Federal Highway Administration
Every Day Counts
Innovation Initiative

Safety Edge$_{SM}$ Demonstration Project State Route 182 Columbus, Mississippi

Field Report
June 27, 2011

U.S.Department of Transportation
Federal Highway Administration

FOREWORD

The purpose of this field report is to provide a summary of observations made during the hot mix asphalt (HMA) Safety Edge$_{SM}$ project located on State Route (SR) 182 near Columbus, Mississippi. 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.

This report is a summary of the observations made on July 12 through 15, 2010 and measurements taken during construction to evaluate the use of the TransTech Shoulder Wedge Maker. Observations and data were collected to evaluate the slope and density of the Safety Edge$_{SM}$, recommend design adjustments, and identify benefits and complications with the use of the edge device.

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7. Authors
Harold Von Quintus and Jagannath Mallela

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Applied Research Associates, Inc.
100 Trade Centre Drive, Suite 200
Champaign, IL 61820

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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 the Safety Edge$_{SM}$ on a two lane highway hot mix asphalt (HMA) overlay project on State Route 182 near Columbus, Mississippi. The TransTech Shoulder Wedge Maker was demonstrated during this project. Details regarding the performance of the 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
Safety Edge$_{SM}$, Slope, HMA, TransTech Shoulder Wedge Maker

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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 yards	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	millimeters	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 L 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 (or "metric ton")	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 per square meter	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	35.314	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 (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela per square meter	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	Newtons	0.225	poundforce	lbf
kPA	kiloPascals	0.145	poundforce per square inch	lbf/in^2 (psi)
MPa	megaPascals	0.145	kips per square inch	k/in^2 (ksi)

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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SUMMARY OF OBSERVATIONS

This section of the field 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 the Safety Edge$_{SM}$ and non-Safety Edge$_{SM}$ portions of this project.

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

The Safety Edge$_{SM}$ device 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. These are noted in some of the following bullet items.

Slope of Safety Edge$_{SM}$

- The average slope of the Safety Edge$_{SM}$ was found to be 37°. Only one slope measurement was found to be near 30°.
- Slope measurements of the Safety Edge$_{SM}$ were taken before and after rolling in separate areas of the project. The slopes before and after rolling were found to be approximately equal (an average slope of 37.0 degrees after rolling compared to an average slope of 40.1 degrees prior to rolling). Rolling did not steepen the slope of the Safety Edge$_{SM}$ along this project.

Placement

- The Safety Edge$_{SM}$ was formed using the TransTech Shoulder Wedge Maker, which was properly bolted to the screed. Construction personnel recommended that the Safety Edge$_{SM}$ device include an automated system for raising and lowering the device.
- The Safety Edge$_{SM}$ shaft or screw for raising and lowering the device had been bent from use on a previous project. Excessive downward pressure from trying to lower the device on a hard surface caused the shaft to bend. The bend caused the device to rotate when the screed operator tried to raise or lower the device – allowing HMA mix to get between the screed end plate and Safety Edge$_{SM}$ device. HMA mix getting between the device and screed end plate varied along the project. This could have resulted in a steeper slope along the project.

Compaction

- The HMA mix density was higher and the air voids lower adjacent to the edge of the mat for the Safety Edge$_{SM}$ sections (average air voids of 10.6 percent) in comparison to the non-Safety Edge$_{SM}$ section (average air voids of 12.3 percent). Thus, the Safety Edge$_{SM}$ is believed to have a confining effect on rolling an unconfined edge condition. This observation is considered a benefit to the use of the Safety Edge$_{SM}$.
- The air voids of the interior HMA mat were considered good with a mean value of about 6.5 percent for both the safety and non-Safety Edge$_{SM}$ sections. The air voids determined

along the edge of the mat were high (varying from 9 to almost 15 percent). This air void content is higher than desirable for long term performance.

Shoulder Construction

- A soil-aggregate mixture is planned to be used for the backing material. Placement of the backing material was not observed because the paving contractor planned to place it after all paving had been completed.

HMA Mixture and Safety Edge$_{SM}$

- No segregation was observed in any of the areas of the mat or Safety Edge$_{SM}$.
- The planned HMA overlay thickness was 1.5 inches. The average overlay thickness of the Safety Edge$_{SM}$ sections was found to be 2.0 inches, while the average thickness of the non-Safety Edge$_{SM}$ section was found to be 2.75 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.

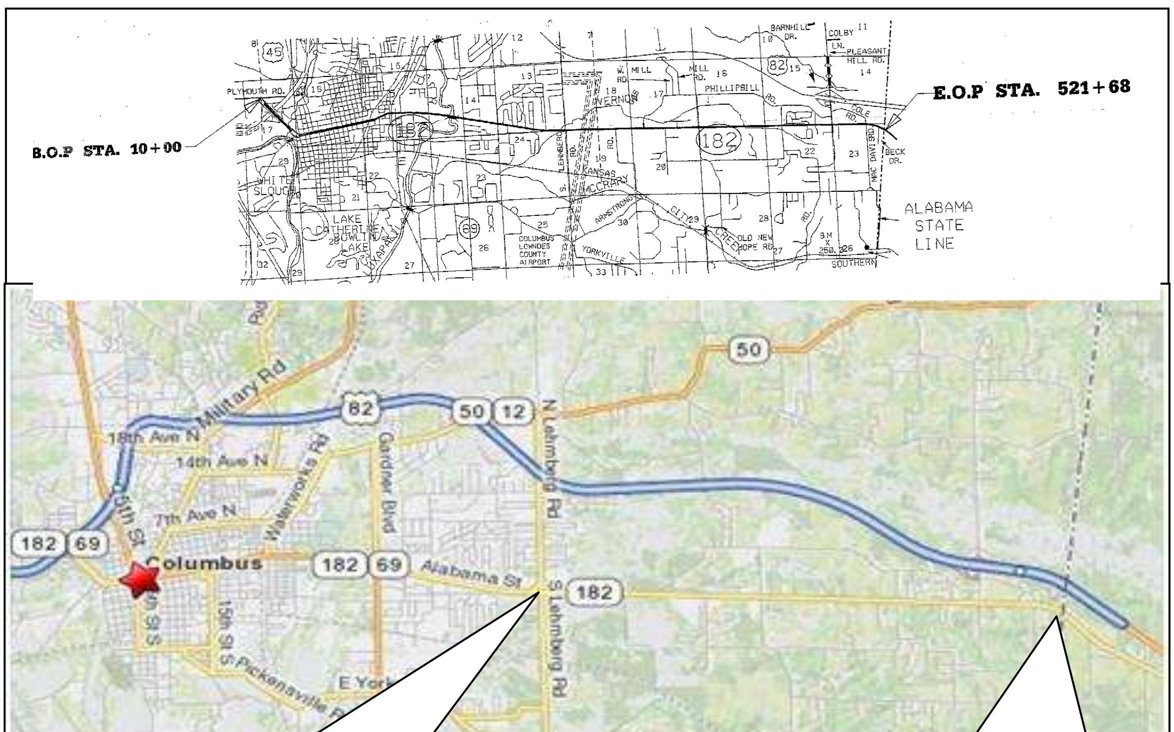
FIELD EVALUATION OF HMA OVERLAY WITH SAFETY EDGE$_{SM}$

Introduction

A series of field tests were carried out to assess the placement and condition of the HMA overlay placed along State Route 182 just east of Columbus, Mississippi, with and without the use of the Safety Edge$_{SM}$ device. The paving contractor for the project was Falcon Construction. The contractor used the TransTech Shoulder Wedge Maker along most of the project. The purpose of this field study was to evaluate the quality of the in-place HMA material and Safety Edge$_{SM}$ by investigating three issues or features.

