Federal Highway Administration
Every Day Counts
Innovation Initiative

Safety Edge$_{SM}$
Demonstration Project
Seaford, Delaware

Field Report
January 30, 2011

U.S.Department of Transportation
Federal Highway Administration

1. Report No.	2. Government Accession No	3. Recipient's Catalog No
3. Title and Subtitle Safety Edge$_{SM}$ Project, Seaford, Delaware		5. Report Date January 30. 2011 6. Performing Organization Code
7. Authors Harold Von Quintus and Jagannath Mallela		8. Performing Organization Report No.
9. Performing Organization Name and Address Applied Research Associates, Inc. 100 Trade Centre Drive, Suite 200 Champaign, IL 61820		10. Work Unit No. 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Office of Infrastructure Federal Highway Administration 1200 New Jersey Avenue, SE Washington, DC 20590		13. Type of Report and Period Covered Report August 2010–January 2011 14. Sponsoring Agency Code
15. Supplementary Notes Contracting Officer's Technical Representative: Byron Lord and Mary Huie Contracting Officer's Technical Manager: Andy Mergenmeier		

16. Abstract

In a coordinated effort with highway authorities and industry leaders, the Every Day Counts initiative serves as a catalyst to identify and promote cost effective innovations to bring about rapid change to increase safety of our nations highway system, decrease project delivery time, and protect our environment. The Safety Edge$_{SM}$ concept is an example of one such initiative in which the edge of the road is beveled during construction for the purpose of helping drivers who migrate off the roadways to more easily return to the road without over correcting and running into the path of oncoming traffic or running off the other side of the roadway.

This field report documents the observations made on the construction of Safety Edge$_{SM}$ on a two lane highway warm mix asphalt (WMA) overlay project near Seaford, Delaware. Safety Edge$_{SM}$ paving devices from two manufacturers were demonstrated during this project. Details regarding the performance of each device along with the shape and physical properties of the finished Safety Edge$_{SM}$ are presented for the purpose of understanding what processes and techniques were most successful in forming the Safety Edge$_{SM}$.

The findings from this overlay project and other similar ongoing projects form the basis for understanding the construction process and material performance necessary to bring this innovation into common highway practice and make our Nation's highways safer.

17. Key Words	18. Distribution Statement
Safety Edge$_{SM}$, Slope, WMA, Advant-Edger, TransTech Shoulder Wedge Maker	No restriction. This document is available to the public through the Highways for LIFE website: http://www.fhwa.dot.gov/hfl/

Security Classif.(of this report)	19. Security Classif. (of this page)	20. No. of Pages	21. Price
Unclassified	Unclassified	30	

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
(none)	mil	25.4	micrometers	µm
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 shall be shown in m^3				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (metric tons)	Mg (or t)
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	Newtons	N
lbf/in^2 (psi)	poundforce per square inch	6.89	kiloPascals	kPa
k/in^2 (ksi)	kips per square inch	6.89	megaPascals	MPa
		DENSITY		
lb/ft^3 (pcf)	pounds per cubic foot	16.02	kilograms per cubic meter	kg/m^3

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
µm	micrometers	0.039	mil	(none)
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or t)	megagrams (metric tons)	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	Newtons	0.225	pounds	lb
kPa	kiloPascals	0.145	pounds per square inch	lb/in^2 (psi)
MPa	megaPascals	0.145	kips per square inch	k/in^2 (ksi)
		DENSITY		
kg/m^3	pounds per cubic foot	0.062	kilograms per cubic meter	lb/ft^3 (pcf)

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised September 1993)

FOREWORD

The purpose of this field report is to provide a summary of observations made during the warm mix asphalt (WMA) Safety Edge$_{SM}$ project located along Old Furnace Road just northeast of Seaford, Delaware. These observations and data are to be used with similar information from other Safety Edge$_{SM}$ projects to facilitate the development of standards and guidance for Safety Edge$_{SM}$ construction and long term performance.

All field and laboratory test results, WMA mixture design data, observations made during paving, and comments provided by construction personnel are included in the Field Evaluation Form that is provided as a separate document to this field report. This field report is a summary of the observations and field data measured during construction on August 25 to 27, 2010. In addition, it includes the results from field tests performed on a section that was paved on August 19 and 20, 2010.

Table of Contents

SUMMARY OF OBSERVATIONS

This section of the report provides a summary and listing of important observations made during the paving operations, interview with paving personnel, and findings from the field measurements taken during paving that are expected to have a significant impact on the performance of this project.

Overall Opinion of the Safety Edge$_{SM}$

- The Safety Edge$_{SM}$ did not have a detrimental impact on the contractor's paving operation during mainline paving. A couple of issues, however, were encountered that need to be resolved and are noted in the following bullet items.

Slope of the Safety Edge$_{SM}$

- The average slope of the Safety Edge$_{SM}$ was found to vary from 37 to 50° for the different sections. It was the opinion of construction personnel that the slope of the Safety Edge$_{SM}$ device would need to be flattened to about 20 to 25° to meet the planned 30° requirement.

Placement

- The Safety Edge$_{SM}$ was formed using two devices at different times during paving; the TransTech Shoulder Wedge Maker device and the Advant-Edger device. The TransTech device was used to place warm mix asphalt (WMA) during the week of August 19. The Advant-Edger device was used during observations made for this field report. Both were properly bolted to the screed. The project superintendent commented that there was no difference between the two devices, but the screed operator commented that the Advant-Edger seemed to work better, resulting in a smoother edge condition.

- Both contractor and agency personnel voiced a concern that paving across intersections or in areas with higher longitudinal profile; the Safety Edge$_{SM}$ devices raise the screed relative to the profile set by the longitudinal ski. Both also commented that it was difficult to get a good tie-in to existing driveways and other hard surfaces.

Compaction

- The WMA density or percent compaction of the Safety Edge$_{SM}$ sections was found to be higher than for the non-Safety Edge$_{SM}$ sections. Thus, the Safety Edge$_{SM}$ is believed to have a confining effect on rolling an unconfined edge. This observation is considered a benefit to the use of the Safety Edge$_{SM}$.

- The air voids of the interior WMA mat were considered good to fair with a mean value from 7.3 to 8.9 percent for the different sections. The air voids determined along the edge of the mat were high; varying from 8.6 to 13.5 percent. High air voids have a detrimental impact on pavement performance.

Shoulder Construction

- Existing fine to coarse-grained soil was planned to be used for the shoulder backing material. Placement of the backing material was not observed because the contractor planned to place it after all paving had been completed.

WMA Mixture and Safety Edge$_{SM}$

- Longitudinal segregation or different surface texture was observed along the edge of each slat conveyor of the paver.

- The planned WMA overlay thickness was 2.0 inches. The average overlay thickness for the Safety Edge$_{SM}$ sections was found to vary from 2.0 to 2.7 inches.

This Safety Edge$_{SM}$ project should be monitored over time to determine its long-term performance and the frequency of any required maintenance operations, as well as the life cycle cost of the Safety Edge$_{SM}$ and its effectiveness over time.

FIELD EVALUATION OF WMA OVERLAY WITH SAFETY EDGE$_{SM}$

Introduction

A series of field tests were carried out to assess the placement and condition of the warm mix asphalt (WMA) overlay placed along Old Furnace Road just northeast of Seaford, Delaware, with and without the use of the Safety Edge$_{SM}$ devices. The paving contractor for this project was American Infrastructure. The Contractor used the TransTech Shoulder Wedge Maker device during the first part of the project and the Advant-Edger device for the latter part. The purpose of this field study was to evaluate the quality of the in-place WMA mixture and Safety Edge$_{SM}$ by investigating three issues or features.

1. Correct use of Safety Edge$_{SM}$ device during paving.
2. Safety Edge$_{SM}$ versus non-Safety Edge$_{SM}$ portions of project.
3. Slope of the Safety Edge$_{SM}$.

The location of the project was in Sussex County, as shown in Figure 1. The project started just east of the intersection between U.S. Highway 13 (Sussex Highway) and Old Furnace Road, and ended at the intersection between Old Furnace and Cokesbury Road; just west of Old Furnace. The Safety Edge$_{SM}$ sections were located along the eastern portion of the project.

