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# Optimizing In-Place Density of Asphalt Pavements During Cold Weather Paving in Nebraska

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# Optimizing In-Place Density of Asphalt Pavements During Cold Weather Paving in Nebraska



Nebraska Department of Transportation Materials and Research - Flexible Pavements and Quality Assurance Section

A Report on Research Sponsored by

Federal Highway Administration (FHWA) Nebraska Department of Transportation (NDOT)

January 2019

# Optimizing In-Place Density of Asphalt Pavements During Cold Weather Paving in Nebraska

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## Disclaimer

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#### Abstract:

Late season paying is common and often performed in colder temperatures, which is the most challenging environment for attaining optimal in-place density/compaction. The inplace density of asphalt pavement greatly affects the lifespan of the pavement. It is also a key factor in preventing major pavement distresses, such as rutting, cracking, stripping (due to water damage) and aging. This research project aims to evaluate and compare the effectiveness of different compaction, delivery, and mix design characteristics to ensure the optimization of in-place asphalt pavement density. To this end, various laydown methods (i.e., Standard Pick-up Machine (SPM) and Material Transfer Vehicle (MTV)) and compaction equipment (i.e., double drum steel rollers, pneumatic rollers, and combination rollers (CR) with both steel and pneumatic tires), using both static and vibratory modes were employed. In addition, the effect of different aggregate blend combinations (i.e., using less coarse ledge rock) and asphalt binders (i.e., PG 58V-34, PG 40-40, and PG 52-40) on in-place density were studied. Four test sections were constructed over four separate days of paving, during cold weather conditions. The in-place density was measured using four methods: 1) Conventional/traditional cut roadway cores, 2) Combination of Infrared Continuous Thermal Scanning (ICTS) with conventional/traditional cut roadway cores, 3) Pavement Quality Indicator (PQI), and 4) Rolling Density Meter (RDM) utilizing Ground Penetrating Radar (GPR). The obtained results were compared and contrasted to the current testing, acceptance and construction methods system at Nebraska Department of Transportation (NDOT) and recommendations for future construction specifications and best practices were presented.

#### **Chapter 1. Introduction**

Asphaltic concrete (AC) is used in approximately 85% of paved roads and highways in Nebraska. AC has a vital role in the United States transportation infrastructure from both a safety and economic perspective. As a result, increasing the durability of asphalt pavements to prevent major damage and deterioration as well as minimizing the large cost of pavement rehabilitation and maintenance has been the focus of Departments' of Transportation (DOTs) for many years. Proper compaction and optimizing in-place pavement density are imperative to achieve high-quality, longer-lasting pavement structures.

Most DOTs specify asphalt pavement to be constructed at a minimum in-place density at 91 to 92.5% of its theoretical maximum density. However, it has been shown that with proper techniques, attaining densities of up to 95% are possible in most cases. Research studies have found that for every 1% increase in density, the roadway service life will increase an estimated 5%, up to as much as 15% [4]. This potential for improving and increasing pavement performance has become a primary focus of DOTs and the Federal Highway Administration (FHWA).

Many studies including the ones aforementioned have evaluated the effects of factors such as; inplace compaction equipment, laydown methods, material delivery, testing methods, and mixture design, on density of asphaltic pavement. However, through advances in testing and measurement technology, there is an opportunity for major advancements for real-time measurement methods to measure in-place density in a more rigorous manner, improve upon functional-structural performance expectations, and improve pavement construction quality in cold weather conditions.

#### 1.1 **Objectives**

This research project objective was to evaluate and compare the effectiveness of different compaction, delivery, and mix design characteristics to ensure the optimization of in-place asphalt pavement density. To this end, various laydown methods (i.e., Standard Pick-up Machine (SPM) and Material Transfer Vehicle (MTV)) and compaction equipment (i.e., double drum steel rollers,

pneumatic rollers, and combination rollers with both steel and pneumatic tires), using both static and vibratory modes were employed. In addition, the effect of different aggregate and binder variations, i.e., using less coarse ledge rock, and different binders PG 58V-34, PG 40-40, and PG 52-40 were studied. Four techniques including: 1) Conventional/traditional cut roadway cores, 2) Combination of Infrared Continuous Thermal Scanning (ICTS) with conventional/traditional cut roadway cores, 3) Pavement Quality Indicator (PQI), and 4) Rolling Density Meter (RDM) utilizing Ground Penetrating Radar (GPR) were used to measure the in-place density. It is worthy to note that 'optimization' in this study means finding a method that provides the most uniform and maximum in-place density/compaction of the asphaltic pavement.

#### 1.2 **Organization of Report**

This report includes four chapters. After this introduction, Chapter 2 presents the mixture, equipment and testing facilities used in this study. Chapter 3 discusses the in-place density measured using different techniques for the sections constructed through different compaction, delivery, and mix design strategies. Finally, Chapter 4 summarizes the main findings and conclusions of this study.

#### Chapter 2. Mixtures, Equipment, Coring, and Test Sections

#### 2.1 Mixture Design

The NDOT Type SLX mixture used in this study is a fine graded mix with a nominal maximum aggregate size (NMAS) of 0.375 inch (9.5 mm), 50 gyration @ N<sub>des</sub>. This mixture contained 35% reclaimed asphalt pavement (RAP) material, a PG 58V-34 binder and an optimum binder content of 5.4% by weight of total mixture. This mix was produced in a continuous parallel flow drum plant. This type of SLX mixture is widely used in Nebraska for lift thicknesses of 1 to 3". For this project, the lift thickness was 1.5", and in a few areas it was thinned down to 1.25" due to geometric elevation issues. One of the mix modifications in this study replaced the PG 58V-34 with softer binders (i.e., PG 40-40 and PG 52-40). With this change, the RAP content increased to 50% to accommodate the softer binders in an effort to prevent excessive softening of the mix. The other mix modification was an aggregate change that lowered the coarse crushed rock content by 10% and increased the natural sand content by 10%, essentially producing a finer graded mix. Table 1 summarizes the mixtures used in this study. The mix designs are described in Appendix A.

Mixture ID	Туре	Mixture Composition	
SLX_S	Standard SLX	PG 58V-34, 35% RAP	
SLX_M_40-40_R50%	Modified SLX	PG 40-40, 50% RAP	
SLX_S_58V-34_0.5	Standard SLX	PG 58V-34 with 0.5% higher binder content	
SLX_M_52-40_R50%	Modified SLX	PG 52-40, 50% RAP	
SLX_M_58V-34_LCR10%	Modified SLX	PG 58V-34 with 10% less crushed rock (LCR) (10% more washed sand), 35% RAP	

Table 1. Asphalt mixtures used in this study.

## 2.2 Equipment

## 2.2.1 Construction Equipment

To construct the sections, two different delivery machines and three different roller compactors are utilized as shown in Table 2. The paver used on this project was a 2018 Caterpillar 1055F with SE60V screed.

Equipment	Brand	Image of Equipment
Standard Pick Up Machine (SPM)	1996 Barber Greene BG650	

Table 2. Equipment used in this study.

Material Transfer Vehicle (MTV)	2018 Weiler 2850B	
7 Tire Pneumatic Roller (Static and Vibratory)	Sakai GW751	
Combination Steel / Pneumatic Roller (Static and Vibratory)	2007 Ingersoll Rand SD77	
Double Drum Steel Rollers	2018 Caterpillar, CAT CB15	

#### 2.2.2 Measuring Equipment

A variety of devices were used to measure the density and temperature of the asphalt layer. These devices included Infrared Continuous Thermal Scanner (ICTS), Pavement Quality Indicator (PQI), and Rolling Density Meter (RDM) – Ground Penetrating Radar (GPR). The ICTS was used to monitor real-time thermal profile of the road during the construction paving. The PQI and RDM-GPR were employed to measure the in-place density of the layers. The recorded densities were then compared to traditional coring and density measurement methods. Each device is briefly described in the following sections:

#### 2.2.2.1 Infrared Continuous Thermal Scanner (ICTS)

In asphalt paving, optimal and uniform temperature of the asphalt materials is a crucial factor which can significantly affect pavement performance. As a result, a thermal visualization of the construction process provides important insights into the temperature consistency of the material and can open up new optimization potentials.