1. Correct use of the 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 is shown in Figure 1. The project started at the intersection with Plymouth Road and ended at the Alabama State line. The western end of the project, through the downtown area, was excluded from the Safety Edge$_{SM}$ project because of curb and gutter within the City Limits and numerous driveways. The portion of the project for the Safety Edge$_{SM}$ started at the intersection with South Lehmberg Road and proceeded east to the Alabama State Line (refer to Figure 1).



Safety Edge$_{SM}$ Portion of Project Started at intersection with S. Lehmberg Rd.

Safety Edge$_{SM}$ Portion of Project ended at the Alabama State Line.

Figure 1. Project location.

Pavement Structure and Project Conditions

The project consisted of milling the existing surface to a depth of about 1.5 inches (basically removing the existing wearing surface) and placing a 1.5 inch lift of a 9.5 mm HMA mix over the existing HMA pavement. Figure 2 provides a general view of the 1.5 inch HMA overlay and typical cross section of the pavement, while Figures 3 and 4 provide a general view on the condition of the existing pavement after milling. These figures show that a thin layer or scab of the existing wearing surface was left in place. This thin layer may become debonded with time and have a detrimental impact on the performance of the HMA overlay.

A leveling course was placed in some areas along the project, and the existing pavement was widened to include two 12-foot lanes and a 2-foot width for the edge stripe and rumble strip planned to be placed on both sides of the roadway. The leveling course was placed along localized areas of the project to improve the transverse and longitudinal profiles (refer to Figure 2). The existing shoulder was trenched 2 feet wide, and a 19 mm HMA base mixture was placed with a motor-grader and compacted in the trench. The 19 mm HMA base was used to widen the roadway by 2-feet on each side and had been placed prior to arriving on site. Figure 5 shows the HMA base to widen the roadway, and the windrow of shoulder material from the trenching operation.

The ditches along the edge of the pavement were generally shallow or level with the existing pavement (refer to Figures 3 to 5). No lane-shoulder drop-offs were observed. As noted above, however, the edge of the pavement had been trenched and the HMA base mix had already been placed to widen the roadway by 2-feet on each side. The Safety Edge$_{SM}$ backing material is the trenched soil-aggregate mixture. The backing material was scheduled to be graded back to the Safety Edge$_{SM}$ near the end of this rehabilitation project.

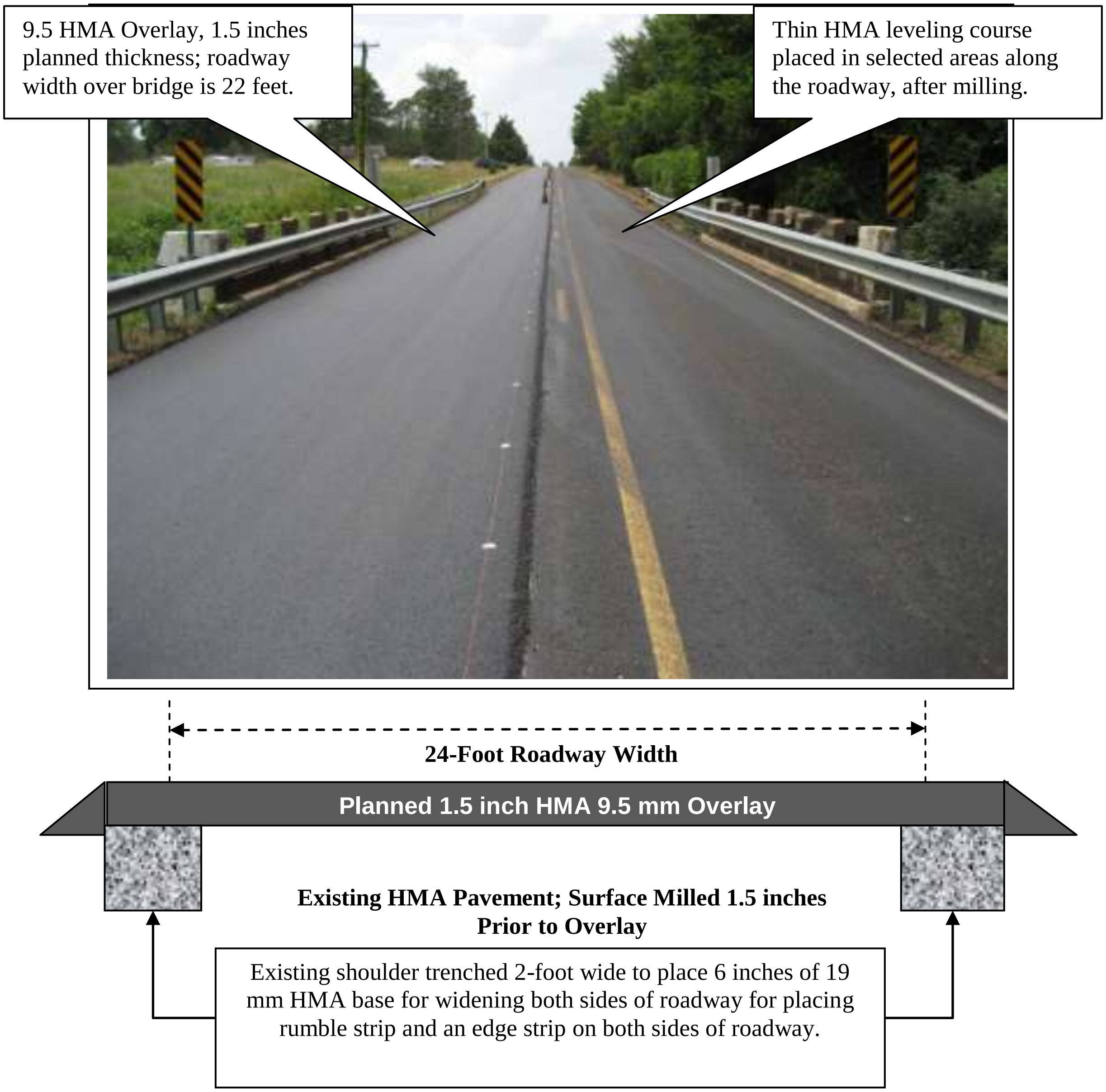


Figure 2. 9.5 mm HMA overlay already placed in one direction and the thin leveling layer placed in opposite direction after milling but prior to overlay placement.

Figure 3. General overview of the existing HMA pavement after milling; heavily distressed area with cracking (view is towards the east).

Figure 4. General overview of the existing HMA pavement after milling; minor distressed area (view is towards the east).