Pavement Structure and Project Conditions

The project consisted of repairing some localized areas with extensive cracking and distortions, widening the roadway by 2 ft, and placing a 2-inch lift of a 9.5-mm WMA mix over the existing HMA pavement. Figure 2 shows the typical cracking and surface condition of the existing pavement along this project. Figure 3 provides a general view of the Figure 2 in WMA overlay and typical cross section of the pavement. In preparation for the WMA overlay, the following activities and repairs were made.

- The existing shoulder was graded along some areas of the project to remove grass and other debris (refer to Figure 4).
- About 1 ft of HMA was placed to widen the roadway on each side (refer to Figure 5).
- Localized repairs or patches were placed in selected areas of the roadway where extensive cracking and distortions have occurred.
- An emulsion tack coat was placed on the existing surface and patches (refer to Figure 5).

The ditches along the edge of the pavement were generally shallow (1 to 3 ft) with shallow slopes (10 to 30°). No lane-shoulder drop-offs were observed; however, the shoulder had been graded and the roadway widened on each side of the roadway prior to visiting the project. Figure 3 through Figure 6 include general views of the roadway during construction. The Safety Edge$_{SM}$ backing material was planned to be an on-site fine to coarse-grained soil. The backing material was scheduled to be graded back to the Safety Edge$_{SM}$ near the end of this rehabilitation project, after paving.

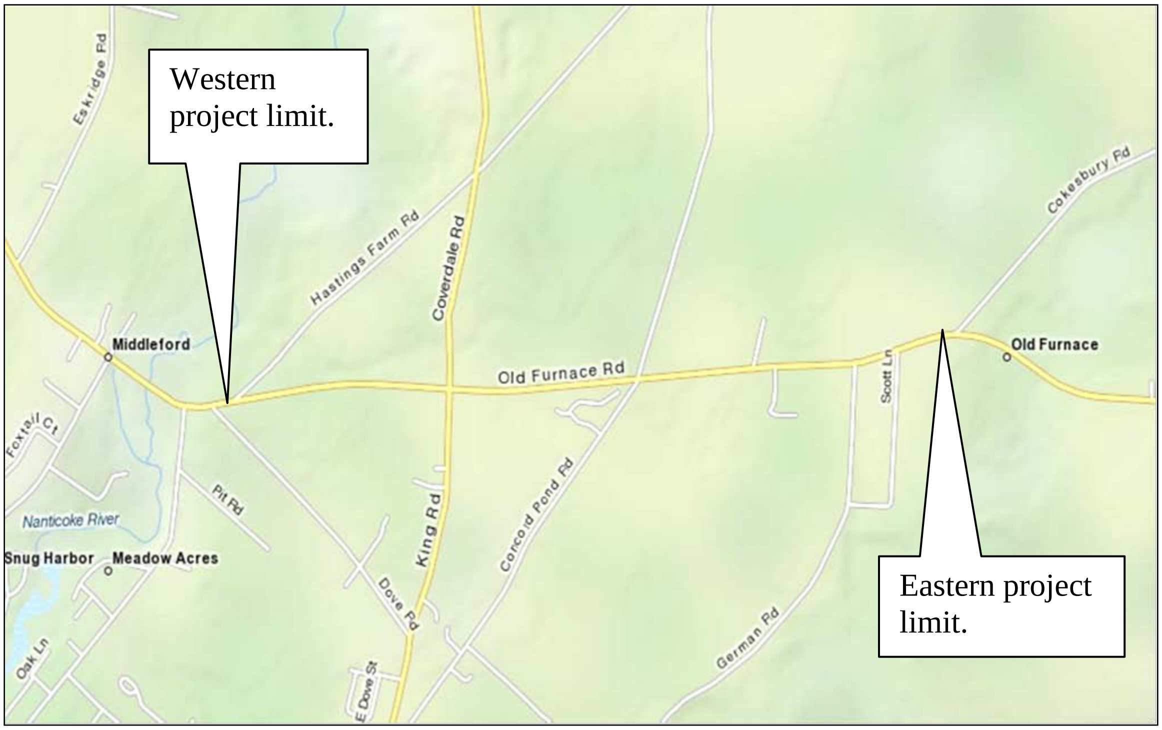


Figure 1. Site location.

Figure 2. Typical condition of the existing surface (with tack coat applied).

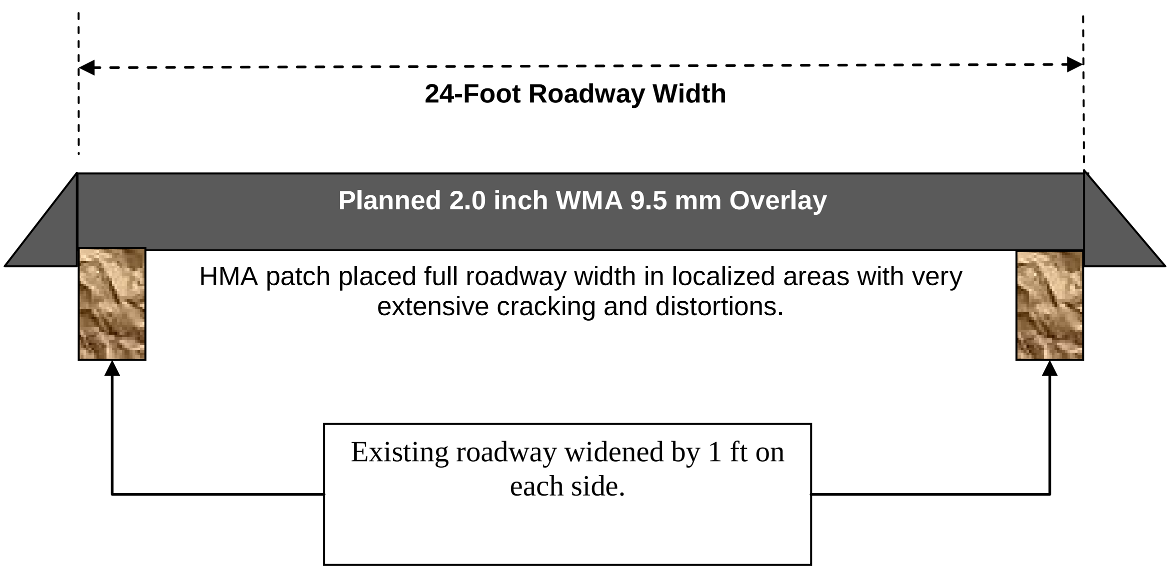


Figure 3. WMA overlay placed in the westbound lane.

Figure 4. Edge of pavement graded in some areas to remove grass and debris.

Figure 5. 1.0-ft widening strip placed on both sides of the roadway.

Figure 6. General view of the roadway and right-of-way.

Field Evaluation

Four sections were identified and marked during the paving operation; three Safety Edge$_{SM}$ sections and one section without the Safety Edge$_{SM}$ device. Station numbers were unavailable for referencing the sections, so all sections were located related to telephone poles along the project. The following summarizes the four sections included within this project.

1. Area #1, Advant-Edger Safety Edge$_{SM}$ section, westbound lane; telephone pole #44155, localized station numbers increase to the west from the designated telephone pole.
2. Area #2, Advant-Edger Safety Edge$_{SM}$ section, westbound lane; telephone pole #44128, localized station numbers increase to the west from the designated telephone pole.
3. Area #3, TransTech Shoulder Wedge Maker Safety Edge$_{SM}$ section, westbound lane; telephone pole #44010, localized station numbers increase to the west from the designated telephone pole.
4. Area #4, non-Safety Edge$_{SM}$ section, westbound lane; telephone pole #44128. This non-Safety Edge$_{SM}$ section was to be located on August 21, 2010, but the plant was not operating because of electrical problems. Thus, the section was located within Area #2 of the Advant-Edger. The non-Safety Edge$_{SM}$ was designated along the centerline joint—the opposite side of the paver without the Safety Edge$_{SM}$ device.

Field tests were conducted within each test section for measuring slope and WMA density. Slope measurements were taken using a straight-edge (4-ft aluminum level) and 6-inch ruler (refer to Figure 7), while density readings were taken adjacent to and 3 ft from the mat's edge using a Troxler 3430 nuclear density gauge (refer to Figure 8).

