Federal Highway Administration
Every Day Counts
Innovation Initiative

innovation
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Every Day Counts
imagination
invention

Safety Edge$_{\text{SM}}$ Demonstration Project Brogden Road in Johnston County, North Carolina

Field Report
June 1, 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 warm mix asphalt (WMA) Safety Edge$_{SM}$ project on Brogden Road (State Route 1007) in Johnston County, North Carolina. 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 April 6, 2011, and measurements taken during construction to evaluate the use of two edge devices, the Troxler SafeT*Slope* Edge Smoother and a device developed by the North Carolina Department of Transportation (NCDOT). Observations and data were collected to compare Safety Edge$_{SM}$ and non-Safety Edge$_{SM}$ portions along the project, evaluate the slope and density of the edges, recommend design adjustments, and identify benefits and complications with the use of the edge devices.

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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 warm mix asphalt (WMA) overlay project on Brogden Road in Johnston County, North Carolina. The Troxler SafeT*Slope* Edge Smoother and a device developed by NCDOT were 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, Troxler SafeT*Slope* Edge Smoother, TransTech Shoulder Wedge Maker, Advant-Edger

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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 report provides a summary of important observations made during the paving operations, interviews 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$_{SM}$.

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

- Both devices were used successfully on this project. One key finding was that the devices increased density and lowered air void content adjacent to the edge.

Slope of the Safety Edge$_{SM}$

- The average slope of the edge produced by the Troxler device was 28°, and the average slope of the NCDOT device was 26°, both slightly less than the targeted 30° slope.
- The slope from both devices increased 1° or less during compaction operations, indicating the WMA was stable.

Edge Preparation

- For this project it is key that the contractor's standard operating practice includes preparing the edge of the existing pavement. Soil and vegetation must be removed to expose the existing pavement and provide a firm base on which to support the edge of pavement. The edge of pavement separated from the mat at an isolated location where the edge of pavement was placed over soft soil/vegetation. This would have occurred regardless of the use of the Safety Edge$_{SM}$; nevertheless, this underscores the importance of preparing the edge of the pavement.

Construction/Compaction

- The contractor used two breakdown rollers in echelon operating close behind the paver. One roller was positioned on the longitudinal joint and the other was dedicated to rolling the edge (overhanging the edge in most passes). Each pass of the rollers generally was in the same position on the mat, such that the edge received the maximum compactive effort. This was the contractor’s preferred method of compacting WMA.
- The densities were higher and the air voids were lower adjacent to the edge in the test sections with the Safety Edge$_{SM}$ compared to the control section. This is an added benefit of using the edge device and may increase the long-term performance of the edge.
- The contractor stated that the edge of pavement when using the Safety Edge$_{SM}$ was not damaged when asphalt trucks drove off the edge of the pavement. Without the

Safety Edge$_{SM}$ the edge would be damaged and the contractor was required to repair the edge. This is an added benefit of using the Safety Edge$_{SM}$ during construction.

WMA Mixture

- The slope face produced by both devices appeared to be smooth and consistent throughout the project.
- Only minor segregation was observed in the mat. Overall, the surface of the WMA appeared uniform.
- Lateral movement under the roller and at the edge was insignificant.

Future Considerations or Material Enhancements to Improve Performance

- The service life of the devices could be extended by using a more wear-resistant steel where the shoe contacts the road. The point of the shoe was worn significantly after only a few miles of service.
- The vertical adjustment screw is easily bent during normal use and should be made of stronger material and/or improved design.
- The cotter pin that secures the top of the spring to the screw falls out easily and could be redesigned.

This project presents the opportunity to evaluate long-term performance in terms of maintenance efforts and life cycle cost of the Safety Edge$_{SM}$ placed by different types of devices.

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

Introduction

A series of field tests were carried out to assess the placement and condition of the WMA overlay along Brogden Road with and without the use of the Safety Edge$_{SM}$ device. The purpose of these tests was to evaluate the quality of the in-place WMA material and Safety Edge$_{SM}$ by investigating the following:

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

This project was located in Johnston County between Smithfield and Goldsboro on Brogden Road from the border with Wayne County and extending west approximately 2 miles. The contract included eight routes, five of which were paved prior to paving Brogden Road. The contractor used NCDOT's first prototype edge device on the previous routes, and the lessons learned are discussed later in the *Placement/Paving Operations* section.

The general project location is shown in Figure 1. The maximum posted speed limit was 55 mph. The contractor was Johnson Brothers Utility and Paving, Inc.

Figure 1. Project location.

Pavement Structure and Project Conditions

The existing pavement was two lanes of HMA with a chip seal wearing surface. The typical lane width was 10.5 feet with 4- to 8-inch-wide unpaved shoulders consisting of fine-grained soil and vegetation. The distresses along the road were varying degrees of longitudinal and transverse cracking.

New construction called for a 1.5-inch WMA overlay placed to match the width of the existing pavement. The edge of the overlay was to be placed directly over the existing pavement edge. The WMA was designed with 23 percent reclaimed asphalt pavement (RAP) and WMA water foam technology.

This demonstration project included several long tangent sections, suitable for demonstrating the Safety Edge$_{SM}$, which was built in both directions. The target slope was 30°, and the contract specification was as follows:

> *Attach a device, mounted on screed of paving equipment, capable of constructing a shoulder wedge with an angle of not more than 30 degrees along the outside edge of the roadway, measured from the horizontal plane in place after final compaction on the final surface course. Use an approved mechanical device or a device provided by the Department that will form the asphalt mixture to produce a wedge with uniform texture, shape and density while automatically adjusting to varying heights. Payment for use of this device will be incidental to the other pay items in the contract.*

Currently, NCDOT does not have a longitudinal joint density specification.

Field Evaluation

Two Safety Edge$_{SM}$ test sections and one non-Safety Edge$_{SM}$ control section were established in the westbound lane. The following summarizes the pavement sections:

- Test Section #1. This section had the edge formed with the Troxler SafeT*Slope* Edge Smoother and was 1,000 feet long, generally located west of the Wayne County border and beginning at 45 feet east of the private residence, 12398 SR 1007.
- Test Section #2. This section had the edge formed with the device developed by NCDOT and was 1,000 feet long, beginning at the entrance to the commercial property of Owen Kornegay Hog Farm, 11819 SR 1007.
- Test Section #3. This section was paved with a conventional edge and was 400 feet long, located near the intersection with Buckleberry Road. This section serves as the control section for comparing the test sections to conventional paving practice.

Slope Measurements

Slope measurements were recorded on test sections #1 and #2 at 25-foot intervals using a straight-edge and ruler to measure the horizontal and vertical dimensions of the edge (see Figure 2). The following summarizes the average slope measurements:

Pavement Section	Slope
Test Section #1, Troxler Device	28°
Test Section #2, NCDOT Device	26°
Section #3, Control	NA

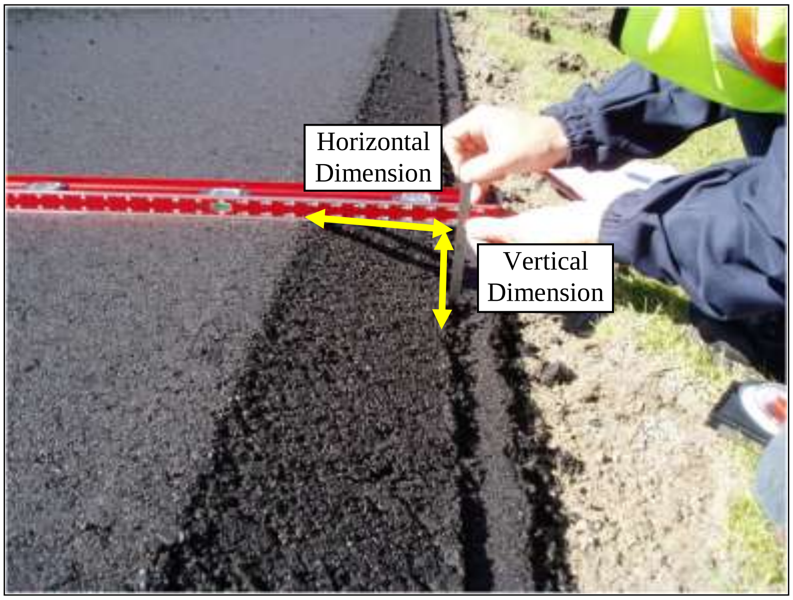


Figure 2. Slope measurement technique.

Table A-1 in Appendix A contains slope measurements recorded at each individual measurement location. Accurate edge thickness measurements were not possible due the new overlay extending over the edge of the existing pavement, thereby exaggerating and confounding the edge thickness measurements.

Cores

Several pairs of cores were cut from each test section. Each pair of cores had a core taken 3-feet from the edge of the mat (where the maximum number of roller passes were made) and a corresponding core taken adjacent to the edge (where fewer roller passes were made). Table A-2 in Appendix A lists the stations from where these cores were taken and the respective core thicknesses measured. The laboratory-determined densities from these cores serve to calibrate the nuclear density measurements. Laboratory density was determined from the bulk specific gravity at saturated surface dry test condition. Tables A-3 in Appendix A includes a summary of the laboratory density test results. Figure 3 compares the laboratory core density readings for the test sections. As expected, the densities 3 feet from the edge were higher than those along the edge of the mat.

