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Every Day Counts
Innovation Initiative

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Safety Edge$_{SM}$ Demonstration Project Elizabethtown, Pennsylvania

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$_{\text{SM}}$ project located near Elizabethtown, Pennsylvania. These observations and data are to be used with similar information from other Safety Edge$_{\text{SM}}$ projects to facilitate the development of standards and guidance for Safety Edge$_{\text{SM}}$ 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 collected during construction on July 6, 7, and 8, 2010 to evaluate the use of the Safety Edge$_{\text{SM}}$ during paving, compare Safety Edge$_{\text{SM}}$ and non-Safety Edge$_{\text{SM}}$ portions along the project, determine the slope of the Safety Edge$_{\text{SM}}$, recommend adjustments to the Safety Edge$_{\text{SM}}$ design if found to be needed, and identify benefits and complications with the use of the Safety Edge$_{\text{SM}}$ 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 Elizabethtown, Pennsylvania. The Advant-Edger 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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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 agency's paving operation during mainline paving. Some issues, however, were encountered that need to be resolved. These are noted in some of the following bullet items.

Slope of the Safety Edge$_{SM}$

- The average slope of the Safety Edge$_{SM}$ was found to be 48°. Only one slope measurement was found to be less than 40°.
- Based on observations during paving, the 9.5 mm HMA mix behind the screed appeared similar in shape with and without the Safety Edge$_{SM}$ device. In addition, the coarse aggregate at the bottom of the Safety Edge$_{SM}$ were loose and could be easily removed, which is similar to sections without the Safety Edge$_{SM}$ device.

Placement

- The Safety Edge$_{SM}$ was formed using the Advant-Edger device, which was properly bolted to the screed of the paver. Construction personnel recommended that the Safety Edge$_{SM}$ device include an automated system for raising and lowering the device.
- A goal of this project was to maximize pavement width. The Safety Edge$_{SM}$ was added to the project after it was designed. In several areas where paving extended beyond the HMA base, the material upon which the Safety Edge$_{SM}$ was placed had not been prepared prior to paving. In these areas, the Safety Edge$_{SM}$ was placed over grass and other loose debris along the edge of the pavement. It is expected that the Safety Edge$_{SM}$ within these areas may break off from the mat with minimal operations of local traffic along the edge. Preparing the edge prior to placing the Safety Edge$_{SM}$ is believed to be important for future performance.
- The Safety Edge$_{SM}$ did create some minor problems for the paving crew at times. This was particularly apparent at intersections, driveways, and changes in longitudinal elevations or profile. It was difficult for the screed operator to adjust four parameters at the same time; raising or lowering the Safety Edge$_{SM}$ device, adjusting the height of the screed end plate, extending or retracting the screed extension, and adjusting the height of the screed. It is expected that an automated system could eliminate or reduce these problems.
- When used per manufacturer's recommendation, the Safety Edge$_{SM}$ device exerts a downward pressure that keeps the bottom of the device in contact with the surface being paved. In some areas, the Safety Edge$_{SM}$ hung up on some of the coarse aggregate particles of the HMA base mix that was used to widen each side of the roadway. When

this occurred the screed would vibrate or exhibit a jerking mode. If excessive downward pressure is used, the screed will no longer operate under the principle of a free floating screed that is important for placing HMA. Thus, monitoring the downward pressure is important.

Compaction

- The HMA mix density was higher and the air voids lower adjacent to the edge of the mat for the Safety Edge$_{SM}$ sections in comparison to the non-Safety Edge$_{SM}$ section. Thus, the Safety Edge$_{SM}$ was believed to have a confining effect on rolling an unconfined edge condition. This observation is considered a benefit to the use of the Safety Edge$_{SM}$.
- The air voids of the HMA mat interior and along the Safety Edge$_{SM}$ varied from 8 to over 18 percent. This air void content is higher than desirable for long term performance.

Shoulder Construction

- HMA millings are planned to be used for the backing material. Placement of the backing material was not observed, because the millings are to be placed later this construction season.

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

- No segregation was observed in any of the areas of the mat or Safety Edge$_{SM}$.
- The screed end plate did plow up some dirt and grass in selected areas when the Safety Edge$_{SM}$ material was extended beyond the HMA base mix used to widen the roadway. When this occurred dirt and grass were pushed into the 9.5 mm HMA mix being placed by the paver. This contamination of the HMA mix will have a detrimental impact on its performance, especially near an unconfined edge with low densities and high air voids.
- The planned HMA overlay thickness was 1.5 inches. The overlay thickness of the cores was found to vary from 1.2 to 2.4 inches along the outside edge of the project.

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 an HMA overlay along State Road 2009 (Bellaire Road) near Elizabethtown, Pennsylvania, with and without the use of the Safety Edge$_{SM}$ device. The objective or 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 Safety Edge$_{SM}$ device attached to the screed for this project was the Advant-Edger. The location of the project is shown in Figure 1. The project started at the intersection with Colebrook Road or State Route 341 and ended at the bridge for Conewago Creek. The speed limit for this section of roadway was 40 mph. The paving crew for this project consisted of Pennsylvania Department of Transportation (DOT) personnel.