Figure 5. General view of the 19 mm HMA base placed to widen the roadway.

Field Evaluation Tests

Three sections were identified and marked during the paving operation; two Safety Edge$_{SM}$ sections and one section without the Safety Edge$_{SM}$ device. The following summarizes the three sections included within this project.

1. Area #1: Non-Safety Edge$_{SM}$ control section located in the eastbound lane from station 397+00 to station 408+00.
2. Area #2: Safety Edge$_{SM}$ section located in the eastbound lane from station 429+00 to station 435+00.
3. Area #3: Safety Edge$_{SM}$ section located in the eastbound lane from station 439+00 to station 445+00.

Field tests were conducted within each test section for measuring slope and HMA density. Slope measurements were taken using a straight-edge (4-foot aluminum level) and six inch ruler (refer to Figure 6), while density readings were taken adjacent to and 3-feet from the mat's edge using a Troxler 3440 nuclear density gauge (refer to Figure 7).

Sixteen cores were taken in the test sections established during the paving operation. The sixteen cores were obtained at eight different locations (4 within the Safety Edge$_{SM}$ and 4 within the non-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.

The longitudinal profile was measured by the paving contractor after each day of paving using a California Profilometer for determining the smoothness of the 9.5 mm overlay.

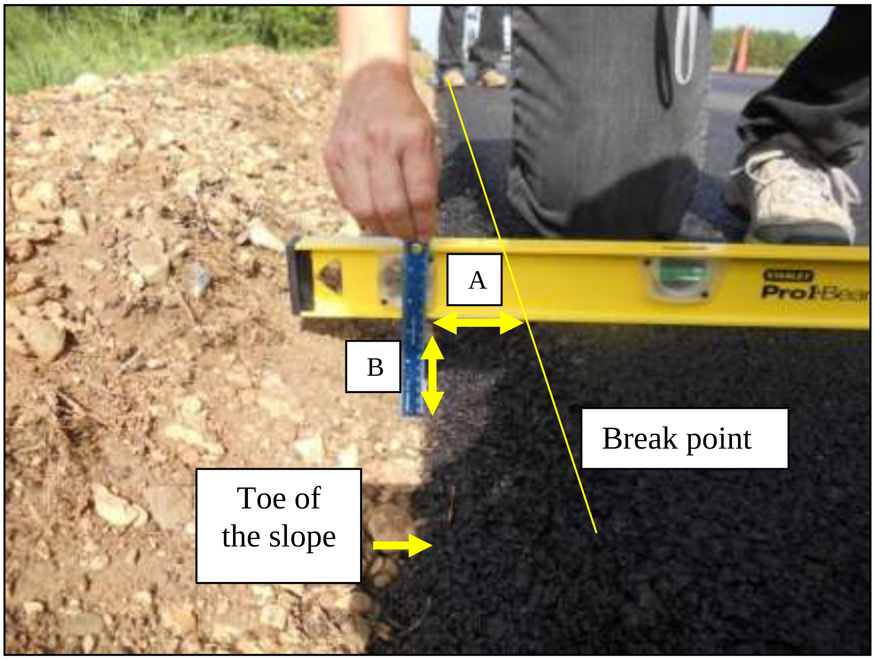


Figure 6. Measurement of the Safety Edge$_{SM}$ angle.

Figure 7. Nuclear gauge used to measure HMA density.

Slope Measurements

Slope measurements were taken using a straight-edge to measure the width and thickness of the taper of the Safety Edge$_{SM}$ (refer to Figure 6). The average slope of the Safety Edge$_{SM}$ was found to be 37°. All slope measurements are listed in Tables A-1 through A-3 in Appendix A. Only one of the measurements was about 30°. Figure 8 includes a comparison between the slope of the Safety Edge$_{SM}$ after final rolling and thickness of the Safety Edge$_{SM}$ for the two test sections. As shown, there appears to be no correspondence between thickness and the slope of the Safety Edge$_{SM}$.

Slope measurements were also made prior to rolling the Safety Edge$_{SM}$. These measurements are in Table A-2 in Appendix A and were compared to the values after final rolling; refer to Figure 8. As shown, the slopes prior to rolling are slightly steeper than after final rolling. These data sets were measured in different areas, so there is no direct correspondence between the individual point measurements. An observation from this comparison is that rolling did not steepen the slope, and suggests that rolling the Safety Edge$_{SM}$ by overhanging the steel drum about 4 to 6 inches over the edge did not increase the slope. The rolling patterns used along the project are explained in the *Compaction Operations* section.

Slopes were also measured along the non-Safety Edge$_{SM}$ section. These slope measurements are included in Table A-3 in Appendix A and shown in Figure 8. As expected, the slopes without use of the Safety Edge$_{SM}$ are greater than when using the Safety Edge$_{SM}$ device.

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.

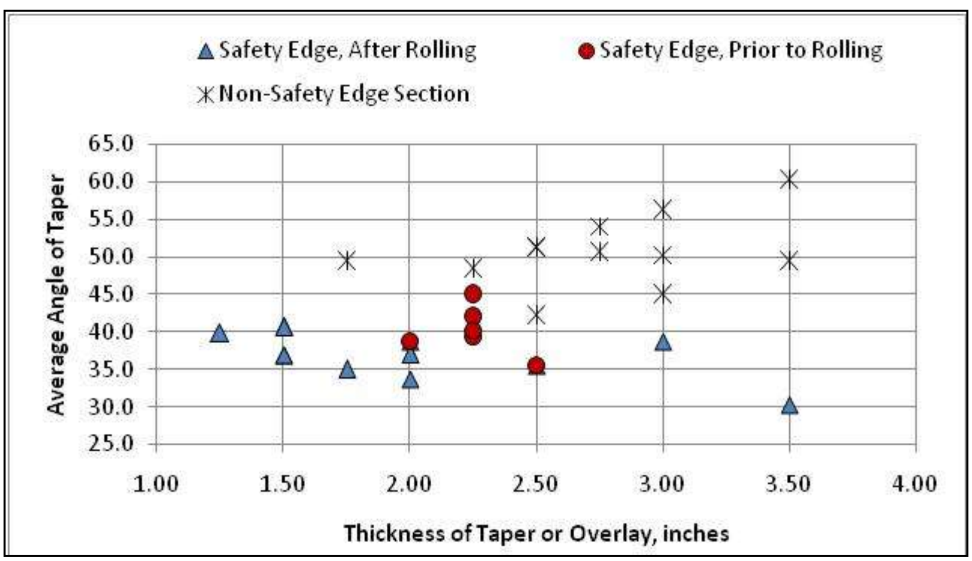


Figure 8. Comparison of the Safety Edge$_{SM}$ slope and thickness of the HMA adjacent to the edge of the HMA overlay.

Cores

A total of sixteen 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 HMA for developing a correction factor for the nuclear density gauge readings taken adjacent to the edge and within the center of the mat. Figure 9 shows the location of the cores and nuclear density readings relative to the edge of the HMA mat. Photographs of each core recovered from the roadway are included in Appendix A.