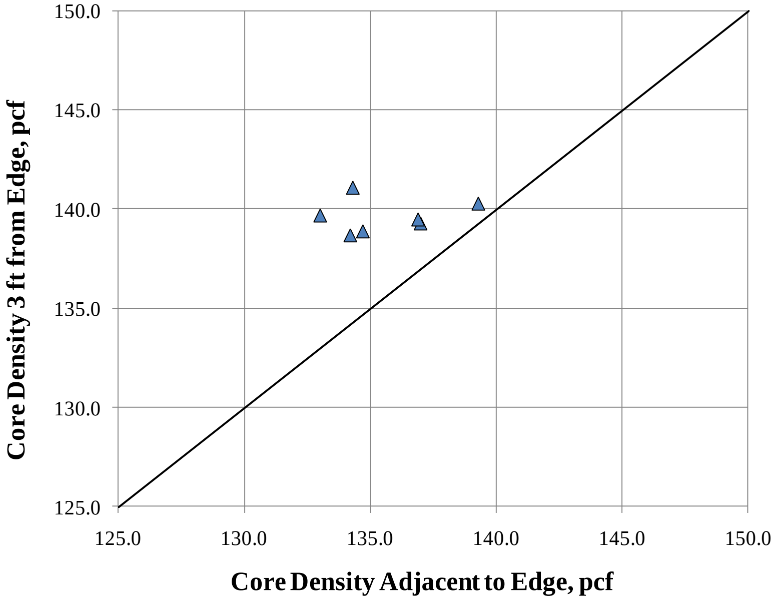


Figure 3. Comparison of core densities adjacent to the edge and 3 feet from the edge.

Nuclear Density Test Results

Density tests were conducted using a nuclear density gauge in backscatter mode for 60-second test durations. The tests were conducted at 50-foot intervals at 3-feet from the edge and adjacent to the edge. Table A-3 in Appendix A presents the results of the nuclear density testing along with the laboratory density results from these locations. Figure 4 compares the nuclear density readings to the densities measured on the cores. As shown, there is close correlation between the nuclear gage and core densities.

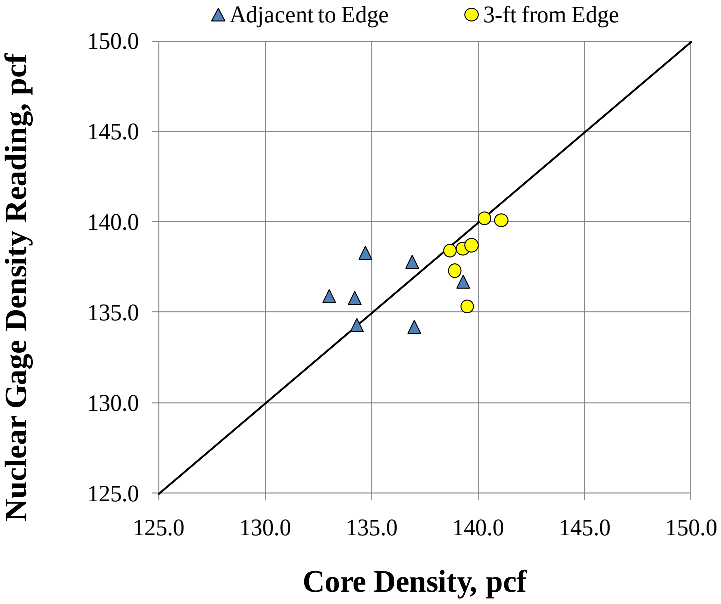


Figure 4. Comparison of the nuclear densities and core densities.

Adjustment factors were determined from correlating the nuclear density readings and the core laboratory density results shown in Table A-3 in Appendix A. The factors were close to unity and were used to adjust the nuclear density gauge readings to be consistent with the densities that were measured in the laboratory. The adjusted or corrected densities using the correction factors are listed in Table A-4 in Appendix A and are summarized as follows:

Location	Adjustment Factor
Adjacent to the edge	0.996
3 feet from the edge	1.009

The control section had a lower average density value (132.2 pcf) adjacent to the edge compared to section #1 (134.9 pcf) or section #2 (134.8 pcf), suggesting the confining effect of the edge devices helped to increase densification near the edge. The rolling pattern was the same for all three sections and is discussed later in this report.

Figure 5 compares the nuclear densities taken adjacent to the edge and 3 feet from the edge. Generally, the densities were higher 3 feet from the edge in all sections.

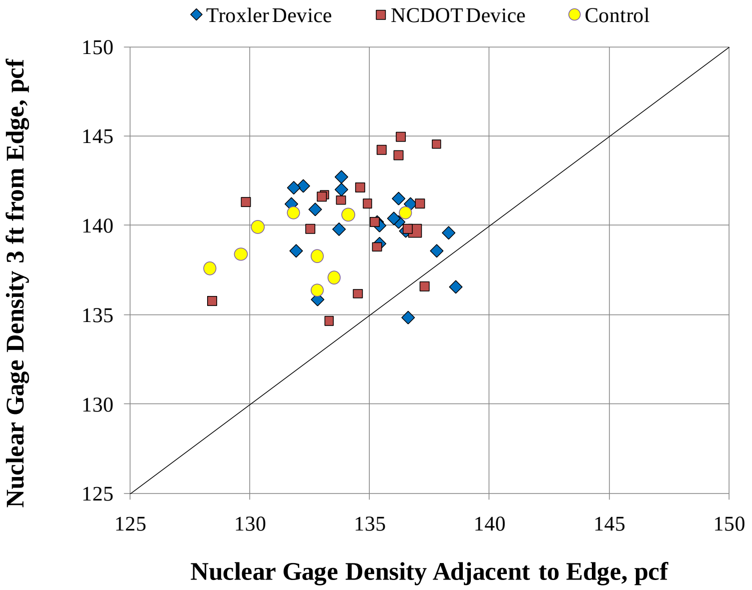


Figure 5. Comparison of the nuclear densities adjacent to the edge and 3 feet from the edge.

Figure 6 compares the air voids (as calculated from the density test results and the maximum theoretical mix density). As shown, the percentages of air voids in the mix usually were higher adjacent to the edge.

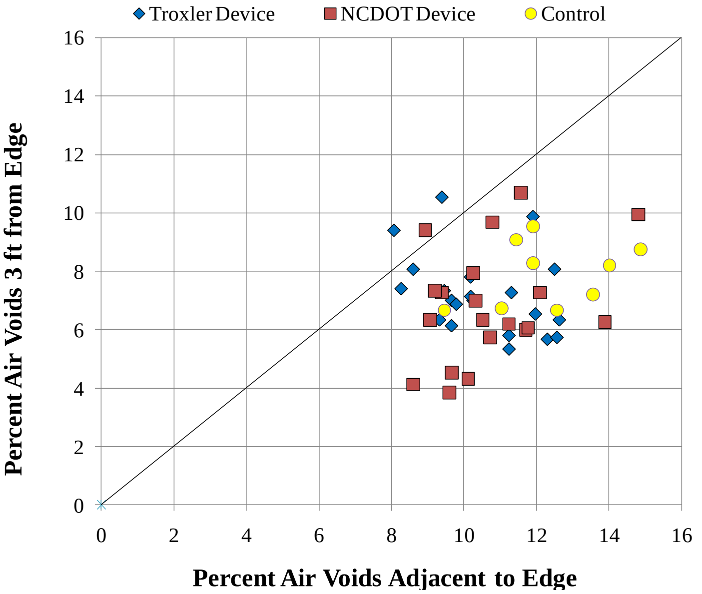


Figure 6. Comparison of the air voids adjacent to the edge and 3 feet from the edge.

Average air voids are summarized in Table 1. This table shows higher air voids in the control section near the edge, underscoring the favorable impact of edge devices on increasing the quality of the mat near the edge. It is theorized that the confining pressure the edge devices exert on the edge adds to the compaction at the edge.

Table 1. Average air voids.

Section Identification	Air Voids Adjacent to the Edge		Air Voids 3 feet from the Edge	
	Mean, %	COV	Mean, %	COV
Test Section #1, Troxler Device	10.5	13.8	7.2	19.2
Test Section #2, NCDOT Device	10.6	15.6	6.8	28.7
Section #3, Control	12.3	13.5	7.9	14.1

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

Milling and significant patching were not preformed on Brogden Road. The existing pavement was cleaned with a power broom, and the edge was bladed with a motor grader to clip areas of soil and vegetation buildup. Clipping the edge with a motor grader or similar equipment is important for three reasons:

- It creates room at the edge so the Safety Edge$_{SM}$ devices can shape the proper angle of edge.
- It creates a firm support for the pavement edge by exposing the existing pavement.
- It reduces the chance the Safety Edge$_{SM}$ device from plowing and mixing soil/vegetation into the fresh asphalt.

For this project it is key that the contractor's standard operating practice includes preparing the edge of the existing pavement. If soil/vegetation adjacent to the pavement is encroaching onto the pavement and/or is higher than the pavement, it is necessary to remove this material to expose the existing pavement edge. This condition often results in poor drainage of the existing surface. Figure 7 shows the exposed pavement after clipping the edge buildup.