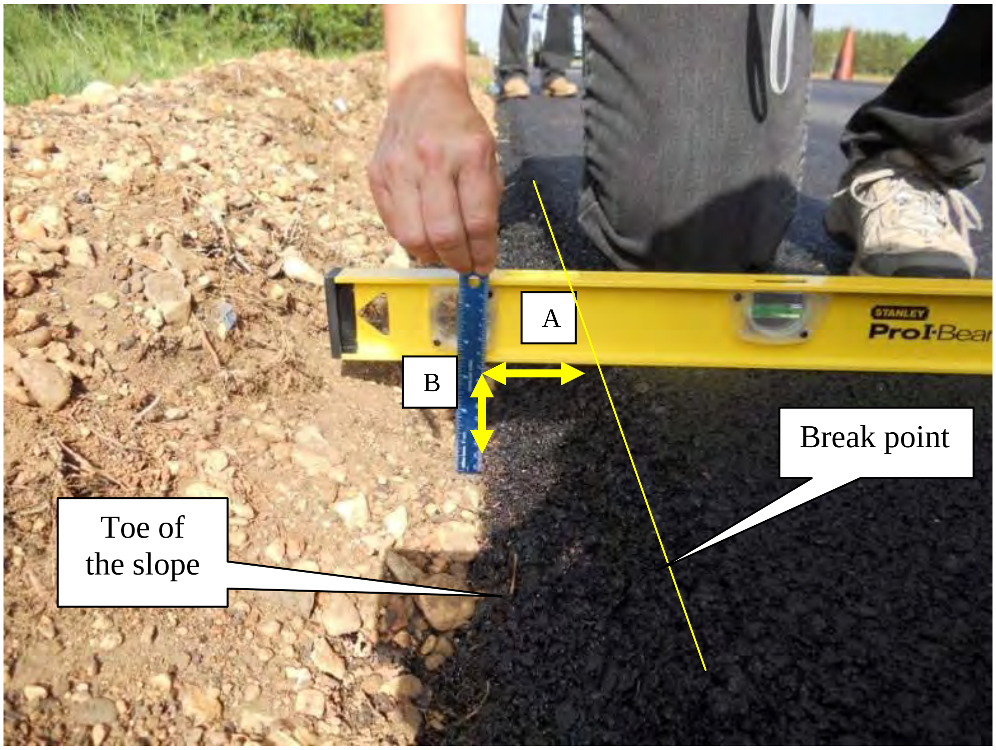


Figure 7. Safety Edge$_{SM}$ angle measurement.

Figure 8. Troxler 3430 nuclear density gauge used to measure WMA density.

Eight cores were taken in the test sections established during the paving operation. The eight cores were obtained at four different locations within the Safety $Edge_{SM}$ sections. The cores were taken for calibration of the nuclear density gauge readings, and to observe the mix near the center of the mat and adjacent to the mat's edge. Cores were planned for two other locations in the non-Safety $Edge_{SM}$ section. However, paving on the last day of the field visit was cancelled because of electrical problems at the plant. The two cores used for acceptance (away from the edge) from the area designated as Area #2 were requested to increase the number of data points for determining the correction or adjustment factors between the nuclear density gauge and laboratory measured densities. Bulk specific gravities of these additional cores were not obtained.

Slope Measurements

Slope measurements were taken using a straight-edge to measure the width and thickness of the taper of the Safety $Edge_{SM}$; prior to any rolling and after final rolling. The average slope of the Safety $Edge_{SM}$ sections is summarized in Table 1.

Table 1. Summary of the Safety $Edge_{SM}$ slope measurements.

Section/Area Designation		Slope of Safety $Edge_{SM}$	
		Mean, degrees	Coefficient of Variation, %
Prior to Rolling; mean of two areas		34.1	5.2
After Final Rolling			
1	Advant-Edger	45.4	10.8
2	Advant-Edger	50.0	11.4
3	TransTech Shoulder Wedge Maker	36.6	24.3

The slope of the Safety $Edge_{SM}$ prior to rolling the unconfined edge was 34.1°. The average slope for the Safety $Edge_{SM}$ created with the TransTech device after final rolling was about the same as prior to rolling, while the slope for Advant-Edger section was much steeper after final rolling. The Safety $Edge_{SM}$ created with the TransTech device was placed on August 19 or 20, and the Safety $Edge_{SM}$ created with the Advant-Edger device was placed on August 25 and 26. The WMA mixture was observed to shove and "push out" under the steel wheel vibratory roller for the paving on August 26. The reason for the difference in Safety $Edge_{SM}$ slopes between the two devices is unknown, but it was reported that the mixture did change and corrections to production had to be made between the two paving dates. In fact, the production plant was shut down on August 26 to make adjustments to the WMA mixture.

The other important observation relates to the variability of the Safety $Edge_{SM}$ slope measurements, as listed above. The coefficient of variation of the Safety $Edge_{SM}$ slope created by the Advant-Edger device prior to any rolling was about half the value determined after final rolling. The coefficient of variation of the Safety $Edge_{SM}$ slope for the TransTech device after final rolling was significantly greater than for the other sections. The reason for the higher variability but lower slope was unknown.

All slope measurements are listed in Tables A-1 through A-3 of Appendix A. Figure 9 includes a comparison between the slope of the Safety $Edge_{SM}$ after final rolling and thickness of the

Safety Edge$_{SM}$ for the three sections. As shown, no correspondence between thickness and the slope of the Safety Edge$_{SM}$ exists.

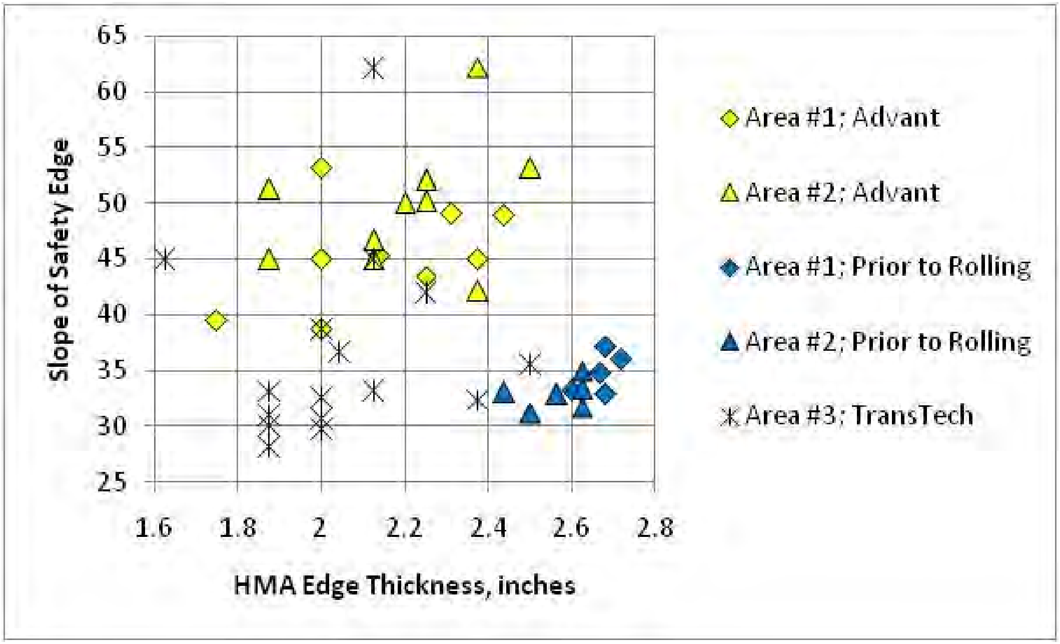


Figure 9. Comparison of the Safety Edge$_{SM}$ slope and thickness of the WMA adjacent to the edge of the HMA overlay.

Other slope measurements were made at random along the Safety Edge$_{SM}$ in other areas of the project and the results were the same as for the specific Safety Edge$_{SM}$ sections established for future performance reviews. Thus, the slope of the Safety Edge$_{SM}$ was found to be steeper than what was planned.