Pavement Structure and Project Conditions

The project consisted of placing a 1.5 inch lift of a 9.5 mm HMA mix over the existing HMA pavement. Pennsylvania DOT project personnel indicated that another 1.5 inch HMA lift may be placed in the next year or two. The existing pavement was widened to include two-twelve foot lanes. Figure 2 provides a general view of the 1.5 inch HMA overlay, and typical cross section of the pavement.

The ditches along the edge of the pavement were generally shallow or almost level with the existing pavement (refer to Figure 2), with the exception of a few areas (refer to Figure 3). An HMA base mix had already been placed on both sides of the road to widen the roadway. Some areas had narrow ditches that were approximately one to two feet in depth, but were covered or hidden in grass.

The Safety Edge$_{SM}$ backing material is planned to be HMA millings. This backing material was planned to be placed in the future and was not stored on the project site. More importantly, there are many areas where placing the HMA millings will be difficult because of the edge/shoulder condition (refer to Figures 2 and 3).

As noted above, the existing pavement was widened on both sides by about 1 foot, by placing an HMA base mix (refer to Figure 4). The HMA base mix had already been placed along the pavement's edge. The surface of this material was rough, as shown in Figures 4 and 5. The width of the pavement varied significantly along the project because of site features and driveways that exist along the project (refer to Figures 3 and 6).

Project Starts at Intersection.

Project Ends at Bridge for Conewago Creek.

Figure 1 – Location of site. Project starts at the intersection between ColeBrook Rd. and Bellaire Rd. and proceeds south to the bridge at Conewago Creek.

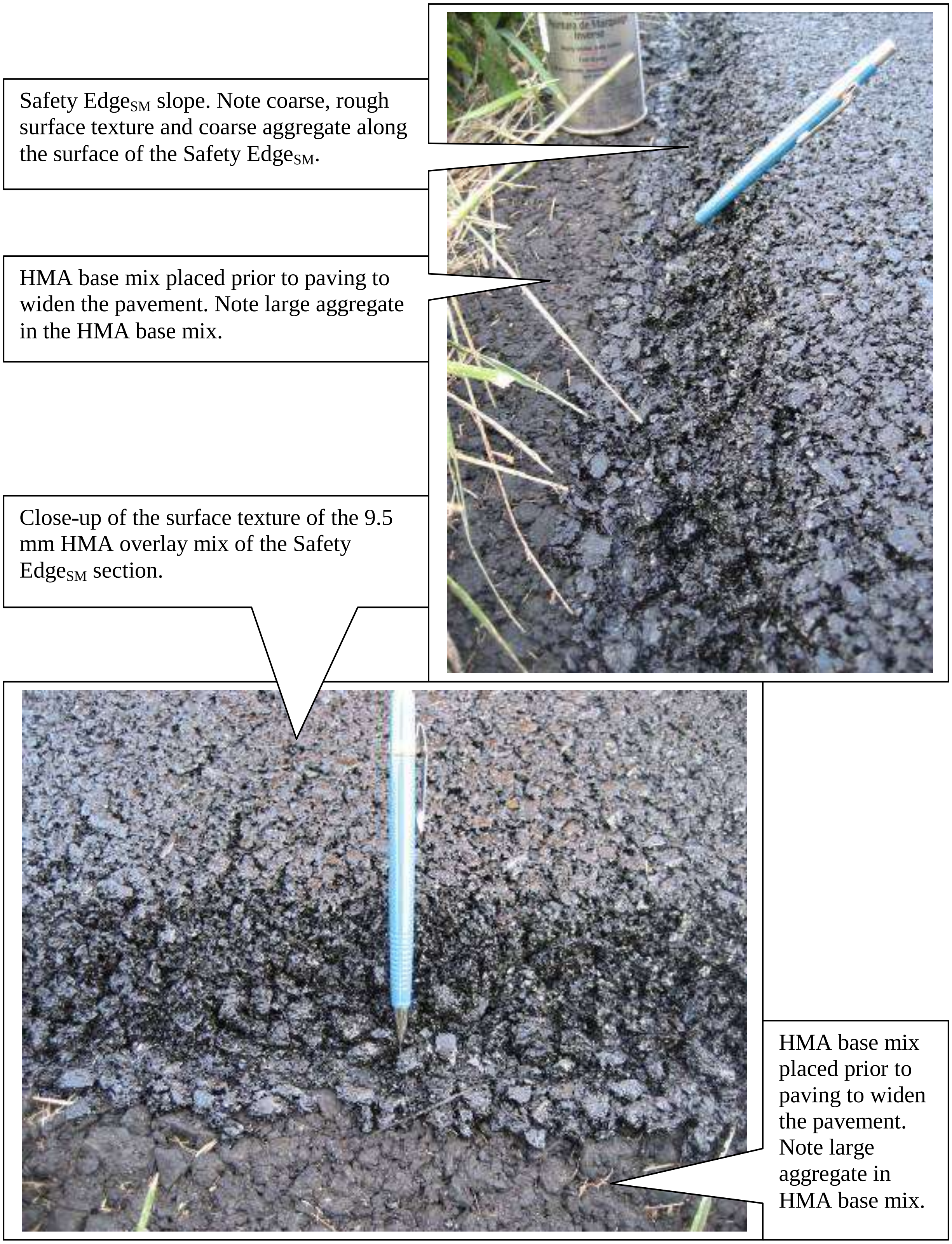
The Safety Edge$_{SM}$ was over the HMA base in some areas and over grass or soil in other areas.

