	93.40	93.74	0.79	1.05	399	231.42
9/26/2000	G9534	512	93.80	94.20	92.50	93.50	94.00	93.60	0.67	1.05	361	209.38

Table C8 Contract 5827 QA Density Results Continued.

Date Paved	Mix Design	Lot #	Random Tests 1	2	3	4	5	Average	Standard Deviation	Lot Pay Factor	Tonnage	Lot Bonus
9/27/2000	G9534	513	93.20	93.60	93.00	92.80	92.90	93.10	0.32	1.05	399	231.42
9/27/2000	G9534	514	93.50	94.00	92.20	91.40	93.30	92.88	1.06	1.05	399	231.42
9/27/2000	G9534	515	93.00	94.70	92.20	91.80	93.20	92.98	1.12	1.05	399	231.42
9/27/2000	G9534	516	92.70	91.80	92.30	92.40	91.80	92.20	0.39	1.05	272	157.76
9/27/2000	G9534	517	93.10	92.70	91.50	91.40	91.00	91.94	0.91	1.02	267	61.94
Totals								**92.98**	**1.37**	**1.022**	**32876**	**10488.14**

$29.00/tonne   Class A   MTV: CMI windrow pick-up machine into a Blaw-Knox MC-30

Profile #1	Average
ΔT=50°F	Readings (pcf)
Average	142.8
Maximum	147.4
Minimum	139.5
	Ranges
Max-Min	7.9
Ave-Min	3.3

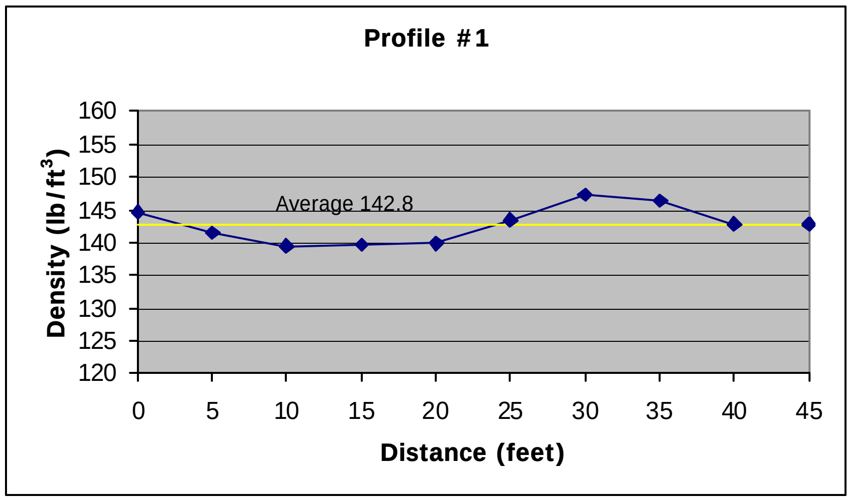


Figure C8-a. Contract 5827 Density Profile #1.

Profile #2	Average
ΔT=40°F	Readings (pcf)
Average	143.2
Maximum	148.4
Minimum	137.9
	Ranges
Max-Min	10.5
Ave-Min	5.3

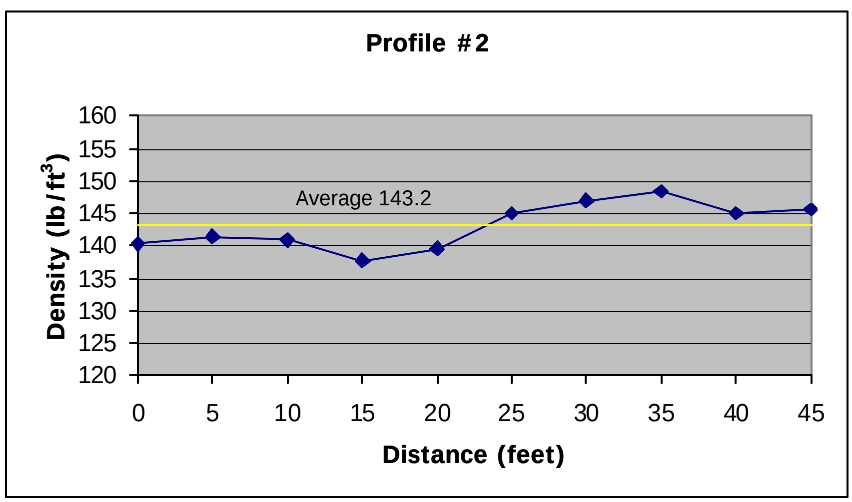


Figure C8-b. Contract 5827 Density Profile #2.

Profile #3	Average
ΔT=30°F	Readings (pcf)
Average	138.2
Maximum	142.6
Minimum	133.4
	Ranges
Max-Min	9.2
Ave-Min	4.8

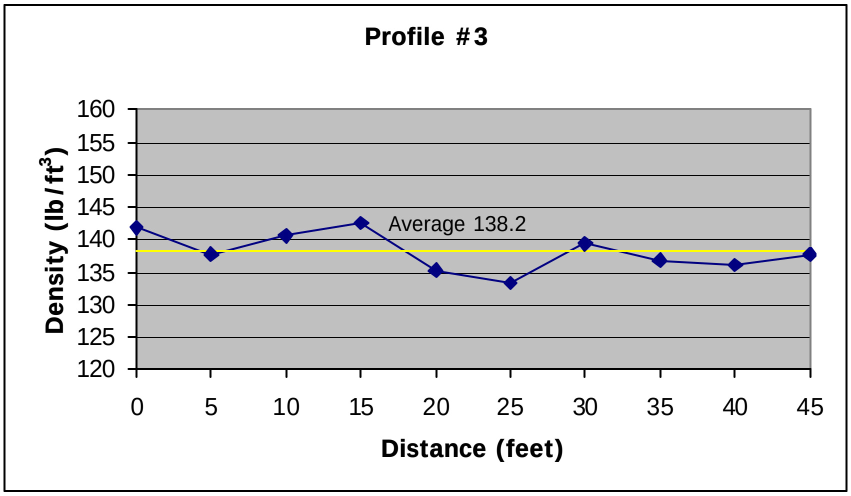


Figure C8-c. Contract 5827 Density Profile #3.

Profile #4	Average
ΔT=11°F	Readings (pcf)
Average	141.8
Maximum	142.7
Minimum	140.4
	Ranges
Max-Min	2.3
Ave-Min	1.4

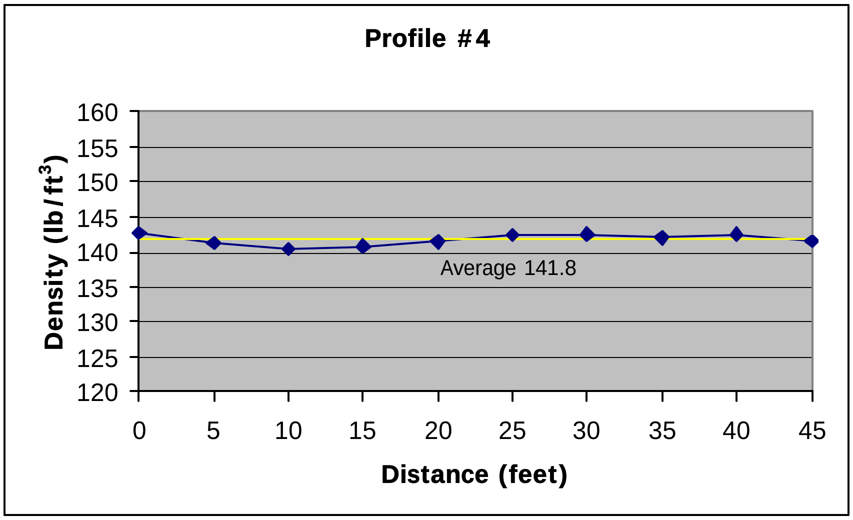


Figure C8-d. Contract 5827 Density Profile #4.

Profile #5	Average
ΔT=3°F	Readings (pcf)
Average	142.2
Maximum	143.8
Minimum	140.7
	Ranges
Max-Min	3.1
Ave-Min	1.5

Figure C8-e. Contract 5827 Density Profile #5.

Table C9. Contract 5831 QA Density Results.

Date Paved	Mix Design	Lot #	Random Tests 1	2	3	4	5	Average	Standard Deviation	Lot Pay Factor	Tonnage	Lot Bonus
6/29/2000	G9445-1	1	92.60	94.80	91.00	93.10	92.50	92.80	1.37	1.04	340	201.28
6/29/2000	G9445-1	2	91.80	94.20	93.40	93.80	94.00	93.44	0.96	1.05	400	296.00
6/29/2000	G9445-1	3	92.80	95.20	95.50	93.80	93.80	94.22	1.11	1.05	400	296.00
6/29/2000	G9445-1	4	93.70	94.00	94.70	94.80	94.20	94.28	0.47	1.05	400	296.00
7/10/2000	G9445-1	5	92.20	92.50	92.90	92.50	93.10	92.64	0.36	1.05	400	296.00
7/10/2000	G9445-1	6	91.20	92.70	92.40	92.80	94.30	92.68	1.11	1.04	400	236.80
7/11/2000	G9445-1	7	90.70	92.60	93.50	92.20	91.20	92.04	1.11	1.01	417	61.72
7/11/2000	G9445-1	8	92.40	92.40	93.00	91.40	93.70	92.58	0.85	1.05	281	207.94
7/11/2000	G9445-1	9	93.60	94.00	92.60	92.70	94.70	93.52	0.89	1.05	162	119.88
7/12/2000	G9445-1	10	91.00	91.80	92.70	91.40	92.60	91.90	0.74	1.03	400	177.60
7/12/2000	G9445-1	11	92.40	91.40	91.00	91.50	93.40	91.94	0.96	1.02	437	129.35
7/13/2000	G9445-1	12	91.40	92.60	92.50	91.70	91.50	91.94	0.57	1.04	400	236.80
7/13/2000	G9445-1	13	94.00	93.00	92.30	93.70	92.00	93.00	0.86	1.05	436	322.64
7/17/2000	G9445-1	14	91.80	94.30	95.40	93.00	92.50	93.40	1.44	1.04	209	123.73
7/17/2000	G9445-1	15	96.90	94.10	94.20	93.50	91.50	94.04	1.93	1.04	134	79.33
7/17/2000	G9445-1	16	93.70	95.60	93.90	94.90	93.70	94.36	0.85	1.05	229	169.46
7/18/2000	G9445-1	17	93.00	93.50	93.50	92.70	91.30	92.80	0.91	1.05	103	76.22
7/18/2000	G9445-1	18	93.60	94.30	94.20	95.80	94.20	94.42	0.82	1.05	98	72.52
7/19/2000	G9445-1	19	93.10	95.00	93.10	94.30	92.20	93.54	1.11	1.05	200	148.00
7/20/2000	G9445-1	20	94.80	93.50	93.30	93.70	93.80	93.82	0.58	1.05	225	166.50
7/25/2000	G9445-1	21	92.70	91.00	91.20	91.10	91.90	91.58	0.72	1.00	136	0.00
Totals								**93.09**	**1.26**	**1.041**	**6207**	**3713.77**

$37.00/tonne   Class A   MTV: Roadtec Shuttle Buggy SB-2500

Profile #1 $\Delta T = 4^{o}F$	Average Readings (pcf)
Average	141.8
Maximum	144.2
Minimum	139.6
	Ranges
Max-Min	4.6
Ave-Min	2.2

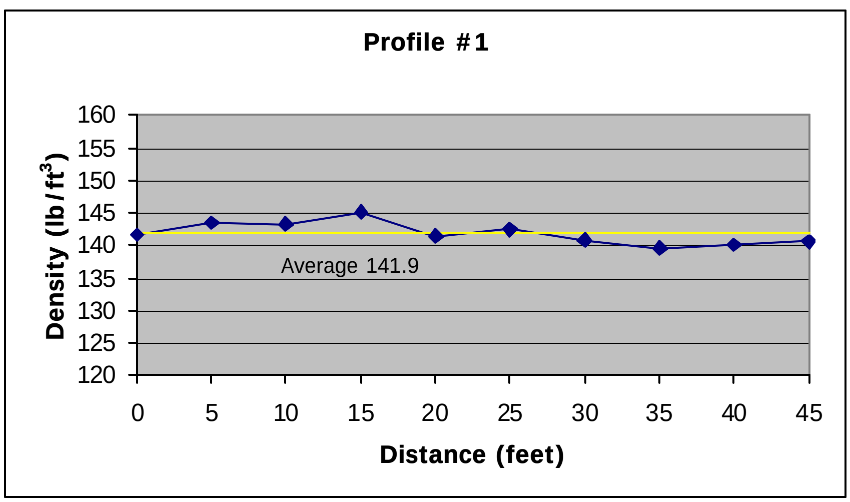


Figure C9-a. Contract 5831 Density Profile #1.

Profile #2	Average
ΔT=2°F	Readings (pcf)
Average	138.7
Maximum	140.6
Minimum	136.7
	Ranges
Max-Min	3.9
Ave-Min	2.0

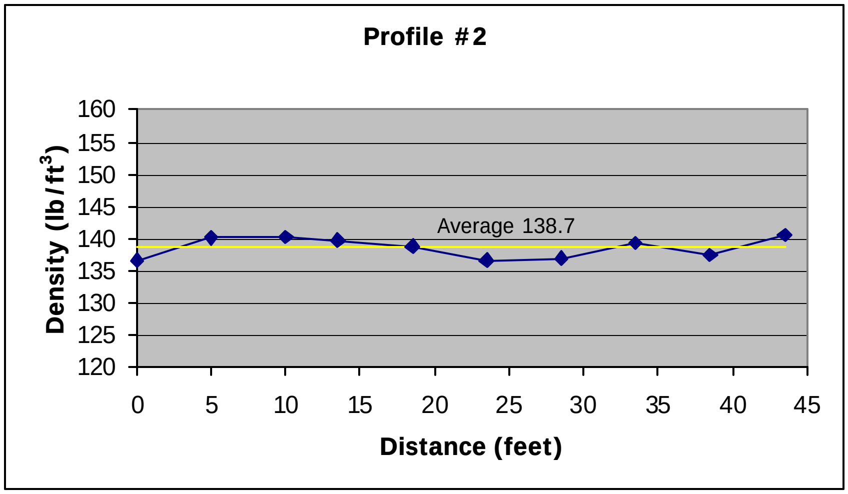


Figure C9-b. Contract 5831 Density Profile #2.

Profile #3	Average
ΔT=58°F	Readings (pcf)
Average	129.7
Maximum	140.9
Minimum	108.5
	Ranges
Max-Min	32.4
Ave-Min	21.2

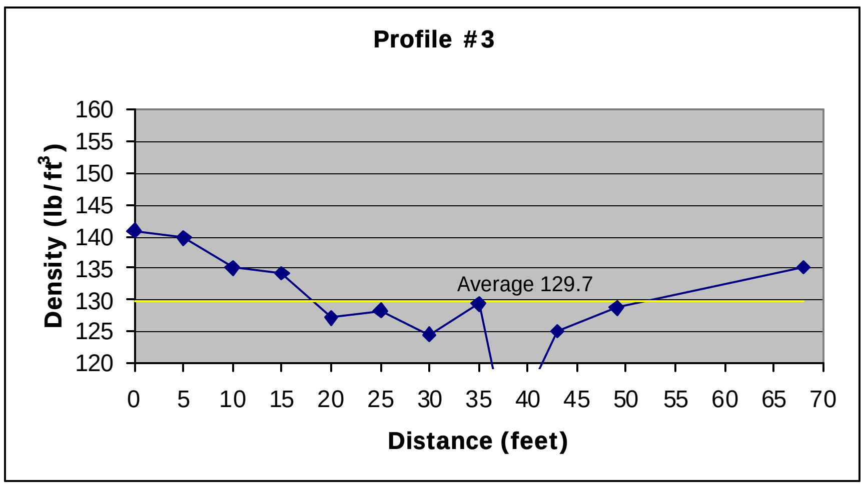


Figure C9-c. Contract 5831 Density Profile #3.

Table C10. Contract 5835 QA Density Results.

Date Paved	Mix Design	Lot #	Random Tests 1	2	3	4	5	Average	Standard Deviation	Lot pay Factor	Tonnage	Lot Bonus
7/24/2000	G9504	1	94.20	92.90	92.30	91.30	92.20	92.58	1.07	1.04	400	208.00
7/24/2000	G9504	2	93.70	94.20	94.30	92.70	92.90	93.56	0.73	1.05	400	260.00
7/24/2000	G9504	3	92.70	94.40	92.30	92.90	91.50	92.76	1.06	1.04	400	208.00
7/24/2000	G9504	4	94.40	92.20	93.20	91.20	92.40	92.68	1.20	1.04	400	208.00
7/24/2000	G9504	5	92.20	93.60	91.90	92.40	91.60	92.34	0.77	1.05	204	132.60
7/25/2000	G9504	6	92.80	93.20	93.30	94.80	93.70	93.56	0.76	1.05	400	260.00
7/25/2000	G9504	7	95.50	93.40	92.50	92.60	92.80	93.36	1.25	1.05	400	260.00
7/25/2000	G9504	8	91.10	91.10	91.70	93.70	93.10	92.14	1.19	1.01	400	52.00
7/25/2000	G9504	9	91.10	91.70	90.90	92.40	91.30	91.48	0.59	1.00	400	0.00
7/25/2000	G9504	10	91.60	89.00	89.50	91.80	91.50	90.68	1.32	0.75	400	-1300.00
7/25/2000	G9504	11	92.60	91.40	91.10	91.50	91.90	91.70	0.58	1.03	444	173.16
7/26/2000	G9504A	12	93.30	93.60	93.90	93.80	93.60	93.64	0.23	1.05	400	260.00
7/26/2000	G9504A	13	93.10	91.60	93.60	91.10	96.60	93.20	2.16	1.02	400	104.00
7/26/2000	G9504A	14	93.80	93.70	95.50	93.10	92.80	93.78	1.05	1.05	400	260.00
7/26/2000	G9504A	15	91.10	91.60	94.40	93.40	92.60	92.62	1.33	1.03	400	156.00
7/26/2000	G9504A	16	93.60	95.00	92.90	92.70	91.70	93.18	1.22	1.05	400	260.00
7/26/2000	G9504A	17	93.30	91.20	93.20	91.10	92.60	92.28	1.07	1.03	400	156.00
7/26/2000	G9504A	18	93.40	91.00	92.90	93.70	91.80	92.56	1.13	1.04	400	208.00
7/26/2000	G9504A	19	92.20	91.20	92.20	91.30	93.30	92.04	0.85	1.03	400	156.00
7/26/2000	G9504A	20	92.10	93.60	93.40	91.20	91.30	92.32	1.13	1.03	400	156.00
7/26/2000	G9504A	21	93.80	93.00	91.10	92.20	92.40	92.50	1.00	1.04	333	173.16
7/27/2000	G9504A	22	92.80	92.70	92.20	91.20	92.90	92.36	0.70	1.05	400	260.00
7/27/2000	G9504A	23	91.20	92.50	92.90	90.70	91.20	91.70	0.95	0.99	400	-52.00
7/27/2000	G9504A	24	90.80	91.20	92.20	92.50	91.20	91.58	0.73	1.00	400	0.00
7/27/2000	G9504A	25	92.40	91.30	92.10	92.40	92.60	92.16	0.51	1.05	400	260.00
7/27/2000	G9504A	26	92.50	91.40	92.70	91.00	91.40	91.80	0.75	1.02	207	53.82
7/27/2000	G9504A	27	93.40	91.50	92.60	92.10	93.50	92.62	0.85	1.05	400	260.00
7/27/2000	G9504A	28	91.40	92.40	91.20	92.90	91.50	91.88	0.73	1.03	400	156.00
7/27/2000	G9504A	29	92.60	91.20	92.50	91.00	91.00	91.66	0.82	1.00	222	0.00
7/31/2000	G9504A	30	92.70	91.10	92.70	91.60	91.10	91.84	0.81	1.02	400	104.00
7/31/2000	G9504A	31	93.00	90.40	91.10	91.60	92.40	91.70	1.03	0.98	274	-71.24
7/31/2000	G9504A	32	92.70	94.20	93.10	92.70	94.50	93.44	0.85	1.05	400	260.00
7/31/2000	G9504A	33	91.50	91.20	91.20	92.40	90.80	91.42	0.60	0.99	153	-19.89
8/1/2000	G9504A	34	93.90	91.90	92.90	92.60	93.00	92.86	0.72	1.05	400	260.00
8/1/2000	G9504A	35	91.90	91.20	92.40	91.10	91.20	91.56	0.57	1.02	141	36.66
8/1/2000	G9504A	36	92.30	92.50	91.80	92.40	92.10	92.22	0.28	1.05	400	260.00
8/1/2000	G9504A	37	93.60	90.60	91.50	92.60	93.40	92.34	1.28	1.02	400	104.00
8/1/2000	G9504A	38	91.90	92.20	92.90	91.50	90.40	91.78	0.93	1.00	400	0.00
8/1/2000	G9504A	39	91.60	94.30	95.30	94.70	91.90	93.56	1.69	1.04	400	208.00
8/4/2000	G9504A	40	91.30	91.40	92.70	91.40	93.80	92.12	1.10	1.02	400	104.00
8/4/2000	G9504A	41	93.10	94.40	92.50	93.30	93.50	93.36	0.69	1.05	400	260.00
8/4/2000	G9504A	42	91.70	91.20	93.30	93.40	92.20	92.36	0.97	1.04	400	208.00
8/4/2000	G9504A	43	93.60	90.30	92.60	92.40	91.30	92.04	1.27	1.00	400	0.00
8/4/2000	G9504A	44	93.60	91.30	94.30	91.50	92.90	92.72	1.30	1.04	440	228.80
8/7/2000	G9504A	45	92.00	93.20	91.50	92.50	91.40	92.12	0.75	1.04	400	208.00
8/7/2000	G9504A	46	92.40	91.30	92.00	91.70	91.70	91.82	0.41	1.05	400	260.00
8/7/2000	G9504A	47	93.90	90.90	90.80	92.90	91.80	92.06	1.33	1.00	400	0.00
8/7/2000	G9504A	48	92.20	91.20	92.60	92.90	91.40	92.06	0.74	1.04	400	208.00
8/7/2000	G9504A	49	92.90	91.80	93.50	92.70	92.80	92.74	0.61	1.05	400	260.00

Table C10 Contract 5835 QA Density Results Continued.