<u>Cores</u>

A total of eight cores were drilled along the project. Two cores were taken at each station or location; in the same areas where the densities were measured with the Troxler nuclear density gauge. These cores were taken to measure the bulk specific gravity of the WMA for developing a correction factor for the nuclear density gauge readings taken adjacent to the edge and within the center of the mat. Figure 10 shows the location of the cores and nuclear density gauge readings relative to the edge of the WMA mat. Photographs of all eight cores recovered from the roadway are included in the appendix. A summary of these test results; core thickness and bulk specific gravities (saturated surface dry) converted to bulk densities is included in Table A-4 in Appendix A. Figure 11 is a comparison of the core densities taken along the edge and 3 ft from the edge (center of the steel drum breakdown roller) for the Safety Edge$_{SM}$ sections. As expected, densities 3 ft from the edge are higher than along the edge of the mat (unconfined edge).

Figure 10. Photos showing location of cores and nuclear density tests made with the Troxler 3430 gauge (nuclear density readings were taken and then the WMA mix was cored).

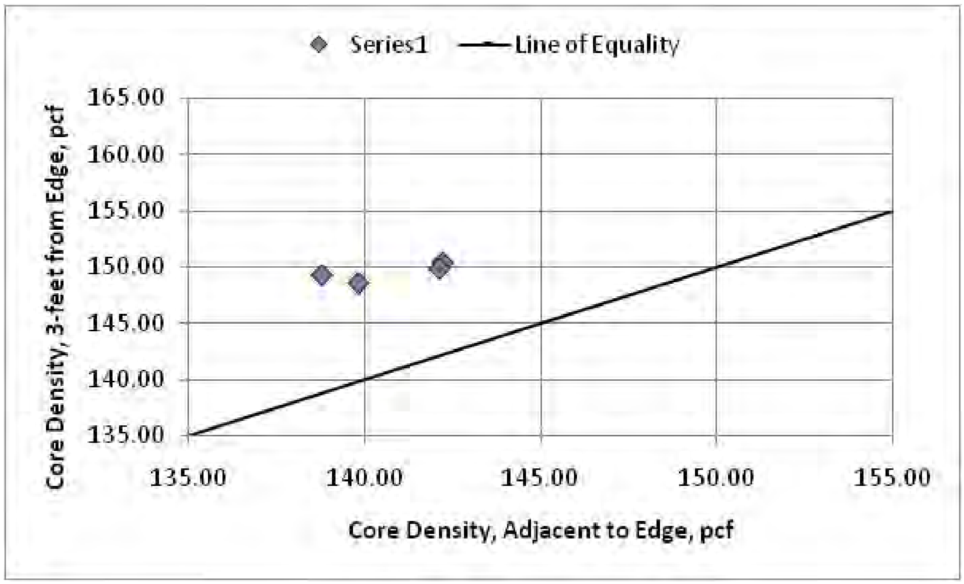


Figure 11. Comparison of core densities adjacent to the edge of pavement and 3 ft from the edge.

Nuclear Density Results

Density measurements were made with a Troxler 3430 gauge. Two readings were taken at each point; one with the gauge parallel and the other perpendicular to the centerline. Two points were marked at each station or location; one point adjacent to the Safety Edge$_{SM}$ and the other 3-ft from the edge.

Nuclear density gauge readings were taken before drilling each core. Figure 12 is a comparison of the nuclear gauge readings and densities measured on the cores. As shown, there is a positive bias for the readings taken adjacent to the edge of the mat. Adjustment factors were determined for the nuclear gauge readings taken at the edge of the mat and 3 ft from the edge. The adjustment factors are included in Table A-4 and the nuclear density gauge readings at each point are listed in Table A-5 and Table A-6 in Appendix A. The following summarizes the adjustment factors determined for this project.

Location	Adjustment Factor
Near Center of Steel Drum	0.957
Adjacent to Safety Edge$_{SM}$	1.000

These factors were used to adjust the nuclear density gauge readings to be consistent with the densities that would be measured in the laboratory. The adjusted densities using the correction factors are included in Table A-5 and A-6 in Appendix A.

Figure 13 shows a comparison of the adjusted nuclear density gauge readings taken adjacent to the Safety Edge$_{SM}$ and 3 ft from the edge. Figure 13 also includes a comparison of the WMA air voids between both of these areas. As shown, the air voids are higher adjacent to the Safety Edge$_{SM}$, in comparison to 3 ft from the Safety Edge$_{SM}$.

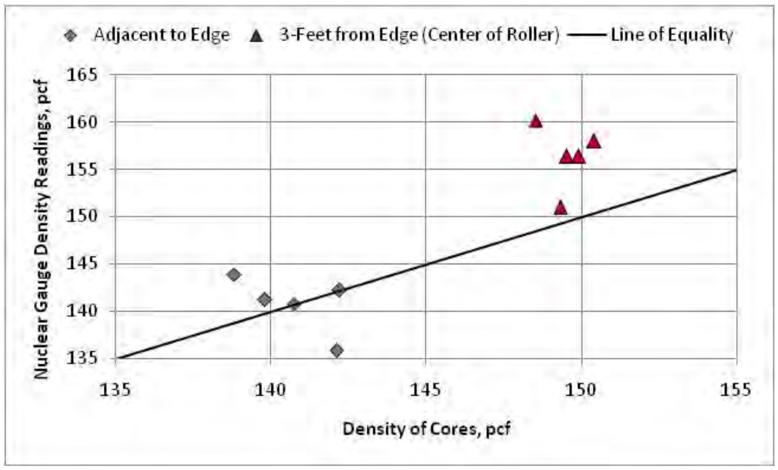
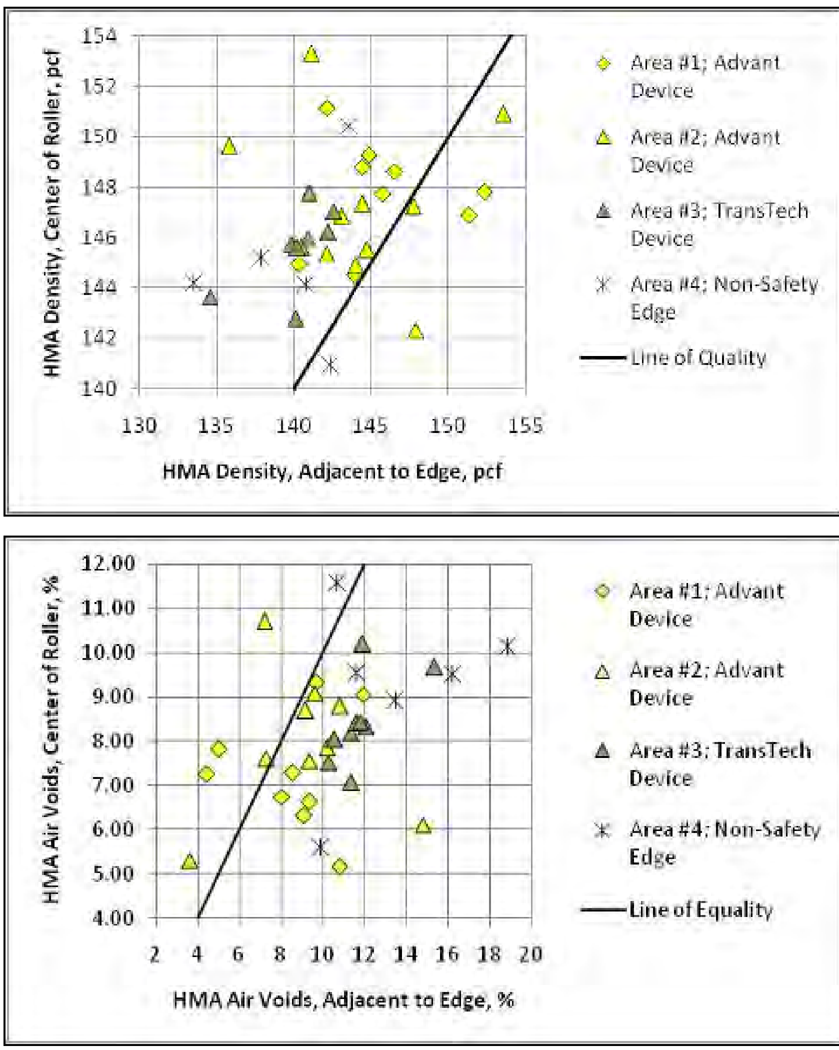


Figure 12. Comparison of the nuclear gauge readings and densities measured on cores recovered from the WMA mat.



Nuclear densities measured in areas adjacent to the edge in comparison to those taken 3 ft from the edge (center of the roller).