3-foot wide 6 inch depth of HMA Base used to widen both sides of roadway; total roadway width equals 24 feet.

Figure 2. General overview of the 1.5 inch HMA layer placed along the project and pavement cross section provided by the Pennsylvania DOT.

Figure 3. Localized area with deep ditches adjacent to the pavement.

Figure 4. Additional HMA base material placed along each edge of the roadway.



Safety Edge$_{SM}$ slope. Note coarse, rough surface texture and coarse aggregate along the surface of the Safety Edge$_{SM}$.

HMA base mix placed prior to paving to widen the pavement. Note large aggregate in the HMA base mix.

Close-up of the surface texture of the 9.5 mm HMA overlay mix of the Safety Edge$_{SM}$ section.

HMA base mix placed prior to paving to widen the pavement. Note large aggregate in HMA base mix.

Figure 5. Surface of the HMA base that had been previously placed to widen the roadway.

Figure 6. Variable pavement width along the project and shoulder condition.

Field Evaluation

Three sections were identified during the paving operation; two Safety Edge$_{SM}$ sections and one section without the Safety Edge$_{SM}$ device. Field density tests were conducted within each test section using a Troxler 3440 nuclear density gauge, while slope measurements were taken using a straight-edge and six inch ruler along the two Safety Edge$_{SM}$ sections. Fourteen cores were also taken in the test sections established during the paving operations. The fourteen cores were obtained at seven different locations within the Safety Edge$_{SM}$ and non-Safety Edge$_{SM}$ sections. The cores were taken for calibration of the nuclear density gauge readings and to observe the mix near the center of the mat and adjacent to the mat's edge.

The longitudinal profile for determining the International Roughness Index (IRI) was not included in the field testing plan for this project for comparing the Safety Edge$_{SM}$ and non-Safety Edge$_{SM}$ sections. The Pennsylvania DOT does not measure longitudinal profile for calculating the IRI or profile index on these types of rehabilitation projects.

Two Safety Edge$_{SM}$ test sections were located, marked and used in the field study, while one non-Safety Edge$_{SM}$ section was included in the field study. During paving, the screed operator raised and lowered the Safety Edge$_{SM}$ device throughout the project. Thus, the Safety Edge$_{SM}$ was not used consistently throughout the project. The reason for periodically raising the Safety Edge$_{SM}$ device is provided under the section on Observations for this field report. The following summarizes the three test sections included within this field study.

1. Safety Edge$_{SM}$ Section #1; southbound lane, just south of the intersection between Bellaire Road and Maple Dale Road. The station numbers used in the data sheets represent the distance from the intersection of the centerlines for these two roadways. This area of the project was selected because it was visually observed that the Safety Edge$_{SM}$ shoe/device was being used.
2. Non- Safety Edge$_{SM}$ Control Section; north bound lane on the opposite side of the roadway from the Safety Edge$_{SM}$ Section #1.
3. Safety Edge$_{SM}$ Section #2; northbound lane, north of the intersection between Bellaire Road and Maple Dale Road – just north of 365 Bellaire Road. Station 0+35 for this section is located at the center of the culvert and PCC drainage pipe (refer to Figure 7). This section was selected because the Safety Edge$_{SM}$ device was visually observed being used and this area is subject to erosion and future lane-shoulder drop-off.

Area of Safety Edge$_{SM}$ Section #2. Station 0+35 is located at the center of the PCC drainage pipe in the northbound lane.

Figure 7. Reference marker for Safety Edge$_{SM}$ Section #2.

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 8). The average slope of the Safety Edge$_{SM}$ was 48°. Table A-1 in Appendix A contains slope measurements recorded at each individual measurement location. Only one of the measurements was less than 40°. Figure 9 includes a comparison between the slope of the Safety Edge$_{SM}$ and mat thickness at the Safety Edge$_{SM}$ for the two test sections. As shown, there appears to be no correspondence between mat thickness and the slope of the Safety Edge$_{SM}$.

