Federal Highway Administration
Every Day Counts
Innovation Initiative

Safety Edge$_{SM}$
Demonstration Project
Kearney, Nebraska

Field Report
May 24, 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 along State Route 10 (referred to as Pleasanton South) just north of Kearney, Nebraska. 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, HMA mixture design information and 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 July 19 and 20, 2010 to evaluate the use of the Safety Edge$_{SM}$ during paving, compare Safety Edge$_{SM}$ and non- Safety Edge$_{SM}$ portions along the project, determine the slope of the Safety Edge$_{SM}$, recommend adjustments to the Safety Edge$_{SM}$ design if found to be needed, and identify benefits and complications with the use of the Safety Edge$_{SM}$ device.

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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 hot mix asphalt (HMA) overlay project near Kearney, Nebraska. The TransTech Shoulder Wedge Maker device 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.

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Safety Edge$_{SM}$, Slope, HMA, TransTech Shoulder Wedge Maker	No restriction.

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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$_{SM}$ 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.

Concern was also acknowledged regarding the long term performance of the Safety Edge$_{SM}$. It was the opinion of some construction personnel that the Safety Edge$_{SM}$ will "break off" during the first year because of local farm traffic. The outside wheel of these farm vehicles is located directly over the Safety Edge$_{SM}$. The shoulder condition is soft in the spring and some of the construction personnel speculate that the heavy duals of the local traffic will break the Safety Edge$_{SM}$ from the mainline pavement. One of these vehicles was observed during the last day of the site visit, but a photograph was not taken.

Slope of the Safety Edge$_{SM}$

- The average slope of the Safety Edge$_{SM}$ was found to be 34°. 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 30° desired slope.

Placement

- The Safety Edge$_{SM}$ was formed using the TransTech Shoulder Wedge Maker device, 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.
- Both contractor and agency personnel voiced a concern that the spring stiffness is too high and the travel length too short. In paving across intersections or in areas with higher longitudinal profile, the Safety Edge$_{SM}$ device may raise the screed relative to the profile set by the longitudinal ski.

Compaction

- The HMA density or percent compaction of the non-Safety Edge$_{SM}$ section was found to be the same as for the Safety Edge$_{SM}$ sections that were compacted using the same rolling pattern.
- The sections for which the rolling pattern was revised to overhang the rollers over the edge of the unconfined mat resulted in slightly lower air voids and higher densities as compared to the sections where rolling the Safety Edge$_{SM}$ was delayed and only one pass of the vibratory roller was used during breakdown rolling.
- The air voids of the interior HMA mat had a mean value varying from 6.6 to 8.5 percent for the different sections. The air voids determined along the edge of the mat varied from 7.8 to 15.9 percent.

Shoulder Construction

- A combination of millings, aggregate and soil will be used as shoulder material. Placement of the shoulder 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 2.0 inches. The average overlay thickness for the Safety Edge$_{SM}$ sections was found to be 1.5 to 2.1 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 10 just north of Kearney, Nebraska, with and without the use of the Safety Edge$_{SM}$ device. The paving contractor for this project was Vontz Paving. The Safety Edge$_{SM}$ device was provided to NDOR by the Federal Highway Administration (FHWA), and was added to the project after it was awarded. The contractor, however, did not request additional payment related to the Safety Edge$_{SM}$ (HMA was paid by the ton). The Contractor used the TransTech Shoulder Wedge Maker device 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.

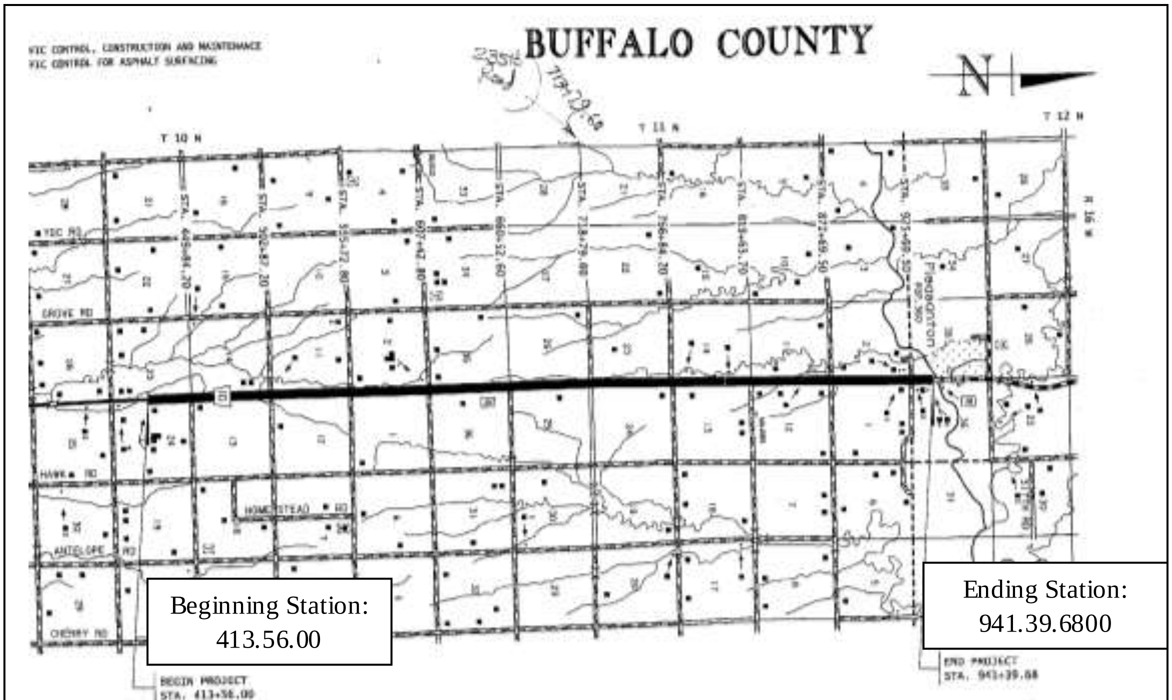
1. Correct use of the Safety Edge$_{SM}$ device during paving.
2. Safety Edge$_{SM}$ versus non-Safety Edge$_{SM}$ portions of project.
3. Slope of the Safety Edge$_{SM}$.

The location of the project is in Buffalo County, as shown in Figure 1. The project started just south of the intersection between Hawk Road and Homestead Road (located one block east of SR 10), and ended on the south end of the Pleasanton City Limits. The portion of the project for the Safety Edge$_{SM}$ sections were located south of the intersection with 235th Road, while the non-Safety Edge$_{SM}$ section was located north of 235th Road – all in the northbound lane.