Air voids in areas adjacent to the edge in comparison to those taken 3 ft from the edge (center of the roller).

Figure 13. Comparison of the adjusted nuclear density readings and air voids between the areas adjacent to the edge and 3 ft from the edge.

Figure 9 included a comparison between the WMA thickness (near the Safety Edge$_{SM}$) and slope of the Safety Edge$_{SM}$. The thickness of the WMA has little to no effect on the slope of the Safety Edge$_{SM}$. Figure 14 shows a comparison of the density and WMA overlay thickness. As shown, there is also little correspondence between the overlay thickness and air voids or densities.

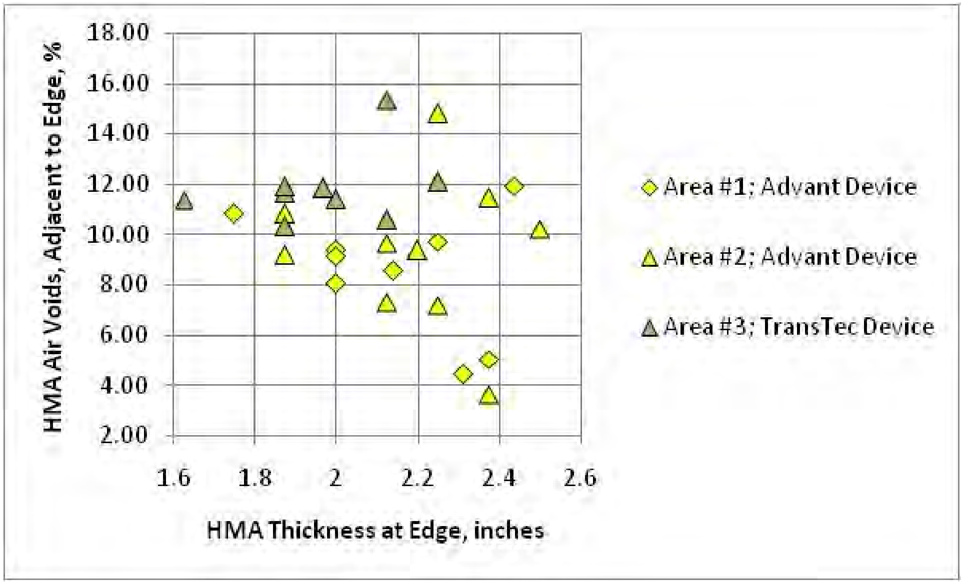


Figure 14. Comparison of WMA thickness at the edge of the mat and WMA air voids.

<u>Longitudinal Profile Measurements</u>

Longitudinal profile measurements were not planned nor measured for this project.

Observations Made During Paving with Safety Edge$_{SM}$

This section discusses the observations made during the paving and rolling operations that could have a significant impact on the performance of the Safety Edge$_{SM}$ over time. As stated in the Introduction to the Field Report section, the objective of this field study was to evaluate the quality of the in-place WMA material and Safety Edge$_{SM}$ by investigating three features.

1. Correct use of Safety Edge$_{SM}$ device during paving.
2. Safety Edge$_{SM}$ versus non-Safety Edge$_{SM}$ portions of project.
3. Slope of the Safety Edge$_{SM}$.

Surface Preparation

The following lists the different activities performed by the contractor prior to placing the WMA overlay.

1. The edge of the pavement was graded to remove grass and other debris along the edge of the roadway prior to placing the overlay (refer to Figure 4).
2. The roadway was widened by 1 ft on each side (refer to Figure 5).
3. Localized WMA patches were placed in selected areas along the project where extensive cracking and surface distortions have occurred.
4. An emulsion tack coat was applied prior to the WMA overlay. The application of the tack coat was uniform and covered the entire surface (refer to Figure 5 and Figure 6).

Placement/Paving Operations

Figure 15 shows the equipment used to place the WMA overlay. The paving contractor operated the paver in the automatic longitudinal grade control mode and used non-contact sonic sensors for controlling the grade. The production plant was down for about 1.5 hours to make some WMA mixture revisions on August 26 to bring the mixture into specification. Free water was observed flowing from the back of a few truck beds. Excess water could explain some of the mixture tenderness characteristics observed during compaction (explained in the next section on *Compaction Operations*).

Figure 16 shows the Advant-Edger device attached to the screed. The project superintendent commented that there was no difference between the two devices, but the screed operator commented that the Advant-Edger seemed to work better than the TransTech device, resulting in a smoother edge condition. Figure 17 shows the slope and surface texture of the Safety Edge$_{SM}$; prior to and after rolling.

Both contractor and agency personnel stated the Safety Edge$_{SM}$ device would raise the screed relative to the profile set by the longitudinal ski when paving across intersections or in areas with higher longitudinal profile with hard surfaces. In addition, both commented that it was difficult to get a good tie-in to existing driveways and other hard surfaces. Figure 18 shows the line caused by the tip of the Safety Edge$_{SM}$ device along the edge of pavement over an intersection driveway.

Figure 15. Equipment used to place the WMA overlay.

Figure 16. Advant-Edger device attached to the screed.

Figure 17. Typical surface texture and slope of the Safety Edge$_{SM}$ sections.

Figure 18. Point of Safety Edge$_{SM}$ scratching the surface of an intersecting driveway.

Compaction Operations

Figure 19 shows the two rollers that were used to compact the 9.5 mm WMA mixture. The primary or breakdown roller was a Volvo DD118 double drum steel wheel vibratory roller, while the finish roller was a Volvo DD112 double drum steel wheel vibratory roller. The field evaluation forms identify the number of passes and coverage used by all rollers (a pass is defined as one movement of the roller in one direction, while coverage is defined as each point on the mat receiving a pass of the roller).

In summary, each roller performed seven passes with two coverages. The following summarizes the rolling pattern (number of passes and location for each roller) used by the contractor.

- Breakdown or primary roller pattern; the roller's vibratory setting was on high frequency and on setting 5 (on a scale of 1 to 10) for the amplitude:
    - First pass was along the Safety Edge$_{SM}$ in the vibratory mode with the roller's edge extended over the Safety Edge$_{SM}$ by 4 to 6 inches.
    - Second pass; same location as for the first pass, but in the reverse direction and in vibratory mode.
    - Third pass was along the centerline construction joint in the vibratory mode with the roller's edge extended over the longitudinal joint by 4 to 6 inches.
    - Fourth pass; same location as for the third pass, but in the reverse direction and in vibratory mode.
    - Fifth pass was down the center of the mat in vibratory mode.
    - Sixth pass; same location as for the fifth pass, but in the reverse direction and in vibratory mode.
    - Seventh pass was along the Safety Edge$_{SM}$ in the vibratory mode with the roller's edge extended over the Safety Edge$_{SM}$ by 4 to 6 inches.

- Finish roller pattern; the roller's vibratory setting was on high frequency and low amplitude:
    - First pass was along the Safety Edge$_{SM}$ in the vibratory mode with the roller's edge extended over the Safety Edge$_{SM}$ by 4 to 6 inches.
    - Second pass; same location as for the first pass, but in the reverse direction and in vibratory mode.
    - Third pass was along the centerline construction joint in the vibratory mode with the roller's edge extended over the longitudinal joint by 4 to 6 inches.
    - Fourth pass; same location as for the third pass, but in the reverse direction and in vibratory mode.
    - Fifth pass was down the center of the mat in vibratory mode.
    - Sixth pass; same location as for the fifth pass, but in the reverse direction and in vibratory mode.
    - Seventh pass along the Safety Edge$_{SM}$ side of the mat in static mode. Additional passes that were needed based on periodic density measurements made with the nuclear density gauge were in the static position.