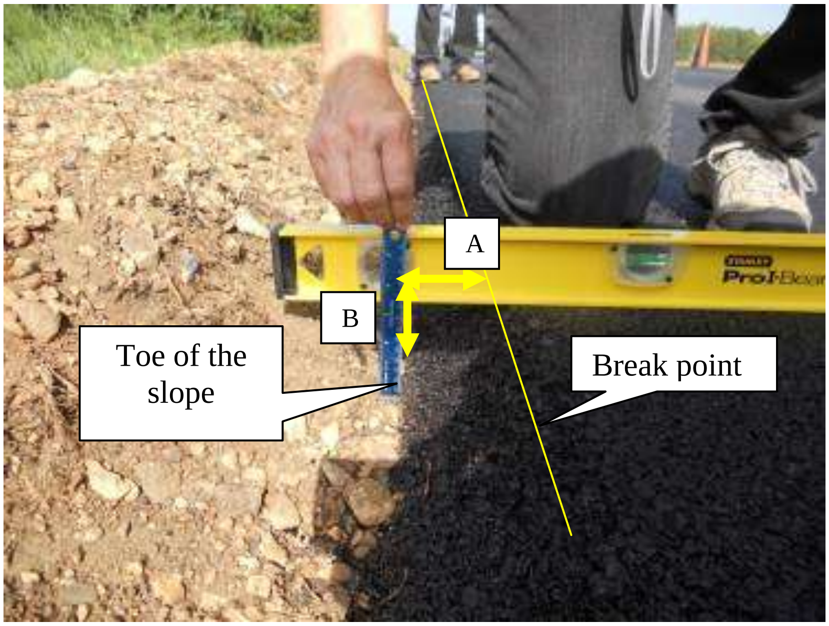


Figure 8. Measurement of the Safety Edge$_{SM}$ angle.

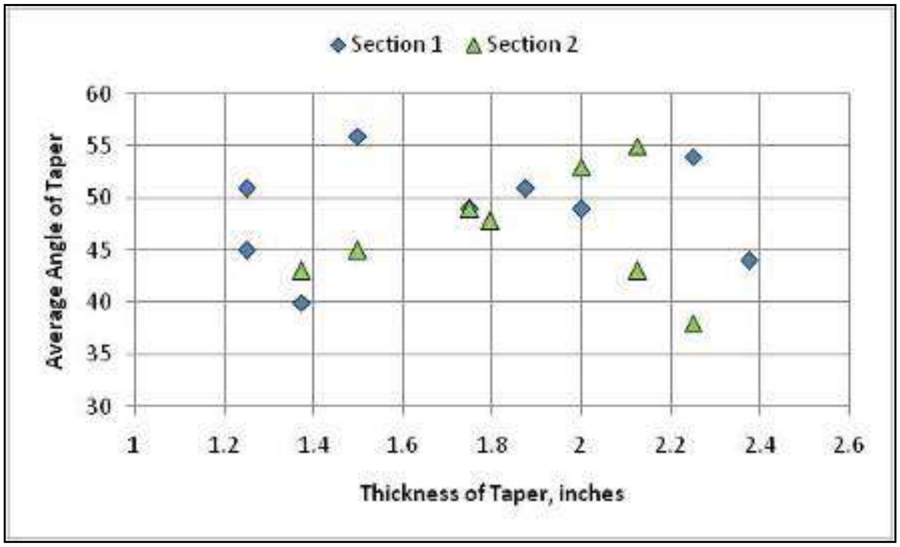


Figure 9. Comparison of the Safety Edge$_{SM}$ slope and mat thickness adjacent to the edge.

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 significantly steeper than what was planned.

The slope measurements were found to be variable, because it was difficult to locate the toe of the slope of the Safety Edge$_{SM}$ in areas where some of the 9.5 mm mixture was under the screed end plate (refer to Figure 5). The screed operator did try to lower the screed end plate, but the end plate pulled dirt and weeds into the mix within the screed extension in some areas.

Cores

A total of fourteen cores were drilled along the project. Two cores were taken at each station or location; one in the same area where the densities were measured with the nuclear gauge. These cores were taken to measure the bulk specific gravity of the compacted HMA mix for developing adjustment factors for the nuclear density gauge readings taken adjacent to the edge and within the center of the mat. Figure 10 shows the location of the cores and nuclear density readings. Nuclear density tests were taken before the cores were drilled.

Tables A-2 and A-3 in Appendix A include a summary of the core thickness and bulk specific gravities (saturated surface dry) converted to bulk densities. Figure 11 shows 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 the densities near the center of roller are significantly higher than along the edge of the mat (unconfined edge). More importantly, the core densities taken along the pavement's edge are consistently higher for the Safety Edge$_{SM}$ section than for the non-Safety Edge$_{SM}$ section. Only one of the cores taken along the edge of the Safety Edge$_{SM}$ section was found to have a lower density than for the non-Safety Edge$_{SM}$ section. These results suggest that the Safety Edge$_{SM}$ is providing better confinement for rolling the unconfined edge of the mat.

Core #1; Safety Edge$_{SM}$ section (A location is adjacent to the Edge; B location is near the center of the steel drum roller (about 3 feet from edge).

Core #2; Non-Safety Edge$_{SM}$ section (A location is adjacent to the Edge; B location is near the center of the steel drum roller (about 3 feet from edge).

Figure 10. Location of cores and nuclear density tests.