Date Paved	Mix Design	Lot #	Random Tests 1	2	3	4	5	Average	Standard Deviation	Lot pay Factor	Tonnage	Lot Bonus
8/7/2000	G9504A	50	92.20	93.00	92.50	92.10	91.60	92.28	0.52	1.05	481	312.65
8/8/2000	G9504A	51	92.10	93.60	91.30	90.70	91.80	91.90	1.09	1.00	400	0.00
8/8/2000	G9504A	52	91.70	92.30	91.30	92.50	92.00	91.96	0.48	1.05	400	260.00
8/8/2000	G9504A	53	92.40	90.60	92.50	92.30	91.40	91.84	0.82	1.02	400	104.00
8/10/2000	G9504A	54	93.40	91.30	91.00	92.00	92.00	91.94	0.93	1.02	400	104.00
8/10/2000	G9504A	55	91.70	93.00	91.60	92.10	92.30	92.14	0.56	1.05	454	295.10
8/10/2000	G9504A	56	94.00	91.50	89.00	94.30	91.40	92.04	2.17	0.95	242	-157.30
8/10/2000	G9504A	57	93.20	91.90	91.20	91.40	92.10	91.96	0.78	1.03	430	167.70
8/11/2000	G9504A	58	91.60	91.80	92.10	90.90	91.00	91.48	0.52	1.01	336	43.68
8/11/2000	G9504A	59	91.10	91.30	91.20	91.10	91.20	91.18	0.08	1.05	479	311.35
8/14/2000	G9504A	60	91.90	91.10	91.00	91.10	92.00	91.42	0.49	1.01	368	47.84
8/14/2000	G9504A	61	91.60	91.30	92.70	91.10	91.40	91.62	0.63	1.02	265	68.90
8/15/2000	G9504A	62	92.70	92.20	92.70	91.40	92.40	92.28	0.54	1.05	332	215.80
8/15/2000	G9504A	63	92.30	92.30	91.40	92.80	94.20	92.60	1.03	1.04	402	209.04
8/16/2000	G9504A	64	91.40	90.30	90.80	91.30	89.70	90.70	0.71	0.00	76	-988.00
8/16/2000	G9504A	65	91.30	91.00	92.90	91.70	92.40	91.86	0.78	1.03	499	194.61
8/21/2000	G9504A	66	92.20	92.70	92.60	91.40	93.30	92.44	0.70	1.05	300	195.00
8/22/2000	G9504A	67	91.50	91.60	93.20	91.50	91.10	91.78	0.82	1.02	459	119.34
8/2/2000	G9427A	1	91.30	91.50	91.10	91.20	93.70	91.76	1.09	1.00	400	0.00
8/2/2000	G9427A	2	91.90	91.40	91.80	91.70	92.60	91.88	0.44	1.05	400	248.00
8/2/2000	G9427A	3	91.90	92.70	94.20	94.10	93.30	93.24	0.97	1.05	147	91.14
8/3/2000	G9427A	4	92.50	92.90	91.20	91.00	92.60	92.04	0.87	1.03	170	63.24
Totals								**92.24**	**1.09**	**1.011**	**26258**	**8073.16**

$32.50/tonne (G9504) Class A MTV: Lincoln 660-H (windrow pick-up machine)
$31.00/tonne (G9427)

Profile #1	Average
ΔT=5°F	Readings (pcf)
Average	148.0
Maximum	152.0
Minimum	145.6
	Ranges
Max-Min	6.4
Ave-Min	2.4

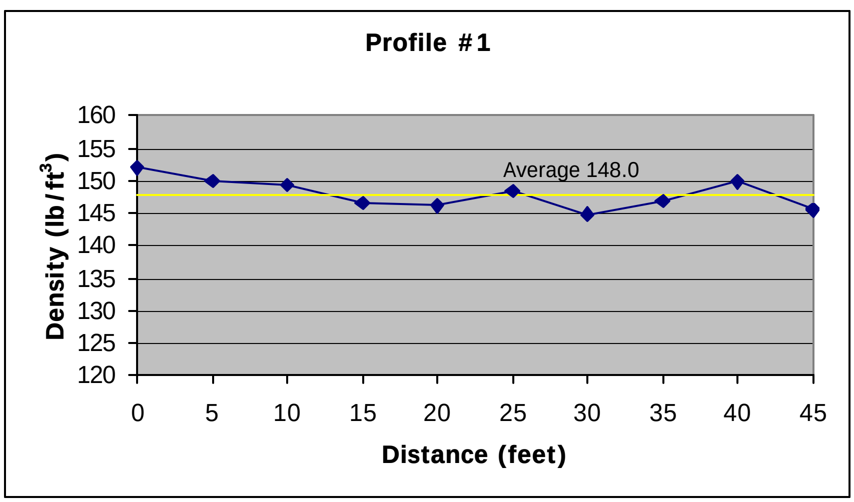


Figure C10-a. Contract 5835 Density Profile #1.

Profile #2	Average
$\Delta T=20^{o}F$	Readings (pcf)
Average	145.4
Maximum	149.0
Minimum	142.2
	Ranges
Max-Min	6.8
Ave-Min	3.2

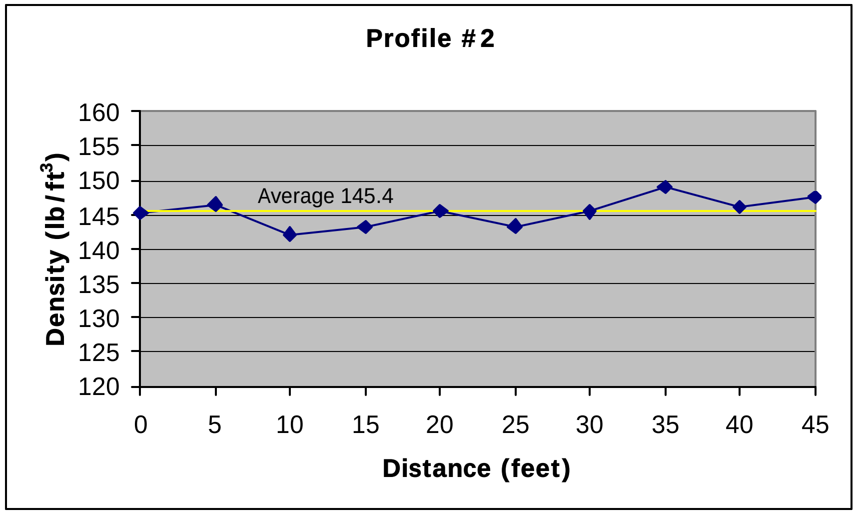


Figure C10-b. Contract 5835 Density Profile #2.

Profile #3	Average
$\Delta T=8^{o}F$	Readings (pcf)
Average	146.1
Maximum	147.4
Minimum	143.9
	Ranges
Max-Min	3.5
Ave-Min	2.2

Figure C10-c. Contract 5835 Density Profile #3.

Profile #4	Average
$\Delta T=0^{o}F$	Readings (pcf)
Average	150.3
Maximum	152.0
Minimum	147.7
	Ranges
Max-Min	4.3
Ave-Min	2.6

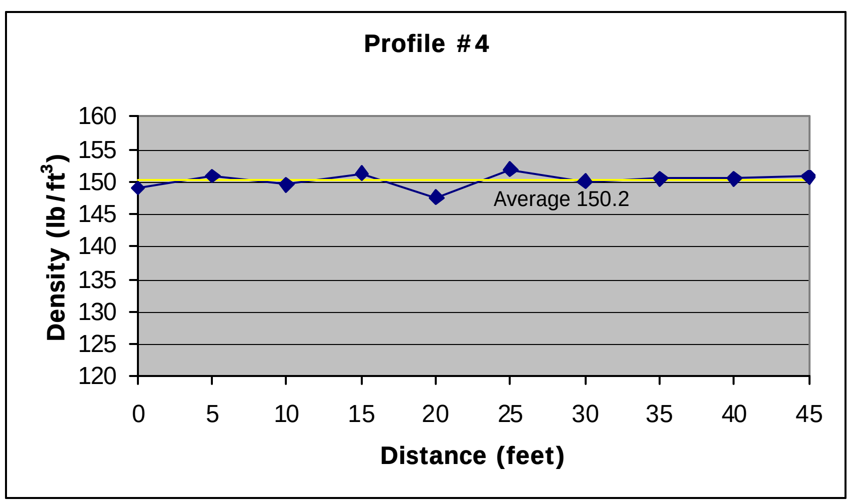


Figure C10-d. Contract 5835 Density Profile #4.

Table C11. Contract 5841 QA Density Results.

Date Paved	Mix Design	Lot #	Random Tests 1	2	3	4	5	Average	Standard Deviation	Lot Pay Factor	Tonnage	Lot Bonus
6/22/2000	G-9460	1	93.80	93.10	92.00	91.80	92.50	92.64	0.82	1.05	400	248.00
6/22/2000	G-9460	2	92.80	91.80	91.80	92.00	91.90	92.06	0.42	1.05	400	248.00
6/22/2000	G-9460	3	91.90	92.10	92.20	92.20	92.60	92.20	0.25	1.05	400	248.00
6/22/2000	G-9460	4	91.60	91.30	91.90	92.80	92.00	91.92	0.56	1.04	431	213.78
6/23/2000	G-9460	5	93.10	91.20	92.60	91.40	92.90	92.24	0.88	1.04	400	198.40
6/23/2000	G-9460	6	91.50	91.60	91.50	92.10	93.40	92.02	0.81	1.03	400	148.80
6/23/2000	G-9460	7	93.10	93.10	91.70	93.10	91.70	92.54	0.77	1.05	400	248.00
6/23/2000	G-9460	8	93.60	91.70	94.00	92.30	91.70	92.66	1.08	1.04	400	198.40
6/23/2000	G-9460	9	92.30	94.00	92.10	91.70	94.10	92.84	1.13	1.04	408	202.37
6/26/2000	G-9460	10	93.50	91.60	91.90	92.60	92.20	92.36	0.74	1.05	419	259.78
6/26/2000	G-9460	11	93.30	92.00	91.70	92.70	92.90	92.52	0.66	1.05	400	248.00
6/26/2000	G-9460	12	93.10	92.10	93.40	93.00	92.00	92.72	0.63	1.05	400	248.00
6/26/2000	G-9460	13	92.90	93.40	93.10	93.00	92.60	93.00	0.29	1.05	420	260.40
6/27/2000	G-9460	14	94.60	92.30	94.20	92.70	93.30	93.42	0.97	1.05	220	136.40
6/27/2000	G-9460	15	91.90	92.90	92.90	91.00	92.90	92.32	0.86	1.04	400	198.40
6/27/2000	G-9460	16	93.40	93.10	92.00	92.90	92.40	92.76	0.56	1.05	400	248.00
6/27/2000	G-9460	17	94.10	92.60	92.00	93.70	92.80	93.04	0.85	1.05	400	248.00
6/27/2000	G-9460	18	92.80	92.90	92.00	92.50	93.30	92.70	0.48	1.05	248	153.76
6/28/2000	G-9460	19	95.00	93.30	93.40	92.80	93.00	93.50	0.87	1.05	400	248.00
6/28/2000	G-9460	20	93.80	94.20	93.60	92.70	93.90	93.64	0.57	1.05	400	248.00
6/28/2000	G-9460	21	92.20	93.10	92.30	92.30	92.40	92.46	0.36	1.05	400	248.00
6/28/2000	G-9460	22	92.00	93.70	91.00	91.50	92.70	92.18	1.06	1.03	400	148.80
6/28/2000	G-9460	23	92.30	91.20	93.60	93.70	93.70	92.90	1.12	1.05	476	295.12
7/5/2000	G-9460	24	91.90	91.80	93.30	92.70	93.40	92.62	0.75	1.05	400	248.00
7/5/2000	G-9460	25	93.60	92.30	92.50	91.90	92.50	92.56	0.63	1.05	465	288.30
7/5/2000	G-9460	26	92.60	92.50	92.70	93.80	92.60	92.84	0.54	1.05	271	168.02
7/6/2000	G-9460	27	91.50	92.90	91.50	92.70	91.60	92.04	0.70	1.04	400	198.40
7/6/2000	G-9460	28	91.30	91.40	93.10	93.10	91.40	92.06	0.95	1.03	400	148.80
7/7/2000	G-9460	29	92.40	92.80	91.80	92.20	92.00	92.24	0.38	1.05	400	248.00
7/7/2000	G-9460	30	92.50	92.70	92.80	92.10	92.50	92.52	0.27	1.05	513	318.06
Totals								**92.58**	**0.80**	**1.046**	**11871**	**6759.99**

$31.00/tonne Class 12.5 mm Superpave MTV: Cedarapids MS-2 (windrow pick-up machine)

Profile #1	Average
ΔT=12°F	Readings (pcf)
Average	136.1
Maximum	140.0
Minimum	134.1
	Ranges
Max-Min	5.9
Ave-Min	2.0

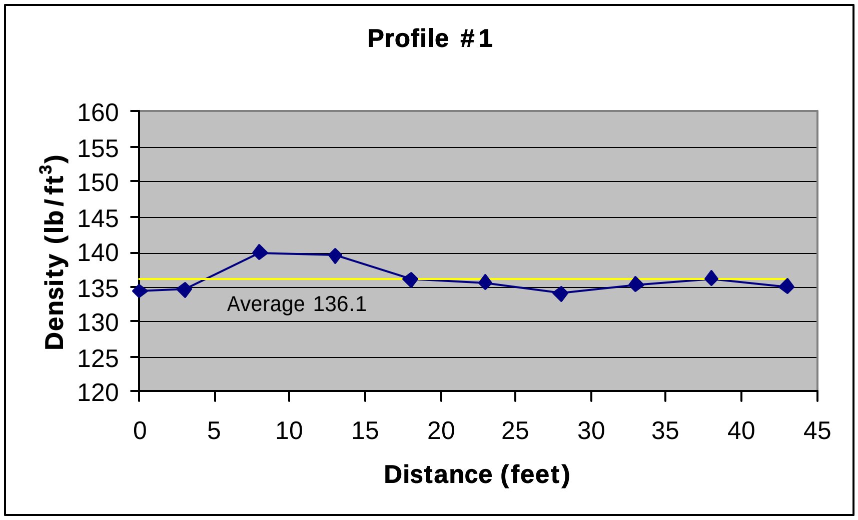


Figure C11-a. Contract 5841 Density Profile #1.

Profile #2	Average
ΔT=30°F	Readings (pcf)
Average	136.4
Maximum	139.8
Minimum	127.8
	Ranges
Max-Min	12.0
Ave-Min	8.6

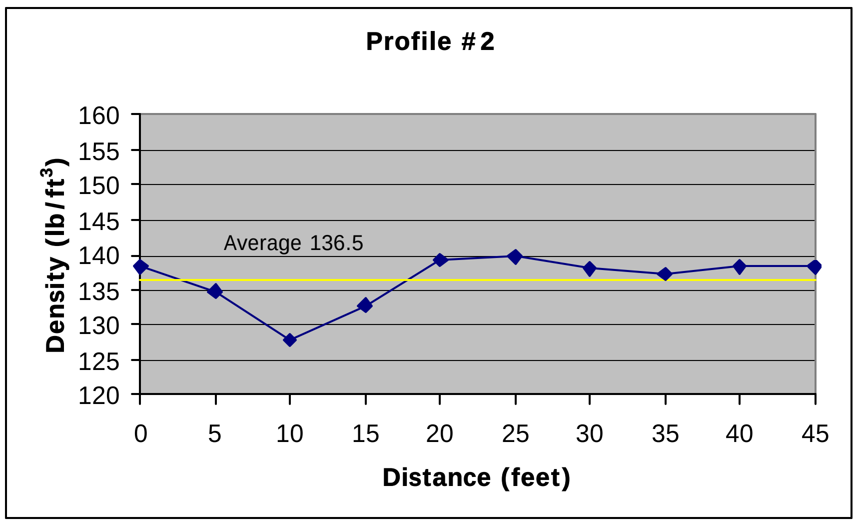


Figure C11-b. Contract 5841 Density Profile #2.

Profile #3	Average
ΔT=1°F	Readings (pcf)
Average	133.6
Maximum	135.8
Minimum	131.3
	Ranges
Max-Min	4.5
Ave-Min	2.3

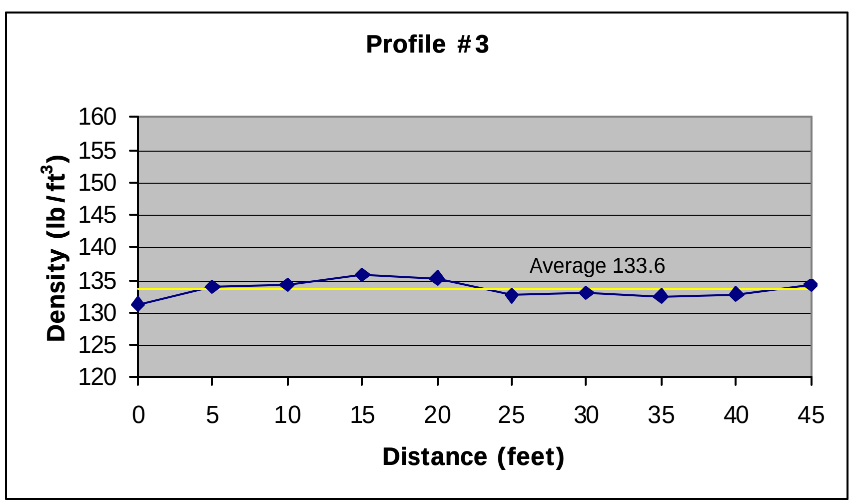


Figure C11-c. Contract 5841 Density Profile #3.

Table C12. Contract 5851 QA Density Results.

Date Paved	Mix Design	Lot #	Random Tests 1	2	3	4	5	Average	Standard Deviation	Lot Pay Factor	Tonnage	Lot Bonus
8/10/2000			First Day - Test Section							1.00		
8/11/2000	G9577	8	91.60	92.20	93.40	92.70	95.40	93.06	1.47	1.04	400	195.84
8/11/2000	G9577	9	93.90	93.30	93.00	95.50	92.20	93.58	1.24	1.05	308	188.50
8/14/2000	G9577	10	96.20	97.70	93.90	93.30	94.80	95.18	1.78	1.05	400	244.80
8/15/2000	G9577	11	96.80	96.50	91.90	92.30	92.70	94.04	2.40	1.03	400	146.88
8/15/2000	G9577	12	92.10	94.10	95.40	93.90	94.50	94.00	1.21	1.05	245	149.94
8/16/2000	G9577	13	92.10	91.30	91.00	92.80	90.60	91.56	0.88	0.97	400	-146.88
8/16/2000	G9577	14	93.90	92.40	92.80	94.90	94.00	93.60	1.00	1.05	400	244.80
8/16/2000	G9577	15	92.50	92.90	93.90	91.40	93.50	92.84	0.97	1.05	219	134.03
8/17/2000	G9577	16	94.70	93.50	92.80	94.00	93.90	93.78	0.70	1.05	400	244.80
8/17/2000	G9577	17	92.70	94.30	93.00	93.50	94.20	93.54	0.71	1.05	400	244.80
8/17/2000	G9577	18	92.80	93.10	92.10	92.20	92.90	92.62	0.44	1.05	400	244.80
8/18/2000	G9577	19	96.30	94.40	91.40	94.70	91.50	93.66	2.14	1.03	400	146.88
8/18/2000	G9577	20	92.60	92.50	92.50	92.40	92.40	92.48	0.08	1.05	381	233.17
8/21/2000	G9577	21	94.00	92.40	91.70	89.30	94.40	92.36	2.04	0.98	299	-73.20
8/21/2000	G9577	22	93.70	92.70	91.30	92.50	93.10	92.66	0.89	1.05	359	219.71
8/21/2000	G9577	23	95.30	90.10	93.30	91.30	91.30	92.26	2.05	0.97	236	-86.66
8/22/2000	G9577	24	93.00	94.00	92.30	92.50	90.50	92.46	1.28	1.03	400	146.88
8/22/2000	G9577	25	91.80	92.20	91.80	92.00	92.30	92.02	0.23	1.05	266	162.79
9/6/2000	G9577	26	93.00	93.00	92.90	93.60	91.70	92.84	0.69	1.05	176	107.71
9/6/2000	G9577	27	91.20	96.00	94.00	93.80	91.00	93.20	2.10	1.02	140	34.27
9/6/2000	G9577	28	91.10	91.30	94.70	95.40	92.30	92.96	1.98	1.02	196	47.98
9/7/2000	G9577	29	91.80	91.00	90.30	92.90	93.50	91.90	1.32	0.98	342	-83.72
9/7/2000	G9577	30	91.20	91.70	93.40	91.00	91.90	91.84	0.94	1.01	235	28.76
9/7/2000	G9577	31	92.60	91.70	91.30	94.10	93.80	92.70	1.24	1.04	242	118.48
9/8/2000	G9577	32	91.30	91.10	92.20	92.70	91.10	91.68	0.73	1.01	341	41.74
8/18/2000	G9572	1	92.60	92.50	92.50	92.40	92.40	92.48	0.08	1.05	0	0.00
8/21/2000	G9572	2	94.70	91.90	90.90	97.50	91.10	93.22	2.83	0.99	387	-43.42
8/22/2000	G9572	3	94.30	92.00	90.90	91.70	93.90	92.56	1.47	1.02	400	89.76
8/22/2000	G9572	4	90.10	91.10	91.00	90.80	90.70	90.74	0.39	0.00	400	-4488.00
8/22/2000	G9572	5	90.30	89.00	91.20	90.70	90.90	90.42	0.86	0.00	440	-4936.80
8/23/2000	G9572	6	92.20	91.70	89.70	91.90	91.30	91.36	0.98	0.92	400	-359.04
8/23/2000	G9572	7	88.20	91.90	90.90	91.80	89.60	90.48	1.57	0.00	400	-4488.00
8/23/2000	G9572	8	91.10	91.10	91.30	91.20	93.20	91.58	0.91	1.00	400	0.00
8/23/2000	G9572	9	91.80	93.00	93.30	91.60	91.60	92.26	0.82	1.04	400	179.52
8/23/2000	G9572	10	91.20	92.10	91.90	93.40	91.40	92.00	0.86	1.03	400	134.64
8/23/2000	G9572	11	93.00	92.40	91.70	90.50	91.60	91.84	0.94	1.01	400	44.88
8/23/2000	G9572	12	89.90	90.60	91.50	90.70	91.70	90.88	0.73	0.77	350	-903.21
8/24/2000	G9572	13	91.00	95.60	93.00	93.20	93.00	93.16	1.63	1.04	400	179.52
8/24/2000	G9572	14	92.80	91.80	93.80	90.50	92.00	92.18	1.23	1.02	400	89.76
8/24/2000	G9572	15	93.00	92.30	94.00	91.80	91.10	92.44	1.11	1.04	400	179.52
8/24/2000	G9572	16	92.40	92.00	95.50	95.00	92.80	93.54	1.60	1.04	400	179.52
8/24/2000	G9572	17	91.50	90.00	91.50	95.50	91.60	92.02	2.06	0.95	400	-224.40
8/24/2000	G9572	18	93.20	91.80	92.60	92.90	93.80	92.86	0.74	1.05	400	224.40
8/24/2000	G9572	19	93.60	91.60	92.00	91.20	91.60	92.00	0.94	1.02	251	56.32
8/25/2000	G9572	20	93.20	91.00	93.30	91.80	93.20	92.50	1.04	1.04	400	179.52
8/25/2000	G9572	21	91.60	92.20	91.50	91.00	93.60	91.98	1.00	1.02	400	89.76
8/25/2000	G9572	22	91.90	92.70	92.00	92.20	93.70	92.50	0.74	1.05	400	224.40
8/25/2000	G9572	23	93.20	93.20	93.50	91.20	91.70	92.56	1.04	1.04	400	179.52

Table C12 Contract 5851 QA Density Results Continued.