Tables A-4 and A-5 in Appendix A include a summary of these test results; core thickness and bulk specific gravities (saturated surface dry) converted to bulk densities. Figure 10 includes a comparison of the core densities taken along the edge and near the center of the steel drum roller for the Safety Edge$_{SM}$ and non-Safety Edge$_{SM}$ sections. As expected, densities near the center of roller are higher than along the edge of the mat (unconfined edge). More importantly, the core densities taken along the pavement's edge are consistently higher for the Safety Edge$_{SM}$ section than for the non-Safety Edge$_{SM}$. These results suggest that the Safety Edge$_{SM}$ is providing better confinement for rolling an unconfined edge of the mat.

Location of nuclear density test; A location is adjacent to the edge; B location is near the center of the steel drum roller (about 3 feet from edge).

Core sets recovered from selected stations; A location is adjacent to the edge; B location is near the center of the steel drum roller (about 3 feet from edge).

Figure 9. Photos showing location of cores and nuclear density tests made with the Troxler 3440 gauge (nuclear density readings were taken and then the HMA overlay was cored).

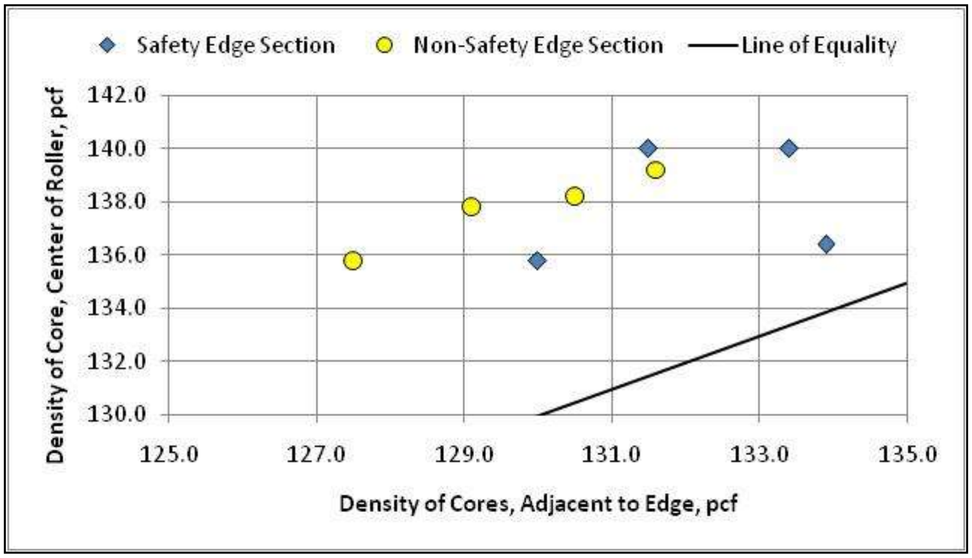


Figure 10. Comparison of core densities adjacent to the edge of pavement and near center of steel drum rollers.

Nuclear Density Test Results

Density measurements were made with a Troxler 3440 gauge (refer to Figure 7). Four readings were recorded at each station or location. Two readings were made at a point adjacent to the Safety Edge$_{SM}$ and two were made near the center of the steel drum roller. At each point, one reading was recorded with the nuclear gauge positioned parallel to the pavement edge and the other positioned perpendicular to the edge. The average nuclear density gauge readings at each point are listed in Table A-5 in Appendix A.

Nuclear density readings were taken before drilling each core. Figure 11 shows a comparison of the nuclear gauge readings and densities measured on the cores. As shown, there is close correspondence between the nuclear gauge readings and core densities. Adjustment factors were determined for the nuclear gauge readings taken at the Safety Edge$_{SM}$ and near the center of the steel drum roller being used to compact the HMA mat. The adjustment factors are included in Table A-4 in Appendix A. The following lists the average factors determined for this project, which are near unity.

Location	Adjustment Factor
Near center of steel drum	1.007
Adjacent to Safety Edge$_{SM}$	1.005

These factors were used to adjust the nuclear gauge readings to be consistent with the densities that would be measured in the laboratory. The adjusted densities using the correction factors are listed in Table A-4 in Appendix A.

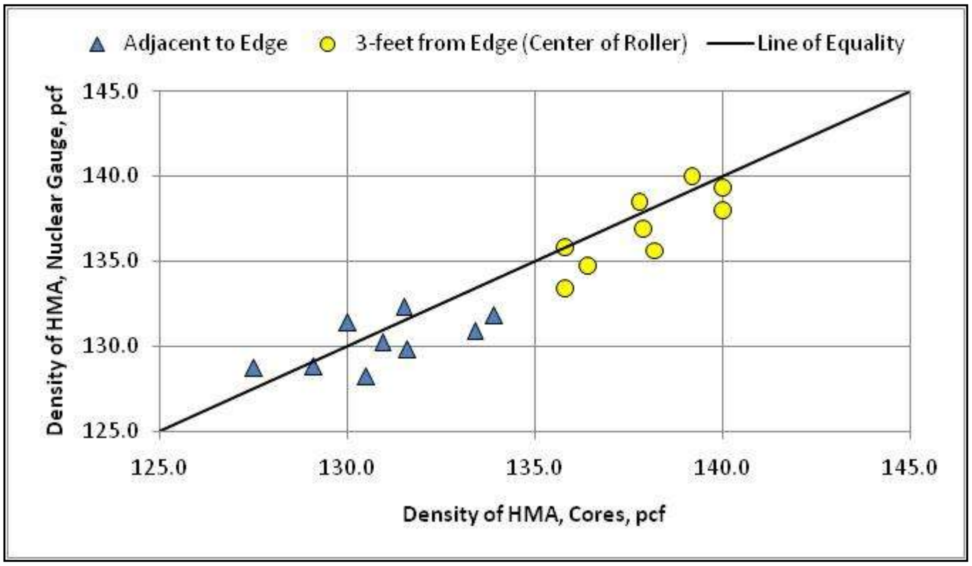


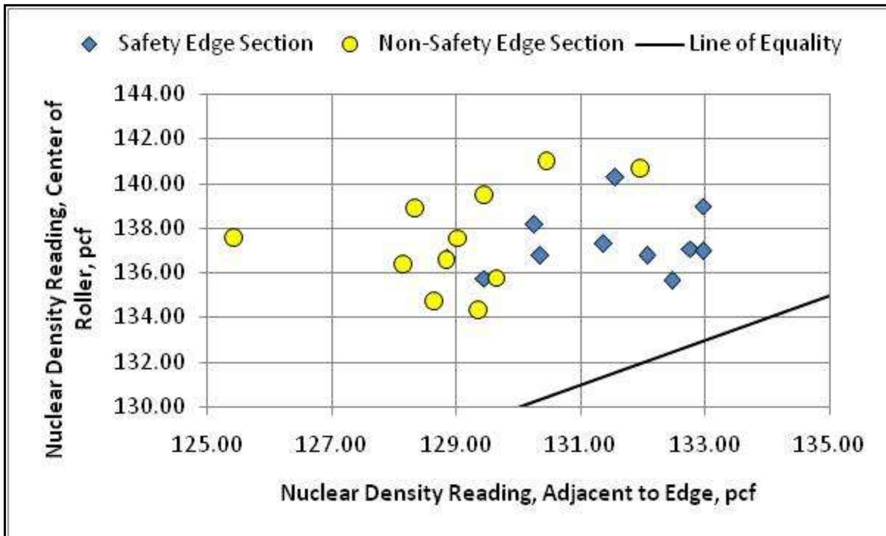
Figure 11. Comparison of the nuclear density readings and densities measured on the cores recovered from the mat.