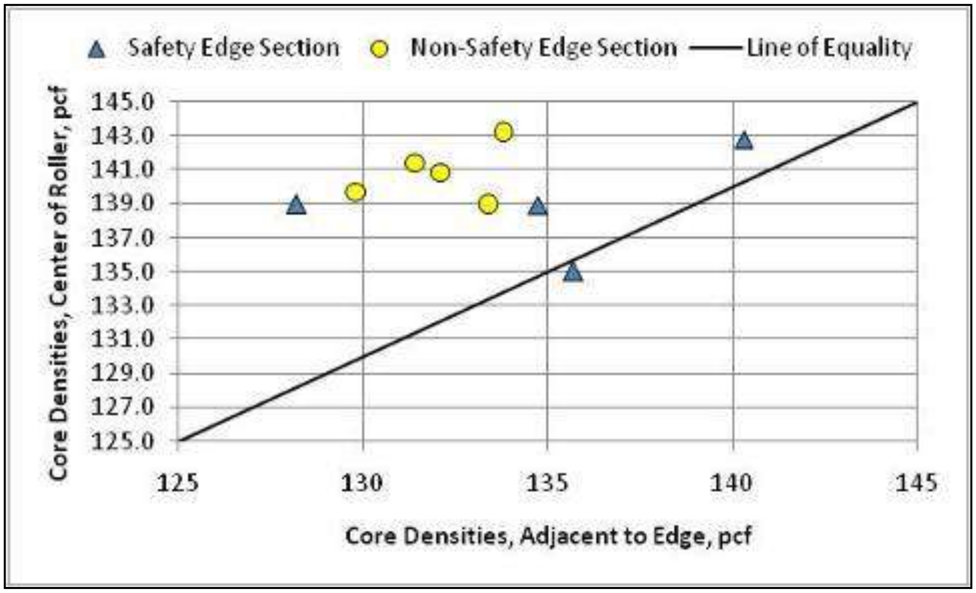


Figure 11. Comparison of core densities adjacent to the edge of pavement and near the center of the steel drum roller.

Nuclear Density Results

Density measurements were made with a Troxler 3440 gauge. Four readings were recorded at each station or location. Two readings were made at a point adjacent to the Safety Edge$_{SM}$ and two were made near the center of the steel drum roller. At each point, one reading was recorded with the nuclear gauge positioned parallel to the pavement edge and the other positioned perpendicular to the edge, which is the Pennsylvania DOT's standard test procedure. The nuclear density gauge readings are listed in Table A-4 in Appendix A.

Nuclear density readings were taken at each core. Figure 12 shows a comparison of the nuclear densities and densities measured on the cores. As shown, there is close correspondence between the nuclear and core densities. Adjustment factors were determined for the nuclear density readings taken at the Safety Edge$_{SM}$ and near the center of the steel drum roller being used to compact the HMA mat. The adjustment factors are included in Table A-3 in Appendix A and are summarized as follows:

Location	Adjustment Factor
Near Center of Steel Drum	1.000
Adjacent to Safety Edge$_{SM}$	0.980

As shown, the value near the center of the steel drum roller is unity and the value near the Safety Edge$_{SM}$ is close to unity. These factors were used to adjust the nuclear density gauge readings to be consistent with the densities that would be measured in the laboratory.

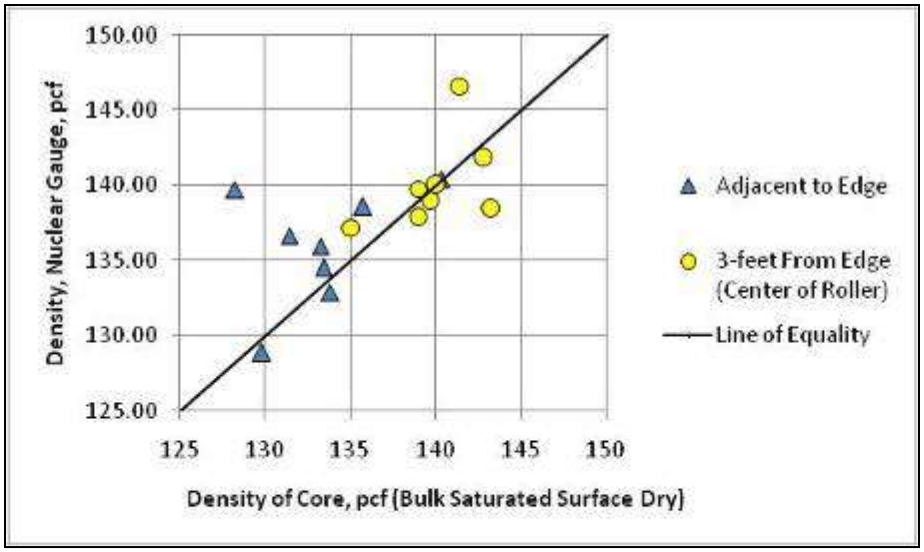
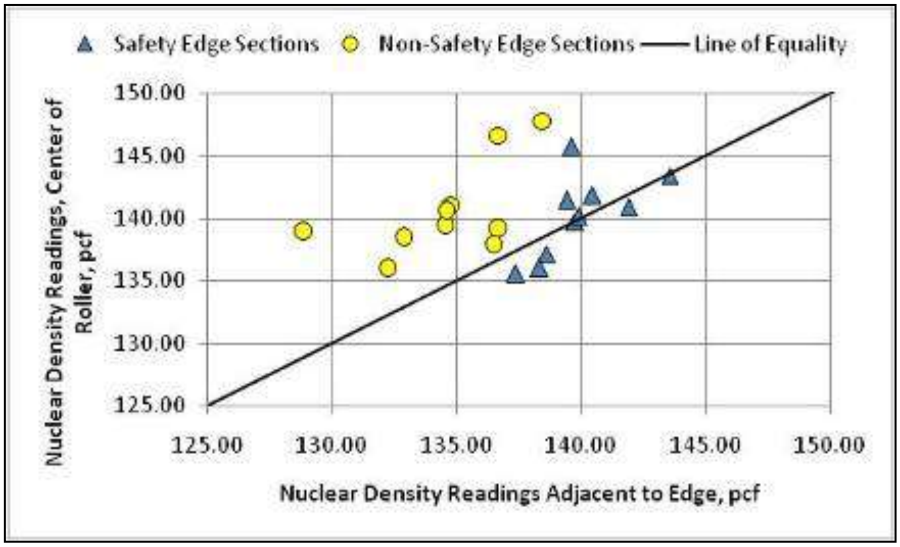