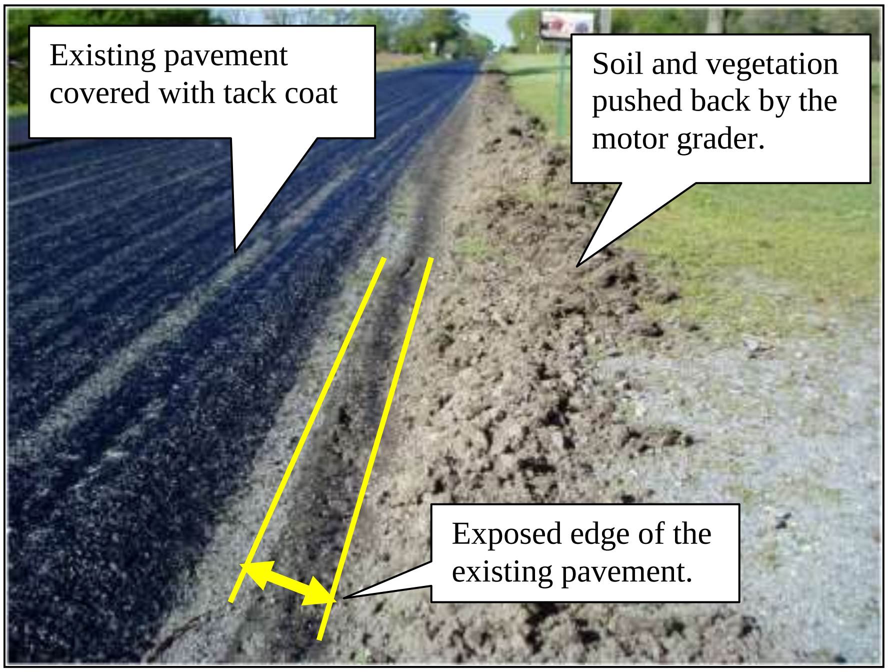


Figure 7. Exposed pavement after edge preparation.

Paving over vegetation results in poor consolidation, and the asphalt material is not expected to perform as well as it would when paved on the existing pavement and soil/aggregate shoulder material. Essentially, the result will be as if no Safety Edge$_{SM}$ were placed. The Safety Edge$_{SM}$ requires a few more inches of clipping width compared to traditional paving without a Safety Edge$_{SM}$. The extra width shown in Figure 8 accommodates not only the Safety Edge$_{SM}$ but the end gate of the paver as well.

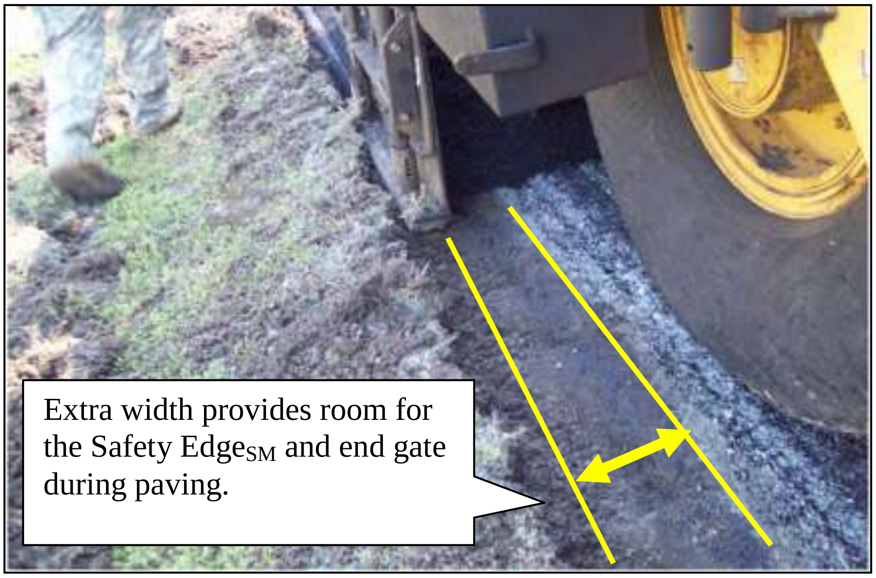


Figure 8. Extra width created by preparing the existing pavement edge/shoulder.

The contractor clipped the shoulder which is standard practice for this scope of project. The conventional shoulder clipping operation was used, which did not take into account the extra width needed for the Safety Edge$_{SM}$. Figure 8 shows there was enough room at this particular location, but that was not always the case. At some isolated locations the shoulder was not clipped wide enough. Although equipment was used to prepare the shoulders, labor was needed occasionally to rake or shovel clumps of soil from the shoulder ahead of the paver. Figure 9 shows an isolated instance in which the Troxler SafeT*Slope* Edge Smoother was running on soft soil, resulting in the device plowing soil into the Safety Edge$_{SM}$.

Figure 9. Example of the Safety Edge$_{SM}$ device plowing up soil into the Safety Edge$_{SM}$.

At some locations the clipping removed a large amount of buildup from the edge of the road. Figure 10 shows mounds of soil/vegetation piled up from the edge preparation.

Figure 10. Soil/vegetation piled up from edge preparation work.

Given the extent of shoulder clipping and preparations needed for the Safety Edge$_{SM}$, it is expected that more asphalt material would be placed than with conventional overlays. However, this will depend heavily on the existing site conditions. On this project, a reliable account of the extra tonnage of WMA was not available, and the contractor stated that all projects overrun the estimated amount of material regardless of a conventional edge or Safety Edge$_{SM}$.

Placement/Paving Operations

Overall, the WMA surface texture was uniform, with isolated areas of minor segregation. The WMA was significantly more stable during compaction than conventional hot mix asphalt (HMA). Little or no lateral movement was observed. The contractor also indicated that, based on his experience, the WMA moved significantly less during compaction than HMA.

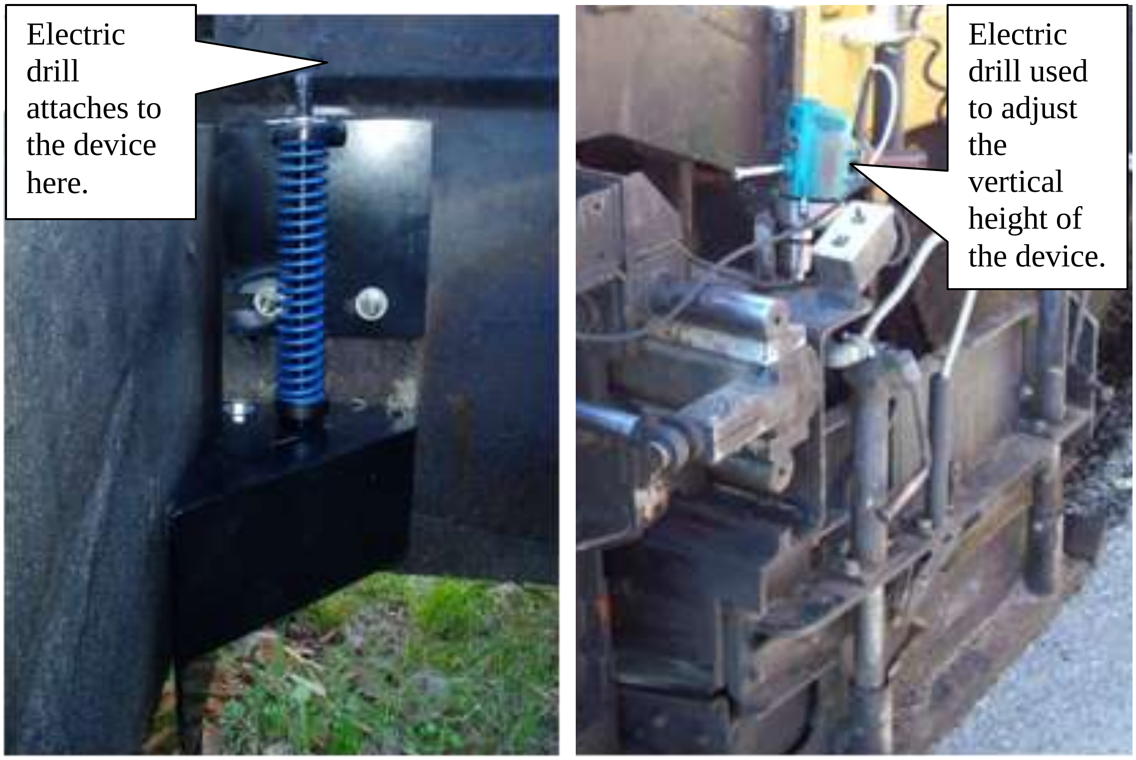
The WMA mat was placed 1.75 inches thick as it left the screed and compacted to 1.5 inches. The mix temperature in the truck at the job site varied from 260 to 275°F. Haul time from the plant was approximately 1 hour and 15 minutes. The contractor used a rubber tire Caterpillar AP-1000B paver with the material feed auger kept within 18 inches of the end gate. On the day of paving the weather in the morning was sunny, 40°F and rising. Paving the day before was postponed due to heavy rain.

The contractor noted the edge of pavement where the Safety Edge$_{SM}$ was used did not break off under traffic from the asphalt trucks, whereas a conventional edge would be damaged, necessitating repair.

Paving operations began with the Troxler device installed on the paver. Later in the day the Troxler device was replaced with the NCDOT device. Both devices were supplied to the contractor through NCDOT. The following discussion addresses the experience with each device.