ICTS used in this study can produce a real-time thermal profile of the road during the construction paving. The manufacturer states that the IR temperature scanner (MTPS-100) covers a wide thermal profile of the built-in layer over a total width of up to 42' (13 m). Although, this device does not directly deal with in-place density, thermal segregation can consequently result in insufficient in-place density. This can be detected in real time during the paving operation, by fully automatic visualization of the temperature. This quick detection of possible thermal segregation may provide an opportunity to take action and find a resolution for the segregated locations while paving. The infrared continuous thermal scanner used in this study is shown in Figure 1.



Figure 1. Infrared continuous thermal scanner (ICTS).

### 2.2.2.2 Pavement Quality Indicator (PQI)

The PQI 380 is a non-nuclear asphalt density gauge that utilizes an advanced GPS system which enables position and independent time logging. The PQI 380 conforms to ASTM standard D7113 and AASHTO T 343-12. Figure 2 shows the PQI device used in this study.



Figure 2. Pavement quality indicator (PQI).

### 2.2.2.3 Rolling Density Meter (RDM) – Ground Penetrating Radar (GPR)

Geophysical Survey Systems, Inc. developed the rolling density meter (RDM) for asphalt paving construction quality assurance/quality control. The RDM is operated on a manually propelled cart to collect the measurements from the field. It measures and records the dielectric constant of asphalt, through ground penetrating radar (GPR) sensors. The GPR sensors make continuous readings and then a concentrator box processes the collected data. Global positioning system (GPS)

data can be recorded in conjunction with GPR data. A view of the RDM-GPR is shown in Figure 3.



Figure 3. Rolling density meter (RDM) – Ground penetrating radar (GPR).

#### 2.3 Coring

The coring process was conducted the following construction day after each test section was constructed, the construction lanes remained closed until the cores were acquired. The coring locations were selected biasedly (highest and lowest temperature regions of asphalt pavement detected by ICTS) to see the effect of mixture temperature during the construction process and density readings were then taken by the PQI and RDM-GPR. Six-inch cores were taken from the selected areas as shown in Figure 4(a) and then were diamond saw cut at the lift line as shown in Figure 4(b) for laboratory density testing. Over 43 cores, a minimum of 3 per section, were taken.



Figure 4. Field samples: (a) Coring 6" diameter, (b) Cut cores for lab density testing.

#### 2.4 Test Sections

There was a total of 13 sections constructed on Hwy 281 North of Hastings, Nebraska. The fourday project took place in October 2018. Two different delivery methods (Standard Pick-up Machine (SPM) and Material Transfer Vehicle (MTV)) were investigated in this study, along with several compaction methods as outlined in Table 3. It should be noted that the compaction procedure "Method 1" is the most common method currently used in the Nebraska. The modifications to the paving mix design studied are outlined in Table 1. The information regarding the type of mixture, delivery methods and compaction process employed in each section is summarized in Table 4. The length of test section varied from a minimum of 500 to 4500'.

Method	Compaction Procedure
1	First pass: Breakdown double steel drum static, then vibratory after- Intermediate
1	double steel drum, Finish: Double steel drum roller
2	First pass: Breakdown double steel drum static, then vibratory after- Intermediate
2	7 tire pneumatic static, Finish: Double steel drum roller
3	First pass: Breakdown double steel drum static, then vibratory after- Intermediate
5	7 tire pneumatic vibratory, Finish: Double steel drum roller
	First pass: Breakdown double steel drum static, then break vibratory after-
4	Intermediate 7 tire pneumatic vibratory, combination roller vibratory,
	Finish: Double steel drum roller
5	First pass: Breakdown steel drum static, then vibratory after- Intermediate,
5	combination roller vibratory, Finish: Double steel drum roller

Table 3. Different compaction methods utilized in this study (rolling patterns were sequential).

Table 4. Construction information and measuring devices used for each section.

Day	Date	Section	Delivery Method	Mixture (see Table 1) Compaction Procedure (see Table 3)		Measuring Techniques			
	Day 1 Main Focus: Effect of Different Delivery Methods								
1	Oct 10	1	PSM	SLX_S	Method 1	ICTS, PQI, RDM-GPR, Coring			
1	Oct 10	2	MTV	SLX_S	Method 1	ICTS, PQI, RDM-GPR, Coring			
		1	L	Day 2 Main Focus: Effect of	Different Compaction Methods				
2	Oct 11	3	MTV	SLX_S	Method 1	ICTS, PQI, RDM-GPR, Coring			
2	Oct 11	4	MTV	SLX_S	Method 2	ICTS, PQI, RDM-GPR, Coring			
2	Oct 11	5	MTV	SLX_S	Method 3	ICTS, PQI, RDM-GPR, Coring			
2	Oct 11	6	MTV	SLX_S	Method 4	ICTS, PQI, RDM-GPR, Coring			
2	Oct 11	7	MTV	SLX_S	Method 5	ICTS, PQI, RDM-GPR, Coring			
				Day 3 Main Focus: Effect	of Different Asphalt Mixtures				
3	Oct 15	8	MTV	SLX_M_40-40_R50%	Method 1	PQI, RDM-GPR, Coring			
3	Oct 15	9	MTV	SLX_S_58V-34_0.5	Method 1	PQI, RDM-GPR, Coring			
3	Oct 15	10	MTV	SLX_S	Method 1	PQI, RDM-GPR, Coring			
	Day 4 Main Focus: Effect of Different Asphalt Mixtures								
4	Oct 16	11	MTV	SLX_M_52-40_R50%	Method 1	PQI, RDM-GPR, Coring			
4	Oct 16	12	MTV	SLX_M_58V-34_LCR10%	Method 1	PQI, RDM-GPR, Coring			
4	Oct 16	13	MTV	SLX_S	Method 1	PQI, RDM-GPR, Coring			

The climate conditions for each of the sections were recorded at the approximate midpoint of time during the paving of each section and are listed in Table 5. A 'Real Feel' factor was calculated by simply adding 10 °F to the calculated wind chill on sunny days for solar temperature gain. There was no allowance for solar gain on cloudy days. The 10 °F allowance was just an estimate. Note that the last two rows do not have a wind chill value, as by definition, a wind chill value cannot be calculated for temperatures greater than 50 °F. While the weather conditions varied, some of the coldest paving occurred on the first and second days, which worked out well for research purposes, as these were the 2 days that infrared continuous thermal scanner (ICTS) was used (the manufacturer had other obligations after the first 2 days). The warmest day of paving was the 4<sup>th</sup> day (Oct 16, 2018-section 13), with a high of 66 °F and sunny. Based on NDOT specification a minimum temperature of 45 °F is required for paving, and 32 °F when Warm Mix Additives (WMA) are used, and this mix contained a WMA additive (see mix design, Appendix A)

Day	Date <sup>1</sup>	Section	Real Temperature (°F)	Wind (mph)	Direction	Wind Chill <sup>2</sup> (°F)	Sky <sup>3</sup>	Real Feel <sup>4</sup> (°F)
1	Oct 10	1	37	19	N	27	C	27
1	Oct 10	2	43	21	Ν	34	C	34
2	Oct 11	3	32	6	Ν	26	C	26
2	Oct 11	4	35	10	Ν	27	S	37
2	Oct 11	5	40	12	N	33	S	43
2	Oct 11	6	46	12	Ν	40	S	50
2	Oct 11	7	46	12	Ν	40	S	50
3	Oct 15	8	32	8	W	25	C	25
3	Oct 15	9	41	11	W	34	S	44
3	Oct 15	10	43	7	W	39	S	49
4	Oct 16	11	36	7	W	30	S	40
4	Oct 16	12	55	11	NW	-	S	-
4	Oct 16	13	66	11	NW	-	S	-

Table 5. Climate conditions for each section at the midpoint of paving.