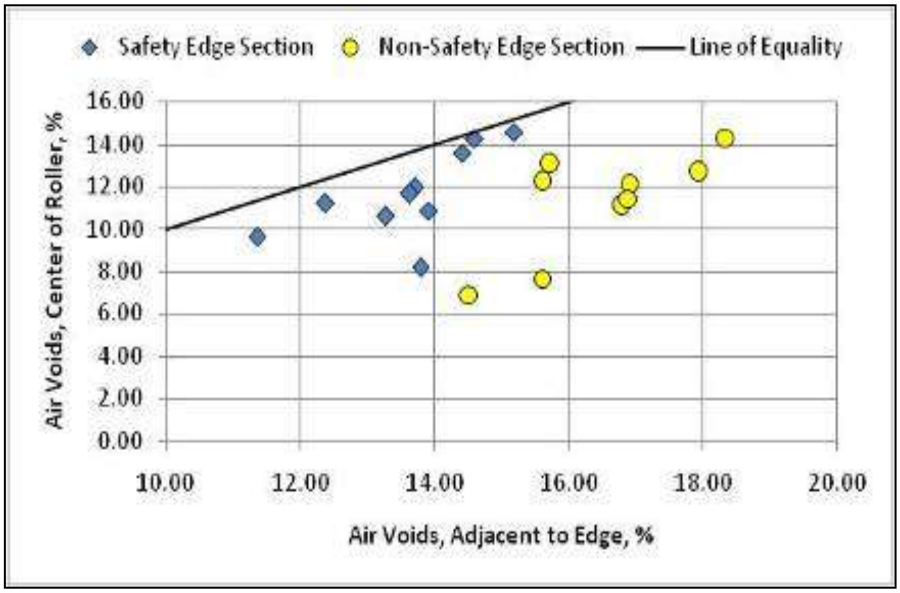
Figure 12. Comparison of the nuclear density readings and densities measured on cores recovered from the HMA overlay.

Figure 13 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 13 also includes a comparison of the HMA air voids between both areas. As shown, the air voids are much higher adjacent to the Safety Edge$_{SM}$, but are higher than desirable for both areas. The other important observation from this data is that the density is higher and the air voids are consistently lower for the Safety Edge$_{SM}$ sections, in comparison to the non-Safety Edge$_{SM}$ section.

Figure 14 compares the HMA mat thickness (near the Safety Edge$_{SM}$) and slope of the Safety Edge$_{SM}$. As shown, the thickness of the HMA mat appears to have no effect or impact on the slope of the Safety Edge$_{SM}$ device.



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

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

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

<u>Surface Preparation Issues</u>

A goal of this project was to maximize pavement width. The Safety Edge$_{SM}$ was added to the project after it was designed. The shoulder or edge of pavement was not specifically prepared to accommodate the Safety Edge$_{SM}$ prior to paving. In fact, the Safety Edge$_{SM}$ was placed over grass and other loose materials in some areas of the project. Grass was observed at the bottom of one of the cores drilled along the non-Safety Edge$_{SM}$ section. It is expected that the edge will deteriorate rapidly with any traffic loadings in these areas (regardless of whether it is a Safety Edge$_{SM}$ or non-Safety Edge$_{SM}$ section). Figures 2, 3, and 6 showed the edge condition of the pavement after paving. In most areas, grass was adjacent to the edge.

Figure 15 shows the condition of the existing pavement and the placement of the emulsion that was used as a tack coat for the HMA overlay. Figure 16 shows the paving adjacent to the shoulder.

Figure 15. An emulsion was used as a tack coat prior to HMA placement (note the material that was added to the edge of the pavement to widen the roadway).

Placement/Paving Operations

DOT personnel operated the paver in manual mode relative to the longitudinal profile to place a 1.5 inch overlay over the existing pavement. The DOT considered this lift as a leveling course, thus it was not correcting the longitudinal profile of the surface. Figure 16 shows the paver in operation, while Figure 17 shows the Safety Edge$_{SM}$ device attached to the screed prior to the paving operation.