Date Paved	Mix Design	Lot #	Random Tests 1	2	3	4	5	Average	Standard Deviation	Lot Pay Factor	Tonnage	Lot Bonus
8/25/2000	G9572	24	94.00	93.50	93.00	92.30	92.10	92.98	0.80	1.05	367	205.89
8/25/2000	G9572	25	91.30	92.70	91.60	92.40	92.40	92.08	0.60	1.05	400	224.40
8/25/2000	G9572	26	91.60	91.60	91.30	91.40	91.10	91.40	0.21	1.05	230	129.03
8/28/2000	G9572	27	92.60	93.10	91.80	93.70	92.30	92.70	0.73	1.05	400	224.40
8/28/2000	G9572	28	92.10	92.30	92.80	91.30	91.50	92.00	0.61	1.04	400	179.52
8/28/2000	G9572	29	91.30	91.40	91.50	94.60	94.00	92.56	1.60	1.02	400	89.76
8/28/2000	G9572	30	95.00	94.20	93.60	94.60	93.60	94.20	0.62	1.05	400	224.40
8/28/2000	G9572	31	93.60	93.40	93.30	93.60	93.40	93.46	0.13	1.05	400	224.40
8/28/2000	G9572	32	93.70	93.60	92.20	92.90	92.80	93.04	0.62	1.05	75	42.08
9/6/2000	G9572	33	91.20	92.70	93.50	93.40	94.80	93.12	1.31	1.04	400	179.52
9/6/2000	G9572	34	94.20	93.50	94.00	94.00	94.00	93.94	0.26	1.05	400	224.40
9/7/2000	G9572	35	90.30	90.60	92.70	92.30	93.70	91.92	1.44	0.98	400	-89.76
9/7/2000	G9572	36	91.00	93.90	93.90	90.60	91.70	92.22	1.58	0.99	227	-25.47
9/7/2000	G9572	37	92.70	92.40	92.50	93.30	92.90	92.76	0.36	1.05	400	224.40
9/7/2000	G9572	38	91.90	93.40	92.50	93.00	93.20	92.80	0.60	1.05	308	172.79
9/8/2000	G9572	39	92.20	92.90	92.90	92.90	92.70	92.72	0.30	1.05	344	192.98
9/8/2000	G9572	40	92.30	93.00	93.40	92.90	93.40	93.00	0.45	1.05	308	172.79
9/8/2000	G9572	41	91.30	91.40	92.30	92.30	91.30	91.72	0.53	1.04	400	179.52
9/8/2000	G9572	42	92.20	93.20	92.70	94.20	91.60	92.78	0.99	1.05	400	224.40
9/8/2000	G9572	43	92.00	92.50	91.50	91.30	91.20	91.70	0.54	1.04	400	179.52
9/8/2000	G9572	44	91.80	94.90	92.40	93.10	92.80	93.00	1.17	1.05	105	58.91
9/9/2000	G9572	45	92.80	93.80	93.40	91.60	95.20	93.36	1.32	1.05	400	224.40
9/9/2000	G9572	46	90.10	90.30	93.20	91.50	90.30	91.08	1.31	0.84	400	-718.08
9/9/2000	G9572	47	92.00	91.50	91.20	91.20	91.30	91.44	0.34	1.04	400	179.52
9/9/2000	G9572	48	93.00	94.50	92.80	91.30	94.10	93.14	1.25	1.05	400	224.40
9/9/2000	G9572	49	92.90	93.60	92.90	93.30	92.20	92.98	0.53	1.05	400	224.40
9/9/2000	G9572	50	92.00	91.60	92.00	93.60	92.20	92.28	0.77	1.04	400	179.52
Totals								**92.54**	**1.37**	**0.984**	**26177**	**-6922.69**

$30.60/tonne (G9577) Class 12.5 mm Superpave MTV: None

$28.05/tonne (G9572)

Profile #1 ΔT=40°F	Average Readings (pcf)
Average	145.1
Maximum	149.9
Minimum	140.1
	Ranges
Max-Min	9.8
Ave-Min	5.0

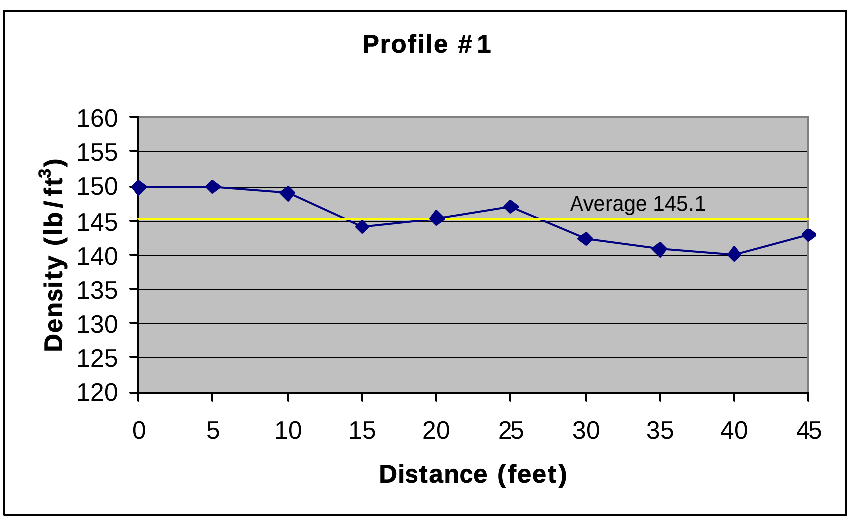


Figure C12-a. Contract 5851 Density Profile #1.

Profile #2	Average
ΔT=36°F	Readings (pcf)
Average	150.2
Maximum	156.5
Minimum	145.2
	Ranges
Max-Min	11.3
Ave-Min	5.0

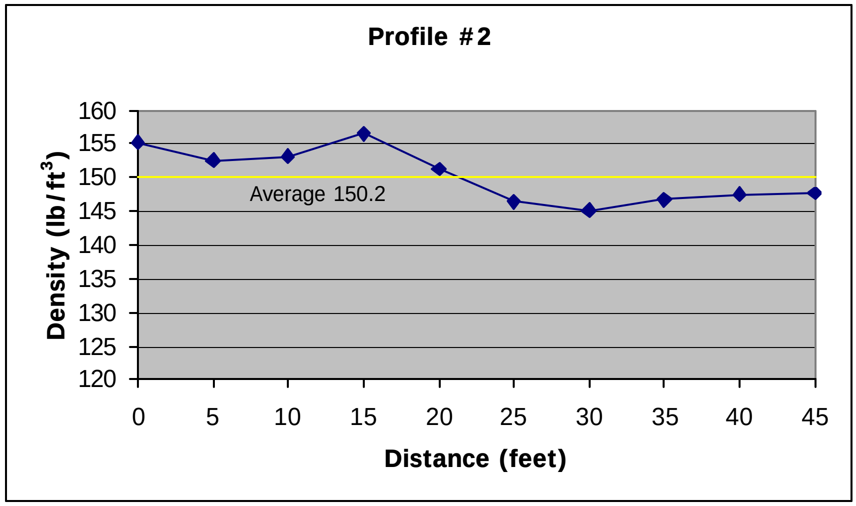


Figure C12-b. Contract 5851 Density Profile #2.

Profile #3	Average
ΔT=40°F	Readings (pcf)
Average	147.9
Maximum	153.1
Minimum	142.7
	Ranges
Max-Min	10.4
Ave-Min	5.2

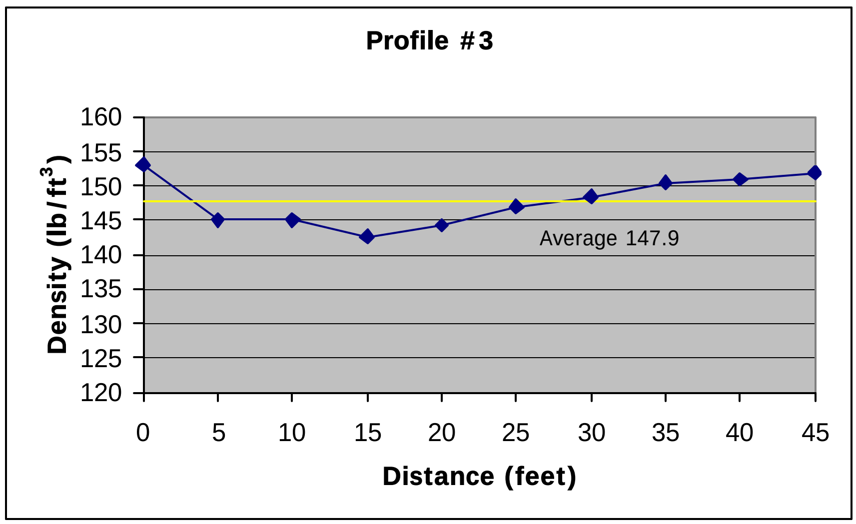


Figure C12-c. Contract 5851 Density Profile #3.

Profile #4	Average
ΔT=40°F	Readings (pcf)
Average	147.3
Maximum	153.4
Minimum	140.1
	Ranges
Max-Min	13.3
Ave-Min	7.2

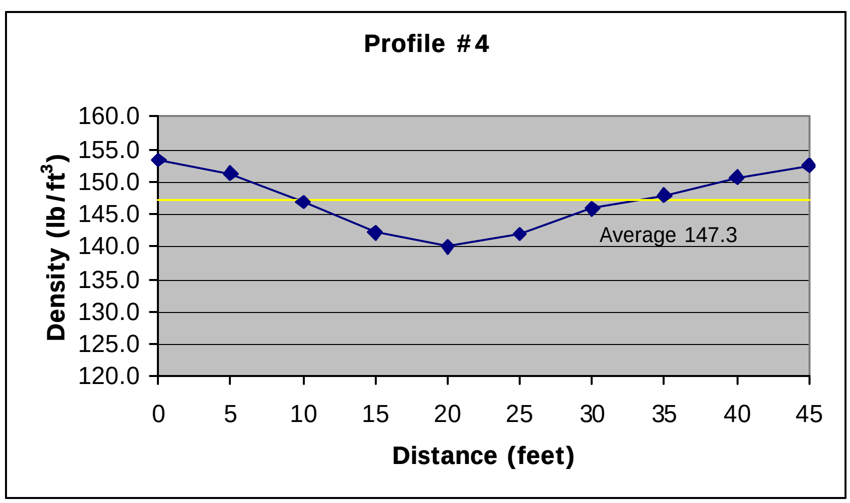


Figure C12-d. Contract 5851 Density Profile #4.

Profile #5	Average
ΔT=13°F	Readings (pcf)
Average	147.3
Maximum	149.9
Minimum	144.0
	Ranges
Max-Min	5.9
Ave-Min	3.3

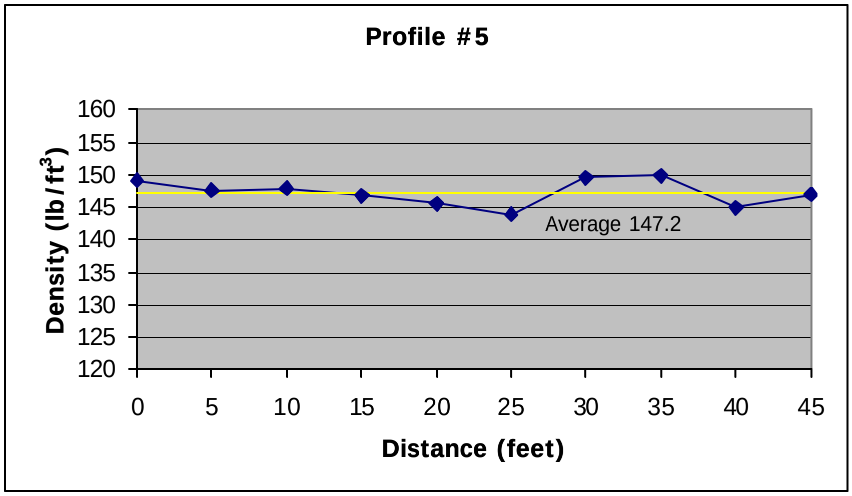


Figure C12-e. Contract 5851 Density Profile #5.

Table C13. Contract 5862 QA Density Results.

Date Paved	Mix Design	Lot #	Random Tests 1	2	3	4	5	Average	Standard Deviation	Lot Pay Factor	Tonnage	Lot Bonus
7/24/2000	G9537	1	95.90	92.60	92.10	94.20	94.50	93.86	1.53	1.05	400	222.80
7/24/2000	G9537	2	92.10	94.40	93.60	94.70	92.80	93.52	1.08	1.05	400	222.80
7/24/2000	G9537	3	92.40	94.30	93.30	92.40	93.20	93.12	0.79	1.05	400	222.80
7/24/2000	G9537	4	95.10	91.40	93.70	93.90	93.70	93.56	1.34	1.05	202	112.51
7/26/2000	G9537	5	91.90	91.80	92.10	93.60	93.60	92.60	0.92	1.05	400	222.80
7/26/2000	G9537	6	91.80	92.90	91.10	91.40	91.70	91.78	0.68	1.03	400	133.68
7/26/2000	G9537	7	91.60	91.10	91.80	91.70	91.10	91.46	0.34	1.04	400	178.24
7/26/2000	G9537	8	91.40	92.80	91.10	91.60	93.10	92.00	0.89	1.03	400	133.68
7/26/2000	G9537	9	91.30	91.70	91.30	91.80	91.10	91.44	0.30	1.04	281	125.21
7/27/2000	G9537	10	91.40	91.80	91.10	92.30	91.30	91.58	0.48	1.03	400	133.68
7/27/2000	G9537	11	93.70	92.10	93.70	92.60	91.40	92.70	1.01	1.05	400	222.80
7/27/2000	G9537	12	91.60	91.30	94.90	92.90	92.50	92.64	1.42	1.03	108	36.09
7/28/2000	G9537	13	91.00	91.70	92.30	91.50	91.00	91.50	0.54	1.01	400	44.56
7/28/2000	G9537	14	91.70	91.10	92.60	91.20	91.90	91.70	0.60	1.03	400	133.68
7/28/2000	G9537	15	91.50	91.10	92.30	93.90	94.60	92.68	1.52	1.03	400	133.68
7/28/2000	G9537	16	91.40	91.20	92.30	91.80	92.60	91.86	0.59	1.04	400	178.24
7/28/2000	G9537	17	91.60	94.10	92.70	91.30	93.90	92.72	1.28	1.04	400	178.24
7/28/2000	G9537	18	92.00	91.40	91.60	91.60	93.70	92.06	0.94	1.03	144	48.12
7/31/2000	G9537	19	91.80	93.90	91.60	91.60	91.40	92.06	1.04	1.02	400	89.12
7/31/2000	G9537	20	95.10	95.40	93.70	90.70	92.80	93.54	1.91	1.04	400	178.24
7/31/2000	G9537	21	94.00	92.00	91.50	92.50	92.70	92.54	0.94	1.04	400	178.24
7/31/2000	G9537	22	92.10	92.20	92.30	94.70	92.10	92.68	1.13	1.04	400	178.24
7/31/2000	G9537	23	92.90	91.20	92.50	91.60	94.90	92.62	1.44	1.03	400	133.68
8/1/2000	G9537	24	91.40	92.90	92.00	91.40	91.60	91.86	0.63	1.04	400	178.24
8/1/2000	G9537	25	94.40	92.90	94.40	92.00	92.30	93.20	1.14	1.05	340	189.38
8/1/2000	G9537	26	93.70	91.40	93.30	92.00	91.00	92.28	1.18	1.03	400	133.68
8/1/2000	G9537	27	91.40	91.40	92.50	91.40	94.10	92.16	1.18	1.02	400	89.12
8/1/2000	G9537	28	91.40	92.00	91.50	93.60	92.60	92.22	0.91	1.04	240	106.94
8/1/2000	G9537	29	91.10	91.40	92.00	91.60	92.00	91.62	0.39	1.04	240	106.94
8/2/2000	G9537	30	91.50	92.10	92.10	93.00	91.30	92.00	0.66	1.04	400	178.24
8/2/2000	G9537	31	92.50	91.80	92.80	92.80	93.50	92.68	0.61	1.05	400	222.80
8/2/2000	G9537	32	91.50	91.60	91.00	91.90	93.10	91.82	0.79	1.02	400	89.12
8/2/2000	G9537	33	91.60	91.10	92.80	92.20	91.60	91.86	0.65	1.04	400	178.24
8/2/2000	G9537	34	91.10	92.20	92.30	93.60	91.70	92.18	0.93	1.03	400	133.68
8/2/2000	G9537	35	91.00	91.30	91.90	92.30	91.70	91.64	0.51	1.03	170	56.81
8/3/2000	G9537	36	92.20	92.30	92.20	91.70	91.80	92.04	0.27	1.05	400	222.80
8/3/2000	G9537	37	92.10	92.50	91.80	92.30	91.20	91.98	0.51	1.05	400	222.80
8/3/2000	G9537	38	91.80	91.40	91.30	91.80	91.60	91.58	0.23	1.05	400	222.80
8/3/2000	G9537	39	92.00	92.30	91.50	91.30	91.30	91.68	0.45	1.04	400	178.24
8/3/2000	G9537	40	91.40	91.60	95.10	93.00	91.30	92.48	1.62	1.01	400	44.56
8/3/2000	G9537	41	91.00	95.50	91.20	92.30	91.40	92.28	1.87	1.00	433	0.00
8/4/2000	G9537	42	91.30	91.00	91.00	92.20	91.20	91.34	0.50	1.00	400	0.00
8/4/2000	G9537	43	93.10	91.00	91.50	91.90	92.10	91.92	0.78	1.03	400	133.68
8/4/2000	G9537	44	92.50	92.30	93.60	91.40	91.30	92.22	0.94	1.04	400	178.24
8/4/2000	G9537	45	91.10	91.30	91.10	91.00	91.20	91.14	0.11	1.03	400	133.68
8/4/2000	G9537	46	91.10	91.00	92.40	91.40	90.80	91.34	0.63	0.96	260	-115.86
8/7/2000	G9537	47	91.20	93.00	91.10	91.50	92.20	91.80	0.80	1.02	400	89.12
8/7/2000	G9537	48	91.20	91.10	92.30	92.00	92.90	91.90	0.76	1.03	400	133.68
8/7/2000	G9537	49	91.10	91.60	91.00	91.60	92.40	91.54	0.55	1.02	400	89.12

Table C13 Contract 5862 QA Density Results Continued.

Date Paved	Mix Design	Lot #	Random Tests 1	2	3	4	5	Average	Standard Deviation	Lot Pay Factor	Tonnage	Lot Bonus
8/7/2000	G9537	50	91.90	91.70	92.00	92.10	92.70	92.08	0.38	1.05	400	222.80
8/7/2000	G9537	51	91.10	92.50	91.00	91.10	91.10	91.36	0.64	1.00	400	0.00
8/7/2000	G9537	52	91.00	91.10	91.40	91.30	91.20	91.20	0.16	1.03	346	115.63
8/8/2000	G9537	53	91.80	91.20	91.80	91.40	91.30	91.50	0.28	1.05	400	222.80
8/8/2000	G9537	54	91.30	91.10	92.20	91.00	91.10	91.34	0.49	1.00	238	0.00
8/9/2000	G9537	55	92.10	94.70	93.00	93.70	91.50	93.00	1.27	1.04	400	178.24
8/9/2000	G9537	56	91.20	92.00	92.20	91.60	92.30	91.86	0.46	1.05	400	222.80
8/9/2000	G9537	57	91.00	91.70	91.80	91.30	91.30	91.42	0.33	1.04	400	178.24
8/9/2000	G9537	58	91.30	91.50	91.70	93.40	91.00	91.78	0.94	1.00	400	0.00
8/9/2000	G9537	59	91.80	91.40	91.50	91.20	91.20	91.42	0.25	1.05	339	188.82
8/10/2000	G9537	60	91.00	91.20	92.10	92.20	91.20	91.54	0.56	1.02	400	89.12
8/10/2000	G9537	61	92.60	92.30	91.40	91.20	91.20	91.74	0.66	1.03	400	133.68
8/10/2000	G9537	62	91.70	91.10	91.30	91.30	91.00	91.28	0.27	1.02	400	89.12
8/10/2000	G9537	63	93.00	91.70	92.70	91.50	91.50	92.08	0.72	1.04	400	178.24
8/10/2000	G9537	64	91.30	91.40	92.00	91.60	91.90	91.64	0.30	1.05	400	222.80
8/11/2000	G9537	65	91.40	91.10	92.70	91.10	91.10	91.48	0.69	1.00	400	0.00
8/11/2000	G9537	66	91.30	92.20	92.50	92.60	91.70	92.06	0.55	1.05	400	222.80
8/11/2000	G9537	67	92.30	91.10	92.60	91.50	92.30	91.96	0.63	1.04	400	178.24
8/11/2000	G9537	68	91.30	91.50	91.60	91.00	91.60	91.40	0.25	1.04	400	178.24
8/11/2000	G9537	69	91.40	92.70	91.20	92.10	91.80	91.84	0.59	1.04	253	112.74
8/14/2000	G9537	70	91.20	91.30	92.00	93.20	92.20	91.98	0.81	1.03	400	133.68
8/14/2000	G9537	71	91.90	91.60	91.40	92.00	93.60	92.10	0.87	1.03	400	133.68
8/14/2000	G9537	72	92.00	91.20	93.40	92.10	91.90	92.12	0.80	1.04	400	178.24
8/14/2000	G9537	73	92.00	92.60	91.80	91.00	91.20	91.72	0.64	1.03	400	133.68
8/14/2000	G9537	74	92.60	91.30	91.70	91.20	91.60	91.68	0.55	1.03	400	133.68
8/15/2000	G9537	75	91.00	91.20	91.70	91.40	91.90	91.44	0.36	1.03	400	133.68
8/15/2000	G9537	76	91.20	91.30	91.70	92.00	92.10	91.66	0.40	1.04	400	178.24
8/15/2000	G9537	77	91.90	91.40	91.90	92.00	91.60	91.76	0.25	1.05	332	184.92
8/16/2000	G9537	78	91.10	91.80	91.00	91.50	92.00	91.48	0.43	1.03	260	86.89
8/16/2000	G9537	79	91.50	93.70	92.00	92.60	91.30	92.22	0.97	1.03	303	101.26
9/28/2000	G9616	1	93.30	93.80	95.60	93.00	94.00	93.94	1.01	1.05	400	222.80
9/28/2000	G9616	2	92.00	94.80	92.40	95.90	96.10	94.24	1.93	1.05	400	222.80
9/28/2000	G9616	3	96.00	95.90	94.00	94.60	94.50	95.00	0.90	1.05	400	222.80
9/28/2000	G9616	4	94.30	93.80	93.10	93.50	91.90	93.32	0.91	1.05	400	222.80
9/28/2000	G9616	5	94.70	91.80	93.10	92.20	94.40	93.24	1.29	1.05	400	222.80
9/28/2000	G9616	6	95.10	91.50	95.30	91.60	93.30	93.36	1.83	1.04	400	178.24
9/28/2000	G9616	7	93.80	95.20	94.00	92.30	92.30	93.52	1.24	1.05	242	134.79
9/29/2000	G9616	8	93.70	91.50	92.40	94.90	92.60	93.02	1.31	1.04	400	178.24
9/29/2000	G9616	9	95.30	92.60	96.00	92.60	93.90	94.08	1.55	1.05	345	192.17
10/2/2000	G9616	10	92.10	91.50	91.50	91.00	92.50	91.72	0.58	1.03	400	133.68
10/2/2000	G9616	11	91.00	91.10	91.80	91.50	92.50	91.58	0.61	1.02	400	89.12
10/2/2000	G9616	12	93.40	92.10	91.00	91.90	92.20	92.12	0.86	1.04	400	178.24
10/2/2000	G9616	13	91.60	91.80	92.70	91.00	93.90	92.20	1.13	1.02	400	89.12
10/2/2000	G9616	14	91.50	94.10	93.80	93.50	93.10	93.20	1.02	1.05	400	222.80
10/2/2000	G9616	15	92.20	93.50	91.70	93.40	93.00	92.76	0.78	1.05	400	222.80
10/2/2000	G9616	16	91.00	91.70	91.50	93.00	94.00	92.24	1.23	1.02	400	89.12
10/3/2000	G9616	17	91.90	91.50	91.30	93.20	92.00	91.98	0.74	1.04	400	178.24
10/3/2000	G9616	18	92.30	91.50	92.50	93.40	92.60	92.46	0.68	1.05	400	222.80

Table C13 Contract 5862 QA Density Results Continued.