<sup>1</sup>Year: 2018

<sup>2</sup>Wind Chill (°F) =  $35.74 + (0.6215 \times T) - (35.75 \times Wind_{sfc}^{0.16}) + (0.4275 \times T \times Wind_{sfc}^{0.16})$ , T = air temperature (°F), Wind\_{sfc} = wind speed (mph)

<sup>3</sup>Sky: C = Cloudy and S = Sunny

<sup>4</sup>Real Feel: if the sky is cloudy, it is equal to wind chill otherwise it is wind chill plus 10 °F.

#### **Chapter 3. Results and Discussion**

Thirteen different sections were constructed on the four days of the demonstration project. Two different delivery methods investigated in this study were: (1) Standard Pick-up Machine (SPM), and (2) Material Transfer Vehicle (MTV). In addition, different compaction methods (see Table 3) and measuring devices (i.e., ICTS, PQI, and RDM-GPR) were employed. It should be noted that the PQI and RDM-GPR both required a correction factor for density measured by each device. This correction factor is defined as "the average difference in density of cores for each section compared to that measured by each device (i.e., PQI and RDM-GPR) for the same section". It is important to note that the density cores were biasedly sampled based on either high or low densities and were not sampled randomly. The only random cores were those taken under the regular project acceptance system RSS (Random Sampling Schedule) which is a random sampling system that provides sampling for every 1000 ton sub-lot, five per lot for a 5000 ton lot size. Acceptance is based on minimum lot average of 92.5% of the theoretical maximum mixture density.

#### 3.1 Day 1: Standard Pick-Up Machine vs Material Transfer Vehicle

Day 1 began after a delay to wait for temperatures to rise above 32 °F. Two segments (section 1 and 2, see Table 4) were constructed. The weather conditions were very cold and windy, the weather conditions are listed in Table 5. Two different delivery machines were tested, a Standard Pick-up Machine (SPM) was used for the first half of construction and a Material Transfer Vehicle (MTV) was used on the second half. In both scenarios, attaining density was difficult and not achieved at several locations in biased (largest differential temperature) sampling. To obtain a real-time thermal profile of the road during the construction process, an ICTS was used. Figure 5 shows an example of the obtained thermal profile for the mixtures delivered by either SPM or MTV and the density of cores. The largest color variation would be from blue (coldest) to pink (hottest) as shown in the color legend at the top of each page of the scan. The images clearly show the SPM had the largest thermal segregation and also yielded the largest variance in density as shown in the bar graph to the right of the scan. Both bar graphs show the line of minimum average density of 92.5. For a 'single point' density, generally a density of 90 or above would be considered

acceptable, conversely the two tests showing 83.4 and 85.3% would be considered not acceptable by all industry standards.

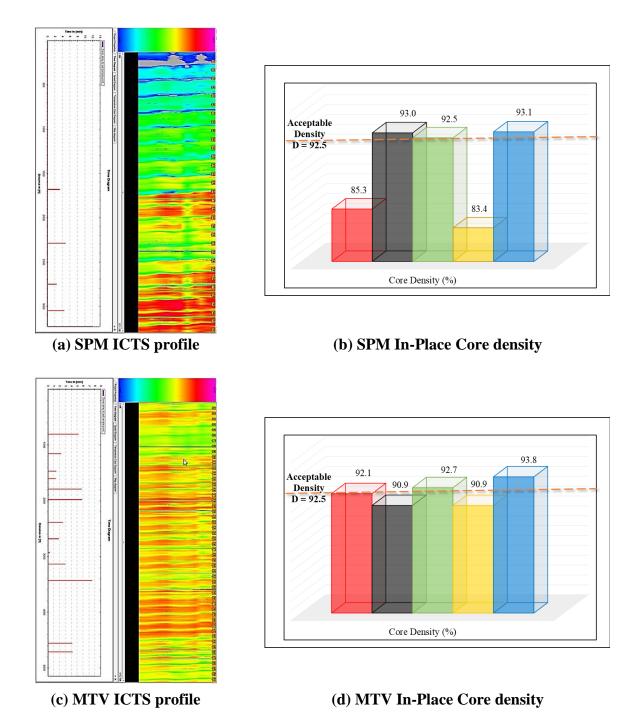


Figure 5. ICTS profile and single core density for mixtures delivered by SPM and MTV.

The ICTS thermal test segments were evaluated in 150' sections. Sections with less than a 25 °F differential were rated as good, sections with 25 to 50 °F differential rated moderate and those over 50 °F rated as being severe. These criteria were based on manufacture's recommendation and typically used by DOTs. For the SPM, 22 sections were evaluated; zero sections rated good, 12 were moderate and ten were severe. For the MTV, 35 sections were evaluated; 13 sections rated good, 19 were moderate and three were severe (Table 6). Figure 6 provide this graphically, and illustrates the largest differences in 'good' versus 'severe' sections for each delivery method.

# of Differential<25°F		<b>Moderate</b> 25°F <differential≤50°f< th=""><th colspan="2"><b>Severe</b> Differential&gt;50°F</th></differential≤50°f<>		<b>Severe</b> Differential>50°F			
Profiles	Number	%	Number %		Number	%	
	SPM						
22	0	0	12	55	10	45	
MTV							
35	13	37	19	54	3	1	

Table 6. Thermal profile results summary.

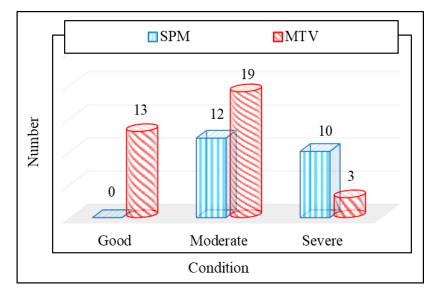


Figure 6. Comparison between MTV and SPM based on thermal differential rate.

Table 7 summarizes the results of each measuring devices' density against the actual roadway cores along with the thermal measurements for mixtures delivered by SPM and MTV. It should be

noted that the RDM-GPR readings were not taken during the MTV section because of some battery issues that occurred for the RDM-GPR, due to the morning delays from the cold weather. The batteries ran out of power and there were no back up batteries. The results indicate that a sharp drop in temperature leads to a decrease in density. Table 7 also shows that the performance of MTV was much better than the SPM delivery system.

	Density			Infrared Continuous Thermal Scanner (ICTS)		
Core Number	RDM-GPR PQI (Corrected (Corrected Density) Density)		6" Core	Temperature (°F)	Temperature Differential (°F)	
	· · · · ·		SPM			
1	89.5	89.6	85.3	216	38.7	
2	89.2	90.2	93.0	250	38.7	
3	89.2	90.2	92.5	244	48.8	
4	90.1	87.3	83.4	190	66.8	
5	89.3	90.1	93.1	269	66.8	
Average	89.5	89.5	89.5		-	
			MTV			
6	N.R	92.1	92.1	273	26.5	
7	N.R	91.3	90.9	279	26.5	
8	N.R	92.6	92.7	270	14.4	
9	N.R	91.7	90.9	278	29.5	
10	N.R	92.9	93.8	275	34.9	
Average	-	92.1	92.1		-	

Table 7. Core density information measured by different techniques and relevant temperatures.

Figure 7 plots temperature versus density measured using the standard/conventional coring technique. Figure 7 displays a linear correlation with  $R^2$  equal to 0.76 between density and temperature. It suggests that, under these paving and temperature conditions, a minimum material temperature of 250 °F (critical minimum) during compaction may promote densities of 90% or greater.