Troxler SafeT*Slop*e Edge Smoother

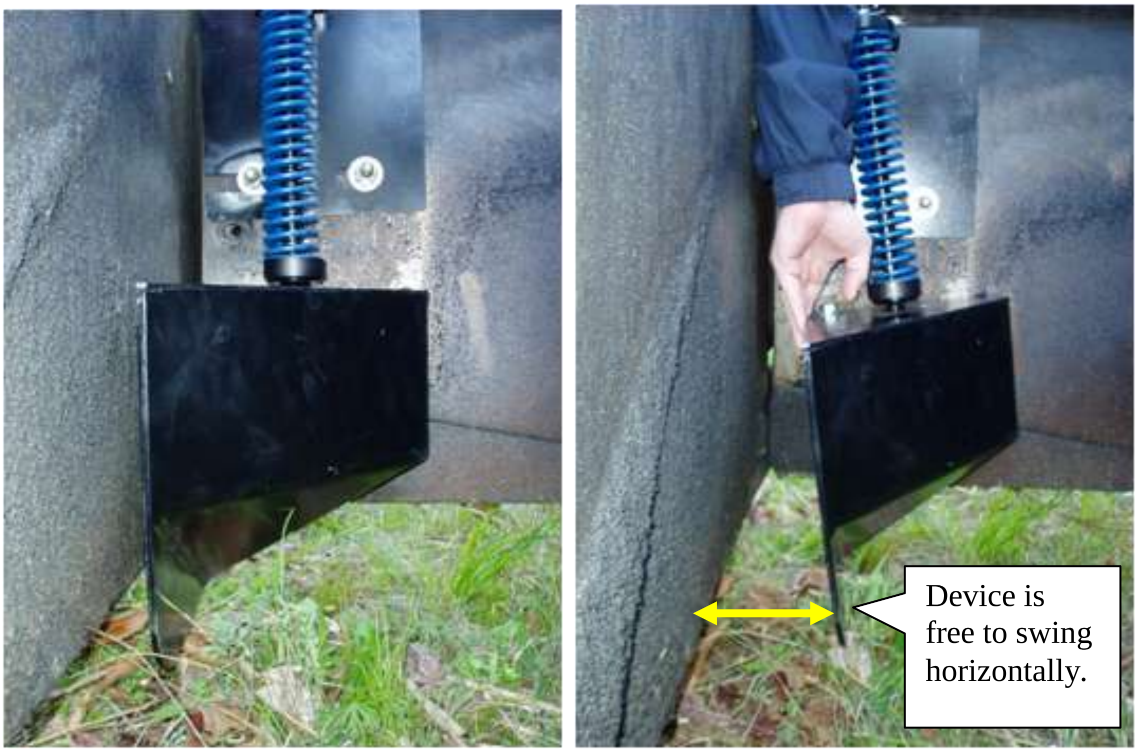
The contractor had no problems operating the Troxler device. The device was raised and lowered quickly with an electric drill attached to the top of the vertical screw shown in Figure 12. Two bolts welded to the face of the screed box held the device in place. As shown in Figure 12, the shoe was free to swing horizontally. Under normal operation the lateral pressure of the asphalt mix holds the shoe against the end gate; however, asphalt can build up between the two surfaces, pushing the shoe to the inside and causing problems, such as increased edge slope angle.



Electric drill attaches to the device here.

Electric drill used to adjust the vertical height of the device.

Figure 11. Troxler SafeT*Slop*e Edge Smoother.



Device is free to swing horizontally.

Figure 12. Troxler SafeT*Slop*e Edge Smoother.

The slope of the edge produced by the Troxler device appeared to be stable during compaction. The following measurements were taken at a single location to document the minor slope increase during passes of the breakdown roller closest to the edge:

Roller Pass	Slope
1st pass, 3 inches over the edge with vibration	31°
2nd pass, 4 inches over the edge with vibration	31°
3rd pass, 6 inches away from the edge with vibration	32°

The texture of the slope face produced by the Troxler device was smooth and uniform. Figure **13** shows the uniform constancy of the slope face.

Figure 13. Slope face produced by the Troxler device.

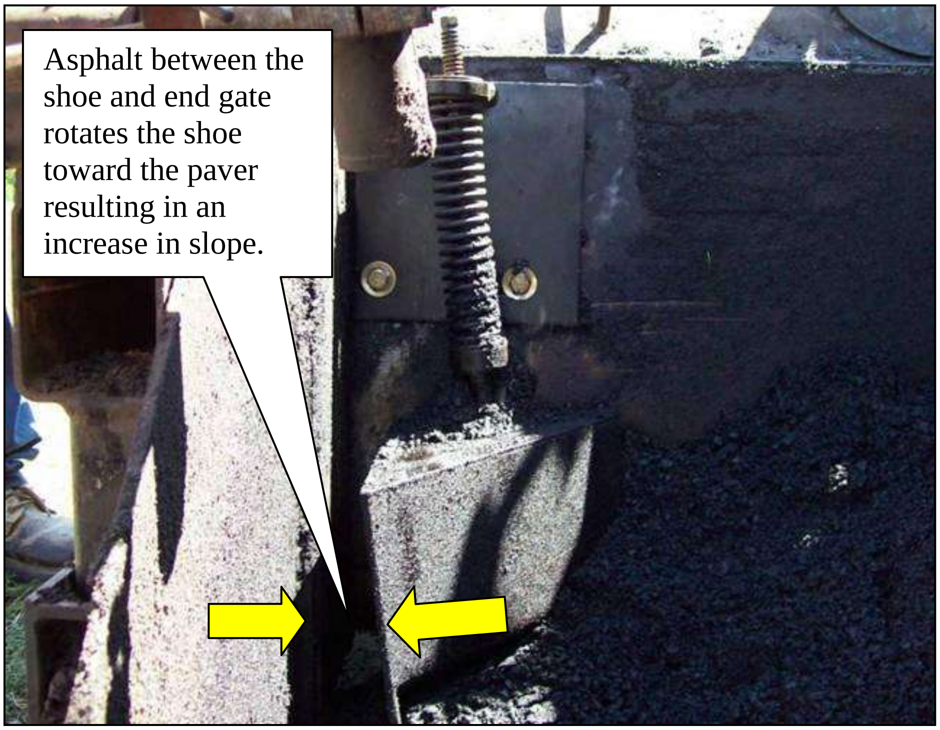
At a few isolated locations, longitudinal cracks quickly developed near the breakpoint of the slope face after the breakdown roller finished making passes (Figure 14). The asphalt mix was removed with hand tools to reveal that the reason for the cracking was the pavement edge was placed over soil/vegetation and not on top of the existing pavement. This resulted in paving on top of differential structural support which resulted in the longitudinal crack. The longitudinal crack would happen regardless of the presence of the Safety Edge$_{SM}$.

Figure 14. Isolated longitudinal edge cracking (left) and investigation revealed soil/vegetation under the pavement edge (right).

<u>NCDOT Device</u>

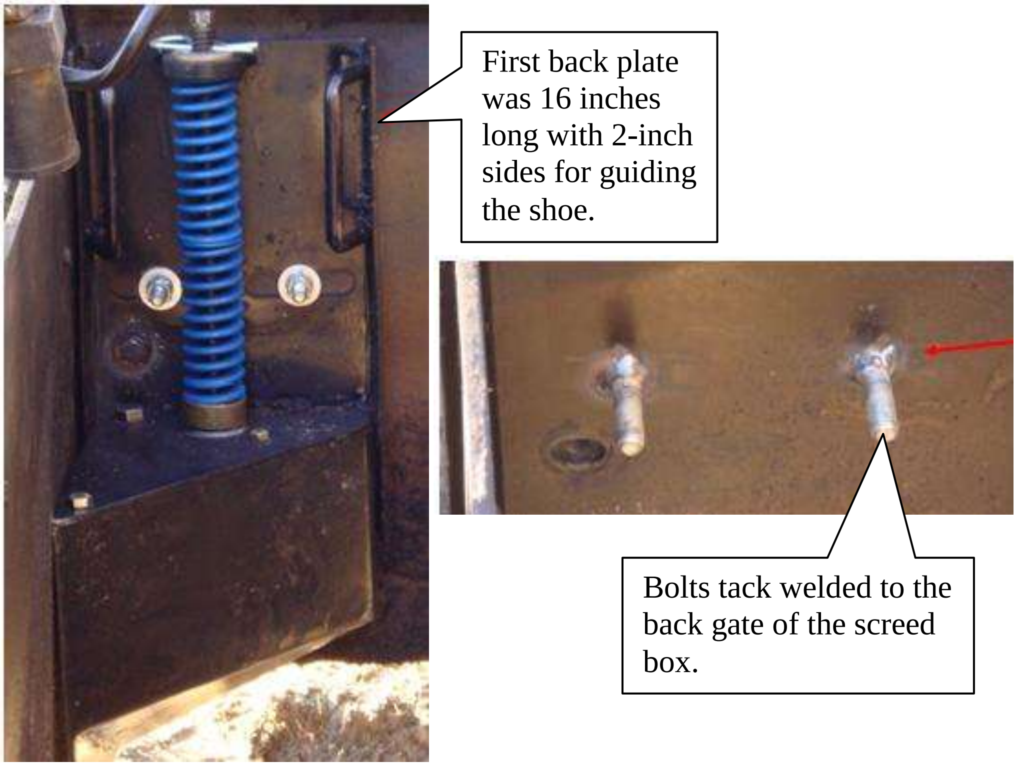
NCDOT purchased two TransTech Shoulder Wedge Makers in 2006. During the first two installations (about 2008 to 2009), NCDOT noticed the final angles approached 45°. Upon investigation of site implementation photos, NCDOT noticed that the shoe was rotating (moving horizontally) from asphalt getting between the end gate and the shoe. Figure 15 shows the shoe rotated toward the paver.

NCDOT decided to make a back plate similar to the Advant-Edger back plate. For the current routes that would receive the Safety Edge$_{SM}$ (first route paved on March 18, 2011), the first change made to the TransTech device was to make a different back plate. NCDOT's first prototype combined the TransTech device with a custom backplate 16 inches long with 2-inch sides for the guide plates on the side with one set of placement slots to attach to the paver. Instead of drilling holes and bolting the device to the screed box, the contractor tack welded two bolt ends to the screed box to attach the device. Figure 16 shows NCDOT's first prototype. Within the first 0.75 mile of use, the contractor snagged a driveway with the device, tore the back plate edge guides, and severely bent the screw.