Figure 12 shows a comparison of the adjusted nuclear density gauge readings taken adjacent to the Safety Edge$_{SM}$ and near the center of the vibratory steel wheel roller. Figure 12 also includes a comparison of the HMA air voids between both areas. As shown, the air voids are higher adjacent to the Safety Edge$_{SM}$, in comparison to 3-feet from the Safety Edge$_{SM}$. The other important observation from this data is that the densities are higher and air voids consistently lower along the mat's edge for the Safety Edge$_{SM}$ sections, in comparison to the non-Safety Edge$_{SM}$ section.

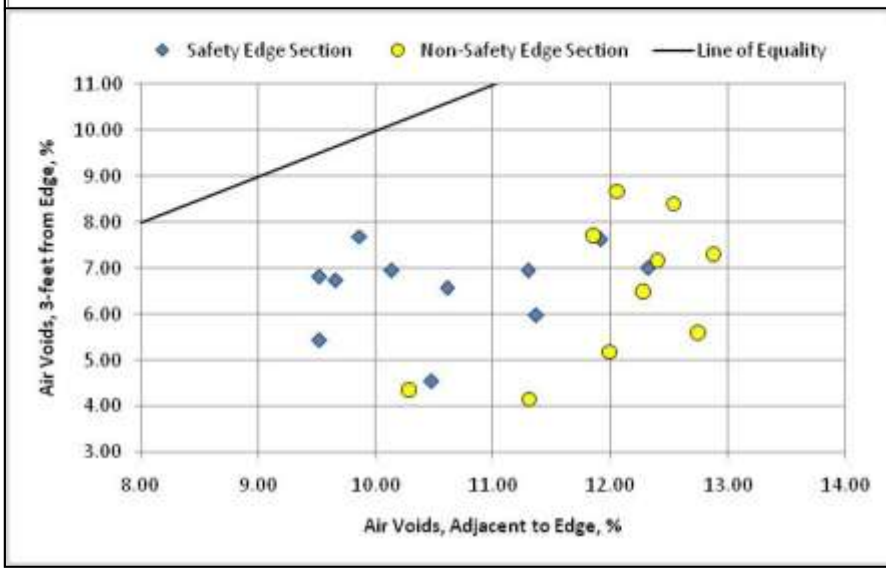
Figure 8 included a comparison between the HMA thickness (near the Safety Edge$_{SM}$) and slope of the Safety Edge$_{SM}$. The thickness of the HMA appears to have no effect or impact on the slope of the Safety Edge$_{SM}$. Figure 13 shows a comparison of the density and HMA overlay thickness. As shown, there is also little correspondence between the overlay thickness and density or air voids.

Longitudinal Profile Measurements

The longitudinal profile measurements made by Falcon Construction using the California Profilometer for each of the three test sections were requested, but were unavailable at the time of this field report. The purpose of these measurements were to compare the smoothness of the Safety Edge$_{SM}$ and non-Safety Edge$_{SM}$ sections to ensure that the Safety Edge$_{SM}$ device was not having a detrimental impact on the contractor's ability to meet the smoothness specification.



Nuclear densities measured in areas adjacent to the edge in comparison to those taken near the center of the steel drum roller.



Air voids in areas adjacent to the edge in comparison to those taken near the center of the steel drum roller.

Figure 12. Comparison of the adjusted nuclear density readings and air voids between the areas adjacent to the edge and center of the steel drum roller.

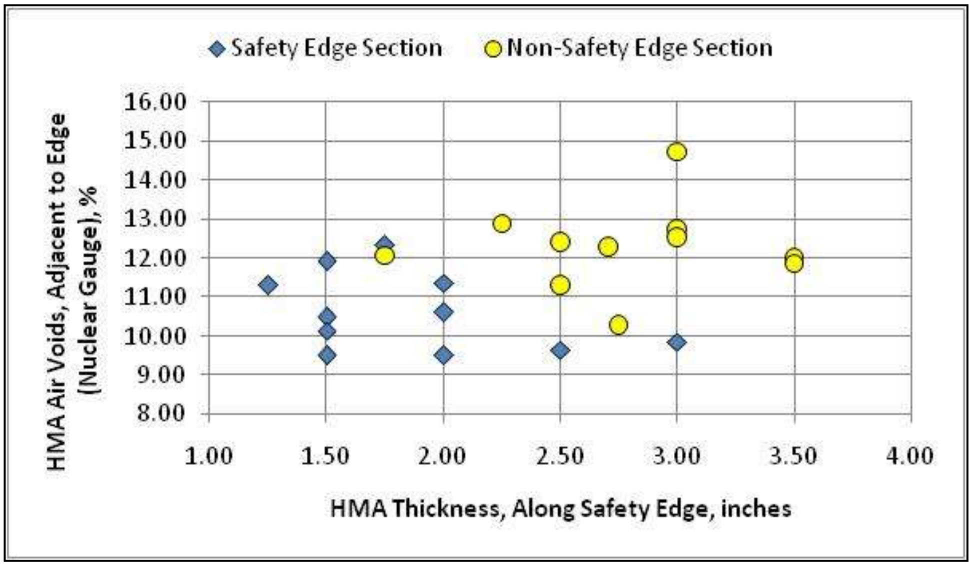


Figure 13. Comparison of HMA thickness at the edge of the mat and HMA air voids.

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

This section provides an overview of the observations made during the paving and rolling operations.

Preparatory Work

Figures 3 and 4 showed examples of the existing pavement after milling but prior to HMA overlay placement. The trenched material that was removed to widen the roadway was windrowed. As previously discussed, the scab of the existing wearing surface that was left in place in some areas after milling could become debonded in the future and have a detrimental impact on the performance of the HMA overlay; regardless of whether it is a Safety Edge$_{SM}$ or non-Safety Edge$_{SM}$ section. The following lists the different activities performed by the contractor in placing the HMA overlay.

1. The edge of the pavement or shoulder was graded to level out the windrowed material, as shown in Figure 14. The edge of this windrowed material was not compacted prior to placing the Safety Edge$_{SM}$. In some areas, this material was loose.
2. The motor grader was followed by a broom to clean the surface, as shown in Figure 14. Cleaning the surface is considered good practice prior to placing the tack coat.
3. An emulsion was applied to serve as a tack coat for the HMA overlay. Figure 14 shows the emulsion being placed prior to paving. The application of the tack coat was uniform and covered the entire surface.

	Motor grader was used to move and level the windrowed material along the edge of the pavement. In a few areas, the motor grader was used after the tack coat had already been applied.
	A motorized broom was used to clean the surface of the pavement prior to applying the tack coat to the surface of the existing pavement.
	A tack coat (emulsion) was applied to the cleaned pavement surface prior to placing the HMA overlay.