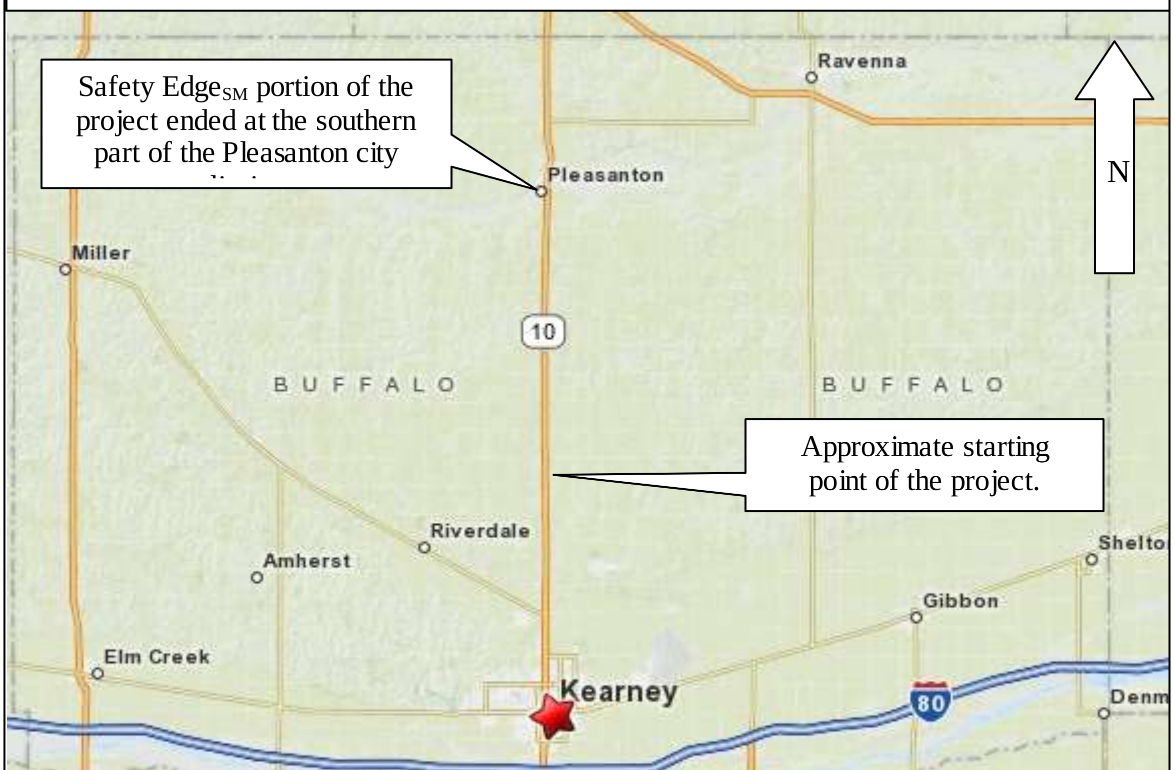
Pavement Structure and Project Conditions

The project consisted of milling the existing surface to a depth of about 2 inches (basically removing the existing wearing surface and some of the underlying layer) and placing a 2 inch lift of a 12.5 mm HMA mix over the existing HMA pavement. Figure 2 provides a general view of the 2 inch HMA overlay and typical cross section of the pavement. Figure 3 provides a general view of the roadway for this project. In preparation for the HMA overlay, the following activities and repairs were made.

- The existing shoulder was graded to remove grass and other debris; no other surface preparation along the shoulder was completed. Figures 2 and 4 show the shoulder that was graded prior to placement of the HMA overlay and Safety Edge$_{SM}$.
- Full depth patches were placed in selected areas of the roadway where the subgrade or subsurface layer was found to be soft. Figure 5 shows a full-depth HMA patch that was used to repair the roadway prior to overlay placement, and shows depressions caused by the paver and belly-dump trucks delivering the 12.5 mm HMA mixture to the project site. The full-depth HMA patch was placed across the entire lane width.
- An emulsion tack coat was placed on the milled surface and patched areas.



1.a Copy of Plan Sheet Showing Limits of Project Station Numbers.



1.b. Map of Area Showing Approximate Limits of Project and other Roadways.

Figure 1. Location of Site.

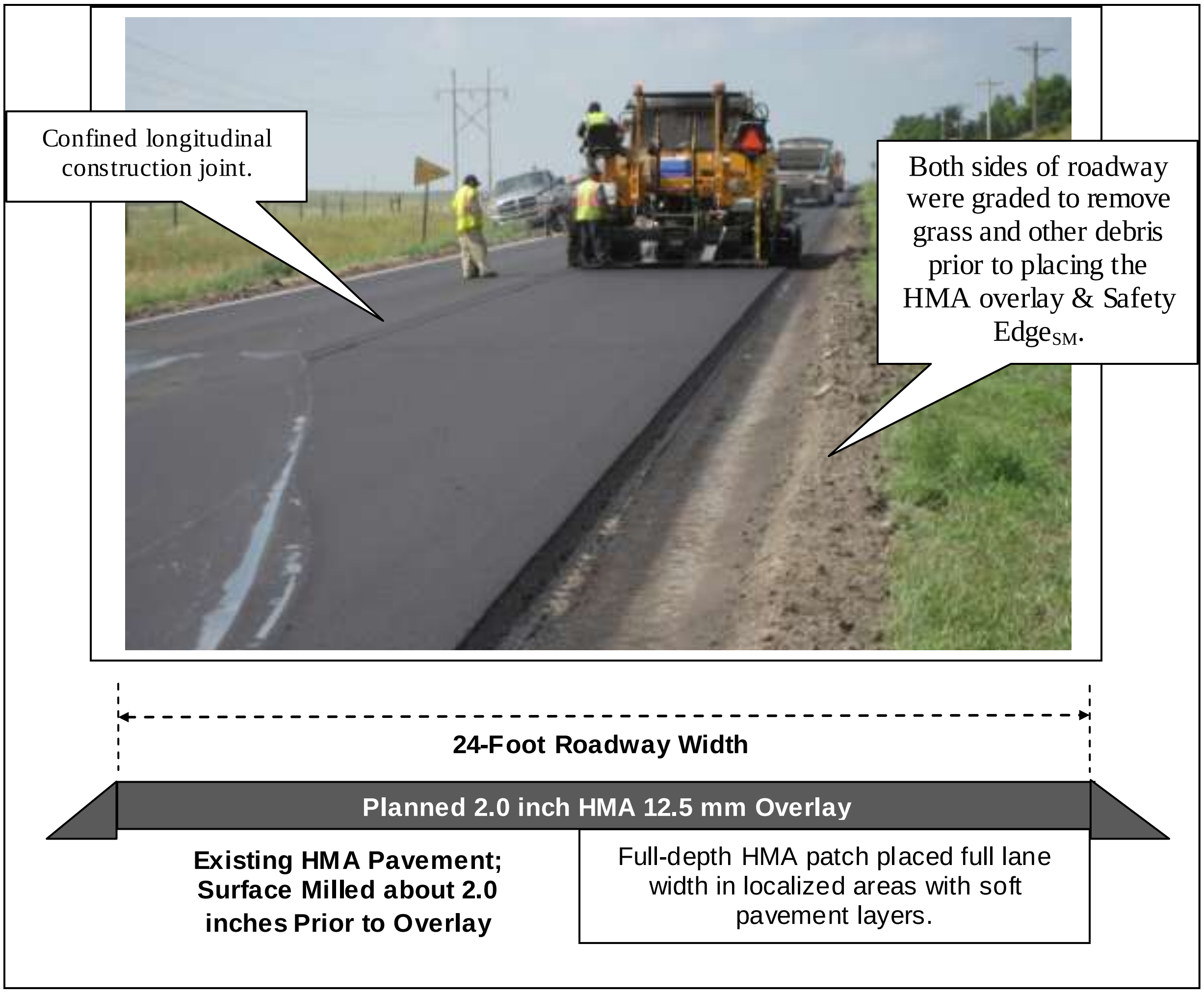


Figure 2. 12.5 mm HMA overlay being placed in one direction where the overlay in the opposite lane has already been placed.

Figure 3. General overview of project location; view is towards the north.