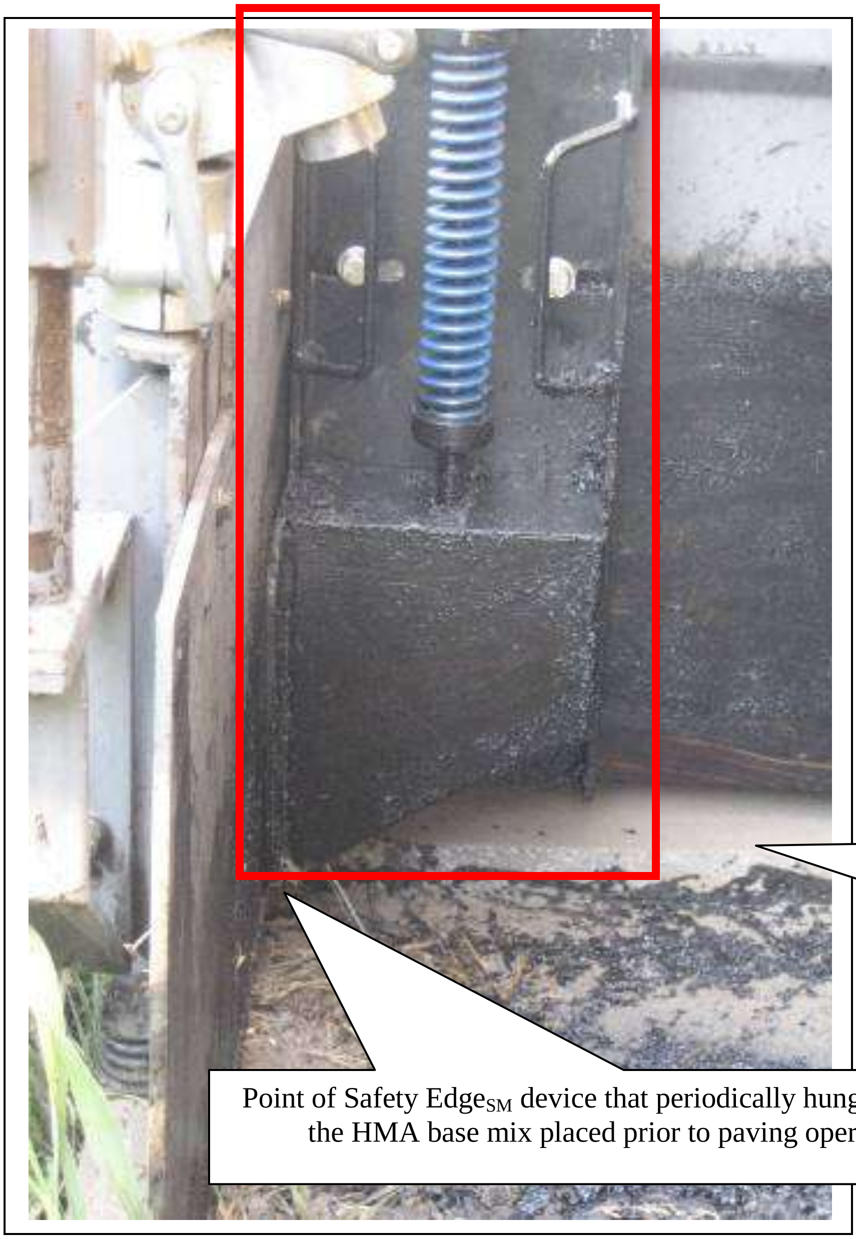
The following summarizes some of the observations and comments made by construction personnel on the use of the Safety Edge$_{SM}$ device.

- The screed operator's opinion was that it was difficult to control the height of the screed, screed end plate, screed extension, and Safety Edge$_{SM}$. It was recommended that the Safety Edge$_{SM}$ device be automated rather than operated by manually turning the screw.
- One major issue that was observed during the paving operation was that the bottom part of the Safety Edge$_{SM}$ device or shoe would periodically get caught on the coarse aggregate of the HMA base mix used to widen the roadway. This caused a sudden jerk in the screed when the coarse aggregate-broke loose or the Safety Edge$_{SM}$ device/screed rose above the aggregate. The screed operator forced the Safety

Edge$_{SM}$ device down onto the HMA base in accordance with the manufacturer recommendations, which was evident by scratch marks on the surface of the HMA base (refer to Figure 18 that shows this condition). It is expected that excessive downward pressure exerted on the Safety Edge$_{SM}$ device could cause the screed to rise in areas where the device was in contact with the HMA base. To prevent this condition, the screed operator suggested raising the Safety Edge$_{SM}$ device to a height about 0.5 inches above the bottom of the end plate. The screed operator also suggested attaching the Safety Edge$_{SM}$ device to the screed end plate rather than to the screed. The screed end plate, however, would need to be significantly stiffened.