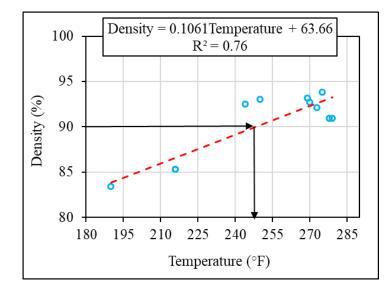


Figure 7. Correlation between temperature and in-place density of core samples.

#### 3.2 **Day 2: Compaction Equipment and Rolling Sequences**

Day 2 began after temperatures rose above 32 °F. Five segments were constructed in these very cold temperatures. Each segment is defined in Table 4, sections 3 through 7. Same mixture type SLX was used in all segments. Different rollers were used in various combinations: (1) double drum steel rollers, (2) 7 tire pneumatic roller and (3) combination of double drum steel and 7 tire pneumatic roller. The average densities shown in Table 8, indicate that the pneumatic rollers help increase density. It was observed that the combination roller (CR, method 4 and 5 in Table 3) consistently increased density during all of spot checks during each roller pass, these readings were taken during compaction. The density results for the sections are listed in Table 8.

		Density		Infrared Con	tinuous Thermal Scanner (ICTS)
Core Number	RDM-GPR (Corrected Density)	PQI (Corrected Density)	6" Core	Temperature (°F)	Temperature Differential (°F)
	(	Compaction	Method 1	(see Table 3)	
11	90.6	92.4	89.7	269	11.7
12	92.5	93.1	95.3	283	17.6
13	N.R	92.9	93.4	275	18
Average	92.8	92.8	92.8		-
	C	Compaction	n Method 2	(see Table 3)	
14	90.6	92.1	93.8	281	13.3
15	91.1	92.4	92.3	276	13.7
16	91.5	88.7	87.3	274	20.7
Average	91.1	91.1	91.1		-
	0	Compaction	n Method 3	(see Table 3)	
17	93.1	94.1	95.4	287	18
18	93.6	93.6	93.1	283	14.4
19	93.8	92.7	92.1	286	21.4
Average	93.5	93.5	93.5		-
	0	Compaction	n Method 4	(see Table 3)	
20	93.6	94.2	94.3	288	16.9
21	93.1	93.0	93.3	277	16.2
22	94.0	93.3	93.0	302	18.4
Average	93.6	93.5	93.5		_
	0	Compaction	n Method 5	(see Table 3)	
23	94.2	94.7	94.7	280	22.3
24	94.6	93.5	92.7	281	14.9
25	93.7	94.5	95.2	287	18
Average	94.2	94.2	94.2		-

 Table 8. Core density information measured by different techniques and the relevant temperatures.

Another area that is worthy of discussion is thermal mass, which is equivalent to thermal capacitance or heat capacity; the ability of a body to store thermal energy. The importance of thermal mass in this study would be the function of heat loss. Heat loss is defined as the amount of heat per unit weight that a material loses or cools, the focus being on the heat loss during construction (before and during compaction). The heat loss can significantly affect the density of the asphaltic layer. It means that the higher heat loss may result in lower density and vice versa. For this study, the heat loss calculation is simplified by assuming all effective parameters do not

change during construction, except mixture temperature during delivery and compaction. In general, Figure 8 shows that a decrease in heat loss results in an increase in density. There were a few results that varied from that (i.e., core number 19, 22, 23 and 24), but most followed that assertion. The green dash line in the Figure 8 shows the acceptance density based on the current standard of 92.5%. Without going into a detailed thermal analysis and assuming all other variables, (e.g., mix delivery temperature, environmental conditions - air, pavement temperature, wind speed, solar gain and etc.) are held constant, the thermal mass would then be simply based on temperature and mass. As a result, an increase in lift thickness from 1.5 to 2" will essentially lead to 25% more heat mass. This provides a 25% longer compaction time before the material drops to the critical minimum compaction temperatures (i.e., 250 °F) as suggested in the earlier discussion (see Figure 7).

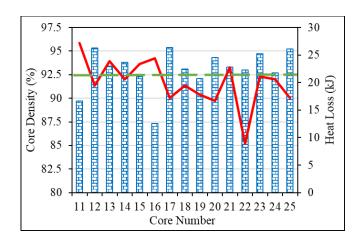


Figure 8. Core density (blue bars) versus heat loss (red line).

#### 3.3 Day 3: Modified Mix Design and Binders

Similar to the first two days of paving, day 3 began after waiting for temperatures to rise above 32 °F. In this section the 'Standard' paving operations were used - Paver, MTV, and three steel double drum rollers. Three segments were constructed and the density readings of each segment are shown in Table 4 (sections 8 through 10).

In the first section, the SLX mixture was modified by using a PG 40-40 and 50% RAP (SLX\_M\_40-40\_R50%). These modifications exhibited a visual appearance-change to the mix

that added a very glassy black shiny look to the mix. In addition, there was a noticeable change to the fumes from the windrow, what could be described as a reduced petroleum-based smell. However, after compaction, this section appeared visually similar to the control sections. Increasing the RAP to 50% in the mixture, seemed to have reduced the softer binder effects to the combined mix. Therefore, the first section really did not experience a significant improvement to compaction. The decision to increase the RAP to 50% was based on preliminary laboratory testing that yielded similar indirect tensile strength results when compared to the standard/control mix, and resulted in very similar field workability and compaction. The standard SLX mix with 0.5% increased binder above the design target was used in the second section, this change did not provide significant changes to laydown or compaction. The density results for the sections are listed in Table 9.

	I	Density	
Core Number	RDM-GPR	PQI	6" Core
	(Corrected Density)	(Corrected Density)	0 Cole
SLX	_M_40-40_R50% (see 7	Table 1)	
26	91.7	91.1	91.8
27	90.6	92.6	93.9
28	92.0	90.4	88.5
Average	91.4	91.4	91.4
SL	X_S_58V-34_0.5 (see Ta	uble 1)	
29	91.3	89.2	86.3
30	90.6	91.2	92.0
31	90.3	91.6	93.7
Average	90.7	90.7	<b>90.7</b>
	<b>SLX_S</b> (see Table 1)		
32	92.0	91.3	91.4
33	90.6	90.8	90.4
34	91.3	91.9	92.1
Average	91.3	91.3	91.3

Table 9. Core density information measured by different techniques.

#### 3.4 Day 4: Modified Mix Design, Modified Gradation, and Binders

Day 4 began with no delay for temperatures. This section again used the 'Standard' paver, MTV, and three steel double drum rollers. Three segments were constructed and each segment built as

defined in Table 4 (section 11 through 13). The SLX mixture was modified by using a PG 52-40 and 50% RAP (SLX\_M\_52-40\_R50%). Similar to Day 3, the following observations were reported by field engineers, however, there may have been a slight reduction in density with the slightly stiffer 52-40 and 50% RAP as shown in Table 10.

- (1) A visual appearance producing a glassy black shiny look to the mix.
- (2) A noticeable change to the fumes from the windrow, seemed less petroleum-based smell.
- (3) Similar appearance compared to the control sections after compaction.

In the second section, the coarse crushed rock was reduced by 10% and added 10% fine natural sand (SLX\_M\_58V-34\_LCR10%). The obtained in-place density results, shown in Table 10, are in good agreement with field observations indicating that the laydown and compaction of SLX\_M\_58V-34\_LCR10% mixtures were fairly similar to control mixture (SLX\_S).

		Density	
Core Number	RDM-GPR (Corrected Density)	PQI (Corrected Density)	6" Core
S	LX_M_52-40_R50% (se	ee Table 1)	
35	91.7	91.2	90.2
36	91.5	90.9	90.7
37	91.1	92.0	93.4
Average	91.4	91.4	91.4
SLX	K_M_58V-34_LCR10%	(see Table 1)	
38	93.0	93.8	93.3
39	93.5	93.9	93.6
40	94.5	93.5	94.2
Average	93.7	93.7	93.7
	SLX_S (see Table	e 1)	
41	93.8	93.4	91.4
42	92.6	95.6	96.9
43	94.2	91.6	92.3
Average	93.5	93.5	93.5

Table 10. Core density information measured by different techniques.