Asphalt between the shoe and end gate rotates the shoe toward the paver resulting in an increase in slope.

Figure 15. Shoe rotation.

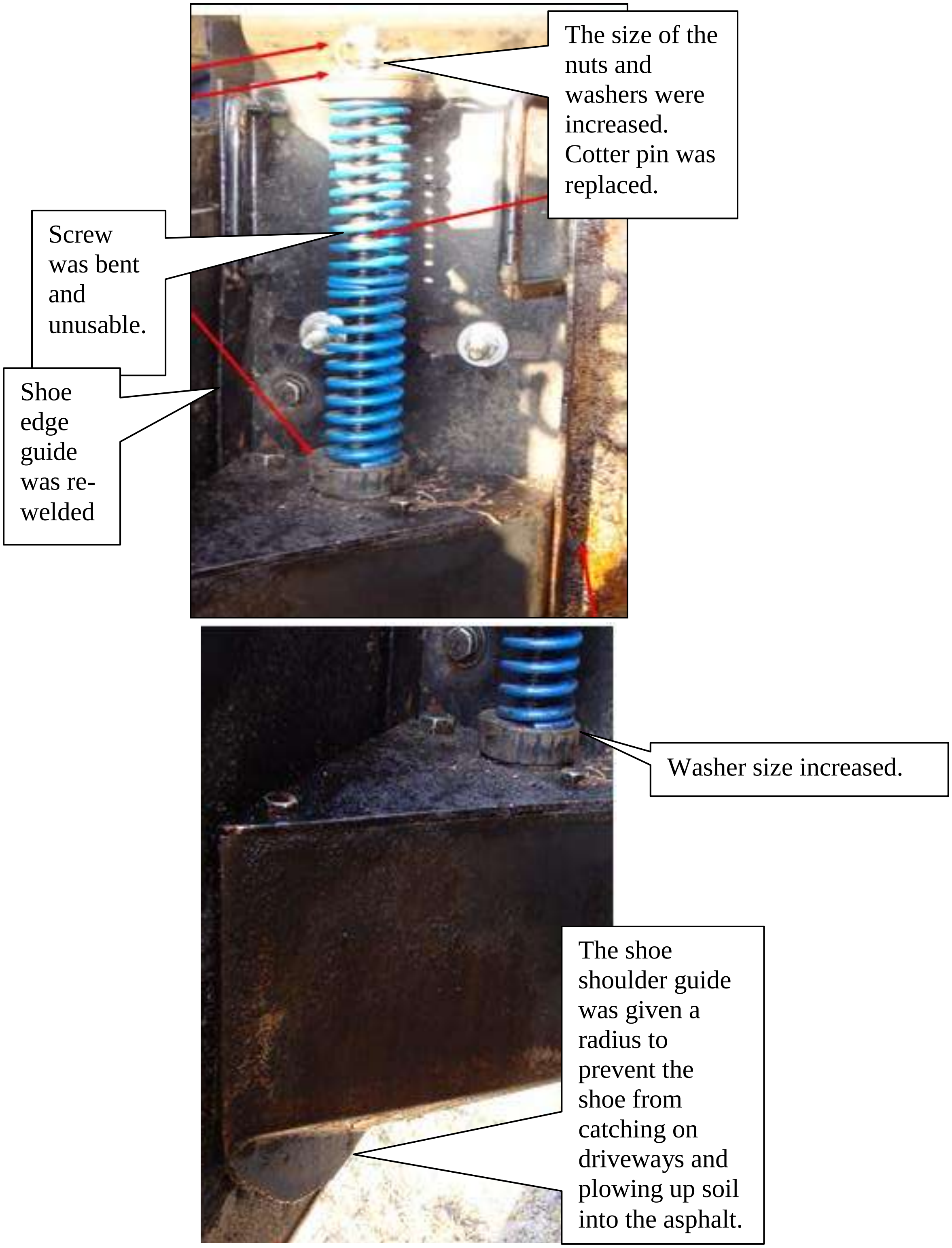


First back plate was 16 inches long with 2-inch sides for guiding the shoe.

Bolts tack welded to the back gate of the screed box.

Figure 16. NCDOT's first prototype.

The next modification was to cut a radius into the leading edge of the shoe guide so it would no longer snag on driveways (this also reduced/eliminated the plowing of soil into the asphalt Safety Edge$_{SM}$). The screw and back plate edge guides were repaired, the cotter pin was replaced, and a new screw nut was welded into place. Figure 17 shows the modifications made to NCDOT's first prototype. The contractor finished the first four routes with the modified prototype.



The size of the nuts and washers were increased. Cotter pin was replaced.

Screw was bent and unusable.

Shoe edge guide was re-welded

Washer size increased.

The shoe shoulder guide was given a radius to prevent the shoe from catching on driveways and plowing up soil into the asphalt.

Figure 17. Images of the NCDOT's first prototype after modification.

During the paving of the second, third, and fourth routes, the contractor had problems raising the device at driveways due to asphalt collecting above the shoe and interfering with the screw/spring. In fact, on the fourth route, the contractor had to remove the device seven times due to the multiple driveways and being unable to raise the device (on a 0.64-mile section of road). This process included stopping the paver, digging out the device, removing the device, paving across the driveway, stopping the paver, digging out the asphalt for the device to be placed back against the screed box and end gate, and finally reattaching the device. This process took 5 to 10 minutes each time (which the contractor estimated as equivalent to not placing one truckload of asphalt).

Asphalt buildup above shoe and interfering with the spring.

Figure 18. Asphalt buildup above the shoe.

NCDOT developed a second prototype based on the experience gained with the first prototype. The second prototype back plate was built with 18-inch-long sides; the side closest to the end gate was built with 2-inch-deep guide plates, and the side closest to the material feed auger was built with 3-inch-deep guide plates. An 8-inch protection plate was bolted to the top of the shoe to prevent asphalt from reaching the screw and spring. Multiple mounting slots were cut into the back plate to accommodate different types of pavers. Figures 19, 20, and 21 show the details of the second prototype.

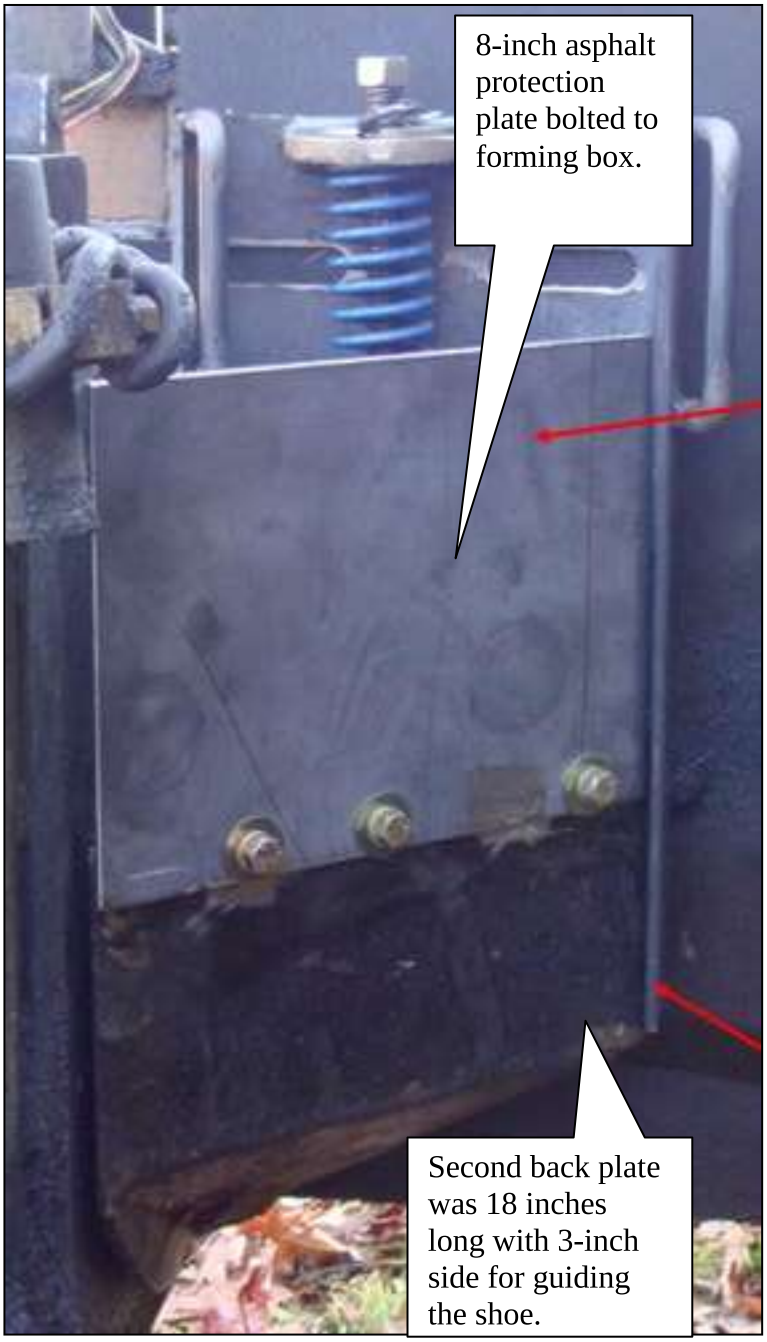


Figure 19. NCDOT's second prototype showing the protection plate and revised back plate and shoe guide.