Date Paved	Mix Design	Lot #	Random Tests 1	2	3	4	5	Average	Standard Deviation	Lot Pay Factor	Tonnage	Lot Bonus
10/3/2000	G9616	19	91.70	92.20	92.00	92.00	92.20	92.02	0.20	1.05	400	222.80
10/3/2000	G9616	20	91.60	93.40	91.90	92.70	92.50	92.42	0.70	1.05	400	222.80
10/3/2000	G9616	21	91.90	91.60	92.70	92.00	92.00	92.04	0.40	1.05	400	222.80
10/3/2000	G9616	22	92.40	93.00	92.20	93.20	92.00	92.56	0.52	1.05	400	222.80
10/3/2000	G9616	23	91.80	91.70	92.20	91.50	91.20	91.68	0.37	1.05	314	174.90
10/4/2000	G9616	24	92.90	92.90	94.40	94.30	91.50	93.20	1.20	1.05	400	222.80
10/4/2000	G9616	25	92.50	92.20	91.00	92.00	91.40	91.82	0.61	1.04	400	178.24
10/4/2000	G9616	26	91.80	91.20	92.50	91.30	91.70	91.70	0.51	1.04	400	178.24
10/4/2000	G9616	27	91.60	91.50	92.70	92.00	91.70	91.90	0.48	1.05	400	222.80
10/4/2000	G9616	28	91.00	92.10	92.90	92.70	92.00	92.14	0.74	1.04	400	178.24
10/4/2000	G9616	29	92.40	94.70	91.70	92.20	92.90	92.78	1.16	1.04	348	155.07
10/5/2000	G9616	30	93.20	93.60	91.80	93.70	91.40	92.74	1.07	1.04	400	178.24
10/5/2000	G9616	31	91.60	92.10	91.10	94.40	92.60	92.36	1.27	1.02	400	89.12
10/5/2000	G9616	32	92.10	91.90	91.60	94.70	92.40	92.54	1.24	1.03	400	133.68
10/5/2000	G9616	33	93.20	91.40	93.90	93.80	93.80	93.22	1.05	1.05	400	222.80
10/5/2000	G9616	34	92.30	91.70	92.70	91.60	91.10	91.88	0.63	1.04	400	178.24
10/5/2000	G9616	35	93.30	92.00	93.80	93.20	91.10	92.68	1.10	1.04	400	178.24
10/5/2000	G9616	36	91.30	91.90	92.60	91.30	91.80	91.78	0.54	1.04	400	178.24
10/5/2000	G9616	37	92.00	92.70	92.50	91.40	91.30	91.98	0.63	1.04	299	133.23
10/6/2000	G9616	38	92.40	92.20	91.90	92.30	91.60	92.08	0.33	1.05	400	222.80
10/6/2000	G9616	39	92.30	93.20	91.60	92.30	91.90	92.26	0.60	1.05	400	222.80
10/6/2000	G9616	40	92.00	93.40	92.20	91.10	91.80	92.10	0.84	1.04	400	178.24
10/6/2000	G9616	41	92.30	93.30	92.00	91.20	93.00	92.36	0.83	1.04	400	178.24
10/6/2000	G9616	42	94.40	92.60	92.60	91.50	93.80	92.98	1.14	1.05	400	222.80
10/6/2000	G9616	43	92.00	91.60	93.40	92.00	93.50	92.50	0.88	1.05	303	168.77
10/9/2000	G9616	44	93.00	91.30	93.10	94.30	92.20	92.78	1.12	1.04	400	178.24
10/9/2000	G9616	45	92.50	93.80	93.00	92.30	92.10	92.74	0.68	1.05	400	222.80
10/9/2000	G9616	46	91.50	93.50	93.70	92.50	92.90	92.82	0.88	1.05	400	222.80
10/9/2000	G9616	47	93.60	92.80	93.00	91.80	93.20	92.88	0.67	1.05	400	222.80
10/9/2000	G9616	48	91.60	91.80	93.10	91.90	91.90	92.06	0.59	1.05	400	222.80
10/9/2000	G9616	49	91.90	92.70	93.50	91.80	94.90	92.96	1.28	1.04	235	104.72
10/10/2000	G9616	50	92.10	92.30	91.60	93.50	94.50	92.80	1.18	1.04	400	178.24
10/10/2000	G9616	51	93.50	95.10	93.50	93.10	92.50	93.54	0.96	1.05	400	222.80
10/10/2000	G9616	52	93.50	93.30	92.00	91.80	92.40	92.60	0.76	1.05	400	222.80
10/10/2000	G9616	53	93.00	92.40	91.80	91.70	92.30	92.24	0.52	1.05	400	222.80
10/10/2000	G9616	54	92.30	92.90	92.40	91.50	92.20	92.26	0.50	1.05	400	222.80
10/11/2000	G9616	55	92.10	92.40	92.50	92.70	94.60	92.86	1.00	1.05	400	222.80
10/11/2000	G9616	56	93.40	93.20	93.50	91.70	92.80	92.92	0.73	1.05	400	222.80
10/11/2000	G9616	57	93.20	93.10	92.90	92.40	93.20	92.96	0.34	1.05	400	222.80
10/11/2000	G9616	58	92.20	92.60	92.20	92.50	93.30	92.56	0.45	1.05	400	222.80
10/11/2000	G9616	59	92.20	92.20	93.50	91.30	92.30	92.30	0.78	1.04	400	178.24
10/11/2000	G9616	60	92.30	93.30	92.50	91.70	92.00	92.36	0.61	1.05	400	222.80
10/11/2000	G9616	61	93.30	92.10	94.00	92.90	94.30	93.32	0.88	1.05	142	79.09
10/12/2000	G9616	62	91.80	93.70	92.10	93.20	93.20	92.80	0.81	1.05	400	222.80
10/12/2000	G9616	63	92.10	93.80	91.10	92.50	92.60	92.42	0.97	1.04	400	178.24
10/12/2000	G9616	64	91.60	92.40	93.10	93.70	92.80	92.72	0.79	1.05	400	222.80
10/12/2000	G9616	65	91.50	93.40	92.80	92.20	93.10	92.60	0.76	1.05	400	222.80
10/12/2000	G9616	66	94.70	94.50	93.00	92.20	91.40	93.16	1.43	1.04	400	178.24

Table C13 Contract 5862 QA Density Results Continued.

Date Paved	Mix Design	Lot #	Random Tests 1	2	3	4	5	Average	Standard Deviation	Lot Pay Factor	Tonnage	Lot Bonus
10/12/2000	G9616	67	92.60	92.20	92.60	91.00	91.90	92.06	0.66	1.04	400	178.24
10/12/2000	G9616	68	92.00	93.30	93.60	91.40	93.20	92.70	0.95	1.05	414	230.60
10/13/2000	G9616	69	91.90	91.60	92.00	93.60	93.60	92.54	0.98	1.04	400	178.24
10/13/2000	G9616	70	93.50	93.30	92.20	93.40	93.10	93.10	0.52	1.05	400	222.80
10/13/2000	G9616	71	95.50	93.60	92.60	91.90	92.20	93.16	1.46	1.04	400	178.24
10/13/2000	G9616	72	92.30	92.30	92.30	92.70	93.80	92.68	0.65	1.05	400	222.80
10/13/2000	G9616	73	92.20	92.30	91.90	91.80	92.40	92.12	0.26	1.05	400	222.80
10/13/2000	G9616	74	92.10	93.90	94.30	93.20	92.70	93.24	0.89	1.05	400	222.80
10/13/2000	G9616	75	92.40	93.60	93.60	92.90	92.90	93.08	0.52	1.05	304	169.33
10/16/2000	G9616	76	91.50	92.00	93.40	93.00	91.80	92.34	0.82	1.04	400	178.24
10/16/2000	G9616	77	93.30	92.70	94.90	93.40	91.70	93.20	1.17	1.05	400	222.80
10/16/2000	G9616	78	91.50	91.20	91.80	91.80	93.20	91.90	0.77	1.03	400	133.68
10/16/2000	G9616	79	92.60	92.70	92.50	93.40	92.60	92.76	0.36	1.05	400	222.80
10/16/2000	G9616	80	93.30	92.40	91.70	93.40	93.50	92.86	0.78	1.05	400	222.80
10/16/2000	G9616	81	91.60	93.10	91.80	93.20	93.50	92.64	0.87	1.05	400	222.80
10/16/2000	G9616	82	92.00	91.50	93.60	92.70	94.40	92.84	1.18	1.04	400	178.24
10/16/2000	G9616	83	93.10	93.40	93.50	91.30	94.80	93.22	1.26	1.05	105	58.49
10/17/2000	G9616	84	91.70	91.90	91.90	92.00	91.70	91.84	0.13	1.05	400	222.80
10/17/2000	G9616	85	93.00	93.80	91.30	92.90	91.60	92.52	1.04	1.04	400	178.24
10/17/2000	G9616	86	91.60	93.80	91.50	91.90	93.30	92.42	1.06	1.04	400	178.24
10/17/2000	G9616	87	91.80	92.10	92.30	92.00	91.40	91.92	0.34	1.05	400	222.80
10/17/2000	G9616	88	91.90	92.20	91.50	91.50	93.40	92.10	0.78	1.04	400	178.24
10/17/2000	G9616	89	93.60	91.60	92.50	92.20	93.60	92.70	0.88	1.05	400	222.80
10/17/2000	G9616	90	93.90	92.40	93.10	93.30	92.10	92.96	0.72	1.05	322	179.35
10/18/2000	G9616	91	91.90	93.70	93.00	93.30	92.10	92.80	0.77	1.05	400	222.80
10/18/2000	G9616	92	92.30	94.50	93.40	92.40	92.40	93.00	0.95	1.05	400	222.80
10/18/2000	G9616	93	91.90	93.40	91.40	91.50	91.40	91.92	0.85	1.02	400	89.12
10/18/2000	G9616	94	94.80	93.70	93.70	91.80	93.20	93.44	1.09	1.05	400	222.80
10/18/2000	G9616	95	91.80	92.20	91.40	91.60	92.20	91.84	0.36	1.05	400	222.80
10/18/2000	G9616	96	92.80	91.80	93.10	92.50	93.70	92.78	0.70	1.05	415	231.16
10/19/2000	G9616	97	92.20	92.60	91.30	93.80	91.20	92.22	1.06	1.03	400	133.68
10/19/2000	G9616	98	91.70	92.00	92.50	93.70	92.30	92.44	0.77	1.05	400	222.80
10/19/2000	G9616	99	92.40	91.40	92.00	93.50	93.00	92.46	0.82	1.05	400	222.80
10/19/2000	G9616	100	92.60	92.20	91.60	91.90	92.90	92.24	0.52	1.05	372	207.20
Totals								**92.35**	**1.03**	**1.040**	**67849**	**29965.67**

$27.85/ton (G9537)   Class A   MTV: Roadtec Shuttle Buggy SB-2500

$27.85/ton (G9616)

Profile #1	Average
ΔT=20°F	Readings (pcf)
Average	142.8
Maximum	144.8
Minimum	140.3
	Ranges
Max-Min	4.5
Ave-Min	2.5

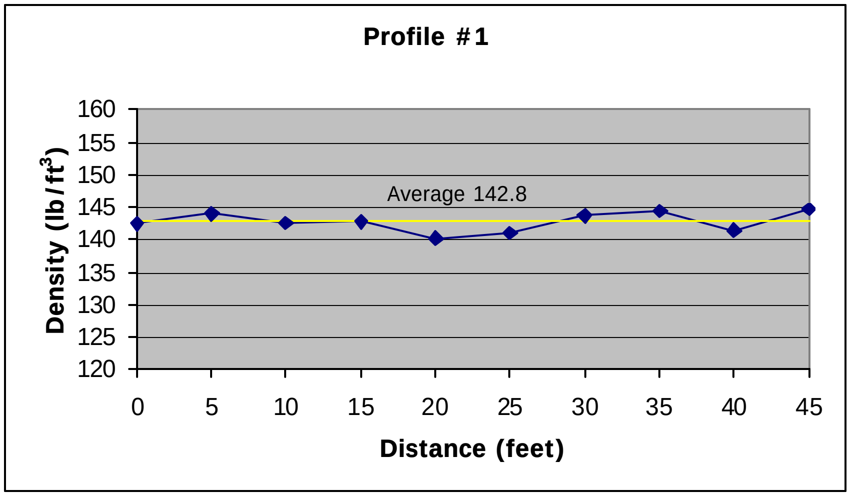


Figure C13-a. Contract 5862 Density Profile #1.

Profile #2	Average
ΔT=15°F	Readings (pcf)
Average	147.4
Maximum	149.1
Minimum	145.5
	Ranges
Max-Min	3.6
Ave-Min	1.9

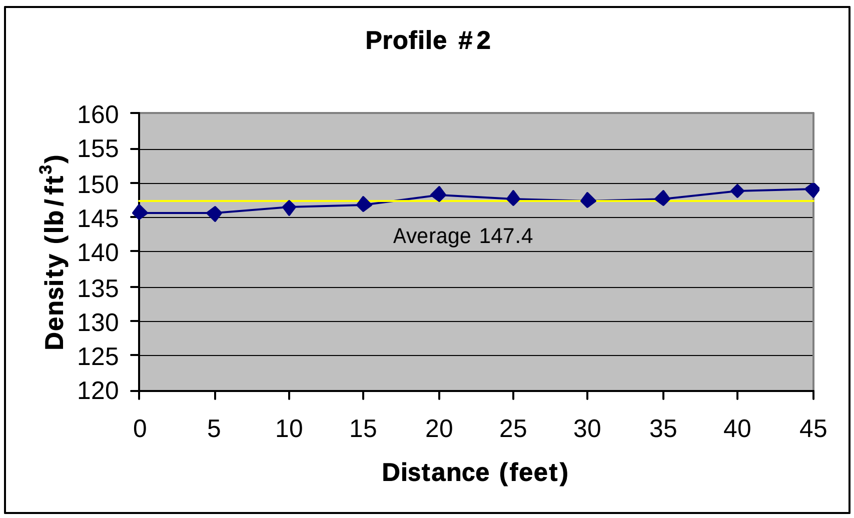


Figure C13-b. Contract 5862 Density Profile #2.

Profile #3	Average
ΔT=16°F	Readings (pcf)
Average	148.4
Maximum	150.8
Minimum	145.5
	Ranges
Max-Min	5.3
Ave-Min	2.9

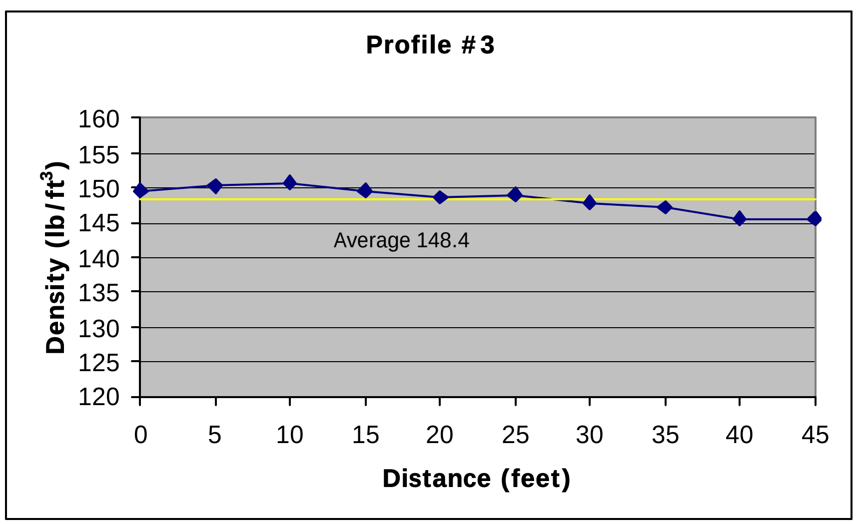


Figure C13-c. Contract 5862 Density Profile #3.

Table C14. Contract 5863 QA Density Results.

Date Paved	Mix Design	Lot #	Random Tests 1	2	3	4	5	Average	Standard Deviation	Lot Pay Factor	Tonnage	Lot Bonus
7/14/2000	G9534	1	91.10	92.80	94.60	94.60	95.70	93.76	1.81	1.04	272	193.66
7/14/2000	G9534	2	95.00	93.90	93.80	93.40	95.20	94.26	0.79	1.05	272	242.08
7/17/2000	G9534	3	95.60	95.10	95.10	96.30	93.80	95.18	0.91	1.05	400	356.00
7/17/2000	G9534	4	93.80	94.10	95.70	96.10	94.50	94.84	1.01	1.05	300	267.00
7/18/2000	G9534	5	95.30	94.90	95.00	94.60	94.20	94.80	0.42	1.05	263	234.07
7/19/2000	G9534	6	96.00	92.70	92.20	92.50	94.40	93.56	1.61	1.04	400	284.80
7/19/2000	G9534	7	94.80	93.20	93.30	95.50	94.30	94.22	0.98	1.05	289	257.21
7/19/2000	G9534	8	90.40	93.90	93.70	94.60	95.40	93.60	1.91	1.04	289	205.77
7/20/2000	G9534	9	95.20	93.90	95.60	93.50	93.50	94.34	0.99	1.05	316	281.24
7/20/2000	G9534	10	93.80	92.70	93.90	94.20	93.50	93.62	0.57	1.05	202	179.78
7/21/2000	G9534	11	90.90	92.90	93.80	91.00	95.40	92.80	1.91	1.01	237	42.19
7/21/2000	G9534	12	95.40	93.10	93.90	93.60	92.10	93.62	1.21	1.05	166	147.74
7/24/2000	G9534	13	94.80	93.70	94.60	94.20	94.20	94.30	0.42	1.05	400	356.00
7/24/2000	G9534	14	95.50	94.30	94.30	94.30	94.10	94.50	0.57	1.05	400	356.00
7/24/2000	G9534	15	95.50	94.10	94.30	94.30	94.80	94.60	0.57	1.05	349	310.61
7/25/2000	G9534	16	93.10	93.10	94.60	94.30	92.70	93.56	0.84	1.05	400	356.00
7/25/2000	G9534	17	93.40	92.70	94.00	89.30	92.90	92.46	1.84	1.00	304	0.00
7/25/2000	G9534	18	94.10	93.10	92.20	91.90	92.00	92.66	0.93	1.05	304	270.56
7/26/2000	G9534	19	92.70	93.70	93.40	92.90	91.80	92.90	0.73	1.05	400	356.00
7/26/2000	G9534	20	91.60	91.90	93.10	92.60	93.40	92.52	0.77	1.05	400	356.00
7/26/2000	G9534	21	92.60	93.60	93.70	94.10	91.00	93.00	1.25	1.04	174	123.89
7/28/2000	G9534	22	92.70	94.00	92.90	92.50	93.00	93.02	0.58	1.05	321	285.69
7/28/2000	G9534	23	91.60	92.10	94.10	92.80	93.20	92.76	0.97	1.05	321	285.69
7/28/2000	G9534	24	91.90	94.10	93.80	93.30	94.10	93.44	0.92	1.05	321	285.69
7/28/2000	G9534	25	94.60	91.30	94.10	93.60	92.90	93.30	1.28	1.05	321	285.69
7/31/2000	G9534	26	94.90	93.30	92.30	92.60	93.60	93.34	1.02	1.05	400	356.00
7/31/2000	G9534	27	93.60	93.60	92.80	93.40	92.40	93.16	0.54	1.05	382	339.98
7/31/2000	G9534	28	93.30	93.00	93.70	94.10	94.60	93.74	0.63	1.05	382	339.98
8/1/2000	G9534	29	93.30	94.00	92.80	94.50	92.20	93.36	0.92	1.05	364	323.96
8/1/2000	G9534	30	93.70	93.90	92.10	93.70	92.60	93.20	0.80	1.05	396	352.44
8/1/2000	G9534	31	93.00	94.30	94.10	94.10	92.60	93.62	0.77	1.05	396	352.44
8/2/2000	G9534	32	91.90	91.50	93.70	91.10	91.00	91.84	1.10	1.00	211	0.00
8/2/2000	G9534	33	95.40	92.50	90.70	90.90	91.80	92.26	1.90	0.98	143	-50.91
8/3/2000	G9534	34	93.30	91.20	91.70	91.10	91.60	91.78	0.89	1.01	195	34.71
Totals								**93.47**	**1.29**	**1.042**	**10690**	**8367.96**

$44.50/tonne Class A MTV: Roadtec Shuttle Buggy SB-2500

Profile #1	Average
$\Delta T=30^oF$	Readings (pcf)
Average	141.8
Maximum	144.2
Minimum	139.2
	Ranges
Max-Min	5.0
Ave-Min	2.6

Figure C14-a. Contract 5863 Density Profile #1.

Profile #2	Average
$\Delta T=10^oF$	Readings (pcf)
Average	137.6
Maximum	139.1
Minimum	135.5
	Ranges
Max-Min	3.6
Ave-Min	2.1

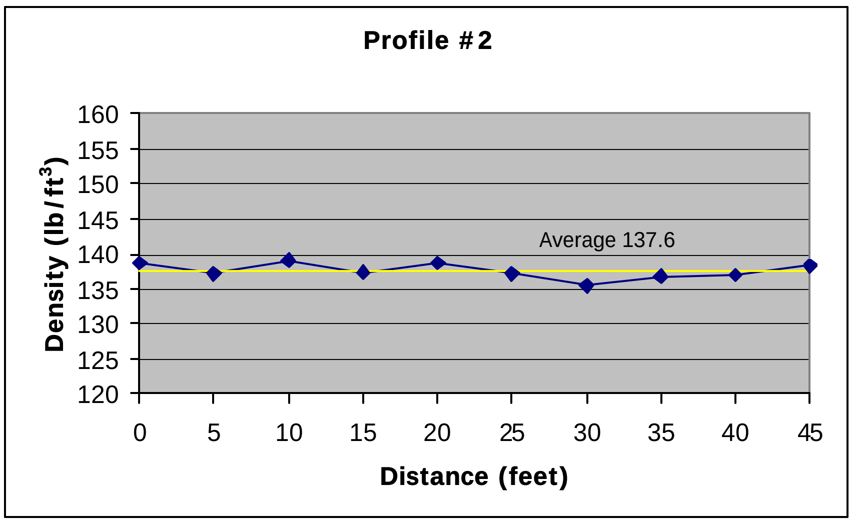


Figure C14-b. Contract 5863 Density Profile #2.

Profile #3	Average
$\Delta T=11^oF$	Readings (pcf)
Average	140.7
Maximum	142.9
Minimum	138.4
	Ranges
Max-Min	4.5
Ave-Min	2.3

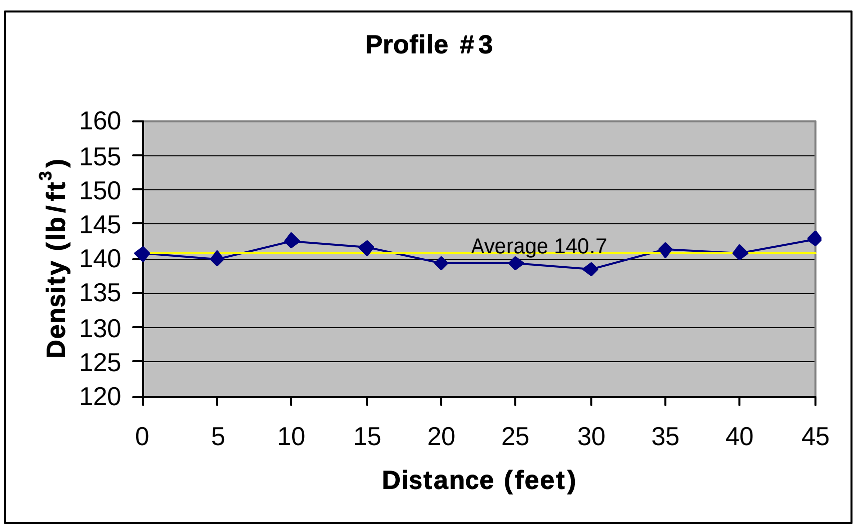


Figure C14-c. Contract 5863 Density Profile #3.

Table C15. Contract 5871 QA Density Results.