#### 3.5 **Correlations between Measuring Devices**

The sequence used in all of the measurement testing was as follows:

- 1) ICTS mapped all of the thermal imaging with GPS and stationing on day 1 and day 2.
- 2) During compaction the spot check of densities using the PQI were performed to see the effect of each compactor and help to establish rolling patterns.
- 3) After compaction was completed, the ICTS scan was used to identify high and low temperature thermal segregation areas which could result in high and low densities,
- 4) Then PQI was employed to verify the densities.
- 5) After PQI densities were completed, the RDM-GPR dielectric reading at each density location were recorded to verify the other readings/findings.
- 6) The standard 6" density cores were taken at each location.

It should be noted, on the first day of the Demo Project, intelligent compaction GPS device/screen (Figure 9) was used on the first two rollers, but only used for demonstration purposes.



Figure 9. GPS device used on Day 1 for demonstration only.

The average densities for each section measured by different techniques are shown in Figure 10. The results indicate that there is linear correlation between density measured using core samples with the other two techniques (i.e., RDM-GPR and PQI); however, the PQI technique shows better

correlation compared to the RDM-GPR based on  $R^2$  value.

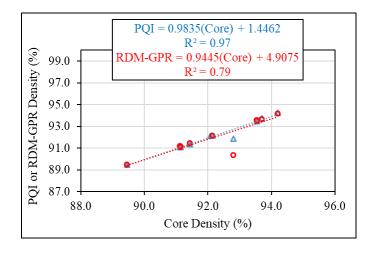


Figure 10. Comparison between core density and measured density using PQI (blue triangular), and RDM-GPR (red circle).

Although the PQI and RDM-GPR techniques showed good correlation with averaged densities, an evaluation of individual core densities, as shown in Figure 11, reveals that further testing and evaluation will be required.

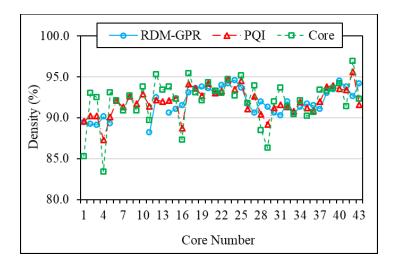


Figure 11. Comparison between measured density using Coring, PQI, and RDM-GPR.

#### 3.6 **Performance of ICTS**

The ICTS performed satisfactory regarding locating thermal segregation and correlated with both high- and low-density areas. Figure 12 shows the correlation between asphalt layer temperature before compaction and density measured by coring.

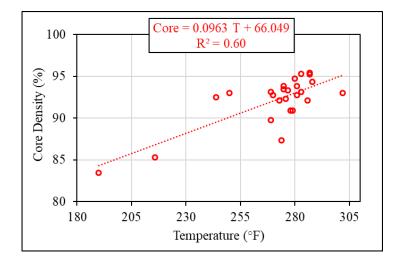


Figure 12. Correlation between temperature recorded by ICTS and density measured by coring.

#### 3.7 The Effects of Environmental Conditions on the Average Pay Factor

Another finding was a parallel trend of better compaction with better environmental conditions. This was evaluated with a 'Real-Feel' factor that took into account solar gain along with temperature, and wind chill. For example, on a 'sunny' day, a 'Real-Feel' factor of +10 °F was added to the calculated wind-chill temperature. This was plotted against the lot average pay factor, as shown in Figure 13. As one would expect, better environmental conditions can provide better compaction.

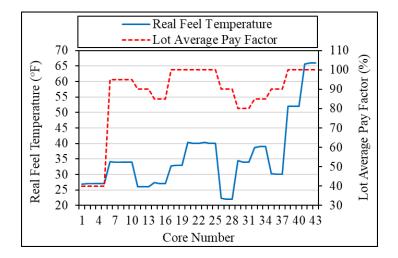


Figure 13. Trend of compaction with the environmental conditions.

#### 3.8 Current In-Place Density Acceptance Specifications

The current Nebraska acceptance standard for in-place density requires that one test per 1000 tons of mixture is randomly sampled and the pay factor is based on a five test average for a 5000 ton lot. The result of this research revealed that the current acceptance methods could be strengthened. For example, the demo project was constructed during lot 6 and 8 resulting in a 100% pay factor according to the project specifications. However, selective/biased sampling density test results showed that there were several areas with substandard densities. For instance, in sub-lot sample 6-4 the density was 94.3% which is very good density which would be considered 100% pay in a full lot, however, the selective/biased sampling of this lot shows that the corresponding core number 16 has a density of 87.3% which is considered a failed density according to the current acceptance criterion (i.e., 92.5%). Table 11 summarizes the random project cores that coincided with the research sections.

Core	6"	Lot 6	Lot 8	Sample	Core	6"	Lot 6	Lot 8	Sample
#	Core	Density	Density	#	#	Core	Density	Density	#
1	85.3				23	94.7			
2	93.0				24	92.7	94.0		6-5
3	92.5	91.3		6-2	25	95.2			
4	83.4				Ave	94.2			
5	93.1				26	91.8			
Ave	89.5				27	93.9			
6	92.1				28	88.5			
7	90.9				Ave	91.4			
8	92.7	92.1		6-3	29	86.3			
9	90.9				30	92.0		91.6	8-3
10	93.8				31	93.7			
Ave	92.1				Ave	87.3			
11	89.7				32	91.4			
12	95.3				33	90.4			
13	93.4				34	92.1			
Ave	92.8				Ave	91.3			
14	93.8				35	90.2			
15	92.3	94.3		6-4	36	90.7			
16	87.3				37	93.4			
Ave	91.1				Ave	91.4			
17	95.4				38	93.3			
18	93.1				39	93.6			
19	92.1				40	94.2			
Ave	93.5				Ave	93.7			
20	94.3				41	91.4			
21	93.3				42	96.9		94.1	8-5
22	93.0				43	92.3			
Ave	93.0				Ave	93.5			

Table 11. Comparison between densities measured for bias core and random core.

#### Chapter 4. Summary, Overall Findings, and Conclusion

#### 4.1 Summary

The in-place density of asphalt pavement is a major factor that prevents pavement distresses that may occur during its service life. Late season paving is common and often must be performed in colder temperatures, which is the most challenging environment for attaining optimal in-place density/compaction. This research project aimed to study and compare the effectiveness of different compaction, delivery, and mix design characteristics to ensure the optimization of in-place asphalt pavement density constructed in cold paving conditions and measured using different devices, methods, and techniques.

The ICTS, PQI, RDM-GPR, and core data look to be very useful for providing more measurement and testing data to strengthen the acceptance program for asphalt pavements. It was reported that the pneumatic rollers provided a slight increase in density, and the combination roller (CR) provided consistent improvement on every roller pass and provided an improvement to the 'Standard' three double steel drum rollers most commonly used in Nebraska. The research did not yield significant effects from the mix changes, binder changes, or aggregate change, as one would have thought. The use of softer binders, increased binder contents and aggregate changes have been shown to be beneficial in other research, however, some of the soft binder effects were definitely offset by the increased RAP content to 50%. The higher binder content of 0.5% and the gradation modifications did not exhibit noticeable compaction improvement. This is possibly due to the extremely cold conditions and/or that the modifications made in the control mixtures were not significant enough on the mix design to provide improvement to the in-place density.

#### 4.2 **Overall Findings**

 MTVs provide an effective method to minimize thermal segregation and therefore provide improved temperature and density consistency.