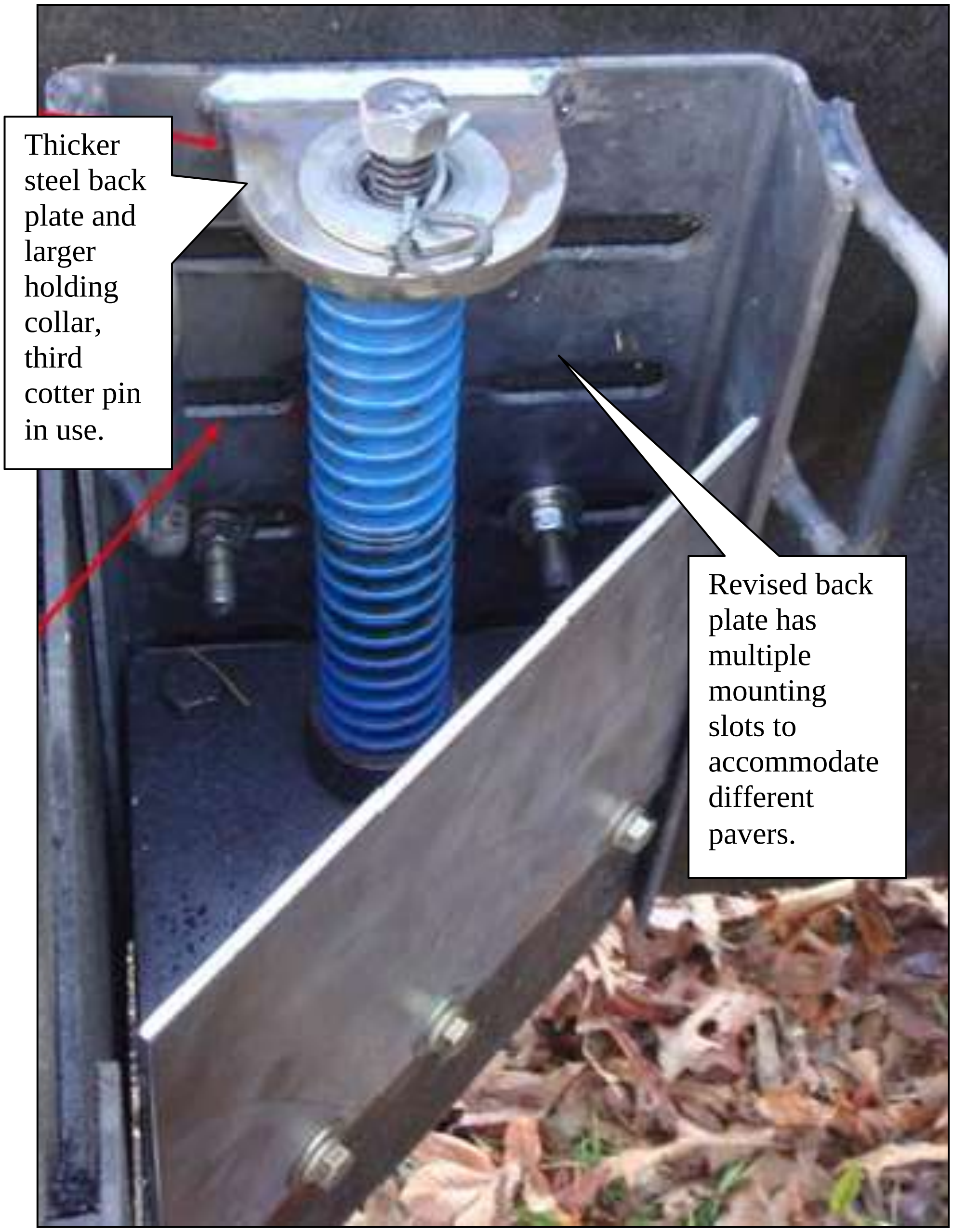


Figure 20. NCDOT's second prototype showing a thicker back plate, larger holding collar and multiple mounting slots.

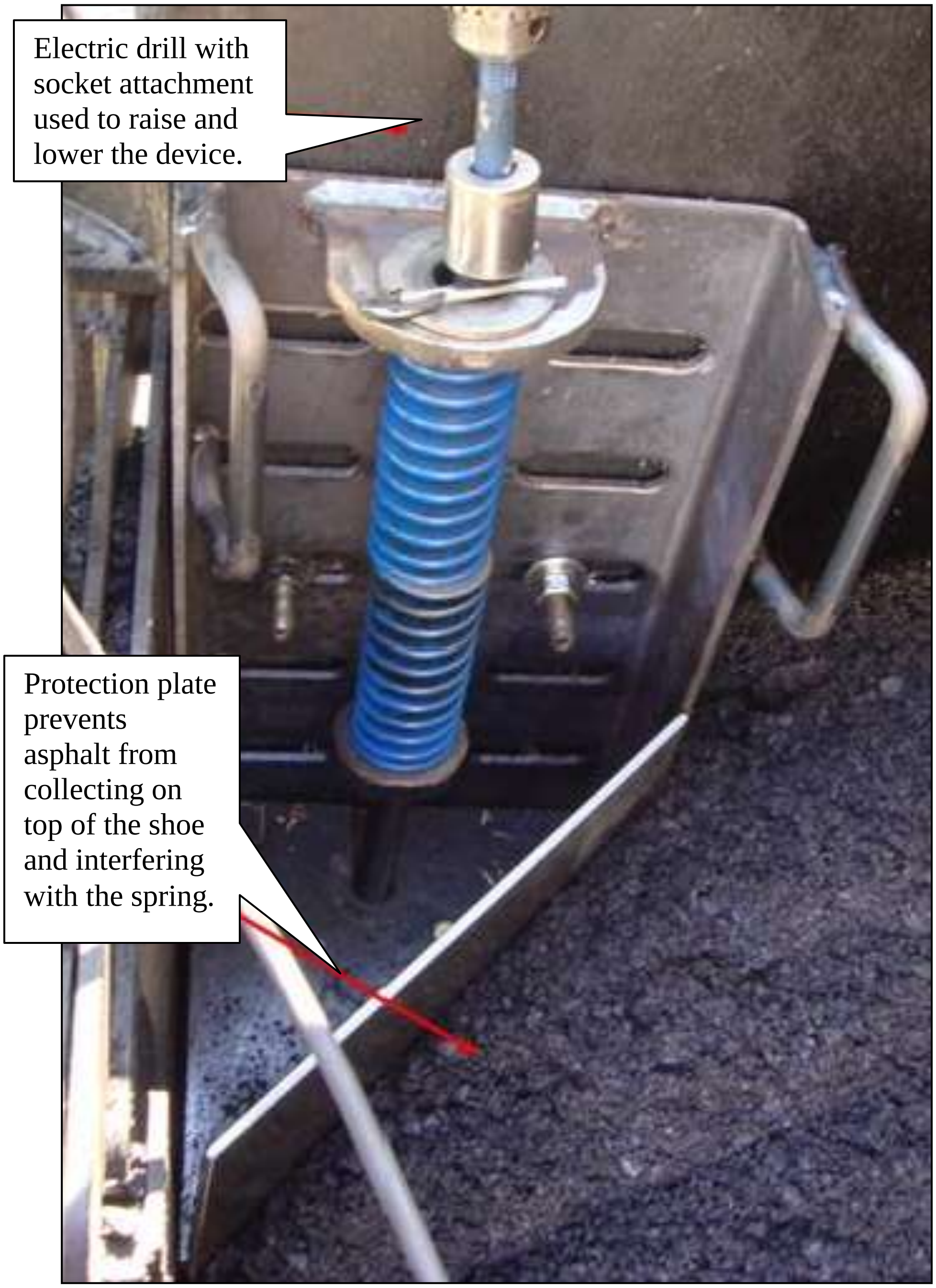


Figure 21. NCDOT second prototype in service showing the protection plate keeping asphalt from collecting on top of the shoe.

The second prototype was used successfully on the fifth route under the contract prior to Brogden Road. The contractor used an electric drill with a 15/16 inch bit to raise and lower the device at driveways in a matter of seconds. Figure 22 shows an example of the short transition length created by the ability to raise the shoe quickly for an approaching driveway. The shoe did not have to be removed; however, the cotter pin holding the shoe up had a tendency to come loose as the device was being raised and lowered.

Figure 22. Transition at a driveway.

Fortunately, the contractor and NCDOT's machine shop were able to make changes to the device on short notice (sometimes hours and minutes). This method of trial and error has led to an efficient, reliable device that NCDOT feels confident using. After 4.75 miles of using the second prototype, NCDOT noted other issues that could be addressed:

- The cotter pin has been replaced three times. The pin could be made of stronger material and/or redesigned to keep it better attached to the device.
- The screw is susceptible to bending and had to be replaced on earlier prototypes. Hopefully, the longer side guide plates and the asphalt protection plate address this issue, but could the screw be made stronger?
- The device already is showing a great amount of wear as shown in Figure 23 (as did the other device used on the first two roads several years ago). Could the leading edge of the shoe be made of stronger steel?
- What is the expected service life for a device?