Date Paved	Mix Design	Lot #	Random Tests 1	2	3	4	5	Average	Standard Deviation	Lot Pay Factor	Tonnage	Lot Bonus
8/14/2000	G9437	1	92.40	92.80	93.60	94.30	90.90	92.80	1.29	1.04	106	66.99
8/14/2000	G9437	2	90.50	90.70	93.30	91.40	91.60	91.50	1.11	0.94	391	-370.67
8/14/2000	G9437	3	93.40	90.50	93.60	93.30	94.30	93.02	1.46	1.04	350	221.20
8/14/2000	G9437	4	92.10	92.10	93.30	92.40	91.60	92.30	0.63	1.05	174	137.46
8/14/2000	G9437	5	91.80	92.20	92.40	91.60	91.80	91.96	0.33	1.05	283	223.57
8/15/2000	G9437	6	93.60	94.60	92.70	93.10	94.50	93.70	0.84	1.05	400	316.00
8/16/2000	G9437	7	91.70	93.00	93.10	94.40	92.60	92.96	0.98	1.05	400	316.00
8/16/2000	G9437	8	92.60	92.90	95.00	93.50	94.30	93.66	0.99	1.05	276	218.04
8/16/2000	G9437	9	93.50	93.50	93.10	92.30	92.00	92.88	0.69	1.05	400	316.00
8/16/2000	G9437	10	93.10	93.00	93.50	93.20	93.50	93.26	0.23	1.05	400	316.00
8/17/2000	G9437	11	93.00	94.70	94.00	93.40	91.30	93.28	1.28	1.05	321	253.59
8/17/2000	G9437	12	93.40	93.00	94.00	91.70	93.70	93.16	0.90	1.05	400	316.00
8/17/2000	G9437	13	94.10	93.30	92.50	94.60	94.00	93.70	0.82	1.05	400	316.00
8/17/2000	G9437	14	92.50	93.20	94.30	92.30	93.80	93.22	0.85	1.05	190	150.10
9/15/2000	G9437	15	94.20	93.30	95.00	93.90	93.00	93.88	0.79	1.05	372	293.88
9/15/2000	G9437	16	93.90	95.10	94.60	94.70	92.00	94.06	1.23	1.05	418	330.22
9/15/2000	G9437	17	93.70	95.10	93.50	93.50	93.90	93.94	0.67	1.05	161	127.19
9/19/2000	G9437	18	93.30	94.50	94.00	94.10	92.80	93.74	0.68	1.05	393	310.47
9/19/2000	G9437	19	94.90	94.40	92.90	95.10	93.40	94.14	0.96	1.05	402	317.58
9/19/2000	G9437	20	94.80	94.00	94.90	94.40	94.20	94.46	0.38	1.05	260	205.40
9/19/2000	G9437	21	92.90	95.70	94.10	94.80	94.60	94.42	1.03	1.05	250	197.50
9/20/2000	G9437	22	93.90	93.10	92.80	94.70	94.70	93.84	0.88	1.05	401	316.79
9/20/2000	G9437	23	95.10	95.20	94.50	95.30	92.90	94.60	1.00	1.05	401	316.79
9/20/2000	G9437	24	96.10	95.70	93.50	94.50	94.20	94.80	1.08	1.05	401	316.79
9/20/2000	G9437	25	95.60	94.40	95.30	95.40	94.50	95.04	0.55	1.05	248	195.92
9/21/2000	G9437	26	92.90	92.70	93.00	92.90	95.80	93.46	1.31	1.05	401	316.79
9/21/2000	G9437	27	93.70	93.30	92.60	91.40	92.70	92.74	0.87	1.05	225	177.75
Totals								**93.53**	**1.17**	**1.045**	**8718**	**6152.36**

$39.50/tonne Class A MTV: None

Profile #1	Average
$\Delta T=48^{o}F$	Readings (pcf)
Average	152.7
Maximum	156.4
Minimum	149.8
	Ranges
Max-Min	6.6
Ave-Min	2.9

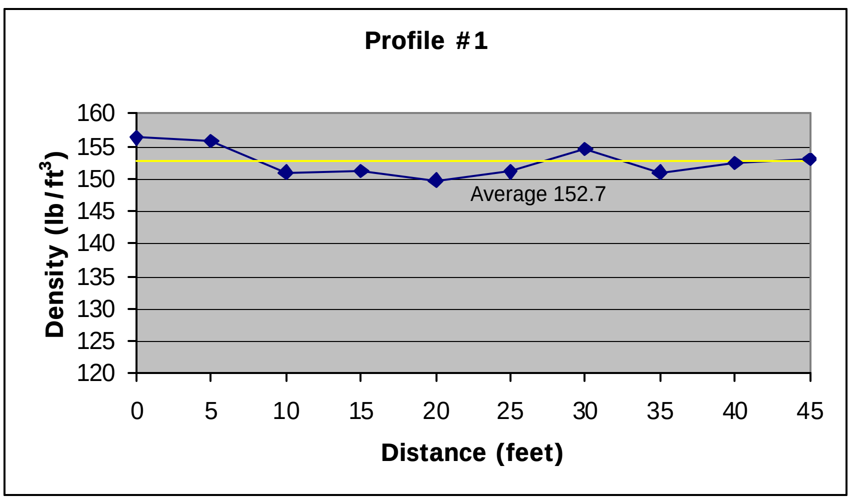


Figure C14-a. Contract 5871 Density Profile #1.

Profile #2	Average
ΔT=37°F	Readings (pcf)
Average	152.6
Maximum	154.4
Minimum	151.4
	Ranges
Max-Min	3.0
Ave-Min	1.2

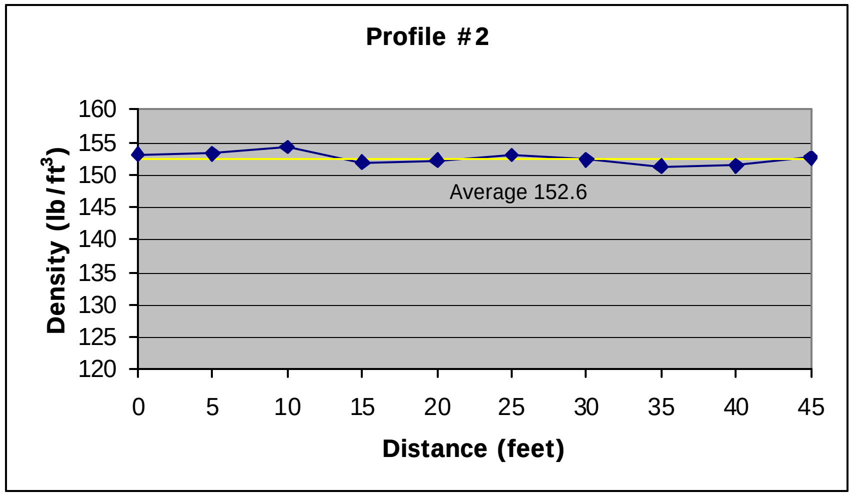


Figure C14-b. Contract 5871 Density Profile #2.

Profile #3	Average
ΔT=53°F	Readings (pcf)
Average	152.1
Maximum	155.7
Minimum	149.0
	Ranges
Max-Min	6.7
Ave-Min	3.1

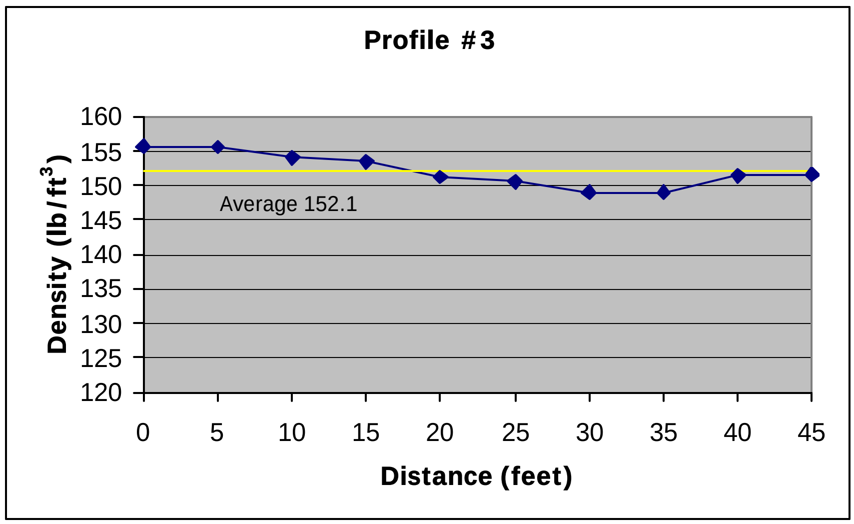


Figure C14-c. Contract 5871 Density Profile #3.

Profile #4	Average
ΔT=72°F	Readings (pcf)
Average	152.0
Maximum	156.0
Minimum	149.0
	Ranges
Max-Min	7.0
Ave-Min	3.0

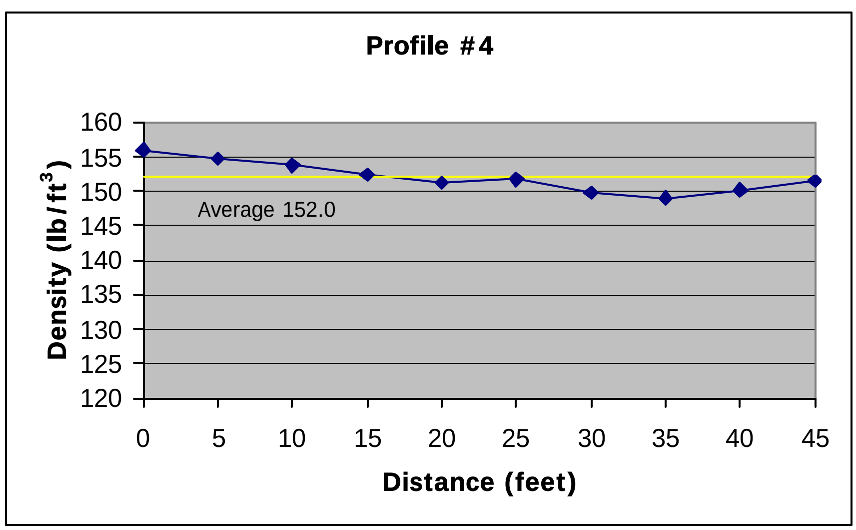


Figure C14-d. Contract 5871 Density Profile #4.

Table C15. Contract 5879 QA Density Results.

Date	Mix	Lot	Random Tests						Standard	Lot Pay		Lot
Paved	Design	#	1	2	3	4	5	Average	Deviation	Factor	Tonnage	Bonus
7/24/2000	9507	1	96.00	98.40	96.40	95.20	96.40	96.48	1.18	1.05	400	300.00
7/24/2000	9507	2	93.90	94.70	95.00	91.80	94.80	94.04	1.32	1.05	355	266.25
7/24/2000	9507	3	93.00	91.80	96.30	95.20	93.90	94.04	1.77	1.05	184	138.00
7/25/2000	9507	4	94.30	95.50	95.90	94.70	95.70	95.22	0.69	1.05	400	300.00
7/25/2000	9507	5	95.80	94.70	95.20	94.40	92.80	94.58	1.13	1.05	400	300.00
7/25/2000	9507	6	94.40	91.50	96.30	94.40	92.80	93.88	1.82	1.04	418	250.80
7/26/2000	9507	7	93.20	92.20	95.30	94.10	93.80	93.72	1.14	1.05	400	300.00
7/26/2000	9507	8	94.80	93.50	94.10	95.40	95.60	94.68	0.88	1.05	400	300.00
7/26/2000	9507	9	95.00	93.90	92.40	91.50	93.70	93.30	1.37	1.05	66	49.50
7/27/2000	9507	10	96.00	94.40	91.70	91.60	92.80	93.30	1.88	1.03	400	180.00
7/27/2000	9507	11	93.70	95.10	93.90	93.80	93.60	94.02	0.61	1.05	400	300.00
7/27/2000	9507	12	93.50	94.50	94.50	94.40	93.10	94.00	0.66	1.05	152	114.00
7/31/2000	9507	13	94.10	93.70	94.00	93.40	94.70	93.98	0.49	1.05	400	300.00
7/31/2000	9507	14	92.40	92.50	94.10	94.00	94.00	93.40	0.87	1.05	400	300.00
7/31/2000	9507	15	93.40	91.80	94.90	94.30	91.50	93.18	1.50	1.04	303	181.80
8/1/2000	9507	16	94.20	93.00	94.10	93.50	91.80	93.32	0.98	1.05	397	297.75
8/1/2000	9507	17	93.40	91.50	93.20	92.70	93.20	92.80	0.77	1.05	317	237.75
8/14/2000	9507	18	93.20	92.70	94.30	92.20	92.90	93.06	0.78	1.05	400	300.00
8/14/2000	9507	19	93.20	94.40	92.40	92.50	93.30	93.16	0.80	1.05	400	300.00
8/15/2000	9507	20	93.80	92.10	93.70	94.20	93.90	93.54	0.83	1.05	400	300.00
8/15/2000	9507	21	93.60	94.00	92.80	91.00	91.50	92.58	1.30	1.03	400	180.00
8/15/2000	9507	22	93.20	93.60	92.30	93.00	93.90	93.20	0.61	1.05	293	219.75
8/16/2000	9507	23	93.60	93.80	91.90	91.80	92.50	92.72	0.94	1.05	400	300.00
8/16/2000	9507	24	93.10	93.00	91.00	91.90	91.60	92.12	0.91	1.03	270	121.50
8/16/2000	9507	25	92.60	91.70	93.60	93.30	91.30	92.50	0.99	1.04	381	228.60
8/17/2000	9507	26	92.30	94.70	92.10	92.00	93.20	92.86	1.13	1.04	400	240.00
8/17/2000	9507	27	94.00	92.80	93.70	92.50	92.60	93.12	0.68	1.05	400	300.00
8/17/2000	9507	28	94.20	91.30	91.40	92.40	91.00	92.06	1.31	1.00	218	0.00
8/21/2000	9507	29	92.20	91.30	94.20	91.50	93.30	92.50	1.23	1.03	400	180.00
8/21/2000	9507	30	90.50	92.70	93.40	92.90	93.90	92.68	1.30	1.04	337	202.20
8/22/2000	9507	31	93.00	92.10	92.30	93.50	92.20	92.62	0.61	1.05	400	300.00
8/22/2000	9507	32	94.30	94.10	93.80	92.70	93.10	93.60	0.68	1.05	400	300.00
8/22/2000	9507	33	93.60	92.50	93.00	93.40	93.40	93.18	0.44	1.05	311	233.25
8/22/2000	9507	34	93.60	90.40	90.40	94.00	92.10	92.10	1.71	0.98	246	-73.80
8/23/2000	9507	35	93.90	93.90	93.50	92.70	93.30	93.46	0.50	1.05	400	300.00
8/23/2000	9507	36	93.40	93.60	94.10	94.00	93.60	93.74	0.30	1.05	400	300.00
8/23/2000	9507	37	94.00	94.90	94.60	92.90	93.20	93.92	0.86	1.05	228	171.00
8/23/2000	9507	38	94.00	94.90	94.10	94.90	92.80	94.14	0.86	1.05	109	81.75
8/24/2000	9507	39	93.70	93.70	94.00	92.10	93.00	93.30	0.76	1.05	400	300.00
8/24/2000	9507	40	92.80	91.50	93.10	94.60	93.00	93.00	1.10	1.05	335	251.25
8/24/2000	9507	41	93.00	93.00	92.50	92.70	94.60	93.16	0.83	1.05	170	127.50
8/28/2000	9507	42	94.00	93.80	92.80	93.10	92.70	93.28	0.59	1.05	400	300.00
8/28/2000	9507	43	93.30	94.10	93.00	93.10	93.90	93.48	0.49	1.05	271	203.25
8/30/2000	9507	44	92.60	92.60	91.70	92.20	92.10	92.24	0.38	1.05	188	141.00
8/31/2000	9507	45	94.70	94.90	93.10	92.70	92.30	93.54	1.19	1.05	400	300.00
8/31/2000	9507	46	93.00	92.20	94.00	95.80	92.00	93.40	1.56	1.04	316	189.60
8/31/2000	9507	47	94.30	93.20	93.00	94.10	91.90	93.30	0.96	1.05	184	138.00
9/5/2000	9507	48	90.60	93.80	92.20	93.60	92.70	92.58	1.29	1.03	400	180.00
9/5/2000	9507	49	93.50	93.80	93.00	93.70	91.60	93.12	0.90	1.05	392	294.00

Table C15 Contract 5879 QA Density Results Continued.

Date	Mix	Lot	Random Tests						Standard	Lot Pay		Lot
Paved	**Design**	**#**	**1**	**2**	**3**	**4**	**5**	**Average**	**Deviation**	**Factor**	**Tonnage**	**Bonus**
9/6/2000	9507	52	93.70	93.50	94.20	93.00	92.40	93.36	0.69	1.05	167	125.25
9/8/2000	9507	53	93.90	93.10	93.30	94.10	95.00	93.88	0.75	1.05	141	105.75
9/8/2000	9507	54	92.60	92.00	94.90	93.00	92.90	93.08	1.09	1.05	400	300.00
9/8/2000	9507	55	94.10	91.70	93.90	93.70	92.10	93.10	1.11	1.05	60	45.00
9/11/2000	9507	56	94.60	93.80	92.30	93.00	92.30	93.20	1.00	1.05	400	300.00
9/11/2000	9507	57	93.20	92.80	92.80	93.10	92.20	92.82	0.39	1.05	400	300.00
9/11/2000	9507	58	90.50	92.00	89.20	93.50	92.50	91.54	1.70	0.91	101	-136.35
9/12/2000	9507	59	93.10	92.40	92.20	91.90	92.80	92.48	0.48	1.05	400	300.00
9/12/2000	9507	60	91.70	91.50	92.10	93.10	93.40	92.36	0.85	1.04	400	240.00
9/12/2000	9507	61	92.50	93.20	92.90	92.80	93.20	92.92	0.29	1.05	300	225.00
9/12/2000	9507	62	93.50	92.60	91.40	93.00	91.20	92.34	1.00	1.04	148	88.80
9/13/2000	9507	63	91.70	92.30	92.10	91.60	92.30	92.00	0.33	1.05	400	300.00
9/13/2000	9507	64	92.40	91.50	91.60	92.50	93.80	92.36	0.92	1.04	400	240.00
9/13/2000	9507	65	93.50	94.50	93.30	92.80	91.40	93.10	1.13	1.05	400	300.00
9/14/2000	9507	66	93.60	94.40	92.40	93.20	92.40	93.20	0.85	1.05	400	300.00
9/14/2000	9507	67	93.00	93.00	92.00	93.80	93.00	92.96	0.64	1.05	400	300.00
9/14/2000	9507	68	93.70	92.60	93.30	94.30	92.40	93.26	0.78	1.05	330	247.50
9/15/2000	9507	69	94.40	94.00	93.50	92.90	91.40	93.24	1.17	1.05	400	300.00
9/15/2000	9507	70	92.20	90.40	90.90	93.10	94.70	92.26	1.73	0.99	400	-60.00
9/15/2000	9507	71	93.30	93.40	92.00	92.40	92.20	92.66	0.65	1.05	197	147.75
9/19/2000	9507	72	92.70	92.30	91.00	92.80	93.30	92.42	0.87	1.04	400	240.00
9/19/2000	9507	73	91.30	92.50	92.40	93.80	93.00	92.60	0.91	1.05	400	300.00
9/20/2000	9507	74	93.60	93.70	93.10	92.00	93.70	93.22	0.73	1.05	400	300.00
9/20/2000	9507	75	92.90	91.50	92.40	91.10	92.90	92.16	0.82	1.04	304	182.40
9/21/2000	9507	76	93.00	93.20	94.40	95.00	92.60	93.64	1.01	1.05	397	297.75
9/21/2000	9507	77	92.00	92.20	93.10	92.70	92.90	92.58	0.47	1.05	400	300.00
9/22/2000	9507	78	92.90	92.40	91.30	91.20	89.70	91.50	1.24	0.92	400	-480.00
9/22/2000	9507	79	92.80	92.00	90.80	92.80	90.70	91.82	1.03	1.00	400	0.00
9/25/2000	9507	80	93.20	91.00	91.00	92.60	90.50	91.66	1.17	0.96	400	-240.00
9/25/2000	9507	81	92.40	92.00	92.40	91.40	92.80	92.20	0.53	1.05	400	300.00
9/26/2000	9507	82	92.30	92.20	92.90	92.30	93.10	92.56	0.41	1.05	400	300.00
9/26/2000	9507	83	93.00	92.00	92.90	91.40	90.00	91.86	1.23	0.99	119	-17.85
9/27/2000	9507	84	92.00	92.20	90.60	91.30	91.90	91.60	0.65	1.01	371	55.65
9/27/2000	9507	85	93.00	91.40	86.90	90.80	94.20	91.26	2.78	0.85	169	-380.25
9/28/2000	9507	86	93.90	92.40	91.60	93.70	93.10	92.94	0.95	1.05	286	214.50
10/2/2000	9507	87	92.80	91.30	91.70	92.50	93.20	92.30	0.78	1.04	319	191.40
Totals								**93.03**	**1.25**	**1.037**	**28250**	**16557.00**

$37.50/tonne Class A MTV: CMI MTP-400

Profile #1	Average
$\Delta T = 21^{o}F$	Readings (pcf)
Average	141.8
Maximum	144.1
Minimum	139.4
	Ranges
Max-Min	4.7
Ave-Min	2.4

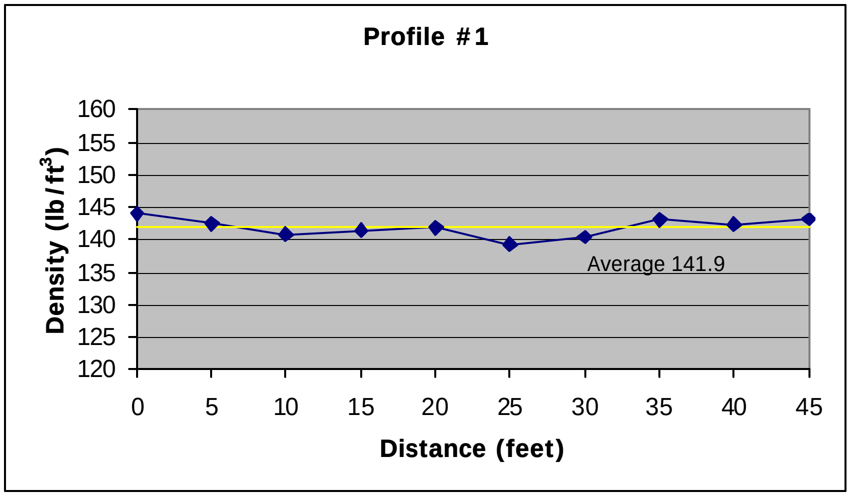


Figure C15-a. Contract 5879 Density Profile #1.

Profile #2	Average
$\Delta T = 23^{o}F$	Readings (pcf)
Average	140.9
Maximum	144.8
Minimum	138.3
	Ranges
Max-Min	6.5
Ave-Min	2.6

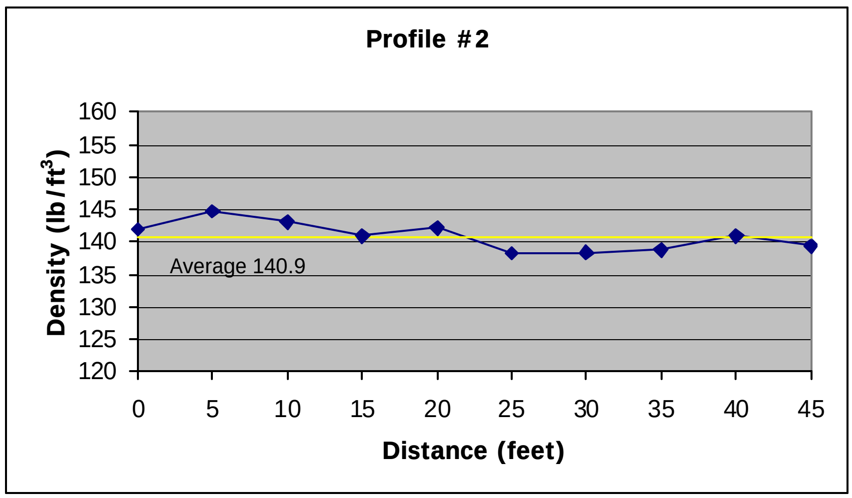


Figure C15-b. Contract 5879 Density Profile #2.