- Pneumatic rollers provide an improved mode of compaction. More specifically the combination roller (CR) provided a consistent improvement compared to the 'Standard' three double drum steel roller compaction method.
- Infrared continuous thermal scanning (ICTS) is an effective measuring technique that provides real-time information to the producer for improving temperature consistency that will result in more uniform densities.
- 4) RDM-GPR provides a continuous density measurement of the entire roadway. Further research and implementation studies with the R06C SHRP-2 research project that is currently underway at NDOT, will continue throughout 2019.
- 5) Heat loss is directly proportional to material mass, i.e., lift thickness. Therefore, lift thickness requirements need to be re-examined, especially for cold weather paving.
- 6) Random sample cores with averaging of 5 tests per lot dampens density variability compared to single test results. The use of non-destructive testing equipment could provide opportunities for a more rigorous acceptance procedure.
- Consideration to the environmental conditions (temperature, wind, solar gain) can provide better pavement densities.

#### 4.3 Conclusion

The Nebraska Department of Transportation (NDOT) is exploring specification improvements to in-place density by focusing on infrared continuous thermal scanning and changes to the in-place density testing, measurement and acceptance methods. These changes may include an increased frequency of density testing, use of single density test values versus lot averages, and a new incentive/disincentive quality pay factor. The NDOT is reviewing current lift thickness practices and making some initial changes. For example, the NDOT is designing multi-lift strategies with minimum 2" lift increments and most importantly top lifts of 2", as compared to the current standard of 1.5", which will improve in-place density in all conditions. Furthermore, for thin-lift strategies (1.5" or less), temperature conditions and delivery specifications need to be revised to include provisions to test thermal segregation along with an increased minimum compaction and ambient

temperature requirements. As a result from these changes, an increased use of MTVs is quite probable. However, some restrictions may need to be applied on roadways that have structural weaknesses or have potential structural issues after milling of the pavement. This is due to the potential heavy axle loads of the MTV. For example, the MTV used in this study weighs 64 tons (128,000 lbs) when fully loaded, with a 2-axle suspension. This equates to 32 tons (64,000 lbs) per axle, an extremely high load that can damage pavements and subgrades, possibly breaking through in weak sections. A long-term concern of this would be micro-cracking that may not be visible during construction, but creates future wheel path cracking issues. As an outcome of this research, the NDOT will continue to move forward with these advancements in technologies and paving techniques to provide new opportunities for longer lasting/better performing pavements.

# Appendix A

# SLX\_S

						State o	of Neb	raska							
								Original De	sign #1-42	432-S	LX(VI	MA)R/	<b>4</b> S-18-	MD	
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	-	Concrete:	SLX						ASPHA			•			
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													5 <b>-00</b> 1	#/Cecab	ase RT 945
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3/8" DRY (	CHIPS	20		SEC		R	3/4 <sup>-</sup> 100.0	1¥2⁼ 100.0	3/8 <sup>-</sup> 99.8	<b>#4</b> 11.4	<b>#8</b> 4.8	<b>#16</b> 4.1	<b>#30</b> 3.7	#50 3.4	#200 2.7
3A GRAVE		20		36		A 10V	100.0	100.0	99.8	11.4 92.5	4.8 52.3	4.1 28.0	3.7	3.4	4.7
VASHISA		30 5		36	9N 9N	10 W	100.0	100.0	100.0	92.5	99.5		62.6	24.4	4.7
2A GRAVE		5		36	9N		99.0	96.0	91.7	60.6	7.1	1.8	0.7	0.4	0.2
RAS		5	MANUFAC				100.0	100.0	99.8	99.1	97.7	81.0	59.7	52.3	35.2
BAP		10	CONTRA				100.0	90.0	84.0	79.0	47.0	38.0	31.0	18.0	8.8
RAP		25	TATE SUP				100.0	98.0	92.0	78.0	55.0	29.0	18.0	11.0	4.0
			COMBIN	ED G	RADA	TION	100.0	98.3	95.9	70.4	45.3	28.8	19.3	12.1	5.7
			SPECIFI	CATI		ANGE		98	93	70.0	45	25	15	10	4
			OFECIFIC	CAIN			100	100	100	87	65	41	31	21	10
			SF EGIL	CAIN			100	100	100	87	65	41	31	21	10
				CATH			100					41			IV
JOE	3 MIX IDE	NTIFICAT		6411			100	CONS	ENSUS PR		TIES		FAA S	SP.GR	10
		NTIFICAT		CAT			100	CONS			TIES	<b>41</b> 4.4	FAA S		10
JOB JMF #	3 MIX IDE 13	NTIFICAT		CAT			100	CONSI FAA	ENSUS PR Results	OPEF	TIES 4	4.4	FAA S	SP.GR	10
JMF #	13			CAT			100	CONSI FAA Dust to /	ENSUS PR Results Asph. Ratio	OPEF	TIES 4	4.4	FAA S	SP.GR	10
JMF #		NTIFICA1		CAT			100	CONSI FAA Dust to /	ENSUS PR Results	OPEF	TIES 4	4.4	FAA S	SP.GR	10
JMF #	13						100	CONSI FAA Dust to /	ENSUS PR Results Asph. Ratio	OPEF	TIES 4	4.4	FAA S	SP.GR	
JMF #	13							CONSI FAA Dust to /	ENSUS PR Results Asph. Ratio	OPEF	TIES 4	4.4	FAA S	SP.GR	
JMF #	13							CONSI FAA Dust to /	ENSUS PR Results Asph. Ratio	OPEF	TIES 4	4.4	FAA S	SP.GR	10
JMF #	13 BINDER	5.40%						CONSI FAA Dust to / Desi	ENSUS PR Results Asph. Ratio gn Gsb	OPER D	TIES 4	4.4	FAA S	SP.GR	10
JMF #	13 BINDER	5.40%						CONSI FAA Dust to /	ENSUS PR Results Asph. Ratio gn Gsb	OPER D	TIES 4	4.4	FAA S	SP.GR	10
JMF # TOTAL	13 BINDER	5.40%		sphalt	binde	r for a	total o	CONSI FAA Dust to A Desi	ENSUS PR Results Asph. Ratio gn Gsb	OPER D	TIES 4	4.4	FAA S	SP.GR	10
JMF # TOTAL	13 BINDER	5.40%	FION	sphalt	binde	r for a	total o	CONSI FAA Dust to A Desi	ENSUS PR Results Asph. Ratio gn Gsb	OPER D	TIES 4	4.4	FAA S	SP.GR	10
JMF # TOTAL	13 BINDER of 2.57% cted by the	5.40% of type PC e contracto	58V-34 a	sphalt e targe	binde: t asph	r for a alt bin	total o der cor	CONSI FAA Dust to A Desi of 5.40% (by whitent.	ENSUS PR Results Asph. Ratio gn Gsb	D	4 1 2.1	4.4	FAA 9	SP.GR	10
JMF # TOTAL	13 BINDER of 2.57% cted by the	5.40% of type PC e contracto	58V-34 a	sphalt e targe	binde: t asph	r for a alt bin	total o der cor	CONSI FAA Dust to A Desi	ENSUS PR Results Asph. Ratio gn Gsb	D	4 1 2.1	4.4	FAA 9	SP.GR	
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## SLX\_M\_40-40\_R50%