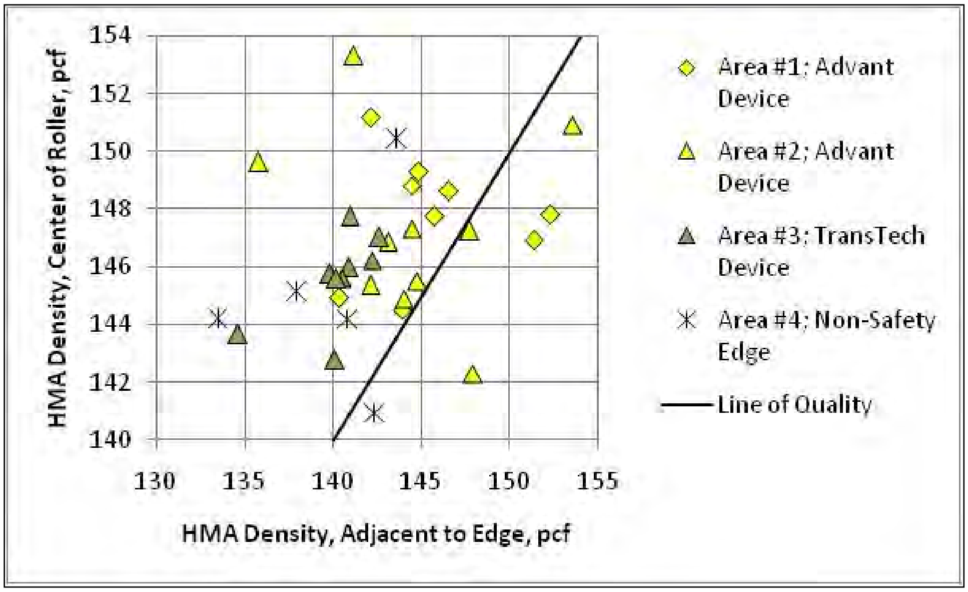
A control strip was not used to confirm that the roller pattern being used was achieving an adequate density of the mix. The Contractor used a Pavement Quality Indicator (PQI) non-nuclear density gauge to ensure that density was being met during paving. The non-nuclear and nuclear density gauge readings and the densities of the cores suggest that adequate density was obtained for this mixture 3 ft from the edge, but the density was low near the edge.

Volvo double drum vibratory steel wheel roller used in breakdown or primary position for compacting the WMA overlay.

Volvo double drum vibratory steel wheel roller used in the vibratory and static mode that was used in the finish position for compacting the WMA overlay.

Figure 19. Rollers used for compacting the 9.5 mm WMA overlay mixture.

Figure 20 shows a comparison of the adjusted nuclear density gauge readings and air voids adjacent to the Safety Edge$_{SM}$ in comparison to 3 ft from the edge. Table 2 summarizes the average air voids and slopes of the Safety Edge$_{SM}$ for the different sections along this project, and is followed by the following important points from these density and slope measurements:



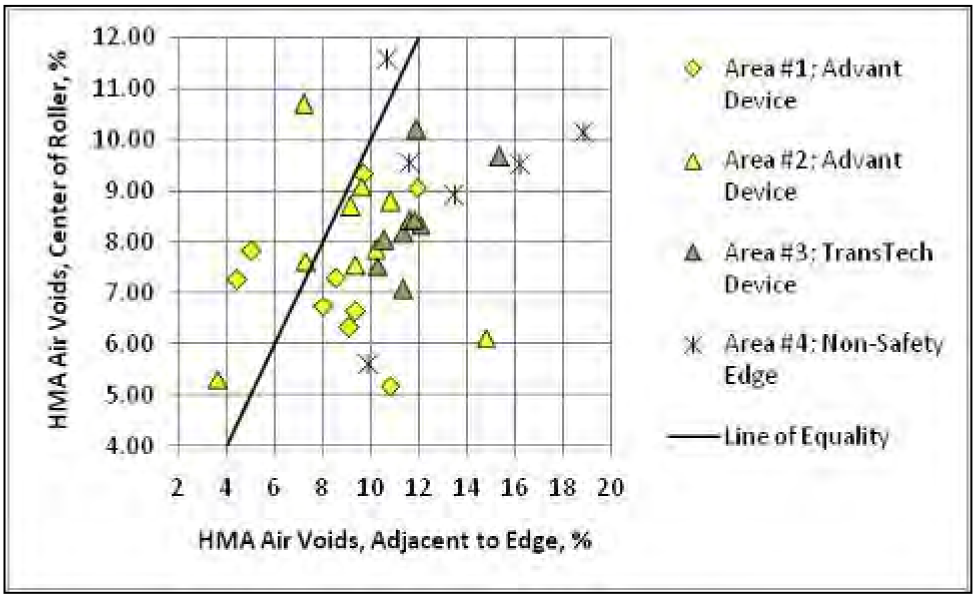


Figure 20. Comparison of volumetric properties between the areas adjacent to the edge and 3 ft from the edge (center of the steel drum roller) for the different sections.

Table 2. Summary of the average slope and air voids.

Section Identification	Average Slope	Air Voids at Edge		Air Voids near Mat Center	
		Mean	COV	Mean	COV
Non-Safety Edge$_{SM}$ Section	---	13.5	28.9	8.92	24.2
Area #1; Advant Section	45.4	8.6	30.7	7.3	19.3
Area #2; Advant Section	50.0	9.4	33.4	7.6	28.3
Area #3; TransTech Section	36.6	11.2	13.1	8.4	12.3

- The air voids measured along the mat's edge of the Safety Edge$_{SM}$ sections are significantly lower than measured along the non-Safety Edge$_{SM}$ section. The Safety Edge$_{SM}$ provided additional confinement along the edge.

- The air voids measured along the mat's edge of the Advant-Edger Safety Edge$_{SM}$ sections are slightly higher than measured within the center of the Volvo double drum steel wheel roller. It was expected that the extra pass of the roller along the Safety Edge$_{SM}$ provides additional densification of the mix.

- The other important observation was the difference between the Advant-Edger and TransTech sections. The TransTech section had higher air voids but lower slopes in comparison to the Advant-Edger sections. The reason for this difference was unknown, because the roller pattern used to compact the TransTech section was not recorded during placement. Two additional roller passes (one for each of the rollers) along the Safety Edge$_{SM}$ was used to compact the Advant-Edger sections. It was expected that this additional pass increased the density (lower air voids) but steepened the slope.

HMA Mixture Characteristics and the Safety Edge$_{SM}$

The WMA mixture design data was obtained from the Delaware DOT. The WMA mixture design parameters are documented in the Field Evaluation Form, which is a separate document to this field report. This WMA includes 21 percent Recycled Asphalt Pavement (RAP) and 6 percent shingles.

The WMA mixture volumetric properties and gradation were considered reasonable. Figure 21 shows the surface texture of the finished HMA mat along different areas of the project; with and without surface defects or surface texture differences. The surface texture and condition were relatively uniform within specific areas of the project. Some agency personnel voiced a concern about the use of some Superpave mixtures; they can be very tender and move under steel wheel rollers.

The WMA mixture did shove and "push out" during the compaction operation, steepening the slope of the Safety Edge$_{SM}$. The WMA mixture exhibited tenderness under the steel wheel rollers. As an example, roller marks were present after the breakdown roller completed its rolling pattern, checking was observed during the rolling operation, and shear cracks were observed along the roller's edge (Figure 22 shows these examples). Chatter from the Volvo breakdown roller was observed in those areas exhibiting the more severe checking and shear cracks (refer to Figure 22).

The temperature of the WMA delivered to the project site was reported to be approximately 260 °F and 160 to 170 ºF during finish rolling. In some cases, the WMA temperature was below 150 ºF during the last pass of the finish roller. The WMA temperature could be related to the roller marks being left in the mat, checking and chatter observed in specific areas, and the steeper slopes than planned.

Longitudinal segregation or surface texture difference was observed along the edges of the slat conveyor (refer to Figure 23). Bulk mixture samples (for gradation testing), nuclear gauge density tests, and cores were not taken within these locations.

Example showing an area with a tight surface, fine texture of the mat; small surface voids.

Example showing an area with a coarse surface texture of the mat; large surface voids.

Example showing an area with localized crushed aggregate at the surface of the mat.

Figure 21. Surface texture of the overlay after final rolling.

Figure 22. Surface defects observed after rolling.

Figure 23. Longitudinal segregation or surface texture differences along the edge of both slat conveyors.

Thus, it was not confirmed whether these areas shown in Figure 23 were caused by segregation or surface texture difference near the surface. It was expected that these areas were a result of longitudinal segregation along the edges of the slat conveyor of the paver. Densities were taken with the nuclear density gauge for the non-Safety Edge$_{SM}$ section near the area in question and some of these densities were found to be low (and high air voids).