Profile #3	Average
$\Delta T = 18^{o}F$	Readings (pcf)
Average	142.0
Maximum	145.6
Minimum	139.0
	Ranges
Max-Min	6.6
Ave-Min	3.0

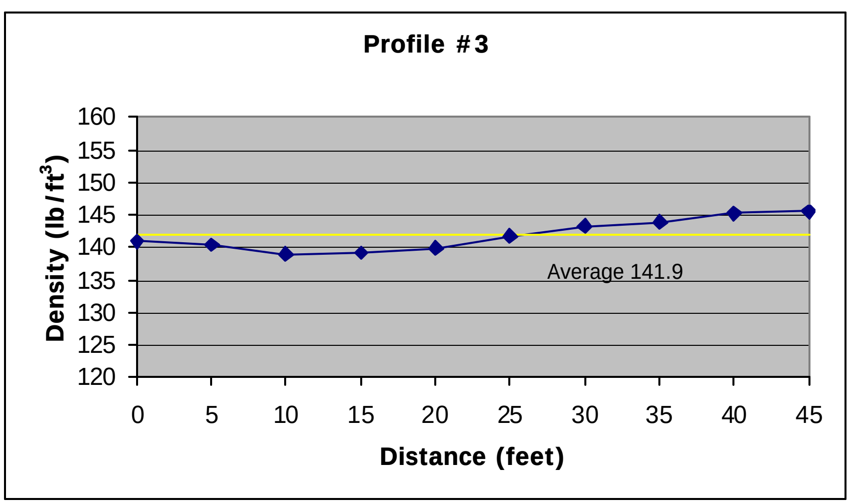


Figure C15-c. Contract 5879 Density Profile #3.

Profile #4	Average
ΔT=24^{o}F	Readings (pcf)
Average	142.8
Maximum	144.4
Minimum	141.1
	Ranges
Max-Min	3.3
Ave-Min	1.7

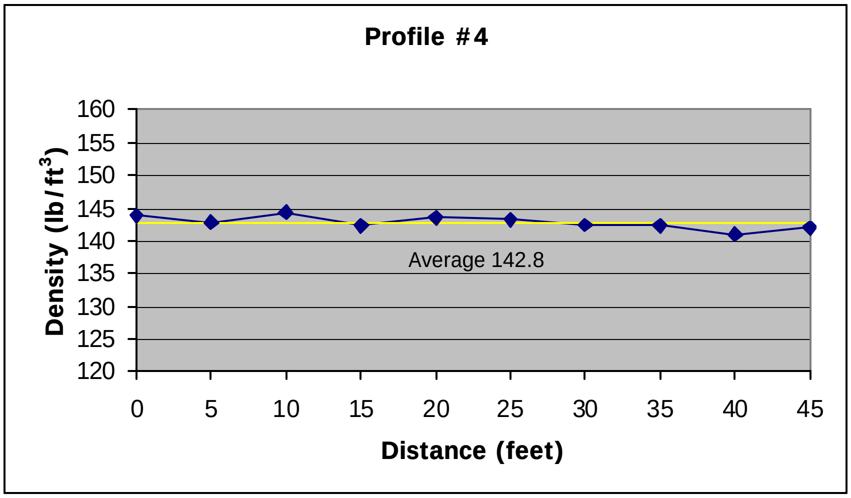


Figure C15-d. Contract 5879 Density Profile #4.

Table C16. Contract 5882 QA Density Results.

Date Paved	Mix Design	Lot #	Random Tests 1	2	3	4	5	Average	Standard Deviation	Lot Pay Factor	Tonnage	Lot Bonus
8/16/2000	test 1	1	92.40	90.70	98.50	94.30	94.10	94.00	2.91	0.82	325	-795.60
8/16/2000	test 1	2	92.90	96.20	97.60	96.80	96.10	95.92	1.79	1.02	325	88.40
8/19/2000	test 2	1	94.60	98.30	97.00	95.60	93.40	95.78	1.93	1.01	229	31.14
8/19/2000	test 2	2	94.60	95.50	93.60	96.70	94.40	94.96	1.18	1.00	229	0.00
8/21/2000	G9552	1	94.50	96.60	96.00	95.00	95.20	95.46	0.84	1.05	400	272.00
8/21/2000	G9552	2	94.40	96.60	96.00	94.20	94.60	95.16	1.07	1.02	400	108.80
8/21/2000	G9552	3	96.10	97.30	95.90	95.90	94.90	96.02	0.86	1.05	400	272.00
8/21/2000	G9552	4	94.20	94.30	95.60	94.80	95.50	94.88	0.65	1.04	375	204.00
8/22/2000	G9552	5	96.90	96.20	96.70	96.70	95.50	96.40	0.57	1.05	400	272.00
8/22/2000	G9552	6	94.20	94.00	94.90	94.90	93.70	94.34	0.54	0.97	400	-163.20
8/22/2000	G9552A	1	95.80	95.70	94.20	95.40	96.50	95.52	0.84	1.05	400	272.00
8/22/2000	G9552A	2	95.60	94.00	95.00	95.80	96.00	95.28	0.81	1.04	400	217.60
8/22/2000	G9552A	3	94.20	95.30	93.90	95.10	96.60	95.02	1.06	1.02	400	108.80
8/22/2000	G9552A	4	96.90	95.60	95.10	96.20	94.70	95.70	0.87	1.05	94	63.92
8/23/2000	G9552A	5	96.40	94.70	96.60	97.10	96.60	96.28	0.92	1.05	400	272.00
8/23/2000	G9552A	6	94.40	95.40	94.70	95.10	96.50	95.22	0.81	1.04	400	217.60
8/23/2000	G9552A	7	95.50	97.20	93.50	94.90	95.60	95.34	1.34	1.02	400	108.80
8/23/2000	G9552A	8	94.00	94.40	96.40	94.10	95.60	94.90	1.05	1.00	141	0.00
8/24/2000	G9552A	9	92.60	93.50	92.40	96.80	96.50	94.36	2.13	0.87	400	-707.20
8/24/2000	G9552A	10	95.20	94.10	95.40	94.80	95.40	94.98	0.55	1.05	400	272.00
8/24/2000	G9552A	11	94.60	94.90	94.00	95.30	94.50	94.66	0.48	1.04	400	217.60
8/24/2000	G9552A	12	95.60	94.30	94.90	94.10	94.70	94.72	0.58	1.03	257	104.86
8/25/2000	G9552A	13	95.00	96.80	96.30	94.90	95.20	95.64	0.86	1.05	400	272.00
8/25/2000	G9552A	14	96.50	96.80	96.60	96.80	96.30	96.60	0.21	1.05	400	272.00
8/25/2000	G9552A	15	95.90	96.70	94.70	94.40	95.50	95.44	0.93	1.04	400	217.60
8/25/2000	G9552A	16	94.90	94.40	95.90	95.80	96.10	95.42	0.73	1.05	400	272.00
8/28/2000	G9552A	17	95.30	95.90	94.90	95.70	94.90	95.34	0.46	1.05	400	272.00
8/28/2000	G9552A	18	94.50	94.80	96.10	95.60	93.80	94.96	0.91	1.02	400	108.80
8/28/2000	G9552A	19	94.90	95.40	96.00	94.20	96.40	95.38	0.87	1.04	400	217.60
8/28/2000	G9552A	20	94.10	90.50	93.00	95.60	94.40	93.52	1.93	0.75	400	-1360.00
8/28/2000	G9552A	21	92.80	93.40	92.50	95.20	93.90	93.56	1.06	0.00	404	-5494.40
8/29/2000	G9552A	22	94.70	95.70	96.00	95.90	95.50	95.56	0.52	1.05	400	272.00
8/29/2000	G9552A	23	95.30	94.10	95.10	96.70	94.70	95.18	0.97	1.03	400	163.20
8/29/2000	G9552A	24	94.80	94.60	94.70	94.40	94.30	94.56	0.21	1.05	400	272.00
8/29/2000	G9552A	25	95.50	94.80	96.60	96.30	94.60	95.56	0.88	1.05	400	272.00
8/29/2000	G9552A	26	95.50	95.10	94.70	94.30	96.30	95.18	0.77	1.04	362	196.93
8/30/2000	G9552A	27	95.20	94.40	94.30	94.80	94.80	94.70	0.36	1.05	400	272.00
8/30/2000	G9552A	28	95.50	95.20	94.70	95.40	94.40	95.04	0.47	1.05	400	272.00
8/30/2000	G9552A	29	94.70	95.70	96.30	96.70	96.50	95.98	0.81	1.05	400	272.00
8/30/2000	G9552A	30	94.40	95.20	95.60	94.50	95.20	94.98	0.51	1.05	400	272.00
Totals								**95.19**	**1.17**	**0.994**	**13633**	**-844.69**

$34.00/tonne　Class 12.5 mm SMA　MTV: Cedarapids MS-2 (windrow pick-up machine)

Profile #1	Average
$\Delta T=5^{o}F$	Readings (pcf)
Average	143.4
Maximum	145.6
Minimum	140.5
	Ranges
Max-Min	5.1
Ave-Min	2.9

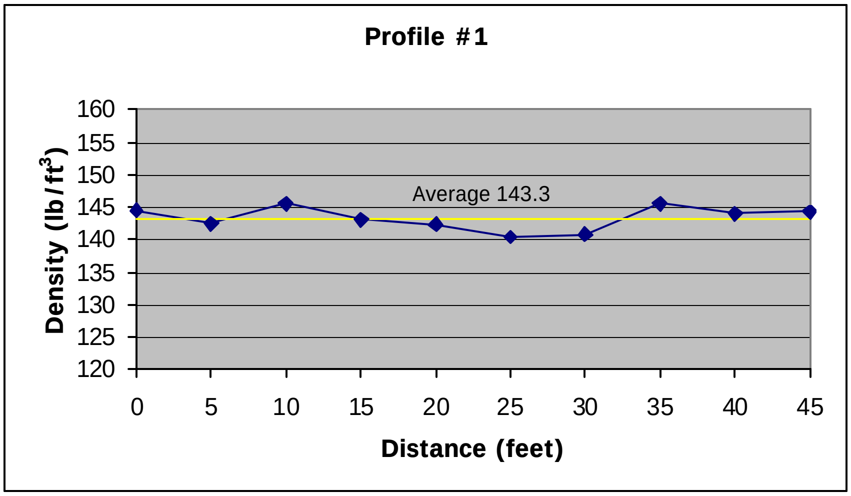


Figure C16-a. Contract 5882 Density Profile #1.

Profile #2	Average
$\Delta T=1^{o}F$	Readings (pcf)
Average	147.5
Maximum	149.8
Minimum	145.4
	Ranges
Max-Min	4.4
Ave-Min	2.1

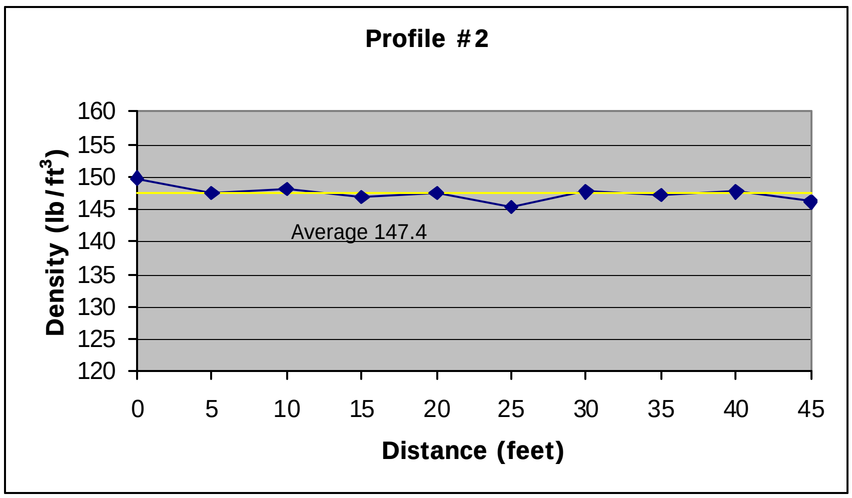


Figure C16-b. Contract 5882 Density Profile #2.

Profile #3	Average
$\Delta T=3^{o}F$	Readings (pcf)
Average	148.7
Maximum	149.8
Minimum	147.1
	Ranges
Max-Min	2.7
Ave-Min	1.6

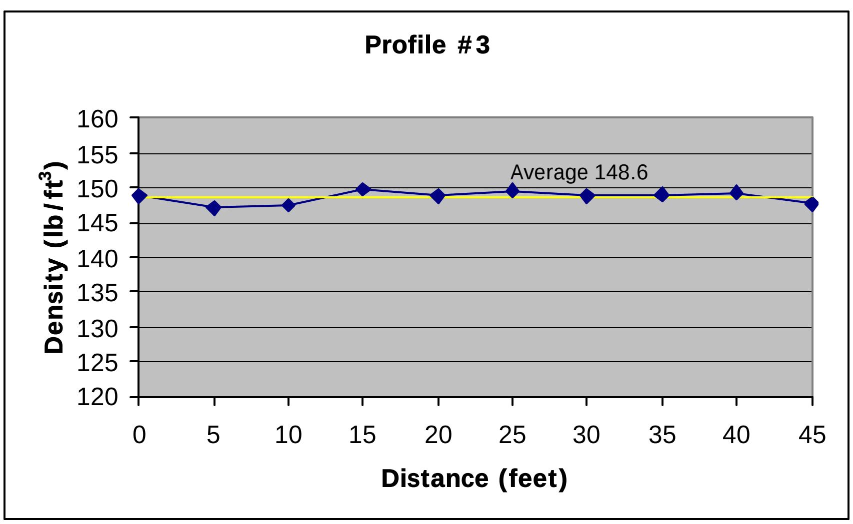


Figure C16-c. Contract 5882 Density Profile #3.

Profile #4	Average
ΔT=16°F	Readings (pcf)
Average	148.0
Maximum	152.5
Minimum	146.0
	Ranges
Max-Min	6.5
Ave-Min	2.0

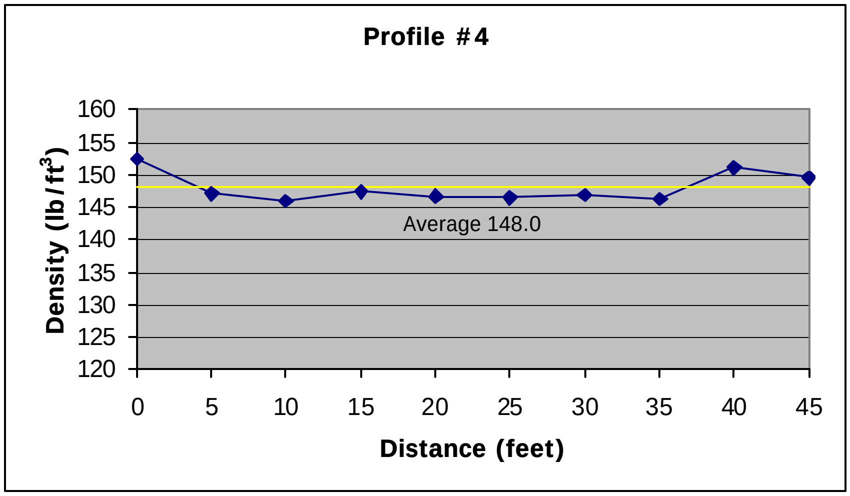


Figure C16-d. Contract 5882 Density Profile #4.

Profile #5	Average
ΔT=3°F	Readings (pcf)
Average	146.5
Maximum	147.4
Minimum	144.6
	Ranges
Max-Min	2.8
Ave-Min	1.9

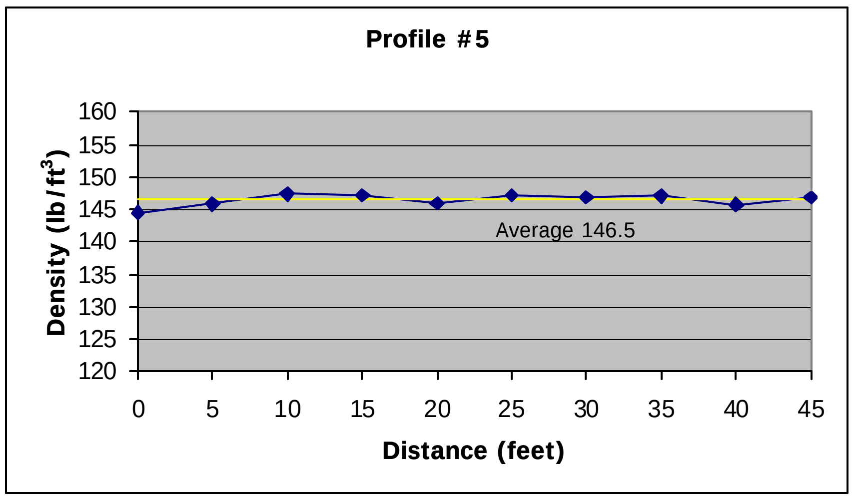


Figure C16-e. Contract 5882 Density Profile #5.

Table C17. Contract 5906 QA Density Results.

Date Paved	Mix Design	Lot #	Random Tests 1	2	3	4	5	Average	Standard Deviation	Lot Pay Factor	Tonnage	Lot Bonus
9/20/2000	G9639	1	91.60	92.20	92.50	92.20	91.30	91.96	0.49	1.05	324	249.48
9/20/2000	G9639	2	92.97	93.20	91.60	93.10	91.90	92.55	0.75	1.05	324	249.48
9/20/2000	G9639	3	93.00	91.90	91.50	91.00	91.40	91.76	0.76	1.02	224	68.99
9/22/2000	G9639	4	95.50	96.30	94.10	93.30	95.00	94.84	1.17	1.05	344	264.88
9/22/2000	G9639	5	94.40	94.20	94.00	92.20	94.90	93.94	1.03	1.05	370	284.90
9/22/2000	G9639	6	94.00	94.20	94.10	93.50	95.20	94.20	0.62	1.05	215	165.55
9/25/2000	G9639	7	91.80	95.40	95.60	95.60	94.70	94.62	1.62	1.05	317	244.09
9/25/2000	G9639	8	93.20	94.20	93.20	94.30	93.80	93.74	0.53	1.05	315	242.55
9/25/2000	G9639	9	92.90	92.30	95.00	95.20	93.30	93.74	1.29	1.05	160	123.20
9/26/2000	G9639	10	93.80	93.50	94.90	93.90	93.50	93.92	0.58	1.05	315	242.55
9/26/2000	G9639	11	91.90	93.20	92.20	95.00	95.00	93.46	1.49	1.04	313	192.81
9/26/2000	G9639	12	91.80	92.50	94.00	93.10	92.60	92.80	0.82	1.05	311	239.47
9/26/2000	G9639	13	93.40	94.20	92.50	93.40	91.90	93.08	0.89	1.05	312	240.24
9/26/2000	G9639	14	92.10	92.60	92.90	92.10	92.60	92.46	0.35	1.05	199	153.23
9/27/2000	G9639	15	95.70	95.50	92.40	93.90	94.20	94.34	1.34	1.05	377	290.21
9/27/2000	G9639	16	92.00	93.20	91.70	94.00	94.20	93.02	1.14	1.05	377	290.21
9/27/2000	G9639	17	93.80	93.40	94.10	94.20	94.10	93.92	0.33	1.05	377	290.21
9/27/2000	G9639	18	92.60	92.60	96.10	93.80	93.60	93.74	1.43	1.05	377	290.21
9/27/2000	G9639	19	94.50	94.70	94.40	91.70	92.50	93.56	1.37	1.05	377	290.21
9/27/2000	G9639	20	93.20	92.90	92.70	94.10	92.50	93.08	0.63	1.05	288	221.61
9/28/2000	G9639	21	92.20	94.80	95.80	94.30	95.40	94.50	1.41	1.05	324	249.25
9/28/2000	G9639	22	93.90	94.70	94.20	95.00	93.10	94.18	0.74	1.05	324	249.25
10/3/2000	G9639	23	96.40	97.00	96.90	92.40	94.80	95.50	1.94	1.05	252	194.35
10/3/2000	G9639	24	96.00	95.50	96.30	94.70	94.10	95.32	0.91	1.05	252	194.35
10/3/2000	G9639	25	93.60	94.80	92.00	95.10	95.30	94.16	1.38	1.05	252	194.35
10/3/2000	G9639	26	95.00	94.40	95.50	96.80	94.50	95.24	0.98	1.05	252	194.35
10/4/2000	G9639	27	92.80	93.20	95.10	95.00	95.60	94.34	1.25	1.05	400	308.00
10/4/2000	G9639	28	94.30	96.50	94.60	95.00	94.20	94.92	0.94	1.05	400	308.00
10/4/2000	G9639	29	92.70	93.20	95.10	95.00	95.60	94.32	1.28	1.05	400	308.00
10/4/2000	G9639	30	95.60	93.50	94.50	94.00	94.20	94.36	0.78	1.05	464	357.28
10/5/2000	G9639	31	95.10	95.10	94.20	92.70	93.90	94.20	0.99	1.05	400	308.00
10/5/2000	G9639	32	94.10	96.60	94.50	93.40	96.00	94.92	1.34	1.05	400	308.00
10/5/2000	G9639	33	93.50	94.60	95.90	95.60	94.60	94.84	0.95	1.05	400	308.00
10/5/2000	G9639	34	94.30	93.80	93.80	93.30	95.90	94.22	1.00	1.05	106	81.62
10/5/2000	G9639	35	93.90	93.50	93.60	92.50	91.60	93.02	0.95	1.05	400	308.00
10/6/2000	G9639	36	94.40	93.80	95.30	94.30	94.00	94.36	0.58	1.05	400	308.00
10/6/2000	G9639	37	92.80	95.60	93.50	93.50	93.50	93.78	1.06	1.05	178	137.06
10/9/2000	G9639	38	96.40	95.70	94.40	94.20	93.60	94.86	1.15	1.05	400	308.00
10/9/2000	G9639	39	94.80	94.00	95.50	93.10	96.00	94.68	1.16	1.05	400	308.00
10/9/2000	G9639	40	93.20	94.50	94.80	96.40	93.70	94.52	1.23	1.05	101	77.62
10/10/2000	G9639	41	95.40	93.90	91.40	94.10	95.60	94.08	1.68	1.05	400	308.00
10/10/2000	G9639	42	93.00	97.00	94.30	93.60	94.80	94.54	1.54	1.05	400	308.00
10/10/2000	G9639	43	96.30	95.60	95.80	95.00	94.50	95.44	0.70	1.05	400	308.00
10/10/2000	G9639	44	93.50	95.80	94.40	94.90	94.50	94.62	0.83	1.05	400	308.00
10/10/2000	G9639	45	96.90	95.60	95.00	94.50	95.20	95.44	0.91	1.05	107	82.01
10/11/2000	G9639	46	97.30	96.90	96.20	95.80	93.60	95.96	1.44	1.05	400	308.00
10/11/2000	G9639	47	94.30	95.70	93.50	94.00	94.80	94.46	0.84	1.05	400	308.00
10/11/2000	G9639	48	92.20	93.40	94.10	94.00	94.60	93.66	0.92	1.05	400	308.00
10/11/2000	G9639	49	97.10	95.20	96.80	93.60	94.60	95.46	1.48	1.05	400	308.00

Table C17. Contract 5906 QA Density Results Continued.