					S	tate o	f Nebr	aska							
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	Increas	e BAP to !	50%					ete Design							
								<b>_</b>							
Project 1	Manager	KEVIN KO	DHMETSCH	ER					Date	02-0	8-18 A	pprov	ed		
Project ]	-	NH-34-4()										-ppie -			
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	•	Concrete:	SLX						ASPI	IALT	BIND				
Design I	No:	2018-1							Sour	ce:	FLIN	T HILI	LS		
									Grad	e:	PG 4	0-40			
GRAD	ATION O	F MATERI	ALS PROP	ÓSED				SI	EVE AN	VALYS	SIS (Y	ASH)			
MATE	RIAL		PIT LO	CATIO	)N		19.0	12.5	9.50	4.75	2.36	1.18	600	300	75
		X	1/4	SEC		R	3/4*	1/2*	3/8"		#8	#16	#30		#200
3/8" DRY		15	MART		RIETT/		100.0	100.0	99.8	11.4	4.8	4.1	3.7	3.4	2.7
3A GRAV		22		36	9N	10 🗸	100.0	100.0	100.0	92.5		28.0	16.1	10.1	4.7
WASH SA		4		36	9N	10 🗸		100.0	100.0	100.0		88.4	62.6	24.4	1.0
2A GRAV	EL	4		36		10 V		96.0	91.7	60.6		1.8	0.7	0.4	0.2
25		5	MANUFAC				100.0	100.0	99.8	99.1		81.0	59.7	52.3	35.2
RAP		25	CONTRA				100.0	90.0	84.0	79.0		38.0	31.0	18.0	8.8
RAP		25	STATE SUP COMBIN					98.0	92.0	78.0		29.0	18.0	11.0	4.0
			COMBIN	cu Gh	NUA	IUN	100.0	96.8	93.6	72.7		31.2	21.9	13.6	6.4
			SPECIFI	CATIO	N RA	NGE	100	98 100	93	70.0 87	45 65	25 41	15 31	10 21	4
				_	_		100	100	100	87	60	41	- ১1	21	10
.10		ENTIFICA	TION					CONSEM	ISUS P	BOPP	BTIF	s	FAA	P.GR	
								FAA B				4.4	r	593	
JMF #	13														
				1				Dust to As	sph. Ra	tio	1	.21	1		
TOTAL	BINDER	5.40%						Desig	n Gisb		2.5	585			
													-		
				_	_				_						
Addition	of 1.82%	of type PG	40-40 aspha	alt bind	der for	a tota	d of 5.4	40% (by wt.of 1	nix) ha	8					
been sele	cte <mark>d b</mark> y th	e contracto	r to be the ta	arget a	sphalt	binder	conte	nt.							
				-	•										
			-	-		•	•	criteria values	• •						
by the co	ntractor.	If it is nece	ssary to cha	nge th	e job n	nix eit	her bef	fore or after the	e job sta	erts,					
including	the aspha	lt binder %.	the contrac	tor sha	all noti	fy the	P.E. /	P.M.							
						-									
	Veete De	ving, Inc.		REM.	ARKS	"Esp	erimen	tal Design usi	ing stai	ndard	miz vi	ith Flir	t Hills	PG 40-4	0 and
00:	Vontz Fa							AP to 50%. R							
cc:															
cc:	Cal Splat														
cc:	Cal Splat Andy Dea	armont													
cc:	Cal Splat	armont													
cc:	Cal Splat Andy Dea	armont			ated by 4021 41			ea & Materials a	nd Res	earch	Divisio	n			

# SLX\_S\_58V-34\_0.5

					S	tate o	f Nebr	aska							
	S	tandard M	fix w/					"Ezp	erimenta	l Desi	gn (S	ee Rei	marks	Section	Below)
	BINDER	INCREAS	E BY 0.5%		Depa	rtmen	t of Tr	ansportation	1						
					Ås	phalt (	Concre	te Design							
Project 1	Manager:	KEVIN KO	OHMETSCH	ER					Date:	02-0	8-18 A	pprov	eđ		
Project 1	No:	NH-34-4()	130)												
Name of			STINGS - D		HAN										
			SLX	ONIFI					ASPH	ATTD	INDE	•			
••	-	oncrete:	SLA												
Design N	No:	2018-1							Source			T HILI			
									Grade	-				7% AD-H	
										(ArrN	laz)	LOF 6	5-00 1	#/Cecaba	ase RT 945
		F MATERI	ALS PROP					S	IEVE AN.	ALYSI	s (¥/	\SH)			
MATE	RIAL		PIT LOO				19.0	12.5		4.75					75
		X	1/4	SEC		R	3/4*	1/2-	3/8"	#4	#8	#16	#30		#200
3/8" DRY (		20			RIETT/		100.0	100.0	99.8	11.4	4.8	4.1	3.7	3.4	2.7
3A GRAVI WASH SA		30		36	9N	10 V	100.0	100.0	100.0	92.5	52.3	28.0	16.1	10.1	4.7
VASH SA 2A GRAVI		5		36	9N	101/	100.0	100.0	100.0	100.0			62.6		1.0
ZA GRAVI RAS	EL	5	MANUFAC	36		10 V		96.0 100.0	91.7	60.6	7.1	1.8	0.7	0.4	0.2 35.2
RAS RAP		5	CONTRA				100.0	90.0	99.8 84.0	99.1 79.0			59.7 31.0	52.3	35.2
BAP		10	STATE SUPI				100.0	90.0	92.0	79.0			18.0	18.0	8.8 4.0
		20	COMBINI					98.3	92.0	78.0		28.8	18.0	12.1	4.0
							100.0	98	93	70.0		20.0	15	10	4
			SPECIFIC	CATIO	IN RA	NGE	100	100	100	87	65	41	31	21	10
JMF #	13	ENTIFICA							Results			4.4	2.	593	
								Dust to A	-	tio		.97			
TOTAL	BINDER	5.90%						Desi	gn Gsb		2.5	585			
Addition	of 3 07%	of tune PG	58V-34 april	alt bie	nder fo	r a tot	tal of 5	.90% (by wt.c	f mix) ha						
		~ ~	r to be the ta						1 IIIA) IIa						
been seleo	cted by the	e contracto	r to be the ta	irget a	sphait	Dinder	conter	it.							
	rated Lime	e will be neo	cessary for th	iis desi	ign due	to the	e use of	0.7% AD-he	re LOF 65	5-00 w	Cecab	ase RT	945.		
*No Hyd:															
*No Hyd:															
		rification o	f the job-miz	c grada	tion a	nd sup	erpave	criteria value	proposed	d					
This cons	stitutes ve		-	-		-	-								
This cons by the co	stitutes ver ntractor.	If it is nece	essary to cha	nge th	e job n	nix eit	her befo	ore or after th							
This cons by the co	stitutes ver ntractor.	If it is nece	-	nge th	e job n	nix eit	her befo	ore or after th							
This cons by the co	stitutes ver ntractor.	If it is nece	essary to cha	nge th	e job n	nix eit	her befo	ore or after th							
This cons by the co including	stitutes ver ntractor. the aspha	If it is nece It binder %,	essary to cha the contrac	nge th tor sha	e job n all noti	ix eit fy the	her before P.E. /	ore or after th P.M.	ie job star	ts,	hinde	inere	250 6	om origi	nal
This cons by the co including	stitutes ves ntractor. the asphal Vontz Pa	If it is nece It binder %, ving, Inc.	essary to cha the contrac	nge th tor sha	e job n all noti	tix eit fy the <b>Exp</b>	her befo P.E. /	ore or after th P.M. Ital Design w	ie job star	ts,	binde	r incre	ase fr	om origi	nal
This cons by the co including	stitutes ves ntractor. the asphal Vontz Pa Cal Splate	If it is nece It binder %, ving, Inc. stoesser	essary to cha the contrac	nge th tor sha	e job n all noti	tix eit fy the <b>Exp</b>	her befo P.E. /	ore or after th P.M.	ie job star	ts,	binde	r incre	ase fr	om origi	nal
This cons by the co including	atitutes ver ntractor. the asphal Vontz Par Cal Splate Andy Dea	If it is nece It binder %, ving, Inc. stoesser armont	essary to cha the contrac	nge th tor sha	e job n all noti	tix eit fy the <b>Exp</b>	her befo P.E. /	ore or after th P.M. Ital Design w	ie job star	ts,	binde	r incre	ase fr	om origi	nal
This cons by the co including	stitutes ves ntractor. the asphal Vontz Pa Cal Splate	If it is nece It binder %, ving, Inc. stoesser armont	essary to cha the contrac	nge th tor sha REM	e job n all noti ARKS:	ix eit fy the Exp appro	her befo P.E. /	ore or after th P.M. Ital Design w Ita design. R	ith 0.5% (	ts, target		r incre	ase fr	om origi	nal
This cons by the co including	atitutes ver ntractor. the asphal Vontz Par Cal Splate Andy Dea	If it is nece It binder %, ving, Inc. stoesser armont	essary to cha the contrac	nge thi tor sha REM/	e job n all noti ARKS:	ix eit fy the "Exp appro	erimen oved m	ore or after th P.M. Ital Design w	ith 0.5% (	ts, target		r incre	ase fr	om origi	nal