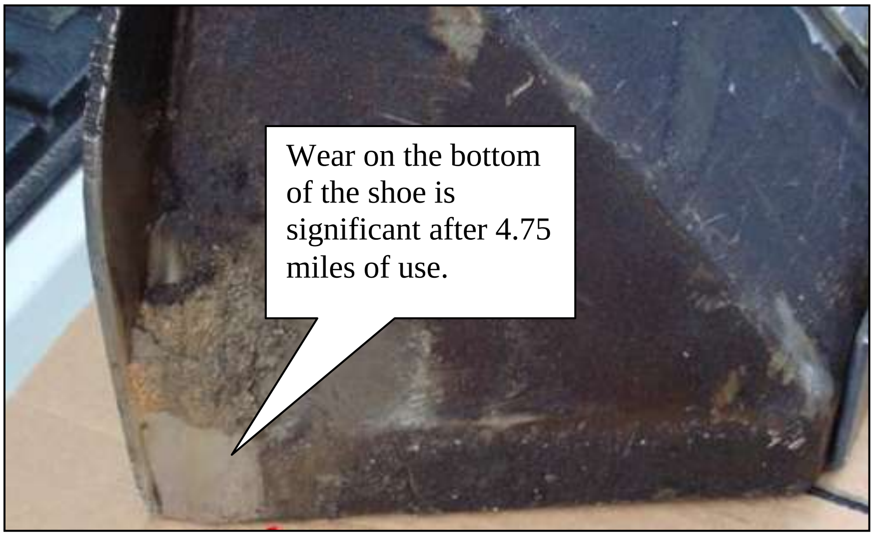


Figure 23. Wear on the bottom of the shoe.

NCDOT's measurements of the slope angles for the first five routes were:

Route	Slope
#1 HMA	27°
#2 HMA	27°
#3 WMA	26°
#4 WMA	29°
#5 WMA	30°

About halfway through the paving day, the Troxler device was replaced with NCDOT's device (second prototype). The contractor noted the side plates performed as intended and prevented the shoe from rotating. The asphalt protection plate also worked as intended, keeping asphalt away from the spring.

The following measurements were taken at a single location to document the lack of slope movement during passes of the breakdown roller closest to the Safety Edge$_{SM}$:

Roller Pass	Slope
slope measured directly behind the paver	29°
1st pass, 3 inches over the edge with vibration	29°
2nd pass, 3 inches over the edge with vibration	29°
3rd pass, 2 inches over the edge with vibration	29°

The slope of the edge produced by the NCDOT device remained the same during compaction. The texture of the slope face was fairly smooth and uniform.

Compaction Operations

The paver was followed closely by two double steel drum breakdown rollers, Caterpillar CB 564D and Hypac C778B, operating in echelon. The Caterpillar roller was in front of the Hypac roller and made passes along the outer edge of the lane, and the Hypac operated along the longitudinal joint at the pavement centerline. Both rollers were set for low amplitude with vibration at about 3700 RPM. The contractor noted that, normally, when placing HMA, only one breakdown roller would be used, in which case the higher mat temperatures allows enough time for a single roller to achieve compaction. The intermediate roller was a Rosco 9-wheel Tru-Pac 915 pneumatic roller. The finish roller was a double steel drum Ingersoll Rand DD-158 operating in static mode.

The two breakdown rollers operating together made three passes, without wandering across the lane, each roller covering one-half of the width of the lane with each pass. Generally, during each of the three passes (one forward, one back, and then forward again) the Caterpillar roller overhung the outer edge 2 to 4 inches and the Hypac rolled over the centerline joint 2 to 4 inches. In some instances, the Caterpillar roller would make two passes overhanging the outer edge and the final pass either on the edge or a few inches away from the edge. The pneumatic roller then made up to 15 passes wandering across the lane, with 4 to 5 passes about 18 to 24 inches from the outer edge. The finish roller made two passes, one at the centerline joint and one right on the outer edge. The operators were observed maintaining this pattern for both test sections.

Shoulder Backing

Topsoil was to be placed as the shoulder backing material. Placement of the backing material was not observed.

Findings and Conclusions

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

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

The following findings and conclusions can be made based on the observations made during the paving/compaction operations:

- Preparing the edge of the existing pavement for this project was important to create room and remove vegetation for the Safety Edge$_{SM}$.
- The edge of pavement separated from the mat at an isolated location where the edge of pavement was placed over soft soil/vegetation. This would have occurred

regardless of the use of the Safety Edge$_{SM}$; nevertheless, this underscores the importance of preparing the edge of the pavement.

- The contractor was able to attach and operate both devices successfully.
- The design of the Troxler device was relatively simple but was free to rotate laterally. In the event that asphalt gets between the shoe and the end gate, the slope of the edge could increase.
- The contractor noted the Safety Edge$_{SM}$ was not damaged under traffic from the asphalt trucks, whereas a conventional edge normally would be damaged and the contractor would then have to repair the edge.
- Guides on the NCDOT device prevent lateral rotation of the shoe. Protective plates attached above the shoe also improve the design by preventing asphalt from collecting on top of the shoe and interfering with the screw and spring.
- The screw bent a few times in normal operation. Improvements should include a stronger materials or better design of the screw mechanism.
- A more wear-resistant steel may help to extend the life of the devices.
- The densities were higher and the air voids were lower adjacent to the edge in the test sections with the Safety Edge$_{SM}$ compared to the control section. The confining effect of the devices, which results in additional densification at the edge, is an added benefit of the Safety Edge$_{SM}$ and may increase the long-term performance of the edge.
- The contractor was able to attach and operate both devices successfully to produce an edge slope close to the targeted 30°. The angle of the slopes made by both devices increased only slightly (1°) or not at all during the rolling process even though the breakdown roller overhung the edge on each pass. Stability of the WMA kept the slope angle increase to a minimum.

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 documents the field measurements recorded during the paving operations. Note that the stationing shown in the tables refer to the length of each section and not the project stationing.

Table A-1. Slope measurements.

Section	Station	Type of Device	Safety Edge		
			Width of Taper, in	Thickness of Taper, in	Slope, deg
1	00+00	Troxler	5.5	2.75	27
1	00+25	Troxler	6	3	27
1	00+50	Troxler	5.25	2.75	28
1	00+75	Troxler	5.5	3	29
1	01+00	Troxler	5	2.75	29
1	01+25	Troxler	5	2.5	27
1	01+50	Troxler	5	2.5	27
1	01+75	Troxler	5.5	3	29
1	02+00	Troxler	5.5	2.75	27
1	02+25	Troxler	4.5	2.5	29
1	02+50	Troxler	4.75	2.75	30
1	02+75	Troxler	4.75	2.75	30
1	03+00	Troxler	5	3	31
1	03+25	Troxler	5	2.5	27
1	03+50	Troxler	5.5	2.5	24
1	03+75	Troxler	6	2.75	25
1	04+00	Troxler	5.25	3	30
1	04+25	Troxler	5.5	3.25	31
1	04+50	Troxler	5	2.75	29
1	04+75	Troxler	5.5	3	29
1	05+00	Troxler	5.5	2.75	27
1	05+25	Troxler	5.5	3	29
1	05+50	Troxler	5	2.75	29
1	05+75	Troxler	5	2.5	27
1	06+00	Troxler	5.25	2.5	25
1	06+25	Troxler	5	2.5	27
1	06+50	Troxler	5.5	2.5	24
1	06+75	Troxler	5	2.75	29
1	07+00	Troxler	5.5	2.5	24
1	07+25	Troxler	5.5	3	29
1	07+50	Troxler	5.5	2.75	27
1	07+75	Troxler	5	2.75	29
1	08+00	Troxler	5	2.5	27
1	08+25	Troxler	5	2.75	29
1	08+50	Troxler	5	2.75	29
1	08+75	Troxler	5	2.5	27
1	09+00	Troxler	5	2.5	27
1	09+25	Troxler	5	2.75	29
1	09+50	Troxler	5.5	3	29
1	09+75	Troxler	5.5	2.75	27
1	10+00	Troxler	5	2	22
Mean Value			5.2	2.7	28
Standard Deviation			0.3	0.2	1.9
Coefficient of Variation, %			6.2	8.5	7.0

Table A-1. Slope measurements, continued.

Section	Station	Type of Device	Safety Edge		
			Width of Taper, in	Thickness of Taper, in	Slope, deg
2	00+00	NCDOT	2.625	1.375	28
2	00+25	NCDOT	2.75	1.5	29
2	00+50	NCDOT	2.625	1.375	28
2	00+75	NCDOT	4.5	2.5	29
2	01+00	NCDOT	3.25	2.25	35
2	01+25	NCDOT	4	2.5	32
2	01+50	NCDOT	3	1.5	27
2	01+75	NCDOT	4.75	2.5	28
2	02+00	NCDOT	3.5	1.5	23
2	02+25	NCDOT	5	2	22
2	02+50	NCDOT	4.25	2.25	28
2	02+75	NCDOT	5.75	2.875	27
2	03+00	NCDOT	5.5	2.75	27
2	03+25	NCDOT	3.5	1.5	23
2	03+50	NCDOT	4	1.75	24
2	03+75	NCDOT	3.75	1.75	25
2	04+00	NCDOT	3.5	1.25	20
2	04+25	NCDOT	4.75	2.5	28
2	04+50	NCDOT	5.25	2.75	28
2	04+75	NCDOT	4.625	2.25	26
2	05+00	NCDOT	3.875	2.25	30
2	05+25	NCDOT	3.5	2.25	33
2	05+50	NCDOT	4.25	2.25	28
2	05+75	NCDOT	5.125	2.375	25
2	06+00	NCDOT	3.625	1.5	22
2	06+25	NCDOT	4.875	2.125	24
2	06+50	NCDOT	3	1.5	27
2	06+75	NCDOT	3.5	1.625	25
2	07+00	NCDOT	4.875	2.25	25
2	07+25	NCDOT	4.875	2.375	26
2	07+50	NCDOT	4.25	2.25	28
2	07+75	NCDOT	4.875	2.375	26
2	08+00	NCDOT	5.25	2.625	27
2	08+25	NCDOT	5	2.625	28
2	08+50	NCDOT	5.75	2.25	21
2	08+75	NCDOT	6	2.5	23
2	09+00	NCDOT	5	2.125	23
2	09+25	NCDOT	4.25	2.5	30
2	09+50	NCDOT	4	1.75	24
2	09+75	NCDOT	4.375	2	25
2	10+00	NCDOT	4.75	2.25	25
Mean Value			4.3	2.1	26
Standard Deviation			0.9	0.4	3.1
Coefficient of Variation, %			20.7	21.2	11.9

Table A-2. Core thickness measurements.