Date Paved	Mix Design	Lot #	Random Tests 1	2	3	4	5	Average	Standard Deviation	Lot Pay Factor	Tonnage	Lot Bonus
10/11/2000	G9639	50	93.60	95.50	93.10	92.60	95.70	94.10	1.42	1.05	212	163.24
10/12/2000	G9639	51	95.30	95.00	94.90	92.90	94.40	94.50	0.95	1.05	400	308.00
10/12/2000	G9639	52	92.10	93.50	93.30	93.20	94.00	93.22	0.70	1.05	400	308.00
10/12/2000	G9639	53	92.60	93.40	96.30	93.90	96.10	94.46	1.66	1.05	400	308.00
10/12/2000	G9639	54	93.70	92.90	94.50	97.30	93.50	94.38	1.73	1.05	365	281.05
10/17/2000	G9639	55	95.00	93.10	95.70	94.20	95.40	94.68	1.05	1.05	400	308.00
10/17/2000	G9639	56	91.50	93.60	91.80	93.00	95.00	92.98	1.42	1.04	400	246.40
10/17/2000	G9639	57	94.20	93.80	94.70	94.80	94.00	94.30	0.44	1.05	426	328.25
10/19/2000	G9639	58	93.80	95.20	93.50	92.80	97.00	94.46	1.67	1.05	400	308.00
10/19/2000	G9639	59	95.50	92.70	92.20	94.50	91.70	93.32	1.61	1.04	400	246.40
10/19/2000	G9639	60	94.40	92.50	94.00	93.90	94.60	93.88	0.82	1.05	400	308.00
10/19/2000	G9639	61	91.90	91.60	94.30	92.50	91.80	92.42	1.10	1.04	400	246.40
10/19/2000	G9639	62	91.30	94.90	93.40	93.20	93.00	93.16	1.28	1.05	167	128.59
Totals								**94.07**	**1.35**	**1.049**	**20798**	**15677.90**

$38.50/tonne Class 12.5 mm Superpave MTV: Blaw-Knox MC-30 (paddles operating on 9/20) (paddles not operating on the 9/28)

Profile #1	Average
ΔT=5°F	Readings (pcf)
Average	141.2
Maximum	142.9
Minimum	139.9
	Ranges
Max-Min	3.0
Ave-Min	1.3

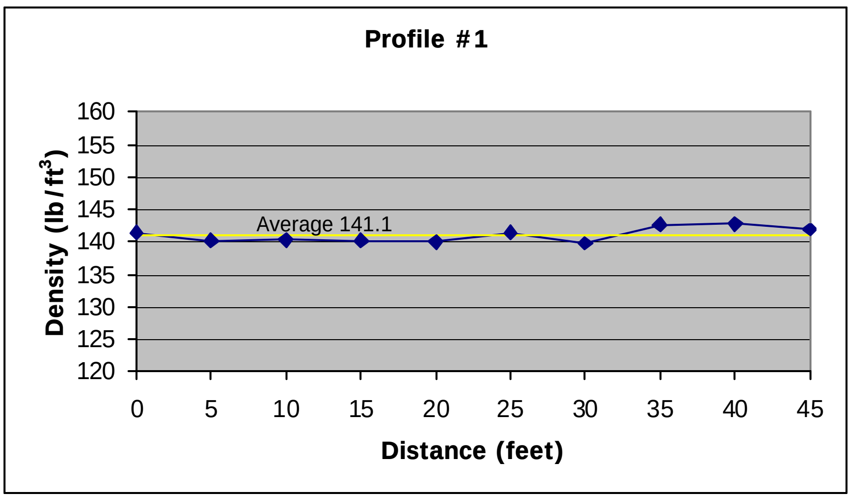


Figure C17-a. Contract 5906 Density Profile #1.

Profile #2	Average
ΔT=23°F	Readings (pcf)
Average	141.8
Maximum	143.3
Minimum	139.8
	Ranges
Max-Min	3.5
Ave-Min	2.0

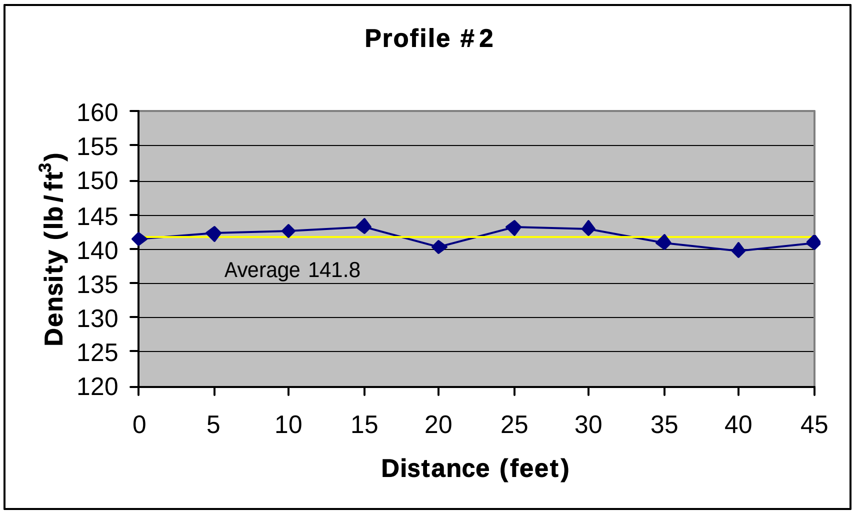


Figure C17-b. Contract 5906 Density Profile #2.

Profile #3	Average
ΔT=34°F	Readings (pcf)
Average	142.2
Maximum	144.4
Minimum	139.1
	Ranges
Max-Min	5.3
Ave-Min	3.1

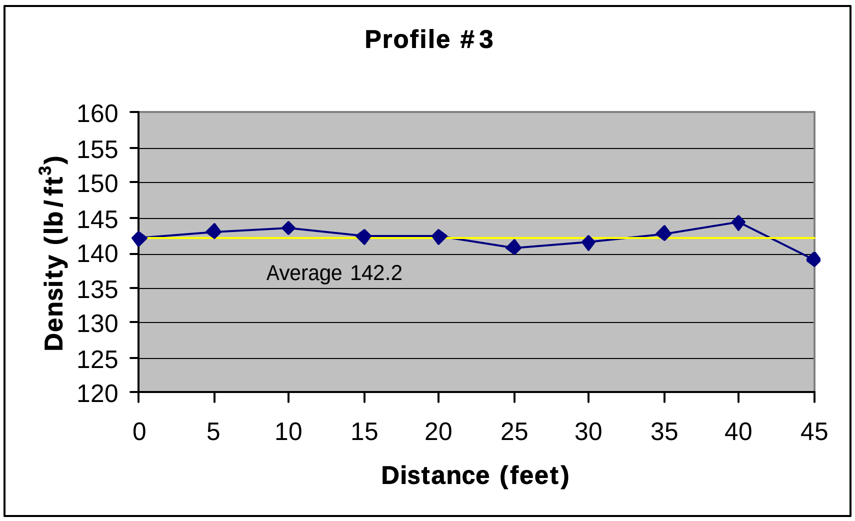


Figure C17-c. Contract 5906 Density Profile #3.

Profile #4	Average
ΔT=22°F	Readings (pcf)
Average	133.3
Maximum	140.3
Minimum	130.0
	Ranges
Max-Min	10.3
Ave-Min	3.3

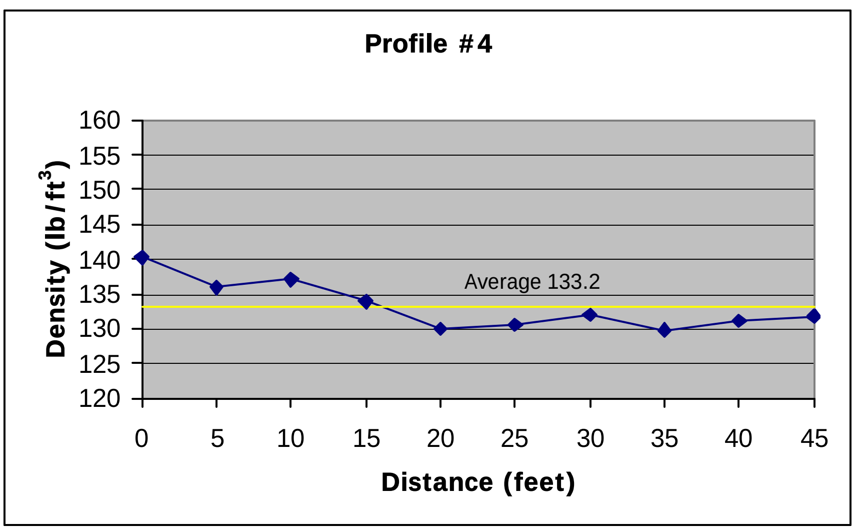


Figure C17-d. Contract 5906 Density Profile #4.

Profile #5	Average
ΔT=25°F	Readings (pcf)
Average	135.5
Maximum	139.8
Minimum	132.7
	Ranges
Max-Min	7.1
Ave-Min	2.8

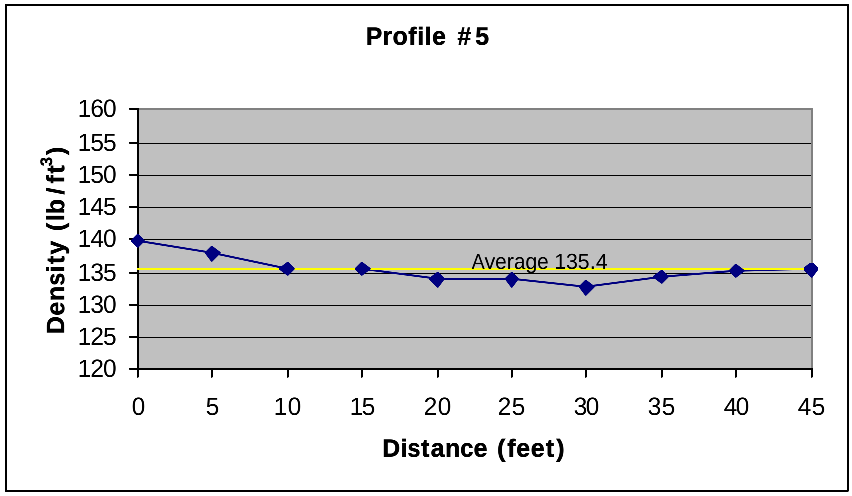


Figure C17-e. Contract 5906 Density Profile #5.

Profile #6	Average
ΔT=56°F	Readings (pcf)
Average	139.2
Maximum	143.6
Minimum	134.4
	Ranges
Max-Min	9.2
Ave-Min	4.8

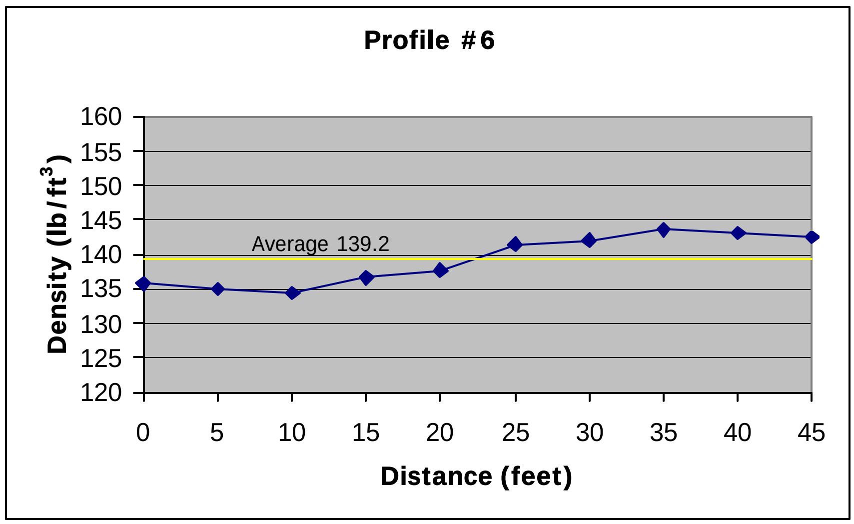


Figure C17-f. Contract 5906 Density Profile #6.

Profile #1	Average
ΔT=39°F	Readings (pcf)
Average	145.0
Maximum	148.5
Minimum	137.7
	Ranges
Max-Min	10.8
Ave-Min	7.3

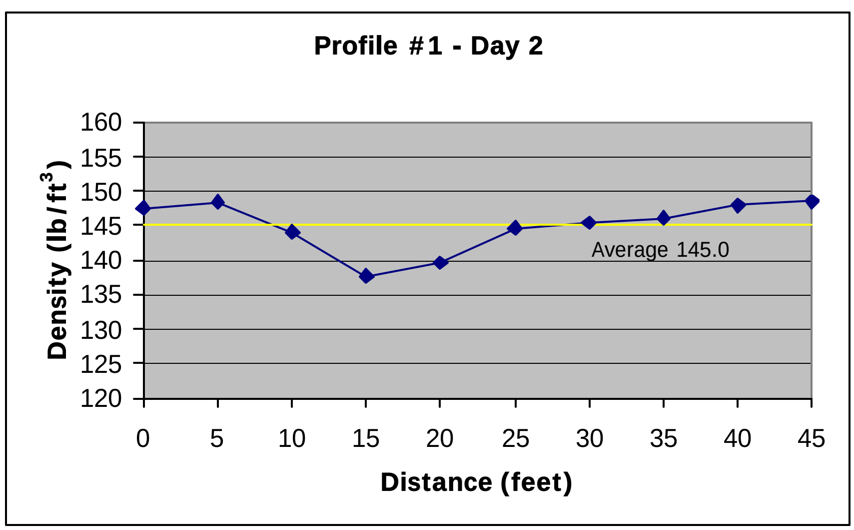


Figure C17-g. Contract 5906 Density Profile #1 – Day 2.

Table C18. Contract 5908 QA Density Results.

Date Paved	Mix Design	Lot #	Random Tests					Average	Standard Deviation	Lot Pay Factor	Tonnage	Lot Bonus
			1	2	3	4	5					
9/12/2000	9566	1	94.40	91.60	94.20	92.40	93.40	93.20	1.19	1.05	400	274.00
9/12/2000	9566	2	92.20	92.80	93.10	92.70	93.00	92.76	0.35	1.05	400	274.00
9/12/2000	9566	3	93.70	92.00	92.00	92.80	93.00	92.70	0.72	1.05	400	274.00
9/12/2000	9566	4	93.00	93.40	92.20	92.10	92.20	92.58	0.58	1.05	400	274.00
9/13/2000	9566	5	92.90	93.50	91.70	93.00	94.30	93.08	0.95	1.05	400	274.00
9/13/2000	9566	6	93.60	92.20	94.30	93.10	94.40	93.52	0.91	1.05	400	274.00
9/13/2000	9566	7	92.30	93.80	93.70	93.90	93.30	93.40	0.66	1.05	400	274.00
9/13/2000	9566	8	92.50	94.30	93.20	93.30	92.20	93.10	0.82	1.05	400	274.00
9/13/2000	9566	9	92.00	92.70	93.50	92.70	92.60	92.70	0.53	1.05	400	274.00
9/18/2000	9566	10	92.30	93.00	92.80	93.40	92.20	92.74	0.50	1.05	400	274.00
9/18/2000	9566	11	92.00	92.30	91.90	92.00	91.20	91.88	0.41	1.05	400	274.00
9/18/2000	9566	12	91.60	92.50	93.00	93.60	92.30	92.60	0.75	1.05	400	274.00
9/19/2000	9566	13	93.00	91.80	93.90	93.50	92.20	92.88	0.88	1.05	400	274.00
9/19/2000	9566	14	93.90	92.70	94.10	92.90	92.10	93.14	0.84	1.05	400	274.00
9/19/2000	9566	15	92.80	93.10	94.70	95.00	93.10	93.74	1.03	1.05	400	274.00
9/19/2000	9566	16	92.20	91.80	92.10	92.50	92.20	92.16	0.25	1.05	400	274.00
9/20/2000	9566	17	92.70	91.90	92.40	92.40	94.10	92.70	0.83	1.05	400	274.00
9/20/2000	9566	18	92.20	91.90	92.30	91.70	92.30	92.08	0.27	1.05	400	274.00
Totals								**92.83**	**0.82**	**1.050**	**7200**	**4932.00**

$34.25/tonne Class B MTV: Roadtec Shuttle Buggy SB-2500

Profile #1	Average
ΔT=5°F	Readings (pcf)
Average	137.7
Maximum	140.3
Minimum	136.0
	Ranges
Max-Min	4.3
Ave-Min	1.7

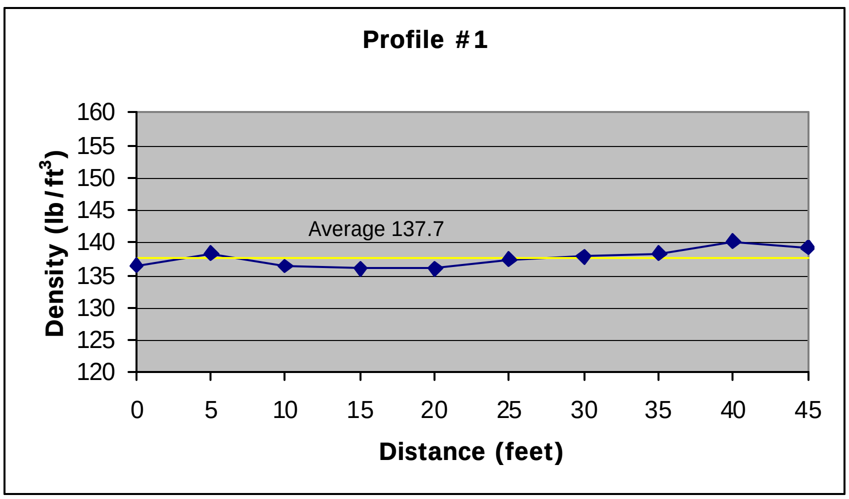


Figure C18-a. Contract 5908 Density Profile #1.

Profile #2	Average
ΔT=4°F	Readings (pcf)
Average	138.5
Maximum	140.8
Minimum	135.1
	Ranges
Max-Min	5.7
Ave-Min	3.4

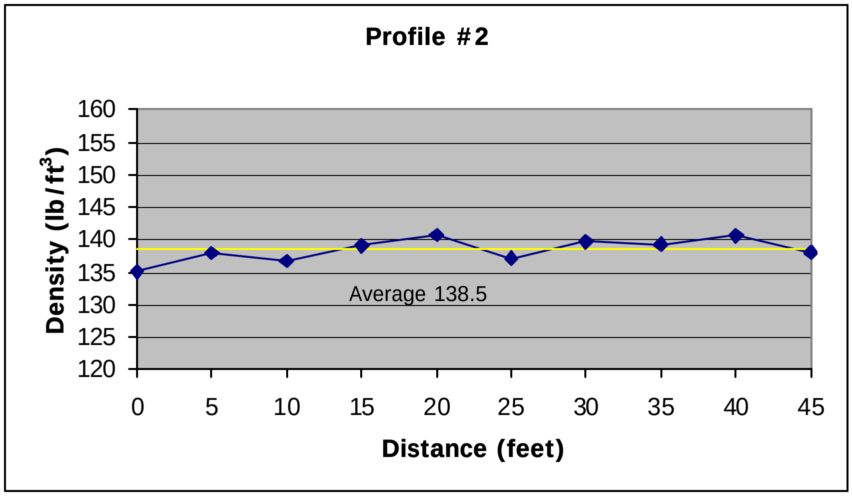


Figure C18-b. Contract 5908 Density Profile #2.

Profile #3	Average
ΔT=7°F	Readings (pcf)
Average	137.1
Maximum	140.0
Minimum	134.7
	Ranges
Max-Min	5.3
Ave-Min	2.4

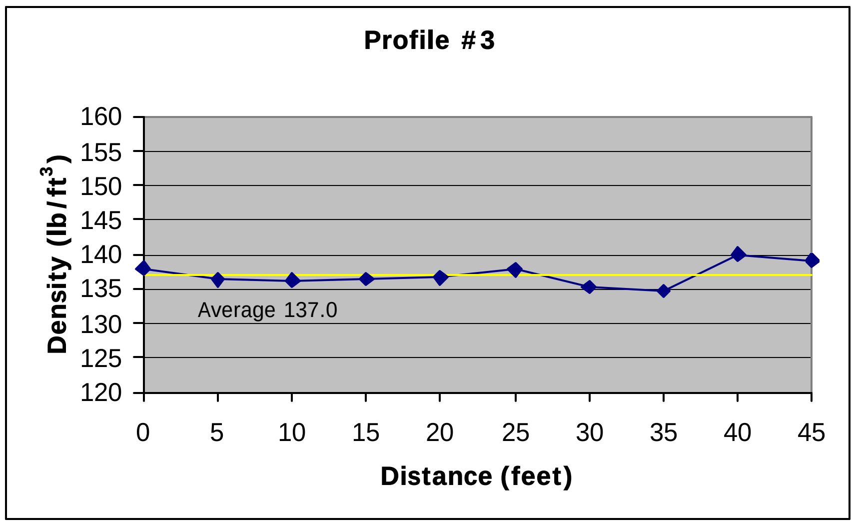


Figure C18-c. Contract 5908 Density Profile #3.

Profile #4	Average
ΔT=6°F	Readings (pcf)
Average	136.6
Maximum	138.8
Minimum	134.3
	Ranges
Max-Min	4.5
Ave-Min	2.3

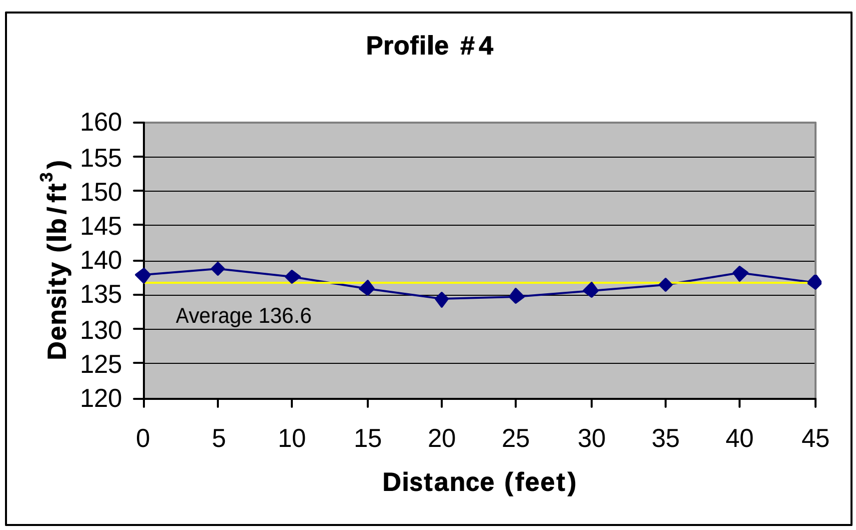


Figure C18-d. Contract 5908 Density Profile #4.

Table C19. Project Specific Data for Projects Using No Material Transfer Device.

Contract	Average	Standard Deviation	Number of Tests	Haul Time	Mat Temperature	Air Temperature	Surface Temperature
5851	Test Section - No QA Densities			20	270	70	100
5871	93.96	0.86	15	5	270	65	72
5562	93.65	0.95	15	16	260	70	107
5592	93.40	1.14	15	30	238	67	74
5606	92.33	2.33	10	10	238	65	125
5614	93.89	1.24	10	80	255	75	120
5657	94.85	1.17	10	10	250	80	120
5665	91.69	0.98	10	30	273	60	65
All	93.44	1.52	85	13	257	69	98

Table C20. Project Specific Data for Projects Using the Blaw-Knox MC-30 with the Paddles Operating.

Contract	Average	Standard Deviation	Number of Tests	Haul Time	Mat Temperature	Air Temperature	Surface Temperature
5700	96.13	1.52	20	20	265	70	120
5816	92.18	0.76	15	8	255	55	80
5906	92.99	1.41	25	25	265	60	58
5701	92.83	1.01	30	23	265	65	90
5673	92.19	1.41	10	26	256	65	85
5554	93.01	1.71	15	100	255	60	68
All	93.32	1.85	115	18	260	63	84

Table C21. Project Specific Data for Projects Using the Blaw-Knox MC-30 with the Paddles Not Operating.

Contract	Average	Standard Deviation	Number of Tests	Haul Time	Mat Temperature	Air Temperature	Surface Temperature
5677	92.39	1.30	45	8	245	70	71
5345	95.94	1.86	20	40	250	60	75
5632	93.76	0.33	10	40	245	60	65
5647	94.37	1.47	20	30	270	75	95
All	93.70	1.98	95	8	253	66	77

Table C22. Project Specific Data for Projects Using the Roadtec Shuttle Buggy.

Contract	Average	Standard Deviation	Number of Tests	Haul Time	Mat Temperature	Air Temperature	Surface Temperature
5807	92.47	0.75	15	60	265	60	72
5831	91.92	0.81	10	20	225	62	60
5862	92.31	1.10	15	12	245	80	105
5863	95.01	0.93	10	10	275	52	70
5908	93.16	0.78	25	80	260	70	82
5645	94.46	1.33	10	6	254	60	75
5654	93.84	0.97	15	40	263	55	65
5666	92.13	0.95	10	30	237	55	63
5545	93.37	0.92	20	30	225	85	125
5576	91.67	0.67	30	17	258	65	95
All	92.88	1.32	160	36	251	64	81

Table C23. Project Specific Data for Projects Using the Cedarapids MS-2 Windrow Elevator.