Figure 14. Surface preparation activities performed by the contractor prior to placing the HMA overlay.

Placement/Paving Operations

Figure 15 shows the equipment used to place the HMA overlay. The paving contractor operated the paver in the automatic longitudinal grade control mode and used non-contact sonic sensors for controlling the grade. Figure 16 shows the TransTech Shoulder Wedge Maker attached to the screed. The following summarizes some of the observations and comments made by construction and other on-site personnel on the use of the Safety Edge$_{SM}$ device.

- The screed operator recommended that the Safety Edge$_{SM}$ device be an automated system rather than manually turning the screw to raise and lower the Safety Edge$_{SM}$ device.
- The shaft of the Safety Edge$_{SM}$ device was bent during use on a previous project, such that when the screed operator turned the screw to raise or lower the device, the device would rotate creating a space between the end plate and Safety Edge$_{SM}$ device. HMA material could then become lodged between the screed end plate and the Safety Edge$_{SM}$ device. The screed operator continued to monitor this condition to prevent it from occurring, but in some cases HMA mix would push the device away from the screed end plate – increasing the slope. This condition may have resulted in some of the steeper slopes that were measured within the Safety Edge$_{SM}$ Area #3 (refer to Table A-1 in Appendix A).

Figure 17 shows the slope and surface texture of the unconfined edge between the Safety Edge$_{SM}$ and non-Safety Edge$_{SM}$ sections.

Figure 15. Equipment used to place the HMA overlay.

Figure 16. TransTech Shoulder Wedge Maker attached to the screed.

Safety Edge$_{SM}$ section   non-Safety Edge$_{SM}$ section

Figure 17. Safety Edge$_{SM}$ and non-Safety Edge$_{SM}$ sections; different days of paving.

Compaction Operations

Figures 18 and 19 show the rollers that were used to compact the 9.5 mm HMA mixture. Two breakdown rollers were used in parallel for most of the project (refer to Figure 18). One of the primary or breakdown rollers was a Sakai double drum vibratory steel wheel (SW990), and the other breakdown roller was a Hypac double drum vibratory steel wheel (C778B). Both rollers were operated in the vibratory mode (low amplitude, high frequency). The third roller used on the project was an Ingram pneumatic, rubber tired roller (5x6 tires) and used in the intermediate position (refer to Figure 19). The finish roller was a Hypac static steel wheel roller (C784 [refer to Figure 19]).

Sakai Double Drum Vibratory SW990 Hypac Double Drum Vibratory C778B

Figure 18. Two double drum vibratory steel wheel rollers were used in parallel in the breakdown position to compact the 9.5 mm HMA mix.

Ingram pneumatic or rubber tired roller (5x6 tires) that was used in the intermediate position.

Hypac Double Drum static steel wheel (C784) that was used in the finish position for compacting the HMA overlay.

Figure 19. Rollers used in the intermediate and finish positions for compacting the 9.5 mm HMA overlay mixture.

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. The contractor used two rolling patterns along the project. The following summarizes the initial rolling pattern (number of passes and location for each roller) used by the Contractor.

- Hypac double drum steel wheel roller; high frequency, low amplitude; primary or breakdown roller (the lead roller in most areas):

    - First pass along the centerline of the roadway with the edge of the drum extended over the hot mat about 2 to 6 inches.
    - Second pass; same location as for the first pass, but in reverse direction.
    - Third pass down the center of the hot mat.
- Sakai double drum steel wheel roller; high frequency, low amplitude; primary or breakdown roller, in parallel with the Hypac roller:
    - First pass near the Safety Edge$_{SM}$, but with the edge of the drum about 6 to 12 inches from the Safety Edge$_{SM}$ on the interior of the mat (refer to Figures 18 and 20.b).
    - Second pass; down the center of the mat.
    - Third pass along the Safety Edge$_{SM}$ with the edge of the drum adjacent to or just over the Safety Edge$_{SM}$.
- Ingram Pneumatic rubber tired roller; intermediate roller:
    - First pass along the Safety Edge$_{SM}$ with the outer tire located a couple of inches from the edge of the mat.
    - Second pass; same as location for the first pass, but in reverse direction.
    - Third pass along the centerline with the outer tire located on the hot mat.
    - Fourth pass; same as location for the third pass but in reverse direction.
    - Fifth pass down the center of the mat.
- Ingersoll-Rand steel wheel roller; static mode; finish roller:
    - First pass along the shoulder edge with the edge of the steel wheel roller extended over the edge about 4 to 6 inches.
    - Second pass; same location as for the first pass.
    - Third pass down the center of the mat.
    - Fourth pass along the center of the roadway with the edge of the steel drum extended over the edge by about 2 to 6 inches.
    - Fifth pass; same location as for the fourth pass, but in reverse direction.

Prior to designating the locations for the Safety Edge$_{SM}$ test sections, the HMA mix at the top of the Safety Edge$_{SM}$ was being pushed out under the third pass of the Sakai roller, steepening the slope of the Safety Edge$_{SM}$. The Contractor was asked to revise the rolling pattern to observe mixture behavior along the Safety Edge$_{SM}$. The major revision was to roll the Safety Edge$_{SM}$ first and extend the edge of the Sakai roller over the Safety Edge$_{SM}$. The Contractor complied with that request, and the HMA mix did not push out as much. The following summarizes the revised rolling pattern (number of passes and location of each roller) used by the Contractor in an attempt to reduce or lower the slope of the Safety Edge$_{SM}$.

(a) First pass of Sakai roller is 4 to 6 inches over the edge of the mat.

(b) First pass of Sakai roller is about 6 to 12 inches away from edge of the mat.

Figure 20. Rolling the unconfined edge with the vibratory steel wheel roller; pattern varied along the project.

- Hypac double drum steel wheel roller; high frequency, low amplitude; primary or breakdown roller (the led roller in most areas); rolling pattern remained the same as described above.
- Sakai double drum steel wheel roller; high frequency, low amplitude; primary or breakdown roller:
  - First pass along and extended over the shoulder edge by about 2 to 6 inches (refer to Figure 18 and 20.a).
  - Second pass; same location as for first pass, but in reverse direction.
  - Third pass along the center of the mat.
- Ingram Pneumatic rubber tired roller, intermediate roller; rolling pattern remained the same as described above.
- Ingersoll-Rand steel wheel roller, static mode, finish roller; rolling pattern remained the same as described above.

This rolling pattern continued to be used by the Contractor and was used for the two Safety $Edge_{SM}$ sections. The Sakai roller operator, however, began to divert back to the initial pattern during the compaction operation of the second Safety $Edge_{SM}$ section. In addition, the Sakai roller was removed from the project for mechanical reasons, so the Hypac was the only breakdown roller used towards the latter part of paving on the last day of the field study.

A control strip was not used to confirm that the roller pattern being used was achieving an adequate density of the mix. The nuclear density gauge readings and the densities of the cores suggest that adequate density was obtained for this mixture away from the edge, but the density was low near the edge.