The distance between the end of the auger and screed end plate was approximately 24 inches (refer to Figure 15 and Figure 16). This distance should be less than 18 inches. The distance between the end of the auger and screed end plate was not believed to be a contributing factor to the steeper slope.

Other Observations

The following lists the observations and comments made by construction personnel and on-site personnel.

- A shallower angle of the Safety Edge$_{SM}$ device will be needed to meet the planned 30° angle.

- There were different opinions on the use of the two Safety Edge$_{SM}$ devices (Advant-Edger and TransTech). One opinion was that there was no difference between two devices, while another opinion was that the Advant-Edger device resulted in a smoother edge.

- The densities measured along the Safety Edge$_{SM}$ created by the TransTech device were consistently lower than those measured along the edge created by the Advant-Edger device. However, the densities measured within the center of the mat (away from the Safety Edge$_{SM}$) are also higher for the Advant-Edger section (about 147 pounds per cubic foot (pcf)) in comparison to the TransTech section (145 pcf). This observation indicates that this difference is more related to the rolling pattern and/or WMA mixture between the different days of paving rather than related to the Safety Edge$_{SM}$ devices.

- Some construction personnel voiced an opinion that the planned 30° slope of the Safety Edge$_{SM}$ will not be met using Superpave designed mixtures that are tender.

- After the evaluation, the Delaware DOT management stated that overlays greater than 1.25 inch will have the Safety Edge$_{SM}$.

- Paving across driveways and other features with hard surfaces causes the screed to rise resulting in a reduction of smoothness in localized areas.

Findings and Conclusions

As previously stated, the objective of this field study was to evaluate the quality of the in-place WMA material and Safety Edge$_{SM}$ by investigating three features.

1. Correct use of Safety Edge$_{SM}$ device during paving.
2. Safety Edge$_{SM}$ versus non-Safety Edge$_{SM}$ portions of project.
3. Slope of the Safety Edge$_{SM}$.

This section of the field report summarizes the findings and conclusions made during the paving/compaction operations related to the long term performance of the WMA mixture and Safety Edge$_{SM}$.

- The average slope of the Safety Edge$_{SM}$ from the TransTech Shoulder Wedge Maker device was 36°, while it was 45 and 50° for the Advant-Edger device; both exceeding the planned value of 30°. It was expected that the slope of the Safety Edge$_{SM}$ device may need to be reduced to a value of about 25° to end up with a 30° slope after rolling.

- The average air voids along the edge of the mat were lower for the Safety Edge$_{SM}$ than for the non-Safety Edge$_{SM}$ section. The reason for this decrease in air voids and increase in density was believed to be related to the added confinement from the Safety Edge$_{SM}$ material. This observation is considered a benefit from the use of the Safety Edge$_{SM}$.

- Breakdown and finish rolling did steepen the slope of the Safety Edge$_{SM}$, especially during the paving operations on August 25 and 26. It was expected that the magnitude of this increase will be mixture dependent. There was much less of an increase in slope during the previous week's paving. The reason for the increase in the slope of the Safety Edge$_{SM}$ during paving on August 25 and 26 was probably related to the tenderness of the WMA, as discussed above. Mix behavior under the steel wheel rollers was not observed during the week of August 19.

- WMA thickness variations measured along the sections had no impact on the slope of the Safety Edge$_{SM}$ or the density adjacent to the Safety Edge$_{SM}$.

The pavement should be inspected after the final shoulders have been constructed. Local soil is planned to be used as the backing material for the Safety Edge$_{SM}$. Care should be taken to observe the material placement and ensure that meets proper relative elevation to the WMA mat. Long term monitoring of the shoulder should be performed to see how well the fine- to coarse-grained shoulder material remains in place and observe any deformation or erosion.

APPENDIX A

DATA TABLES AND CORE PHOTOGRAPHS

DATA TABLES FROM FIELD MEASUREMENTS

This section of the field report provides a summary and listing of all field measurements recorded during the paving operations. These data are also included in the detailed evaluation forms for the Safety Edge$_{SM}$ projects.

Table A-1. Safety Edge$_{SM}$ slope measurements for sections placed with the Advant-Edger device after final rolling.

Section Identifier	Core/Section ID	Station	Safety Edge		
			Width of Taper	Thickness	Slope
Area #1; Telephone Pole #44155; Advant-Edger	Core #1	0+50	2.125	1.75	39.5
		1+00	2	2	45
		1+50	1.5	2	53.1
		2+00	2.125	2.4375	48.9
	Core #2	2+50	2.375	2.25	43.5
		3+00	2.5	2	38.7
		3+50	2	2.3125	49.1
		4+00	2.375	2.375	45
Mean Value			2.13	2.14	45.35
Standard Deviation			0.313	0.238	4.911
Coefficient of Variation			14.75	11.12	10.83
Area #2; Telephonee Pole #44128; Advant-Edger		1+00	1.5	1.875	51.3
		1+50	2.125	2.125	45
		2+00	1.875	1.875	45
	Core #3	2+50	1.75	2.25	52.1
		3+00	1.875	2.5	53.1
		3+50	2	2.125	46.7
		4+00	1.875	2.25	50.2
		4+50	1.25	2.375	62.2
	Core #4	5+00	2.625	2.375	42.1
		5+50	1.75	2.25	52.1
Mean Value			1.863	2.200	49.980
Standard Deviation			0.365	0.206	5.699
Coefficient of Variation			19.6	9.4	11.4

Table A-2. Safety Edge$_{SM}$ slope measurements for sections placed with the TransTech shoulder wedge maker device after final rolling.

Section Identifier	Core/Section ID	Station	Safety Edge		
			Width of Taper	Thickness	Slope
Area #3; Telephone Pole #44010; TransTec Device; HMA Placed August 19 or 20, 2010		0+00	1.625	1.625	45
		0+25	3.5	1.875	28.2
		0+50	2.875	1.875	33.1
		0+75	2.5	2	38.7
		1+00	3.5	2	29.7
		1+25	3.5	2.5	35.5
		1+50	2.5	2.25	42
		1+75	3.75	2.375	32.3
		2+00	3.125	1.875	31
		2+25	3.125	2	32.6
		2+50	3.25	1.875	30
		2+75	3.25	2.125	33.2
		3+00	1.875	2.125	62.1
		3+25	3.375	2	30.7
		3+50	2.125	2.125	45
Mean Value			2.925	2.042	36.61
Standard Deviation			0.653	0.220	8.914
Coefficient of Variation			22.3	10.8	24.3

Table A-3. Safety Edge$_{SM}$ slope measurements for sections placed with the Advant-Edger device; prior to rolling.

Section Identifier	Core/Section ID	Station	Safety Edge		
			Width of Taper	Thickness	Slope
Area #1; East of German Road; Slope Measurements Prior to Rolling		A	4	2.6	33.2
		B	4.13	2.68	32.9
		C	3.74	2.72	36
		D	3.54	2.68	37.1
Mean Value			3.85	2.67	34.80
Standard Deviation			0.264	0.050	2.074
Coefficient of Variation			6.85	1.89	5.96
Area #2; West of German Road; Slope Measurements Prior to Rolling		E	4	2.625	33.3
		F	4.125	2.5	31.2
		G	4.25	2.625	31.7
		H	3.75	2.625	35
		I	3.75	2.4375	33
Mean Value			3.975	2.563	32.84
Standard Deviation			0.224	0.088	1.491
Coefficient of Variation			5.6	3.4	4.5

Table A-4. Nuclear density adjustment ratios; core density/nuclear density.