Contract	Average	Standard Deviation	Number of Tests	Haul Time	Mat Temperature	Air Temperature	Surface Temperature
5823	94.60	1.04	25	15	250	85	120
5841	92.85	0.79	25	20	245	60	60
5497	94.22	1.25	40	8	245	80	110
5544	93.50	0.40	30	30	230	65	70
5598	92.60	1.71	25	10	235	80	102
5628	95.04	1.18	40	12	233	65	85
5659	92.73	1.17	25	10	245	95	137
5663	92.65	1.25	35	18	255	80	115
5675	93.20	1.27	25	30	236	80	100
5627	92.86	0.86	25	22	253	102	140
All	93.57	1.40	295	22	243	79	104

Table C24. Project Specific Data for Projects Using the Cedarapids MS-3.

Contract	Average	Standard Deviation	Number of Tests	Haul Time	Mat Temperature	Air Temperature	Surface Temperature
5609	93.43	1.45	10	28	250	60	95
5679	93.29	1.16	20	20	255	55	54
All	93.34	1.24	30	24	253	58	75

Table C25. Project Specific Data for Projects Using Other Windrow Elevators.

Contract	Average	Standard Deviation	Number of Tests	Haul Time	Mat Temperature	Air Temperature	Surface Temperature
5835	91.90	0.77	15	15	250	90	120
5054	93.77	0.99	15	40	245	65	75
5519	94.34	0.81	15	45	245	70	85
5581	92.30	1.05	40	5	283	104	140
5664	92.40	1.08	15	26	275	85	120
All	92.78	1.29	100	28	260	83	108

Table C26. Project Specific Data for Projects Using the CMI MTP-400.

Contract	Average	Standard Deviation	Number of Tests	Haul Time	Mat Temperature	Air Temperature	Surface Temperature
5879	93.38	0.52	10	12	240	63	65

Table C27. Project Specific Data for Projects Using a Windrow Elevator into the Blaw-Knox MC-30 with the Paddles Operating.

Contract	Average	Standard Deviation	Number of Tests	Haul Time	Mat Temperature	Air Temperature	Surface Temperature
5827	93.09	0.60	10	15	250	55	60

APPENDIX D

Density Profile Procedure and Related Documents

"Determination of Mat Density Differentials Using the Nuclear Density Gauge"
WSDOT Test Method 7XX

1. GENERAL SCOPE

   a. The objective of this test method is to give guidance on establishing a density profile behind the laydown machine. This is accomplished by taking multiple readings within a 50-foot section.
   b. A density profile shall be performed on locations that include temperature differentials or aggregate segregation and checked for a drop in density.
   c. Asphalt concrete density measurements are made using a nuclear moisture density gauge in the backscatter or thin layer mode of transmission.
   d. A density measurement shall be the average of two density readings taken in the same location at 90 degrees from each other. The readings shall agree within 1.0 lbs/ft^3 (16 kg/m^3) of the average to be valid.
   e. On the basis of specified acceptance criteria, the results are used to determine the variability of mat density.

2. EQUIPMENT

   a. Infrared Digital Camera (Inframetrics ThermaSNAP or ThermaCAM cameras, or Infrared Solutions IR SnapShot) or handheld noncontact infrared thermometers (features should include continuous reading, minimum, maximum, and average readings, and laser sighting).
   b. Nuclear density gauge and standardizing block (reference standard). (The Troxler 3450 and 4640-B gauges have the thin layer mode of transmission option.)
   c. Tape measure.
   d. A can of spray paint or crayons for marking test sites.
   e. Required report forms.

3. GAUGE CALIBRATION

   a. Follow the gauge calibration as outlined in WSDOT Test Method 715.
   b. Locate the test site as described in the Density Profile section.

4. TEMPERATURE CRITERIA

   $\Delta T \geq 25^oF$ (14^oC) – Perform Density Profile
   $\Delta T < 25^oF$ (14^oC) – No need to perform Density Profile unless visible segregation exists

   Normal Quality Assurance Testing will be performed throughout entire job in addition to any Density Profiles that may need to be performed.

5. USE OF INFRARED DIGITAL CAMERA

a. Stand about 20 to 30 feet (6.1 to 9.1 meters) behind the screed of the paver.
b. Look towards the paver and view the entire paving lane.
c. Adjust the camera to include the high and low temperatures.
d. View two truckloads of mix being laid on the mat and observe the location and temperature of any cool spots. These observations should allow the camera operator to become familiar with the location and extent of the temperature differentials, if any.
e. Begin viewing when a truck starts to dump into the paver or material transfer device and continue viewing until the paver stops (discontinuous mix delivery) or until another truck starts to dump (continuous mix delivery). Make sure the camera is approximately the same distance away from the paver during viewing. Record the high and low temperatures on the mat within one truckload. (Include temperature measurements that have not been compacted or been on the mat for more than one minute.)
f. If the temperature differential is 25°F (14°C) or more, perform density profile. If the temperature differential is less than 25°F (14°C), there is no need to perform density profile unless visible segregation is present.
g. Make sure to record the affected areas starting point (also called zero point), offset, type of temperature differential (spot or streak – see Figures 1 and 2), and if it is visibly segregated for testing and possible future evaluation. The zero point is the beginning location of the spot or streak in the direction of paving.

6. USE OF HANHELD NONCONTACT INFRARED THERMOMETER

a. Stand at the edge of the paving lane about 5 to 10 feet (1.5 to 3.0 meters) back from the paver.
b. Scan the mat with the handheld noncontact thermometer continuously in a longitudinal manner by walking behind the paver in the direction of paving, staying the same distance away from the paver for one truckload of hot mix. The offset for the longitudinal profile should be anywhere from 24 inches (0.6 meters) from the edge to no more than half the width of the mat. (The need to vary the longitudinal offset will be necessary to get an accurate representation of the whole mat.)
c. At the end of each longitudinal scan, make a separate transverse scan across the mat approximately 5 to 10 feet (1.5 to 3.0 meters) behind the screed to check for streaking of the mat.
d. View two truckloads of mix being laid on the mat at two separate offsets and observe the location and temperature of any cool spots. These observations should allow the operator to become familiar with the location and extent of the temperature differentials, if any.
e. Begin the longitudinal scan when a truck starts to dump into the paver or material transfer device and continue until the paver stops (discontinuous mix delivery) or until another truck starts to dump (continuous mix delivery). Perform a transverse scan after completion of the longitudinal scan, making sure to scan the entire width of the mat excluding the outer 24 inches (0.6 meters) on each side. Record the high and low temperatures on the mat within one truckload for the longitudinal and transverse profiles. (Include temperature measurements that have not been compacted or been on the mat for more than one minute.)

f. If the temperature differential is 25°F (14°C) or more, perform density profile. If the temperature differential is less than 25°F (14°C), there is no need to perform density profile unless visible segregation is present.
g. Make sure to record the affected areas starting point (also called zero point), offset, type of temperature differential (spot or streak – see Figures 1 and 2), and if there is any visible segregation for testing and possible future evaluation. Typically, temperature differentials or segregation at the end of a truckload can be captured using the longitudinal scan and streaking will be captured by the transverse scan. The zero point is the beginning location of the spot or streak in the direction of paving.

7. DENSITY PROFILE PROCEDURE

a. A density profile is defined as a 50-foot (15 meters) length of mat with readings taken approximately every five feet (1.5 meters). Additional readings shall be taken wherever visible segregation is present.
b. The zero point will be the starting point as indicated by the temperature profile. The first reading will be approximately 10 feet (3 meters) behind the zero point.
c. The transverse offset is determined by the location of the temperature profile and at least 24 inches (0.6 meters) or more from the pavement edge. Depending on the type of temperature differential or segregation, the transverse offset may vary (see Figures 1 and 2). Visually observe the mat and note the surface texture along with the density profile. Make note of areas that appear to be segregated. Visually segregated areas, if any, must be included in the section to be checked with a density profile if along the same offset.
d. Take two one-minute readings at 90° with the nuclear density gauge in the backscatter or thin layer mode of transmission in the same location and record.
e. Before moving the gauge, average the two readings. Compare each individual reading to the average. If either of these readings vary more than 1.0 lb/ft^3 (16 kg/m^3) from the average, take additional readings until two readings at 90° of each other have been obtained that are within 1.0 lb/ft^3 (16 kg/m^3) of the average and discard all other readings.
f. Move the gauge approximately 5 feet (1.5 meters) forward in the direction of the paving operation. If a segregated area is visible in between the 5-foot (1.5 meter) distance, take an additional set of readings at that location.
g. Repeat steps d, e, and f. Continue to take readings until a minimum 50-foot section has been covered. There should be a minimum of eleven sets of readings.
h. Determine the average density for the profile from each of the average readings. This is the mean reading.
i. Determine the highest average reading from the minimum of the eleven sets. This is the maximum reading.
j. Determine the lowest average reading from the minimum of the eleven sets. This is the minimum reading.
k. Determine the difference between the maximum (step i) and minimum (step j) readings. This is the maximum – minimum density range.
l. Determine the difference between the mean (step h) and minimum (step j) readings. This is the mean – minimum density range.
m. Record and plot the data on the Nuclear Density Profile Form. Report.

8. NUMBER AND LOCATION OF NUCLEAR DENSITY TESTS

   a. The Engineer *or Contractor* shall take at least five temperature profiles per 400-ton lot.
   b. No temperature or density profiles shall be performed within the first three delivered truckloads of production each day.
   c. A density profile shall be performed whenever the temperature profile fails to meet the stated criterion, visible segregation is present, or a minimum of four per day per type of mix, whichever is greater. If the four initial density profiles have met the density criterion, a density profile is not needed if the temperature profiles meet the stated temperature criterion and visible segregation is not present. The Engineer may reduce the frequency of the temperature profiles if the four initial profiles pass.
   d. Quality assurance testing will be performed according to WSDOT Test Method 715 and WSDOT Test Method 716.

9. ACCEPTANCE

   a. The density ranges (maximum – minimum and mean – minimum) must be within the maximum allowable criterion to be considered passing.
   b. If one density profile fails, the Contractor will be allowed to make changes to the production, equipment, or process at the Contractor's expense as approved by the Engineer to correct within one hour of notification.
   c. If two consecutive density profiles fail, production must stop and correction must be made to the paving process, equipment, or production at the Contractor's expense as approved by the Engineer.
   d. Report the density profile results on the Nuclear Density Profile Form.

10. CORRELATION OF NUCLEAR GAUGE DETERMINED DENSITIES WITH ASPHALT CONCRETE PAVEMENT CORES

   a. Density determination for mat density differentials on asphalt concrete pavement shall be made in the backscatter or thin layer mode of transmission.
   b. Gauge-core correlation is not required for the density differential determination of asphalt compaction.

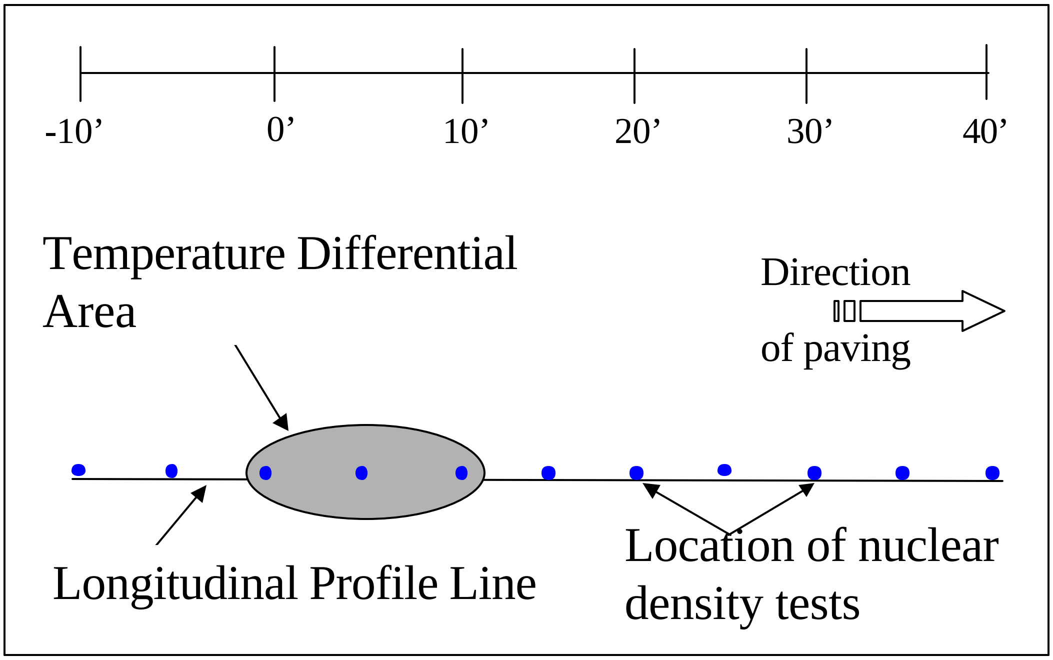


Figure 1. Temperature differential as typical end dump (spot or chevron).

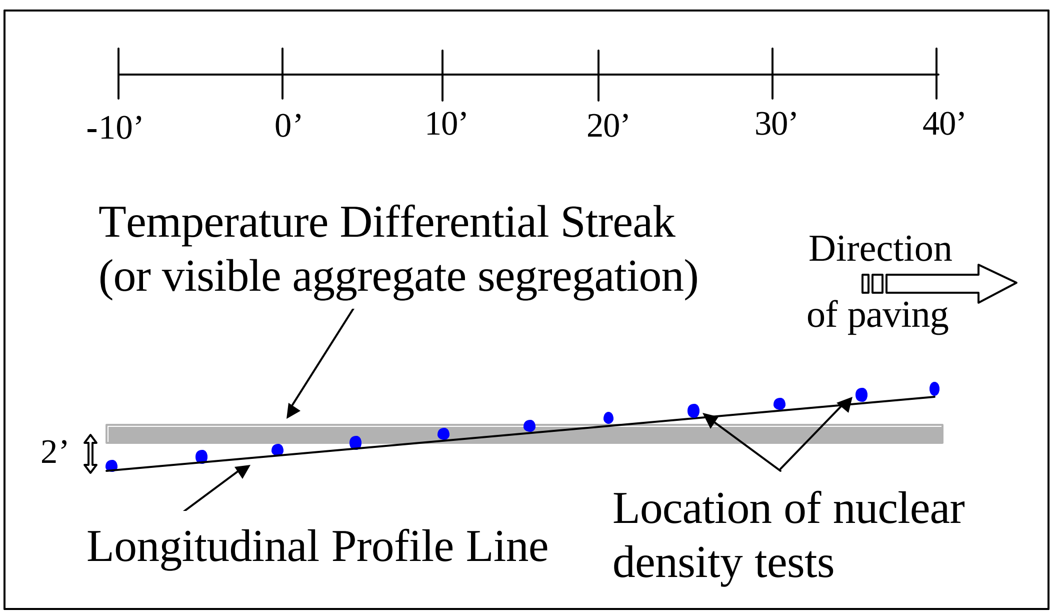


Figure 2. Temperature differential or aggregate segregation in longitudinal streak.

Nuclear Density Profile Form

Asphalt Concrete Pavement

Contract No.:	**Profile No.:**	**Location Information (1st Reading)**	
Route:	**Test Date:**	**Station/Milepost:**	
District:	**Mix Type:**	**Lane Direction:**	**Lane: 1 2 3 4 5**
County:	**Lift Thickness:**	**NB SB EB WB**	**Lift: wearing or base**
Tested By: DOT ☐	**Nuclear Gauge Operator**	**Offset From Outside Edge of Lane (ft):**	
Contractor ☐	**Name:**	**Edge conditions:**	**Confined**
Contractor:	**Phone:**	**(C/L and shoulder)**	**Unconfined**
Brand and Model of Paver:	**Visible Segregation: Yes** ☐ **No** ☐	**Temperature Profile DT:**	
		Type of DT: Truck Load or Streaks	
Describe Type of Remix Equipment Used In or Ahead of Paver:			

	Feet from Prev. Read.	**Readings (lb/ft^3)**				
		1st	2nd	3rd*	4th*	Average
1	0.0					
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						

Mean Reading	
Maximum Reading	
Minimum Reading	
Max Density Ranges:	
Maximum - Minimum	
Mean - Minimum	

Temperature Criteria

$\Delta T \geq 25^oF$

$\Delta T < 25^oF$

Density Criteria

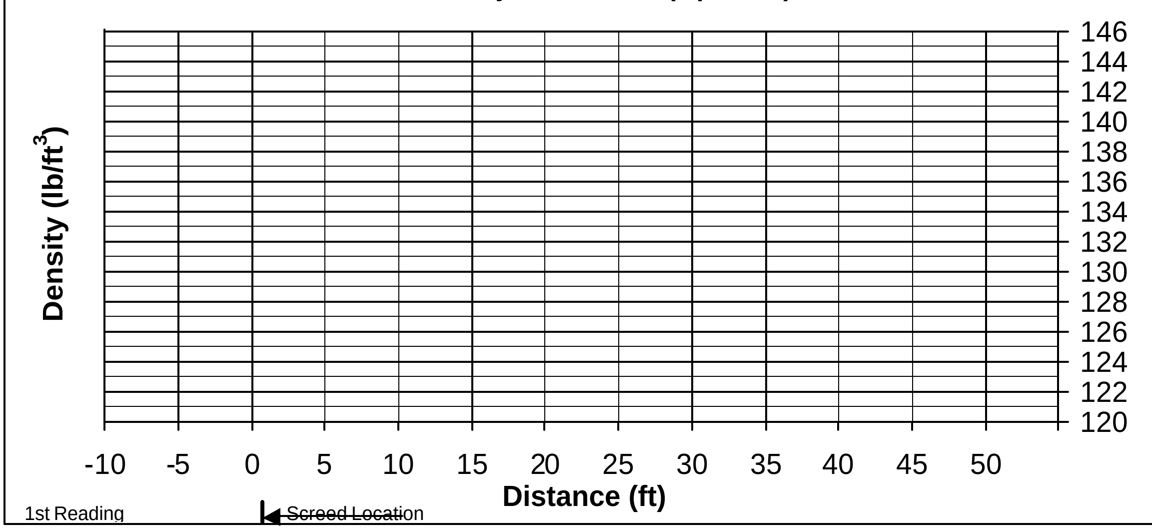
Maximum - Minimum < 6.0 lb/ft^3

Mean - Minimum < 3.0 lb/ft^3

When temperature profile is greater than 25^{o}F, perform density profile.
Provide the results of the Density Profiles to the Engineer or Contractor immediately.

*3rd or 4th readings are needed only if the average of the first two readings are not within 1.0 lb/ft^3.
The average should include two readings at 90^o from each other.

Density Profile Plot (Optional)



APPENDIX E

Summary of Research Done in Other States

Summary

In 1998, the Connecticut DOT (ConnDOT) performed field research with an infrared camera on eleven sites (Henault (1999)). Six of these eleven sites will be monitored for five years following construction. ConnDOT personnel performed nuclear density testing in the cool areas and in normal temperature areas and took cores from both areas to test for asphalt content and gradation. Table E1 has a summary of the test results for the six sites and the general observations for the other five sites that were visited during the 1998 paving season.

Table E1. 1998 Connecticut DOT Projects Viewed With the Infrared Camera.

Site	**Average DT (^{o}F)**	**Average V_a difference (%)***	**V_a range (%)**	**AC difference (%)**	**V_a higher in warm area (%)**	**Sieve Analysis**	**MTV Used**
1	27	2.8	-1.1 to 7.6	0 to 0.8	5	1 sample 6.5% coarser on #8 sieve	None
2	27	1.0	-3.5 to 6.4	0.2 to 0.6	36	No significant difference	None
3	29	-1.4	-3.5 to 2.0	0.2 to 0.5	86	2 samples, 5.7% and 3.6% coarser on #8 sieve	None
4	52	1.6	-1.0 to 7.7	-0.4 to 0.2	31	No significant difference	None
5	34	0.5	-5.9 to 7.7	-0.4 to 0.0	42	2 samples coarser, 17.5% on #4 and 4.0% on #8 sieve	None
6	41	0.8	-8.1 to 6.4	-1.2 to 0.2	40	2 samples coarser, 11.1% and 3.8% on #8 sieve	None
7	ΔT's observed - no data collected						MC-30
8	ΔT's at beginning of paving operations, uniform afterward - no data collected						Shuttle Buggy
9	ΔT's after paver stoppages and truck changes - no data collected						None
10	ΔT's in longitudinal strips						None
11	ΔT's in longitudinal strips						None

* Difference in air voids (V_a) between normal temperature and cool areas

ConnDOT personnel noted that a low temperature crust formed in the hot-mix load during transport, cool temperatures appeared in the paved mat as longitudinal strips or spots, projects paved with the Shuttle Buggy had significant reduction in temperature differentials, and projects paved with the Blaw-Knox MC-30 can reduce temperature differentials but cool spots are still noticeable in the mat. They also noted that dumping hopper wings contribute to temperature differentials seen in the paved mat.

ConnDOT personnel came to the following conclusions after viewing the 1998 project sites:

- In general, the cooler areas tended to be less dense than the surrounding pavement (5 out of the 6 sites)
- Asphalt content and gradation analysis were similar in cool areas and normal temperature areas
    - One set of cores exceeded 1 percent in the asphalt content difference
    - One set of cores exceeded 8 percent coarser on the No. 8 sieve

The Minnesota DOT also used an infrared camera to view paving projects during the 2000 construction season. Their images, along with WSDOT's and ConnDOT's can be viewed at the following website: **http://www.wsdot.wa.gov/fossc/mats/pavement/sptc.htm**. A final report has not been issued at this time, but the general conclusions (as noted by the primary author's review of the data on the website) agree with WSDOT and ConnDOT's findings. Table E2 is a summary of the density profile results obtained during the 2000 construction season in Minnesota. The results for the density profiles are slightly different than WSDOT's results, but this can probably be attributed to the fact that many of the cool areas that are just above 25°F are appearing as thin streaks or small areas. The WSDOT research team has found that a break of 25°F between normal temperature areas and cool areas works well, but Minnesota may find that a higher temperature may work better for them. See Figure E1 for a typical infrared image that just breaks the 25°F temperature differential from Minnesota.

Table E2. Density Profile Results from Minnesota's 2000 Construction Season.

	$\Delta T \geq 25^oF$	$\Delta T < 25^oF$
Number of Profiles	40	18
Failed both density criteria	13	1
Passed both density criteria	22	17
Failed only high - low	1	0
Failed only mean - low	4	0
Percent passing	55.0	94.4
Percent failing	45.0	5.6

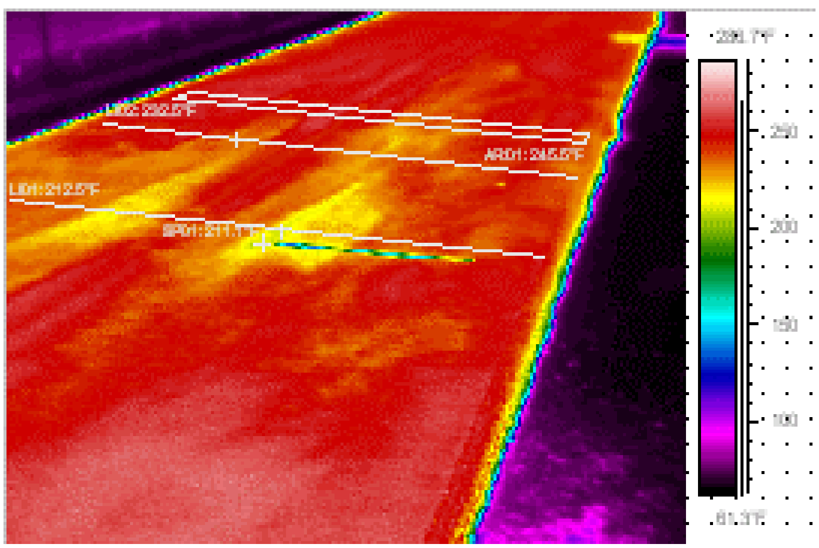


Figure E1. Typical Infrared Image From Minnesota That Just Exceeds 25°F.