Figure 4. Graded shoulder ready for placing shoulder material.

Figure 5. Close-up of the full-depth patch area with surface depressions from the belly-dump trucks and paver.

The ditches along the edge of the pavement were generally shallow (2 to 5 feet in depth) with shallow slopes (10 to 30°). No lane-shoulder drop-offs were observed, however, the shoulder had been graded on each side of the roadway prior to visiting the project. A combination of millings, aggregate and soil will be used as shoulder material. The shoulder material was scheduled to be graded back to the Safety Edge$_{SM}$ near the end of this rehabilitation project; after overlay placement.

Field Evaluation

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

1. Area #1: Northbound lane; Safety Edge$_{SM}$ section located from station 652+20 to station 656+20.
2. Area #2: Northbound lane; Safety Edge$_{SM}$ section located from station 694+00 to station 698+00.
3. Area #3: Northbound lane; Safety Edge$_{SM}$ section located from station 569+15 to station 573+15.
4. Area #4: Northbound lane, Safety Edge$_{SM}$ section located from station 613+71 to station 617+71.
5. Area #5: Northbound lane, non-Safety Edge$_{SM}$ section located from station 720+00 to station 725+00.

Field tests were conducted within each test section for measuring slope and HMA density. Slope measurements were taken using a 4-foot aluminum straight-edge 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).

Ten cores were taken in the test sections established during the paving operation. The ten cores were obtained at five different locations (4 within the Safety Edge$_{SM}$ sections and 1 within the non- Safety Edge$_{SM}$ section). 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 not measured along this project because the 2.0 inch HMA overlay was considered a temporary repair to this roadway. Agency personnel noted that they expect this roadway to need additional strengthening and rehabilitation within 5 years.

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$_{SM}$ for all four test sections was found to be 34°. Table A-1 in Appendix A contains slope measurements recorded at each individual measurement location. 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 four test sections. As shown, there appears to be no correspondence between thickness and the slope of the Safety Edge$_{SM}$.

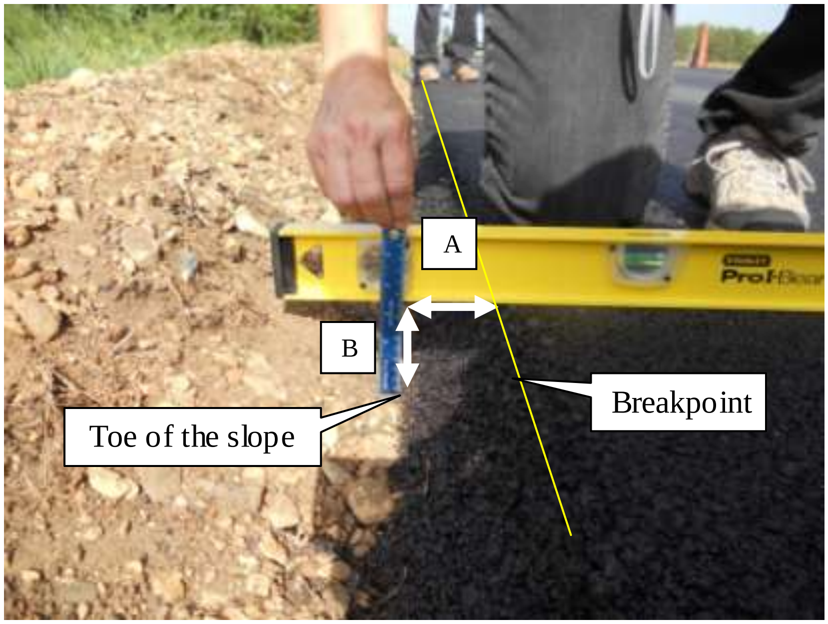


Figure 6. Measurement of the Safety Edge$_{SM}$ slope angle.

Figure 7. Troxler nuclear density gauge used to measure HMA density.

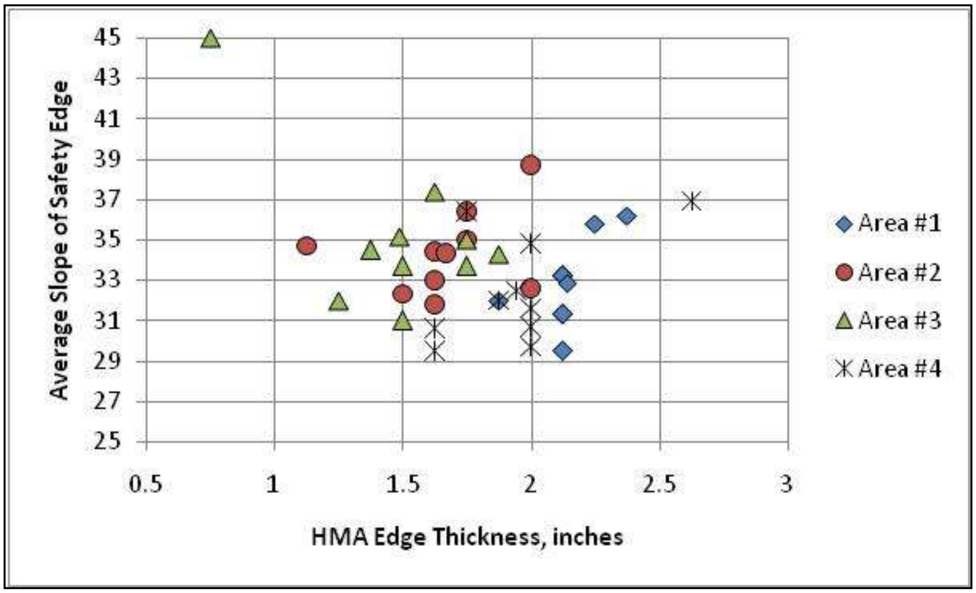


Figure 8. Comparison of the Safety Edge$_{SM}$ slope and thickness of the HMA adjacent to edge of the HMA overlay.

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 slightly steeper than what was planned.

<u>Cores</u>

A total of ten 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 adjustment factors for the nuclear density gauge readings taken adjacent to the edge and within the center of the mat. Table A-2 in Appendix A includes a summary of the bulk specific gravities (saturated surface dry) converted to bulk densities and the adjustment factors. Figure 9 shows the location of the cores and nuclear density gauge readings relative to the edge of the HMA mat. Figure A-1 in Appendix A shows five of the ten cores recovered from the roadway.

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). As shown, one of the densities of the cores taken along the edge is extremely low and considered an outlier. The core densities taken along the pavement's edge are approximately equal for the Safety Edge$_{SM}$ and non-Safety Edge$_{SM}$ sections.

Nuclear Density Results

Density measurements were made with a Troxler 3440 gauge (refer to Figure 7). Two readings were recorded at each station or location; one reading was taken at a point adjacent to the Safety Edge$_{SM}$ and one near the center of the steel drum roller. The nuclear gauge was positioned parallel to the pavement edge (refer to Figure 7). The nuclear gauge readings at each point are listed in Table A-3 in Appendix A.

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 the edge).

Location A; adjacent to the edge of the mat where nuclear density readings were made and a core was extracted from the overlay.

Location B; the approximate center of the double drum steel wheel roller used to compact the HMA overlay where nuclear readings were made and a core was extracted from the overlay.