The Safety $Edge_{SM}$ was rolled inconsistently along the project. The rolling pattern used along most of the project, however, was that the first pass of the Sakai breakdown roller was along the Safety $Edge_{SM}$ with the roller extended over the edge of the HMA mat by about 4 to 6 inches (refer to Figures 18 and 20). As noted above, the Sakai roller operator did divert back to initially rolling the mat away from the edge and delayed rolling the edge until the last pass in different locations (refer to Figures 18 and 20). For the initial rolling pattern, the edge of the mat along the Safety $Edge_{SM}$ received only one pass of the breakdown roller. The exact locations of the different rolling patterns were not identified along the project.

No visual signs of shoving or tearing of the mixture were noted or observed during the compaction operation. In addition, the Safety $Edge_{SM}$ did not shove out, or stand up, during the compaction operation. Figure 21 shows the surface texture of the finished HMA mat along the project. The surface texture and condition was relatively uniform throughout the project.

Figure 21. Surface texture of the 9.5 mm HMA overlay after final rolling.

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

The HMA mixture design data was obtained from the Mississippi DOT, as well as data collected during construction from Falcon Contracting. The HMA mixture design parameters are documented in the Field Evaluation Form, which is a separate document to this field report. The HMA mixture volumetric properties and gradation are considered reasonable.

The distance between the end of the auger and screed end plate was about 18 to 24 inches. This distance should be less than 18 inches. The temperature of the HMA being delivered to the project site was reported to be 295 to 305 °F. Mix temperature and the distance between the end of the auger and screed end plate, however, are not believed to be contributing factors to the steeper slopes.

Observations made during paving showed that the HMA mixture was not being pushed to the end of the Safety Edge$_{SM}$ device. Figure 22 shows HMA behind the screed and the Safety Edge$_{SM}$ slope prior to rolling. The slope of the Safety Edge$_{SM}$ was steeper than planned prior to rolling. A reason for the steeper slope, however, could be related to the bent shaft of the Safety Edge$_{SM}$ device.

Figure 22. HMA under and behind the screed; the HMA was not being pushed to the end of the Safety Edge$_{SM}$, which resulted in a steeper slope prior to rolling.

Other Observations Related to Site Features

As reported earlier in the document, two narrow bridges were located within the project limits. One of these was located within the non-Safety Edge$_{SM}$ section (refer to Figure 23). The first narrow bridge was located within the non-Safety Edge$_{SM}$ section. The contractor was able to retract the extension on the shoulder side of the paver, so that paving across the bridge did not result in any problem. The Safety Edge$_{SM}$ sections were paved the following day and none of the narrow bridges were encountered.

The contractor voiced a concern about being unable to retract the extension on the shoulder side of the paver sufficiently, so that the paver operator would not have to steer the paver closer to the centerline and retract the other extension. Steering the paver closer to the centerline and retracting the other extension could potentially create a longitudinal joint that would be difficult to match and compact (refer to Figure 23).

Figure 23. One of the narrow bridges located on the project (about 22-feet wide).

The other concern of the contractor was that the smoothness of the mat would decrease in those areas, and smoothness was a pay item (refer to Figure 24). The contractor requested that the Mississippi DOT permit the Safety Edge$_{SM}$ device to be removed in those areas. It is unknown whether the Mississippi DOT permitted the contractor to remove the Safety Edge$_{SM}$ device in those areas.

Figure 24. Longitudinal Profile Testing of Final Surface of Overlay

Findings and Conclusions

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

1. Correct use of the 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 some of the findings and conclusions made during the paving/compaction operations related to the long term performance of the HMA mixture and Safety Edge$_{SM}$.

- The average slope of the Safety Edge$_{SM}$ was 37°, exceeding the target value of 30°. The shaft or screw of the Safety Edge$_{SM}$ was bent. The bend in the rod or shaft may have resulted in a steeper angle because HMA was observed between the screed end plate and Safety Edge$_{SM}$ device.
- The density of the HMA mixture adjacent to the Safety Edge$_{SM}$ was found to be higher than along the unconfined edge in the areas placed without the Safety Edge$_{SM}$ – a positive benefit from the Safety Edge$_{SM}$ device.

- Breakdown and finish rolling did not steepen the slope of the Safety Edge$_{SM}$, even when the first pass of the vibratory roller was over the Safety Edge$_{SM}$. Based on visual observations of the mix behavior under the Sakai roller, the 9.5 mm mixture shoved out more at the surface by delaying rolling of the outer 6 to 12 inches of the mat, in comparison to rolling the Safety Edge$_{SM}$ first and extending the roller's edge over the Safety Edge$_{SM}$. It is expected, however, that this observation or finding will be mixture dependent. The Contractor's stated opinion was that the revised rolling pattern was better than the initial pattern used at the beginning of the project.
- The contractor did obtain adequate density within the interior of the mat, and adjacent to the Safety Edge$_{SM}$ in some areas. The variability in densities adjacent to the Safety Edge$_{SM}$ is believed to be related to the inconsistency in rolling the Safety Edge$_{SM}$, as explained in the field report. Although the rolling pattern of the Safety Edge$_{SM}$ will be dependent on the mixture properties, it is recommended that the Safety Edge$_{SM}$ be rolled first and not delayed, as recommended in some of the literature for rolling the Safety Edge$_{SM}$. It is believed that the air voids adjacent to the Safety Edge$_{SM}$ would have been less than 10 percent if the edge was rolled consistently by overhanging the roller over the mat's edge by 4 to 6 inches.
- The 9.5 mm HMA mixture is considered a relatively fine aggregate mixture, and the surface texture was dense. Water beads were observed on the surface after rains that occurred during one of the evenings during the paving operation. This observation indicates that permeability of the HMA overlay is low.
- HMA 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 shoulder material windrowed along the roadway from the trenching operation to widen the road is planned to be used as the backing material for the Safety Edge$_{SM}$. The Safety Edge$_{SM}$ should be inspected after the shoulder material has been placed to the final pavement elevation. Monitoring of this site would be beneficial in evaluating the long-term performance of the Safety Edge$_{SM}$.

APPENDIX A. DATA TABLES FROM FIELD MEASUREMENTS

This section of the field report provides a listing of the field measurements recorded during the paving operations.