# SLX\_M\_52-40\_R50%

					C:		Nebr	ack a						ረ ጋ	
	Stan	dard Mix u	sing				Nebi		ntal Des	ian (S	ee Re	marks	Secti	on Below)	
	Flint Hi	lls PG 52-	40 and		Depart	tment	of Tra	nsportation						<b>,</b>	
	Increas	se RAP to	50%		Ası	ohalt C	Concre	te Design							
								_							
Project M	lanagei	KEVIN KO	HMETSC	HER					Date	02-0	8-18 A	pprov	ed		
Project N	No:	NH-34-4(1	30)												
-		US-34, HA		DONT	ρηδη										
		Concrete:							ASD	татт	BIND	FR			
Design N	•	2018-1	JUA			-			Sour			T HILI			
Design N	10:	2018-1											Lð		
									Grad	e:	PG 5	2-40			
CDAD		F MATERI		DOOL						1.41.07	10 0	ACID			
MATER		F MATERI	PIT LO				19.0	12.5			2.36	1.18	600	300	75
MATER	IIAL	×	1/4	SEC		в	3/4"	1/2"	3/8"		#8	#16	#30	#50	#200
3/8" DRY 0	CHIPS	15			ARIETT		100.0	100.0	99.8	11.4	4.8	4.1	3.7	3.4	2.7
3A GRAVE	EL	22		36	9N	10 V	100.0	100.0	100.0			28.0	16.1	10.1	4.7
VASH SAI		4		36	9N	10 V	100.0	100.0		100.0		88.4		24.4	1.0
2A GRAVE	EL	4		36	9N	10 V	99.0	96.0	91.7			1.8	0.7	0.4	0.2
25		5	MANUEA				100.0	100.0	99.8			81.0	59.7	52.3	35.2
RAP		25			RSUPP		100.0	90.0	84.0			38.0	31.0	18.0	8.8
RAP		25	STATE SU				10.010	98.0	92.0			29.0		11.0	4.0
			COMBI	NED 0	iHADA	TION	100.0	96.8	93.6			31.2	21.9	13.6	6.4
			SPECIF	ICAT	ION RA	NGE	100	98 100	93	70.0 87	45 65	25 41	15 31	10 21	4
							100	100	100	87	60	41	31	21	10
JOB	MIX ID	ENTIFICAT	ION					CONSE	NSUS P	ROPI	ERTIE	S	FA	A SP.GR.	
1									Results			4.4		2.593	
JMF #	13														
								Dust to A	-	tio		.21			
TOTAL E	BINDER	5.40%						Desi	gn Gsb		2.9	585			
Addition	of 1.82%	of type PG	52-40 200	nhalt h	inder fr	vr a tot	al of 5	.40% (by wt.c	f mix) h	20					
		ie contracto								40					
been selec	cied by tr	ie contracto	t to be the	e targe	t aspna	n omde	n cont	ent.							
This cons	titutes v	erification o	f the job-	mix gr	adation	and su	perpav	e criteria valu	es propo	sed					
by the con	ntractor.	If it is nece	essary to c	hange	the job	mix ei	ther be	efore or after	the job st	tarts,					
-		alt binder %	-	-	-					-,					
	and apply		,												
cc:	Vontz P	aving, Inc.		REM	ARKS	"Espe	erimen	tal Design u	sing star	ndard	miz vi	th Flin	t Hills	PG 52-40	and
		ttstoesser						AP to 50%.	_						
	Andy De						_								
	a nay be														
	Dobort D														
	Robert F	lea		Q. E.	مهم وال	Data :	C D:	0 M-1							
	Robert F	lea			1 ated by 4021 47:			a & Materials a	nd Resea	arch D	ivision				

# SLX\_M\_58V-34\_LCR10%

					S	tate o	f Nebr	aska							
	Sta	ndard Mix	w/					"Es	perimenta	al Des	ign (S	ee Rer	narks	Section	Below)
	10% LES	S CRUSHE	D ROCK		Depa	rtmen	t of Tr	ansportation			3				,
	10% MOI	RE VASH	SAND					ete Design							
						1	- C	_ נ							
Project ]	Manager:	KEVIN KO	OHMETSO	HER					Date:	02-0	8-18 A	pprov	eđ		
Project 1	-	NH-34-4(										••			
Name of		US-34, HA		DON	DHΔ	J									
		Concrete:	SLX	DOIN					ASPH	ATTD	INDE	P			
••	•		SLA												
Design I	No:	2018-1							Sourc			T HILI			
									Grade					7% AD-H	
													5-00 i	//Cecaba	ase RT 945
		F MATERI							EVE AN	ALYSI	5 (V/	(SH)			
MATE	RIAL		PIT LO			-	19.0	12.5		4.75			600	300	75
3/8" DRY	CLIDE	×	1/4	SEC			3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#200
378° DRY 3A GRAV		10 30	MAR	11N M. 36			100.0	100.0 100.0	99.8	11.4	4.8	4.1	3.7	3.4	2.7
VASH SA		30		36	9N 9N	10 V	100.0	100.0	100.0	92.5 100.0	52.3 99.5	28.0 88.4	16.1 62.6	10.1	4.7
2A GRAV		5		36	9N	10 0	99.0	96.0	91.7	60.6	7.1	1.8	0.7	0.4	0.2
RAS		5	MANUFA				100.0	100.0	99.8	99.1	97.7	81.0	59.7	52.3	35.2
BAP		10	CONTRA				100.0	90.0	84.0	79.0	47.0	38.0	31.0	18.0	8.8
RAP		25	TATE SUP				100.0	98.0	92.0	78.0	55.0	29.0	18.0	11.0	4.0
			COMBIN	IED G	RADA	TION	100.0	98.3	96.0	79.3	54.8	37.3	25.2	14.2	5.5
			SPECIF	CATI		INCE		98	93	70.0	45	25	15	10	4
							100	100	100	87	65	41	31	21	10
JMF #		INTIFICAT							ENSUS P Results			4.4		6P.GR. 593	
JMF #	13							Dust to /	snh Bat	in	1	.02			
TOTAL	BINDER	5.40%							an Gsb			585			
								5151	gn 450						
						_									
		~ •		•				f 5.40% (by w	t.of mix)	has					
been sele	cted by th	e contracto	r to be the	targe	t aspha	alt bind	ler con	tent.							
*No Hyd	rated Lim	e will be nee	cessary for	this d	esign d	lue to	the use	of 0.7% AD-1	here LOF	65-00	w/Cec	abase R	T 945		
-			-												
This con-	stitutes ve	rification o	f the job-r	nix era	dation	and s	merna	ve criteria vali	les propo	ed					
			-	-			• •		•••						
has the en			-	_	-				the job st	a115,					
by the co		it binder %,	, the contr	actor	inali n	otiry t	ne P.E	. / P.M.							
by the co including	the aspha														
-	the aspha				ADVC	*E	orimo	ıtal Design <del>v</del>	ith 10m la		ched.	rock -	nd 10-	( more -	and
including						C XP	ermer					IOCK a	na 102	a more sa	and
including	Vontz Pa			REM.		Acres 1									
including	Vontz Pa Cal Splat	tstoesser		REM.		from	origin	al approved i	nız aesig	II. NN	ulb.				
including	Vontz Pa Cal Splat Andy Dea	tstoesser armont	1	REM		from	origin	al approved i	ni <b>z</b> desig	II. NN	ulb.				
including	Vontz Pa Cal Splat	tstoesser armont													
including	Vontz Pa Cal Splat Andy Dea	tstoesser armont		Valid	ated by		rt C. Re	al approved i ea & Materials							