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

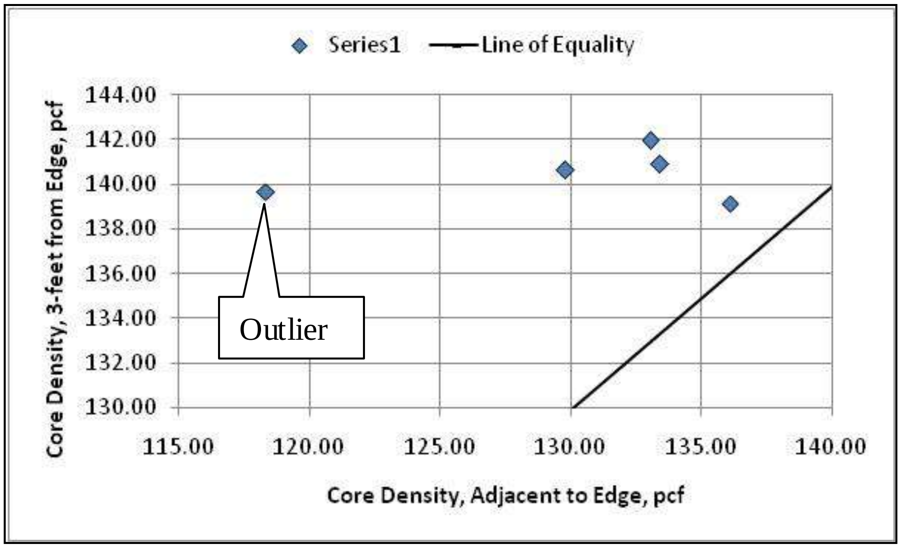


Figure 10. Comparison of core densities adjacent to the edge of pavement and near center of the steel drum rollers.

Nuclear gauge 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 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 HMA mat and near the center of the steel drum roller being used to compact the HMA mat. The following lists the average adjustment factors determined for this project:

Location	Adjustment Factor
Near Center of Steel Drum	1.009
Adjacent to Safety Edge$_{SM}$	1.026

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 adjustment factors are included in Table A-3 in Appendix A.

Figure 12 shows a comparison of the adjusted nuclear density gauge readings taken adjacent to the Safety Edge$_{SM}$ and in the center of the vibratory steel wheel roller. Figure 12 also includes a comparison of the HMA air voids between both of these areas. As expected, the air voids are higher adjacent to the Safety Edge$_{SM}$ in comparison to 3-feeet from the Safety Edge$_{SM}$. The other observation from this data and comparison is that the densities and air voids are similar between the Safety Edge$_{SM}$ and non-Safety Edge$_{SM}$ measurements adjacent to the edge of the HMA mat.

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 air voids or densities.

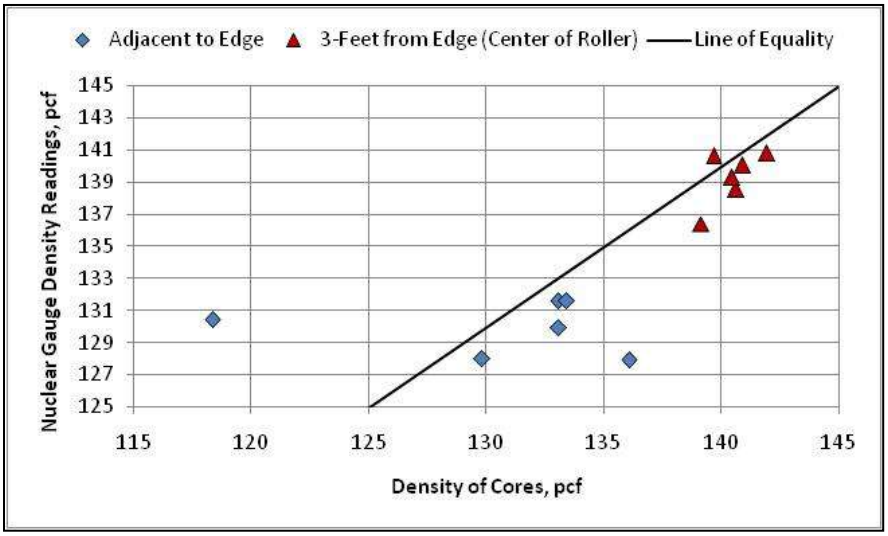
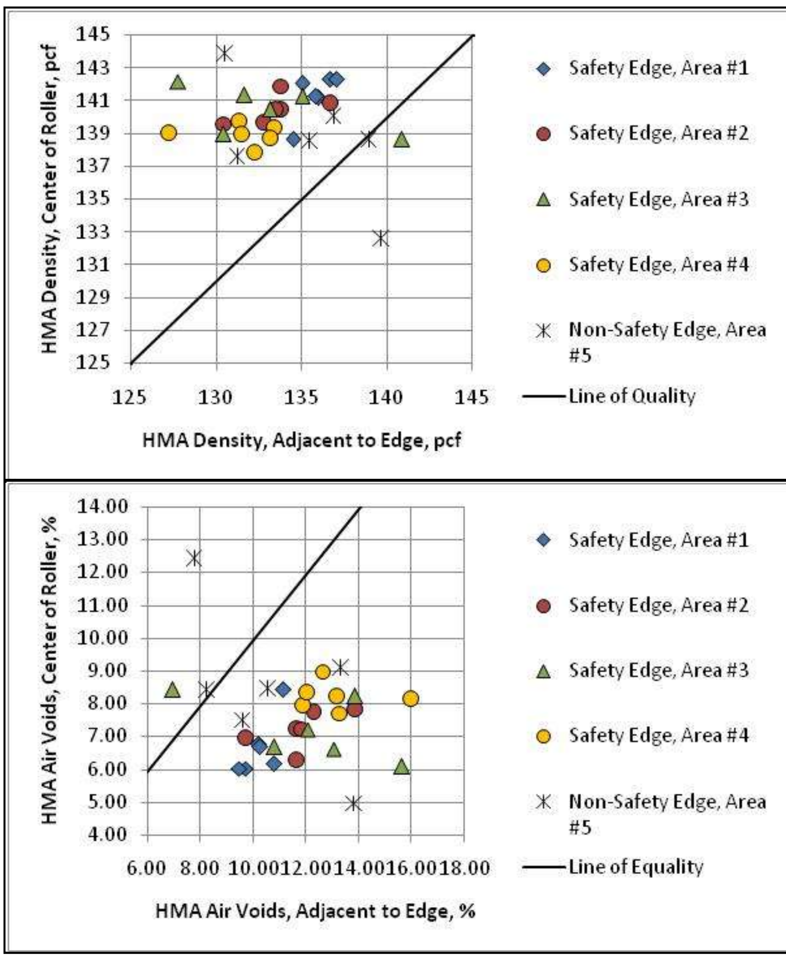


Figure 11. Comparison of the nuclear gauge readings and densities measured from cores.



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.