Table A-1. Safety Edge$_{SM}$ Slope Measurements; After Final Rolling

Section Identifier	Core/Section ID	Station	Safety Edge		
			Width of Taper	Thickness	Slope
Area #2; Safety Edge Section	5	430+00	2.00	1.50	36.9
		431+00	2.50	1.75	35.0
	6	432+00	1.75	1.50	40.6
	Driveway	432+50	6.00	3.50	30.3
		433+00	3.00	2.00	33.7
		434+00	3.50	2.50	35.5
Area #3; Safety Edge Section		440+00	2.00	1.50	36.9
	7	441+00	2.50	2.00	38.7
		442+00	1.50	1.25	39.8
	8	443+00	3.75	3.00	38.7
		444+00	1.75	1.50	40.6
Mean Value			2.75	2.00	36.97
Standard Deviation			1.304	0.716	3.187
Coefficient of Variation			47.4	35.8	8.6

Table A-2. Safety Edge$_{SM}$ Slope Measurements; Prior to Rolling with Primary Roller

Section Identifier	Core/Section ID	Station	Safety Edge		
			Width of Taper	Thickness	Slope
Slope measurements taken before rolling the safety edge within an independent area to determine the change in slope after rolling. No cores were taken in this area.		A	2.50	2.00	38.7
		B	2.75	2.25	39.3
		C	2.25	2.25	45.0
		D	3.50	2.50	35.5
		E	2.50	2.25	42.0
Mean Value			2.700	2.250	40.10
Standard Deviation			0.481	0.177	3.584
Coefficient of Variation			17.81	7.86	8.94

Table A-3. Slope Measurements Along Non-Safety Edge$_{SM}$ Portion; After Final Rolling

Section Identifier	Core/Section ID	Station	Safety Edge		
			Width of Taper	Thickness	Slope
Area #1; Control, Non-Safety Edge Section		397+00	2.00	2.50	51.3
	1	398+00	2.00	3.50	60.3
		399+00	2.00	2.75	54.0
		400+00	2.50	3.00	50.2
		401+00	3.00	3.50	49.4
		402+00	3.00	3.00	45.0
	2	403+00	2.00	2.50	51.3
		404+00	2.00	3.00	56.3
	3	405+00	2.75	2.50	42.3
	Long. Crack	406+00	2.00	2.25	48.4
	4	407+00	1.50	1.75	49.4
Mean Value			2.25	2.75	50.72
Standard Deviation			0.487	0.524	4.971
Coefficient of Variation			21.7	19.1	9.8

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; Control Section, Non-Safety Edge	1	Eastbound	398+00	Non-Safety Edge	129.1	137.8	128.8	138.5	1.002	0.995	129.44	139.47
	2	Eastbound	403+00	Non-Safety Edge	131.6	139.2	129.8	140.0	1.014	0.994	130.45	140.98
	3	Eastbound	405+00	Non-Safety Edge	130.5	138.2	128.2	135.6	1.018	1.019	128.84	136.55
	4	Eastbound	407+00	Non-Safety Edge	127.5	135.8	128.7	133.4	0.991	1.018	129.34	134.33
Area #2; Safety Edge Section	5	Eastbound	430+00	Safety Edge	133.4	140.0	130.9	139.3	1.019	1.005	131.55	140.28
	6	Eastbound	432+00	Safety Edge	130.0	135.8	131.4	135.8	0.989	1.000	132.06	136.75
	7	Eastbound	441+00	Safety Edge	131.5	140.0	132.3	138.0	0.994	1.014	132.96	138.97
	8	Eastbound	443+00	Safety Edge	133.9	136.4	131.8	134.7	1.016	1.013	132.46	135.64
Mean					130.94	137.90	130.24	136.91	1.005	1.007	130.89	137.87
Standard Deviation					2.133	1.760	1.570	2.364	0.0128	0.0101	1.578	2.381
Coefficient of Variation					1.63	1.28	1.21	1.73	1.27	1.00	1.21	1.73

Table A-5. Density Readings Made with a Nuclear Density Gauge (Troxlor Gauge 3440)

Cores 1-4	Maximum Specific Gravity of Mix:	2.357	Max. Density:	147.08
Cores 5-8	Maximum Specific Gravity of Mix:	2.355	Max. Density:	146.95
	Adjustment Ratios for Nuclear Gauge: A=	1.005		
	B=	1.007		

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	5	Eastbound	430+00	Safety Edge	130.9	139.3	131.55	140.28	1.50	10.48	4.54
		Eastbound	431+00	Safety Edge	128.2	135.7	128.84	136.65	1.75	12.32	7.01
	6	Eastbound	432+00	Safety Edge	131.4	135.8	132.06	136.75	1.50	10.13	6.94
	Driveway	Eastbound	432+50	Safety Edge					3.50		
		Eastbound	433+00	Safety Edge	129.6	137.2	130.25	138.16	2.00	11.37	5.98
		Eastbound	434+00	Safety Edge	132.1	136.1	132.76	137.05	2.50	9.66	6.74
		Eastbound		Safety Edge							
Area #3		Eastbound	440+00	Safety Edge	132.3	136	132.96	136.95	1.50	9.52	6.80
	7	Eastbound	441+00	Safety Edge	132.3	138	132.96	138.97	2.00	9.52	5.43
		Eastbound	442+00	Safety Edge	129.7	135.8	130.35	136.75	1.25	11.30	6.94
	8	Eastbound	443+00	Safety Edge	131.8	134.7	132.46	135.64	3.00	9.86	7.69
		Eastbound	444+00	Safety Edge	128.8	134.8	129.44	135.74	1.50	11.91	7.63
		Eastbound		Safety Edge							
Average Value					130.71	136.34	131.36	137.29	2.00	10.61	6.57
Standard Deviation					1.523	1.433	1.531	1.443	0.716	1.042	0.982
Coefficient of Variation					1.17	1.05	1.17	1.05	35.79	9.82	14.95
Area #1		Eastbound	397+00	Non-Safety Edge					2.00		
	1	Eastbound	398+00	Non-Safety Edge	128.8	138.5	129.44	139.47	3.50	11.99	5.17
		Eastbound	399+00	Non-Safety Edge	131.3	139.7	131.96	140.68	2.75	10.28	4.35
		Eastbound	400+00	Non-Safety Edge	127.7	137.9	128.34	138.87	3.00	12.74	5.59
		Eastbound	401+00	Non-Safety Edge	129.0	134.8	129.65	135.74	3.50	11.85	7.71
		Eastbound	402+00	Non-Safety Edge	124.8	136.6	125.42	137.56	3.00	14.72	6.48
	2	Eastbound	403+00	Non-Safety Edge	129.8	140.0	130.45	140.98	2.50	11.31	4.15
		Eastbound	404+00	Non-Safety Edge	128.0	133.8	128.64	134.74	3.00	12.54	8.39
	3	Eastbound	405+00	Non-Safety Edge	128.2	135.6	128.84	136.55	2.50	12.40	7.16
	Long. Crack	Eastbound	406+00	Non-Safety Edge	127.5	135.4	128.14	136.35	2.25	12.88	7.30
	4	Eastbound	407+00	Non-Safety Edge	128.7	133.4	129.34	134.33	1.75	12.06	8.67
		Eastbound		Non-Safety Edge							
Average Value					128.38	136.57	129.02	137.53	2.70	12.28	6.50
Standard Deviation					1.681	2.362	1.690	2.379	0.568	1.149	1.617
Coefficient of Variation					1.31	1.73	1.31	1.73	21.01	9.36	24.90

Photographs of the Cores Recovered from the Project

This section of the field report provides a photograph of each core set that was recovered for laboratory density testing.

Core 8B

Core 7B

Core 8A

Core 7A

Core 8B

Core 7B

Core 8A

Core 7A

Core 6B

Core 5B

Core 6A

Core 5A

Core 6B

Core 5B

Core 6A

Core 5A

Core 4B

Core 3B

Core 4A

Core 3A

Core 4B

Core 3B

Core 4A

Core 3A

Core 2B

Core 1B

Core 2A

Core 1A

Core 2B

Core 1B

Core 2A

Core 1A