Area/Location	Core #	Lane Direction	Station	Type of Section	Density of Cores		Nuclear Density Values		Adjustment Ratio		Adjusted Nuclear Values	
					A – Adjacent to Edge	B – 3 feet from Edge	A – Adjacent to Edge	B – 3 feet from Edge	A – Adjacent to Edge	B – 3 feet from Edge	A – Adjacent to Edge	B – 3 feet from Edge
Area #1; Telephone Pole #44155	C 1	Westbound	0+50	Advant-Edger	142.20	150.40	142.20	158.00	1.000	0.952	145.90	159.42
	C 2	Westbound	2+50	Advant-Edger	138.80	149.30	143.90	151.00	0.965	0.989	147.64	152.36
Area #2; Telephone Pole #44128	C 3	Westbound	2+50	Advant-Edger	142.10	149.90	135.80	156.40	1.046	0.958	139.33	157.81
	C 4	Westbound	5+00	Advant-Edger	139.80	148.50	141.20	160.20	0.990	0.927	144.87	161.64
	C T-1	Westbound	0+95	Advant-Edger								
	C T-2	Westbound	2+32	Advant-Edger								
	CT-3	Westbound		Advant-Edger								
	CT-4	Westbound		Advant-Edger								
	Average				140.725	149.525	140.775	156.400	1.000	0.957	144.435	157.808
	Standard Deviation				1.696	0.818	3.499	3.923	0.034	0.025	3.590	3.958
	Coefficient of Variation				1.21	0.55	2.49	2.51	3.42	2.66	2.49	2.51

Table A-5. Density readings made with a nuclear density gauge (Troxler Gauge 3430) for the sections placed with the Advant-Edger device.

Overall Average	Max. Specific Gravity:	2.555	Max. Density:	159.432
TransTech Device		2.548		158.995
Advant Device		2.554		159.370
Adjustment Ratios for Nuclear Gauge:	A=	1		
	B=	0.957		

Location/Area	Core Location	Lane Direction	Station	Type of Section	Nuclear Densities		Adjusted Nuclear Values		HMA Thickness, in.	Air Voids, %	
					A – Adjacent to Edge	B – 3 feet from Edge	A – Adjacent to Edge	B – 3 feet from Edge		A – Adjacent to Edge	B – 3 feet from Edge
Area #1; Safety Edge Section; Telephone Pole # 44155	C 1	Westbound	0+50	Advant	142.15	157.95	142.15	151.15815	1.75	10.81	5.15
		Westbound	1+00	Advant	144.45	155.5	144.45	148.8135	2	9.36	6.62
		Westbound	1+50	Advant	146.55	155.3	146.55	148.6221	2	8.04	6.74
		Westbound	2+00	Advant	140.35	151.45	140.35	144.93765	2.4375	11.93	9.06
	C 2	Westbound	2+50	Advant	143.9	151	143.9	144.507	2.25	9.71	9.33
		Westbound	3+00	Advant	144.85	156	144.85	149.292	2	9.11	6.32
		Westbound	3+50	Advant	152.3	154.45	152.3	147.80865	2.3125	4.44	7.25
		Westbound	4+00	Advant	151.35	153.5	151.35	146.8995	2.375	5.03	7.82
Average Value					145.74	154.39	145.74	147.75	2.141	8.55	7.29
Standard Deviation					4.191	2.338	4.191	2.237	0.238	2.630	1.404
Coefficient of Variation					2.88	1.51	2.88	1.51	11.12	30.74	19.26

Location/Area	Core Location	Lane Direction	Station	Type of Section	Nuclear Densities		Adjusted Nuclear Values		HMA Thickness, in.	Air Voids, %	
					A – Adjacent to Edge	B – 3 feet from Edge	A – Adjacent to Edge	B – 3 feet from Edge		A – Adjacent to Edge	B – 3 feet from Edge
Area #2; Safety Edge Section; Telephone Pole #44128		Westbound	1+00	Advant	144.75	152.05	144.75	145.51	1.875	9.17	8.70
		Westbound	1+50	Advant	144	151.4	144.00	144.89	2.125	9.64	9.09
		Westbound	2+00	Advant	142.1	151.9	142.10	145.37	1.875	10.84	8.79
	C 3	Westbound	2+50	Advant	135.8	156.35	135.80	149.63	2.25	14.79	6.11
		Westbound	3+00	Advant	143.1	153.45	143.10	146.85	2.5	10.21	7.85
		Westbound	3+50	Advant	147.7	153.85	147.70	147.23	2.125	7.32	7.61
		Westbound	4+00	Advant	147.9	148.7	147.90	142.31	2.25	7.20	10.71
		Westbound	4+50	Advant	153.55	157.7	153.55	150.92	2.375	3.65	5.30
	C 4	Westbound	5+00	Advant	141.15	160.2	141.15	153.31	2.375	11.43	3.80
		Westbound	5+50	Advant					2.25		
Average Value					144.45	153.96	144.45	147.34	2.20	9.36	7.55
Standard Deviation					4.983	3.554	4.983	3.401	0.206	3.127	2.134
Coefficient of Variation					3.45	2.31	3.45	2.31	9.36	33.40	28.26

Table A-6. Density readings made with a nuclear density gauge (Troxler Gauge 3430) for the section placed with the TransTech Shoulder Wedge Maker device and the section without the Safety Edge$_{SM}$.

Location/Area	Core Location	Lane Direction	Station	Type of Section	Nuclear Densities		Adjusted Nuclear Values		HMA Thickness, in.	Air Voids, %	
					A – Adjacent to Edge	B – 3 feet from Edge	A – Adjacent to Edge	B – 3 feet from Edge		A – Adjacent to Edge	B – 3 feet from Edge
Area#3; Safety Edge Section; Telephone Pole #44010; HMA Placed August 19 or 20, 2010		Westbound	0+00	TransTec	140.95	154.4	140.95	147.76	1.625	11.35	7.07
		Westbound	0+50	TransTec	142.6	153.65	142.60	147.04	1.875	10.31	7.52
		Westbound	1+00	TransTec	140.9	152.55	140.90	145.99	2	11.38	8.18
		Westbound	1+50	TransTec	139.8	152.3	139.80	145.75	2.25	12.08	8.33
		Westbound	2+00	TransTec	140.5	152.15	140.50	145.61	1.875	11.64	8.42
		Westbound	2+50	TransTec	140.1	149.2	140.10	142.78	1.875	11.89	10.20
		Westbound	3+00	TransTec	134.6	150.1	134.60	143.65	2.125	15.35	9.66
		Westbound	3+50	TransTec	142.2	152.8	142.20	146.23	2.125	10.57	8.03
		Westbound	4+00	TransTec							
				Average Value	140.21	152.14	140.21	145.60	1.97	11.82	8.43
				Standard Deviation	2.462	1.725	2.462	1.651	0.198	1.548	1.038
				Coefficient of Variation	1.76	1.13	1.76	1.13	10.04	13.10	12.32

Location/Area	Core Location	Lane Direction	Station	Type of Section	Nuclear Densities		Adjusted Nuclear Values		HMA Thickness, in.	Air Voids, %	
					A – Adjacent to Edge	B – 3 feet from Edge	A – Adjacent to Edge	B – 3 feet from Edge		A – Adjacent to Edge	B – 3 feet from Edge
Area #4; Non-Safety Edge; Along the Centerline of Roadway; Plant down so section located along the centerline of previously placed mix from yesterday; Telephone Pole #44128.		Westbound	0+00	Non-Safaety Edge		154.6		147.95			7.16
	Core T-1	Westbound	0+45	Non-Safaety Edge	133.5	150.7	133.50	144.22		16.23	9.51
		Westbound	0+95	Non-Safaety Edge	140.8	150.65	140.80	144.17		11.65	9.54
	Core T-2	Westbound	1+45	Non-Safaety Edge	143.6	157.2	143.60	150.44		9.90	5.60
		Westbound	2+32	Non-Safaety Edge	129.3	149.65	129.30	143.22		18.87	10.14
		Westbound	2+82	Non-Safaety Edge	142.35	147.25	142.35	140.92		10.68	11.58
		Westbound		Non-Safaety Edge							
		Westbound		Non-Safaety Edge							
		Westbound		Non-Safaety Edge							
				Average Value	137.91	151.68	137.91	145.15	#DIV/0!	13.47	8.92
				Standard Deviation	6.205	3.599	6.205	3.444	#DIV/0!	3.894	2.161
				Coefficient of Variation	4.50	2.37	4.50	2.37	#DIV/0!	28.92	24.23

Photographs of Selected Cores Recovered from the Project

This section of the field report provides a photograph of the cores that were recovered for laboratory density testing, and visual observations of the mixture along the edge and 3 feet from the edge. No systematic visual differences were noted between the different core sets.

Cores 1B (3 ft from edge)
and 1A (adjacent to edge)

Cores 2B (3 ft from edge)
and 2A (adjacent to edge)

Cores 3B (3 ft from edge)
and 3A (adjacent to edge)

Cores 4B (3 ft from edge)
and 4A (adjacent to edge)