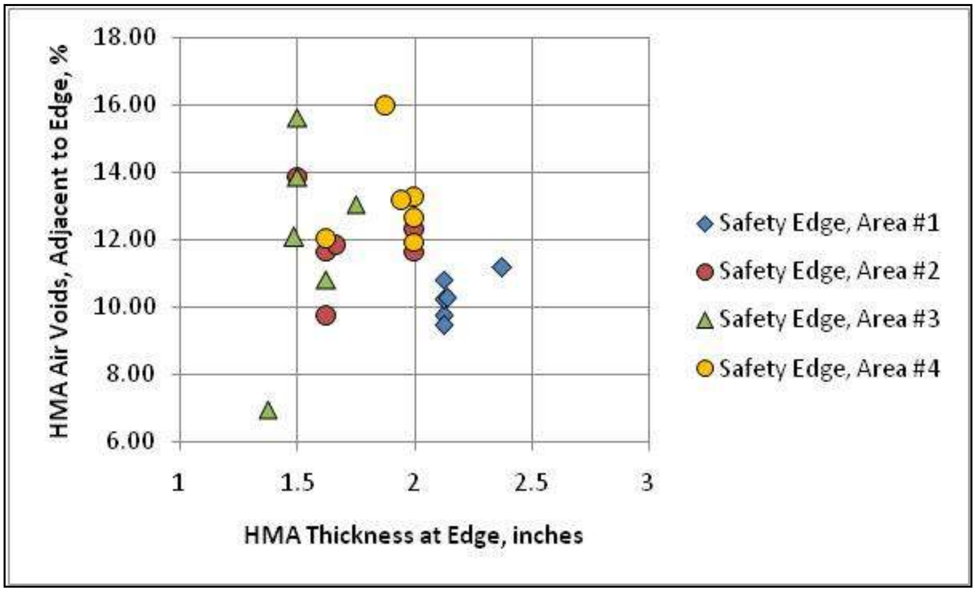


Figure 13. Comparison of HMA thickness at the edge of the mat and HMA air voids.

Longitudinal Profile Measurements

As noted above, the longitudinal profile was not measured along this project because the 2.0 inch HMA overlay was considered a temporary repair to this roadway. Agency personnel noted that they expect this roadway to need additional strengthening and rehabilitation within 5 years.

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

This section overviews some of the observations made during the paving and rolling operations.

Surface Preparation

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

1. Full-depth patches were placed in selected areas along the project where the subsurface pavement layers and subgrade were weak or soft. Some of the areas after patching were considered weaker than desirable (refer to Figure 5).
2. An emulsion was applied to serve as a tack coat for the HMA overlay. The application of the tack coat was uniform and covered the entire surface.

Placement/Paving Operations

Figure 14 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 15 shows the TransTech Shoulder Wedge

Maker device attached to the screed. The HMA overlay was placed in windrows using belly-dump trucks. The use of windrows and associated paving equipment allowed the paver to place the HMA at a constant and uniform rate with few stops of the paver.

Figure 16 shows the slope and surface texture of the Safety Edge$_{SM}$. The contractor superintendent/owner 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.

Figure 14. Equipment used to place the HMA overlay.

Figure 15. TransTech Shoulder Wedge Maker device attached to the screed.

Figure 16. Typical surface texture and slope of the Safety Edge$_{SM}$ sections.

Compaction Operations

Figure 17 shows the two rollers that were used to compact the 12.5 mm HMA mixture. The primary or breakdown roller was a Caterpillar double drum vibratory (CB 534D), while the finish roller was an Ingersoll-Rand double drum vibratory (DD118 420HFA). 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 had 5 passes with 2 coverages, except for the area adjacent to (within 6 inches) and along the Safety Edge$_{SM}$, which only received one pass of the breakdown roller.

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.

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

Ingersoll-Rand double drum vibratory steel wheel roller used in the vibratory and static mode that was used in the finish position for compacting the HMA overlay.

Figure 17. Rollers used for compacting the 12.5 mm HMA overlay mixture.

Project personnel indicated that during the first day of paving significant effort was expended to assess various rolling patterns. It was clear that NDOR and contractor project personnel considered this as a demonstration type project and worked cooperatively to assess how best to construct the Safety Edge$_{SM}$. The goal of the rolling pattern assessment was to obtain as close to a 30 degree Safety Edge$_{SM}$ slope after compaction was completed.

The first rolling pattern used was the standard rolling pattern the contractor uses for this HMA mix under similar conditions. The first pass of the breakdown roller had the roller's edge extended over the Safety Edge$_{SM}$ by about 6 inches. This resulted in the Safety Edge$_{SM}$ slope being pushed close to vertical. This did not accomplish the goal of maintaining a 30 degree slope, so several different rolling patterns were attempted at the beginning of the project (i.e., changes in location of first pass of roller, waiting some time before rolling commenced near Safety Edge$_{SM}$, etc.). NDOR and contractor personnel agreed on the rolling pattern to use for production that balanced obtaining a reasonable Safety Edge$_{SM}$ slope with adequate HMA production. Figure 18 shows the variation in the location of the roller's edge along the Safety Edge$_{SM}$.

Initial rolling pattern; rolling the Safety Edge$_{SM}$ was delayed, and the location of the steel wheel roller varied along the edge from successive passes.

Initial rolling pattern; rolling the Safety Edge$_{SM}$ was delayed, and the location of the steel wheel roller varied along the edge from successive passes.

Figure 18. Initial rolling pattern; edge of the breakdown roller varied along the Safety Edge$_{SM}$, prior to finish rolling.

The contractor was asked to revise the initial rolling pattern for a couple of the test sections. Two of the five sections, were rolled differently than the majority of the project to determine if different rolling patterns had an impact on the density of the unconfined edge (Safety Edge$_{SM}$ and non-Safety Edge$_{SM}$ sections). The following summarizes the two rolling patterns (number of passes and location for each roller) used by the contractor.

Initial Rolling Pattern – This pattern was used along most of the project, and for test sections 2, 3 and 4 (refer to Table A-1 in Appendix A.).

- Caterpillar Breakdown Roller: The following describes the pattern used by the breakdown roller for rolling the mat in locations with a confined longitudinal centerline joint. The rolling pattern for an unconfined centerline joint is described in a latter part of this section.

- First pass was along the longitudinal centerline joint in the static position along the cold side of the joint (refer to Figure 19.a; cold-side-pinch).
- Second pass was along the longitudinal centerline joint but on the hot side of the joint in the vibratory mode (low frequency, low amplitude [refer to Figure 19.b]).
- Third pass was near the center of the mat but about 6 to 12 inches from the Safety Edge$_{SM}$; also in the vibratory mode (refer to Figure 20).
- Fourth pass was over the same location as for the third pass but in the reverse direction and in vibratory mode.
- Fifth pass of the roller was delayed for a short time period and along the Safety Edge$_{SM}$ (edge of drum varied from near the edge to about 6 inches from the Safety Edge$_{SM}$, refer to Figure 18) in the vibratory mode.
- Sixth pass; same location as for the fifth pass, but in the reverse direction in vibratory mode. In some areas, the roller's edge was located slightly away from the Safety Edge$_{SM}$.
- Seventh pass; same location as for the second pass, but in the reverse direction in vibratory mode.

It was observed that only five passes of the breakdown roller was applied in a few areas of the roadway where the adjacent lane had not already been paved. In summary, Passes #6 and #7 were not used or omitted from the rolling pattern of the breakdown roller.

The pattern used to compact areas with an unconfined centerline construction joint required fewer passes. For the first pass the roller's edge was located about 6 inches from the centerline joint or unconfined edge; for the second pass the roller's edge was extended over the unconfined edge by about 2 to 4 inches; for the third pass the roller's edge was located about 6 to 12 inches from the Safety Edge$_{SM}$; the fourth pass was the same as for the third pass; and the fifth pass was delayed and located along or slightly over the Safety Edge$_{SM}$.