Section	Lane Direction	Station	Type of Section	Core Thickness, in	
				A – Adjacent to Edge	B – 3 feet from Edge
1	WB	0+00	Troxer	1.88	2.00
1	WB	0+50	Troxler	1.88	1.75
1	WB	5+00	Troxler	1.75	1.38
1	WB	8+50	Troxler	1.50	1.50
2	WB	2+50	NCDOT	1.75	1.75
2	WB	5+00	NCDOT	1.50	2.00
2	WB	8+50	NCDOT	2.00	1.75
3	WB	0+50	Control	1.88	--
Mean, in.				1.75	1.73
Standard Deviation, in.				0.19	0.23
Coefficient of Variation, %				10.91	13.45

Table A-3. Nuclear density adjustment ratios; core density/nuclear density.

Section	Lane Direction	Station	Type of Device	Density of Cores		Nuclear Density Values		Adjustment Ratio	
				A – Adjacent to Edge	B – 3 ft from Edge	A – Adjacent to Edge	B – 3 ft from Edge	A – Adjacent to Edge	B – 3 ft from Edge
1	WB	0+00	Troxer	139.3	140.3	136.7	140.2	1.019	1.001
1	WB	0+50	Troxler	137.0	139.3	134.2	138.5	1.021	1.006
1	WB	5+00	Troxler	133.0	139.7	135.9	138.7	0.979	1.007
1	WB	8+50	Troxler	134.7	138.9	138.3	137.3	0.974	1.012
2	WB	2+50	NCDOT	134.3	141.1	134.3	140.1	1.000	1.007
2	WB	5+00	NCDOT	136.9	139.5	137.8	135.3	0.993	1.031
2	WB	8+50	NCDOT	134.2	138.7	135.8	138.4	0.988	1.002
3	WB	0+50	Control	133.2	--	132.3	139.4	1.007	--
Mean Value, pcf				135.6	139.6	136.1	138.4	0.996	1.009
Standard Deviation, pcf				2.2	0.8	1.6	1.7	0.018	0.010
Coefficient of Variation, %				1.6	0.6	1.2	1.2	1.840	1.011

Table A-4. Nuclear gauge readings.

Maximum Specific Gravity of Mix (Gmm):		2.416	Max. Density, pcf:	150.8
Adjustment Ratios for Nuclear Gauge:	A=	0.996		
	B=	1.009		

Section	Lane Direction	Station	Type of Device	Nuclear Densities, pcf		Adjusted Nuclear Densities, pcf		Core Thickness Adjacent to Edge, in.	Air Voids, %	
				A – Adjacent to Edge	B – 3 ft from Edge	A – Adjacent to Edge	B – 3 ft from Edge		A – Adjacent to Edge	B – 3 ft from Edge
1	WB	00+00	Troxler	136.7	140.2	136.2	141.5	1.875	9.7	6.1
1	WB	00+50	Troxler	134.2	138.5	133.7	139.8	1.875	11.3	7.3
1	WB	01+00	Troxler	135.8	138.9	135.3	140.2		10.3	7.0
1	WB	01+50	Troxler	137.2	139.9	136.7	141.2		9.3	6.3
1	WB	02+00	Troxler	132.2	139.9	131.7	141.2		12.6	6.3
1	WB	02+50	Troxler	135.9	137.7	135.4	139.0		10.2	7.8
1	WB	03+00	Troxler	132.4	137.3	131.9	138.6		12.5	8.1
1	WB	03+50	Troxler	134.3	140.7	133.8	142.0		11.2	5.8
1	WB	04+00	Troxler	133.2	139.6	132.7	140.9		12.0	6.5
1	WB	04+50	Troxler	132.7	140.9	132.2	142.2		12.3	5.7
1	WB	05+00	Troxler	135.9	138.7	135.4	140.0	1.75	10.2	7.1
1	WB	05+50	Troxler	138.8	138.3	138.3	139.6		8.3	7.4
1	WB	06+00	Troxler	133.3	134.6	132.8	135.9		11.9	9.9
1	WB	06+50	Troxler	134.3	141.4	133.8	142.7		11.2	5.3
1	WB	07+00	Troxler	136.7	138.9	136.2	140.2		9.7	7.0
1	WB	07+50	Troxler	136.5	139.1	136.0	140.4		9.8	6.9
1	WB	08+00	Troxler	137.1	133.6	136.6	134.9		9.4	10.5
1	WB	08+50	Troxler	138.3	137.3	137.8	138.6	1.5	8.6	8.1
1	WB	09+00	Troxler	137.0	138.4	136.5	139.7		9.5	7.3
1	WB	09+50	Troxler	132.3	140.8	131.8	142.1		12.6	5.7
1	WB	10+00	Troxler	139.1	135.3	138.6	136.6		8.1	9.4
Average Value, pcf				135.4	138.6	134.9	139.9	1.8	10.5	7.2
Standard Deviation, pcf				2.2	2.1	2.2	2.1	0.2	1.5	1.4
Coefficient of Variation, %				1.6	1.5	1.6	1.5	10.1	13.8	19.2

Table A-4. Nuclear gauge readings, continued.

Section	Lane Direction	Station	Type of Device	Nuclear Densities, pcf		Adjusted Nuclear Densities, pcf		Core Thickness Adjacent to Edge, in.	Air Voids, %	
				A – Adjacent to Edge	B – 3 ft from Edge	A – Adjacent to Edge	B – 3 ft from Edge		A – Adjacent to Edge	B – 3 ft from Edge
2	WB	00+00	NCDOT	133.8	133.4	133.3	134.7		11.6	10.7
2	WB	00+50	NCDOT	137.1	138.5	136.6	139.8		9.4	7.3
2	WB	01+00	NCDOT	130.3	140.0	129.8	141.3		13.9	6.3
2	WB	01+50	NCDOT	133.0	138.5	132.5	139.8		12.1	7.3
2	WB	02+00	NCDOT	138.7	--	138.2	--		--	--
2	WB	02+50	NCDOT	134.3	140.1	133.8	141.4	1.75	11.2	6.2
2	WB	03+00	NCDOT	133.6	140.4	133.1	141.7		11.7	6.0
2	WB	03+50	NCDOT	135.0	134.9	134.5	136.2		10.8	9.7
2	WB	04+00	NCDOT	128.9	134.5	128.4	135.8		14.8	9.9
2	WB	04+50	NCDOT	133.5	140.3	133.0	141.6		11.8	6.1
2	WB	05+00	NCDOT	137.8	135.3	137.3	136.6	1.5	8.9	9.4
2	WB	05+50	NCDOT	135.4	139.9	134.9	141.2		10.5	6.3
2	WB	06+00	NCDOT	136.7	142.6	136.2	143.9		9.7	4.5
2	WB	06+50	NCDOT	136.8	143.6	136.3	144.9		9.6	3.9
2	WB	07+00	NCDOT	136.0	142.9	135.5	144.2		10.1	4.3
2	WB	07+50	NCDOT	137.6	139.9	137.1	141.2		9.1	6.3
2	WB	08+00	NCDOT	135.8	137.5	135.3	138.8		10.3	7.9
2	WB	08+50	NCDOT	137.4	138.4	136.9	139.7	2	9.2	7.3
2	WB	09+00	NCDOT	135.1	140.8	134.6	142.1		10.7	5.7
2	WB	09+50	NCDOT	135.7	138.9	135.2	140.2		10.3	7.0
2	WB	10+00	NCDOT	138.3	143.2	137.8	144.5		8.6	4.1
Average Value, pcf				135.3	139.2	134.8	140.5	1.8	10.7	6.8
Standard Deviation, pcf				2.5	2.9	2.5	2.9	0.3	1.6	2.0
Coefficient of Variation, %				1.9	2.1	1.9	2.1	14.3	15.1	28.7

Table 4. Nuclear gauge readings, continued.

Section	Lane Direction	Station	Type of Device	Nuclear Densities, pcf		Adjusted Nuclear Densities, pcf		Core Thickness Adjacent to Edge, in.	Air Voids, %	
				A – Adjacent to Edge	B – 3 ft from Edge	A – Adjacent to Edge	B – 3 ft from Edge		A – Adjacent to Edge	B – 3 ft from Edge
3	WB	00+00	Control	137.0	139.4	136.5	140.7		9.5	6.7
3	WB	00+50	Control	132.3	139.4	131.8	140.7	1.875	12.6	6.7
3	WB	01+00	Control	133.3	135.1	132.8	136.4		11.9	9.5
3	WB	01+50	Control	130.1	137.1	129.6	138.4		14.0	8.2
3	WB	02+00	Control	130.8	138.6	130.3	139.9		13.6	7.2
3	WB	02+50	Control	133.3	137.0	132.8	138.3		11.9	8.3
3	WB	03+00	Control	134.6	139.3	134.1	140.6		11.0	6.7
3	WB	03+50	Control	134.0	135.8	133.5	137.1		11.4	9.1
3	WB	04+00	Control	128.8	136.3	128.3	137.6		14.9	8.7
Average Value, pcf				132.7	137.6	132.2	138.8	1.9	12.3	7.9
Standard Deviation, pcf				2.5	1.7	2.5	1.7	0.0	1.7	1.1
Coefficient of Variation, %				1.9	1.2	1.9	1.2	0.0	13.5	14.1