The delay in rolling the Safety Edge$_{SM}$ caused the roller operator to increase the speed of the breakdown roller to keep up with the paver. The increase in speed resulted in chatter in localized areas of the mat surface (roller being operated too fast for the frequency selected). The other important point is that the outer edge of the mat (6 to 12 inches from the Safety Edge$_{SM}$) only received one pass of the breakdown roller in some areas prior to the first pass of the Ingersoll-Rand roller (refer to Figure 21).

- Ingersoll-Rand Finish Roller: The first pass of the finish roller was delayed up to about 2 hours after paving to retain the angle of the Safety Edge$_{SM}$.
  - First pass of the roller (refer to Figure 21) was along and over the Safety Edge$_{SM}$ (the edge of the roller was about 4 to 6 inches over the Safety Edge$_{SM}$) in the vibratory mode (high frequency, low amplitude).
  - Second pass; same location as for the first pass but in the reverse direction and in vibratory mode.

- Third pass was about 6 inches from the centerline longitudinal joint in the vibratory mode.
- Fourth pass was over the centerline longitudinal joint in vibratory mode.
- Fifth pass was along the center of the lane in the static mode.

The finish roller appeared to remove most of the chatter caused by the breakdown roller. The finish roller did not eliminate the longitudinal roller mark left by delaying the breakdown roller along the outside edge of the mat (refer to Figure 22). It is expected that this mark will eventually result in a longitudinal crack along the edge of the mat.

(a) First pass of Caterpillar breakdown roller in static mode along the cold-side of the longitudinal joint.

(b) Second pass of Caterpillar breakdown roller in vibratory mode along the hot-side of the longitudinal

Figure 19. Initial rolling pattern; cold-side-pinch was used to compact the confined longitudinal construction joint.

Pass #3 of Caterpillar roller is 6 to 12 inches from the edge of the mat.

Note the location of the roller's edge for the third pass. This may result in a longitudinal crack with time where the passes were along the same line and the rolling of the edge is delayed.

Figure 20. Rolling the unconfined edge with the vibratory steel wheel roller.

Figure 21. First pass of the Ingersoll-Rand finish roller along the Safety Edge$_{SM}$.

Figure 22. Longitudinal mark left by delaying the breakdown rolling of the Safety Edge$_{SM}$; image taken after finish rolling.

***Revised Rolling Pattern* —** At the request of the field evaluation team, this pattern was used for a couple of the test sections; one of the Safety Edge$_{SM}$ sections (test section 1, refer to Table 1) and the non-Safety Edge$_{SM}$ section (test section 5, which was the non-Safety Edge$_{SM}$ section).

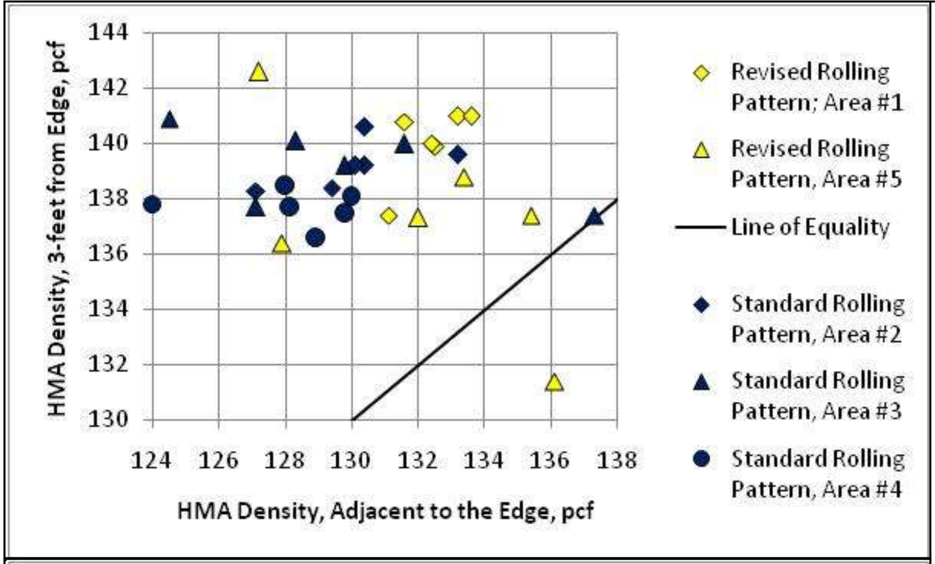
- Caterpillar Breakdown Roller: The only difference between the initial rolling pattern used along most of the project was that the first two passes of the breakdown roller were in the vibratory mode with the edge of the roller extended over the Safety Edge$_{SM}$ by about 4 to 6 inches.
  - First pass of roller 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 longitudinal centerline joint with the roller's edge extended over the joint by 4 to 6 inches and in vibratory mode.
  - Fourth pass; same location as for the third pass, but in the reverse direction and in vibratory mode.
  - Fifth pass down the center of the mat in vibratory mode.
- Ingersoll-Rand Finish Roller: The revised rolling pattern was the same as used for the initial rolling pattern; no change in rolling pattern was made to the finish roller.

Figure 23 shows a comparison of the adjusted nuclear density gauge readings and air voids adjacent to the Safety Edge$_{SM}$ in comparison to the center of the breakdown roller (3-feet from the edge) for the two rolling patterns. The air voids adjacent to the edge were dependent on the rolling pattern used to compact the HMA unconfined edge. The following summarizes the average air voids and slopes of the Safety Edge$_{SM}$ for the two rolling patterns in comparison to the initial or standard pattern that was being used by the contractor.

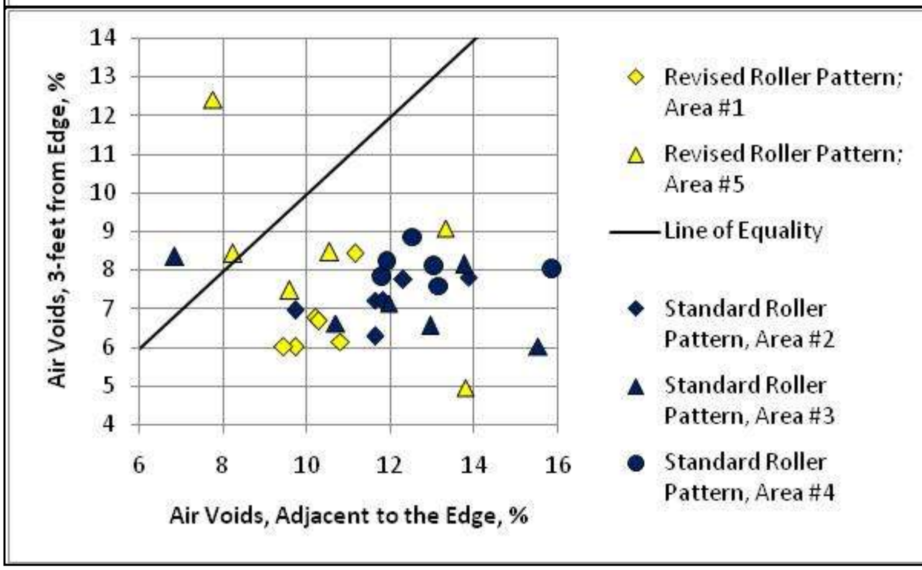
Rolling Pattern	Average Slope of Safety Edge$_{SM}$	Air Voids Adjacent to Edge
Delay Rolling the Safety Edge$_{SM}$ Pattern	34	12.3
No Delay in Rolling the Safety Edge$_{SM}$ Pattern	34	10.4

As tabulated above and shown in Figure 23, rolling the Safety Edge$_{SM}$ first without delay and extending the edge of the breakdown roller over the Safety Edge$_{SM}$ by 4 to 6 inches resulted in lower air voids and higher densities without significantly steepening the average slope of the Safety Edge$_{SM}$, as compared to delaying rolling of the Safety Edge$_{SM}$.

No shoving or tearing of the mixture was observed during the compaction operation. In addition, the Safety Edge$_{SM}$ did not shove out, or "stand up", during the compaction operation. Figure 24 shows the surface texture of the finished HMA mat along the project. The surface texture and condition was relatively uniform throughout the project.



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 23. Comparison of volumetric properties between the areas adjacent to the edge and center of the steel drum roller for the two different rolling patterns.

Figure 24. Surface texture of the 12.5 mm HMA overlay after final rolling.

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

The HMA mixture design data was obtained from the Nebraska Department of Roads. 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.

Figure 14 showed the HMA behind the screed and the Safety Edge$_{SM}$ slope prior to rolling. The slope of the Safety Edge$_{SM}$ prior to rolling was equal to or slightly steeper than the planned 30°. The distance between the end of the auger and screed end plate was about 18 inches (refer to Figure 15). This distance should be less than 18 inches. The temperature of the HMA being delivered to the project site was reported to be 310 to 318 °F. Mix temperature and the distance between the end of the auger and screed end plate are not believed to be contributing factors to the steeper slopes.

Other Observations

The following lists some of the observations and comments made by construction personnel.

- Density along the edge of the HMA mat is a concern.
- It was also the opinion of construction personnel that the Safety Edge$_{SM}$ will "break-away" from the HMA mainline pavement in a short period of time, because of local farm traffic where the outer tire is located along the edge of the pavement. NDOR personnel indicated that as part of their future Safety Edge$_{SM}$ efforts, they were planning to investigate adding some structural material beneath the Safety Edge$_{SM}$ to alleviate agricultural/heavy vehicle damage.

- The contractor had manufactured a separate Safety Edge$_{SM}$ device that was used on a portion of the project, but not included in any of the test sections established for this demonstration project. The contractor's special device had a longer travel length and a weaker spring stiffness. The contractor's opinion was that the travel length of the TransTech device was too short and the spring was too stiff. Project personnel noted that the stiff spring and short travel length could cause the screed to rise when paving across intersections or when paving over hard surfaces with higher elevations.

Findings and Conclusions

As stated above, 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 34°, slightly exceeding the target value of 30°. Project personnel indicated 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. NDOR personnel indicated that as part of their future Safety Edge$_{SM}$ efforts, they were planning to use Safety Edge$_{SM}$ equipment with a 20˚ slope and more compactive effort that would allow them to get the rollers on the mat sooner and result in higher density and a finished slope closer to 30˚.

- Breakdown and finish rolling did not steepen the slope of the Safety Edge$_{SM}$, even when the first pass of the Caterpillar vibratory roller was over the Safety Edge$_{SM}$ along test section 1. Based on visual observations, the mixture did not shove out more or less than when the edge of the roller was extended over the Safety Edge$_{SM}$ without any delay in rolling the Safety Edge$_{SM}$. Project personnel did report that the slope did steepen using their standard rolling pattern during the first day of paving. It is expected that this observation or finding will be mixture dependent.

- The contractor did revise the rolling pattern for a short segment to eliminate any delay in rolling the Safety Edge$_{SM}$ and extending the edge of the roller over the Safety Edge$_{SM}$ by 4 to 6 inches (test section 1). The revised rolling pattern increased the density of the HMA adjacent to the edge without significantly increasing the slope of the Safety Edge$_{SM}$. The density of the HMA mat along the Safety Edge$_{SM}$ is lower and the air voids higher in the areas where the Safety Edge$_{SM}$ was rolled last and only received one pass of the Caterpillar steel wheel roller. High air voids have a detrimental effect on performance of the mixture.

- The contractor did obtain adequate density within the interior of the mat, and adjacent to the Safety Edge$_{SM}$ in areas with the revised rolling pattern. It is recognized that the rolling pattern of the Safety Edge$_{SM}$ will be dependent on the mixture properties. It is expected that as Safety Edge$_{SM}$ equipment and procedures are enhanced, an improvement in efficiently obtaining density will occur.

- The density of the HMA mixture adjacent to the Safety Edge$_{SM}$ was found to be similar to the areas without the Safety Edge$_{SM}$ when similar rolling patterns were used to compact or roll an unconfined edge.

- The 12.5 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 just prior to the demonstration project. 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 pavement should be inspected after the final shoulders have been constructed. The onsite windrowed material that is a combination of millings, aggregate and soil are planned to be used as the unpaved shoulder. Care should be taken to observe the shoulder construction and ensure that meets proper relative elevation to the HMA mat. Long term monitoring should be conducted of the Safety Edge$_{SM}$ to assess heavy vehicle impacts on the wedge and monitoring to observe how well the coarse-grained shoulder remains in place and any deformation or erosion in the shoulder material.

APPENDIX A. 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$_{SM}$ demonstration projects.

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 #1,Northbound Lane	C 3-1	652+20	3.5	2.125	31.3
		652+70	3.25	2.125	33.2
		653+20	3.5	2.125	31.3
		653+70	3.125	2.25	35.8
		654+20	3.25	2.125	33.2
		654+70	3.25	2.125	33.2
		655+20	3.25	2.375	36.2
		655+70	3	1.875	32
		656+20	3.75	2.125	29.5
Mean Value			3.32	2.14	32.86
Standard Deviation			0.226	0.132	2.152
Coefficient of Variation			6.82	6.16	6.55
Area #2, Northbound Lane	TS-3	694+00	3.125	2	32.6
		694+50	1.625	1.125	34.7
		695+00	2.375	1.5	32.3
		695+50	2.5	1.75	35
		696+00	2.5	1.625	33
		696+50	2.375	1.625	34.4
		697+00	2.5	2	38.7
		697+50	2.375	1.75	36.4
		698+00	2.625	1.625	31.8
Mean Value			2.444	1.667	34.322
Standard Deviation			0.386	0.265	2.215
Coefficient of Variation			15.8	15.9	6.5

Section Identifier	Core/Section ID	Station	Safety Edge		
			Width of Taper	Thickness	Slope
Area #3, Northbound Lane	C 2-4	569+15	2.5	1.5	31
		569+65	0.75	0.75	45
		570+15	2.25	1.5	33.7
		570+65	2.625	1.75	33.7
		571+15	2.125	1.625	37.4
		571+65	2	1.25	32
		572+15	2	1.375	34.5
		572+65	2.75	1.875	34.3
		573+15	2.5	1.75	35
Mean Value			2.17	1.49	35.18
Standard Deviation			0.596	0.339	4.102
Coefficient of Variation			27.52	22.82	11.66
Area #4, Northbound Lane	C 2-5	613+71	3.375	2	30.7
		614+21	3.25	2	31.6
		614+71	2.875	2	34.8
		615+21	3.5	2.625	36.9
		615+71	3.5	2	29.7
		616+21	2.375	1.75	36.4
		616+71	3	1.875	32
		617+21	2.75	1.625	30.6
		617+71	2.875	1.625	29.5
Mean Value			3.056	1.944	32.47
Standard Deviation			0.381	0.300	2.842
Coefficient of Variation			12.5	15.5	8.8

Table A-2. Nuclear density adjustment factors; core density/nuclear density.

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
C 3-1	Northbound	654+20	Safety Edge	133.05	141.95	131.60	140.80	1.011	1.008	135.02	142.07
C 2-4	Northbound	571+15	Safety Edge	133.40	140.89	131.60	140.00	1.014	1.006	135.02	141.26
C 2-5	Northbound	615+71	Safety Edge	129.81	140.63	128.00	138.50	1.014	1.015	131.33	139.75
C 3-2	Northbound	722+46	Non-Safety Edge	136.08	139.14	127.9	136.4	1.064	1.020	131.23	137.63
TS-3	Northbound	696+00	Safety Edge	118.35	139.68	130.40	140.60	0.908	0.993	133.79	141.87
Average				133.085	140.458	129.900	139.260	1.026	1.009	133.277	140.513
Standard Deviation				1.979	1.094	1.847	1.835	0.002	0.010	2.133	1.852
Coefficient of Variation				1.49	0.78	1.42	1.32	0.16	1.01	1.60	1.32

NOTE: The density measured on the core TS-3 adjacent to the edge is believed to be in error (the highlighted cells).
The highlighted values noted above was excluded from determining the average adjustment ratio and other statistical values.

Table A-3. Density readings made with a nuclear density gauge (Troxlor gauge 3440).

Maximum Specific Gravity of Mix:		2.423	Max. Density:	151.2
Adjustment Ratios for Nuclear Gauge:	A=	1.026		
	B=	1.009		

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, Northbound Lane		Northbound	652+20	Safety Edge	133.2	141	136.6632	142.269	2.125	9.72	6.02
		Northbound	652+70	Safety Edge					2.125		
		Northbound	653+20	Safety Edge	133.6	141	137.0736	142.269	2.125	9.45	6.02
		Northbound	653+70	Safety Edge					2.25		
	C 3-1	Northbound	654+20	Safety Edge	131.6	140.8	135.0216	142.0672	2.125	10.81	6.15
		Northbound	654+70	Safety Edge					2.125		
		Northbound	655+20	Safety Edge	131.1	137.4	134.5086	138.6366	2.375	11.15	8.42
		Northbound	655+70	Safety Edge					1.875		
		Northbound	656+20	Safety Edge	132.5	139.9	135.945	141.1591	2.125	10.20	6.75
Average Value					132.40	140.02	135.84	141.28	2.139	10.26	6.67
Standard Deviation					1.051	1.534	1.079	1.547	0.132	0.712	1.022
Coefficient of Variation					0.79	1.10	0.79	1.10	6.16	6.94	15.32

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 #2, Northbound Lane		Northbound	694+00	Safety Edge	129.4	138.4	132.76	139.65	2	12.30	7.75
		Northbound	694+50	Safety Edge					1.125		
		Northbound	695+00	Safety Edge	127.1	138.3	130.40	139.54	1.5	13.86	7.82
		Northbound	695+50	Safety Edge					1.75		
	TS-3	Northbound	696+00	Safety Edge	130.4	140.6	133.79	141.87	1.625	11.62	6.29
		Northbound	696+50	Safety Edge					1.625		
		Northbound	697+00	Safety Edge	130.4	139.2	133.79	140.45	2	11.62	7.22
		Northbound	697+50	Safety Edge					1.75		
		Northbound	698+00	Safety Edge	133.2	139.6	136.66	140.86	1.625	9.72	6.95
Average Value					130.10	139.22	133.48	140.47	1.67	11.82	7.21
Standard Deviation					2.195	0.944	2.253	0.953	0.265	1.488	0.630
Coefficient of Variation					1.69	0.68	1.69	0.68	15.91	12.59	8.74

Table A-3. Continued.

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
		Northbound	569+15	Safety Edge	124.5	140.9	127.74	142.17	1.5	15.52	6.02
		Northbound	569+65	Safety Edge					0.75		
		Northbound	570+15	Safety Edge	127.1	137.7	130.40	138.94	1.5	13.75	8.16
		Northbound	570+65	Safety Edge					1.75		
Area #3, Northbound Lane	C 2-4	Northbound	571+15	Safety Edge	131.6	140	135.02	141.26	1.625	10.70	6.62
		Northbound	571+65	Safety Edge					1.25		
		Northbound	572+15	Safety Edge	137.3	137.4	140.87	138.64	1.375	6.83	8.36
		Northbound	572+65	Safety Edge					1.875		
		Northbound	573+15	Safety Edge	128.3	140.1	131.64	141.36	1.75	12.94	6.56
Average Value					129.76	139.22	133.13	140.47	1.49	11.95	7.14
Standard Deviation					4.927	1.567	5.055	1.582	0.339	3.344	1.045
Coefficient of Variation					3.80	1.13	3.80	1.13	22.82	27.98	14.63

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
		Northbound	613+71	Safety Edge	128.9	136.6	132.25	137.83	2	12.53	8.84
		Northbound	614+21	Safety Edge					2		
		Northbound	614+71	Safety Edge	130	138.1	133.38	139.34	2	11.79	7.84
		Northbound	615+21	Safety Edge					2.625		
Area #4, Northbound Lane	C 2-5	Northbound	615+71	Safety Edge	128	138.5	131.33	139.75	2	13.14	7.58
		Northbound	616+21	Safety Edge					1.75		
		Northbound	616+71	Safety Edge	124	137.8	127.22	139.04	1.875	15.86	8.04
		Northbound	617+21	Safety Edge					1.625		
		Northbound	617+71	Safety Edge	129.8	137.5	133.17	138.74	1.625	11.92	8.24
Average Value					128.14	137.70	131.47	138.94	1.94	13.05	8.11
Standard Deviation					2.447	0.718	2.511	0.724	0.300	1.660	0.479
Coefficient of Variation					1.91	0.52	1.91	0.52	15.45	12.73	5.91

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
		Northbound	720+46	Non-Safety Edge	135.4	137.4	138.92	138.64		8.23	8.42
		Northbound	721+46	Non-Safety Edge	133.4	138.8	136.87	140.05		9.59	7.49
	C 3-2	Northbound	722+46	Non-Safety Edge	127.9	136.4	131.23	137.63		13.31	9.08
Area #5, Northbound Lane		Northbound	722+46	Non-Safety Edge							
		Northbound	723+46	Non-Safety Edge	127.2	142.6	130.51	143.88		13.79	4.95
		Northbound	724+46	Non-Safety Edge	136.1	131.4	139.64	132.58		7.76	12.42
Average Value					132.00	137.32	135.43	138.56	#DIV/0!	10.54	8.47
Standard Deviation					4.189	4.061	4.298	4.098	#DIV/0!	2.839	2.707
Coefficient of Variation					3.17	2.96	3.17	2.96	#DIV/0!	26.95	31.95

Photograph of Selected Cores

This section of the field report provides a photograph of five 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. Some of the cores did exhibit much larger aggregate than included in the test results for mixture design, quality control and other tests, as shown in the picture for two of the five cores. Larger aggregate would tend to steepen the slope of the Safety Edge$_{SM}$, because those larger aggregate would prevent the finer aggregate particles being nearer the bottom of the slope. Based on visual observations of the Safety Edge$_{SM}$, this is not believed to be the case, with the possible exception in a few localized areas.

Figure A-1. Cores recovered for laboratory density testing.