- The other detrimental issue was that the screed end plate ski was riding on the surface of the shoulder and in some cases, pulled dirt and weeds into the mix. The screed operator felt that the screed end plate ski had to be lowered sufficiently so that the mix was being retained by the Safety Edge$_{SM}$ shoe.
- The screed and paver operators were concerned about overrunning the quantity of HMA estimated for this project because of the additional material being placed along the edge (increasing yield). For this reason and dragging the shoulder edge noted above, the screed operator tried to keep the Safety Edge$_{SM}$ and edge of the mat on the HMA base.
- There were localized areas along the northern portion of the project where the slope of the shoulder was steeper than 30° for an extended distance past the pavement's edge. In these areas, the screed operator did not extend the screed out, but raised the Safety Edge$_{SM}$ device and lowered the screed end plate ski to create a non-Safety Edge$_{SM}$. This is what the screed operator should do under these conditions. One of these areas is shown in Figure 19.
- The Safety Edge$_{SM}$ device was able to move in some areas when the paver was placing the HMA mixture near the intersections and driveways; when the screed was extended further out from the mainline paving (refer to Figure 20). Once a sufficient amount of mixture was pushed out to the screed end plate, the Safety Edge$_{SM}$ device remained in close contact with the screed and screed end plate.

Figure 16. Photo illustrating the edge condition of the pavement.

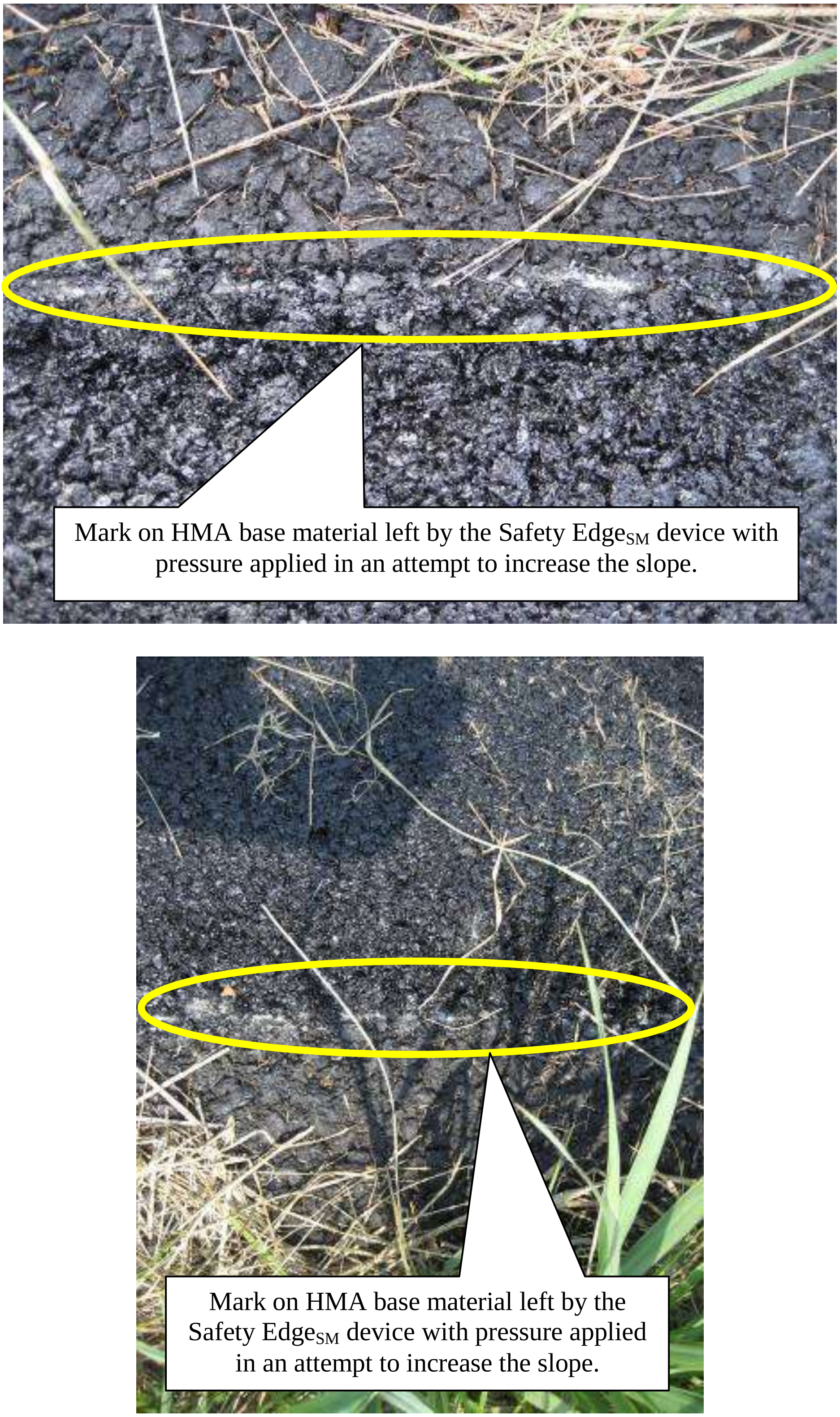


Safety Edge$_{SM}$ device attached to screed and in place at the beginning of the paving.

Beginning of day's construction; transverse joint created prior to paving.

Point of Safety Edge$_{SM}$ device that periodically hung on the larger aggregate of the HMA base mix placed prior to paving operations (see Figure 5).

Figure 17. Safety Edge$_{SM}$ device attached to the screed.



Mark on HMA base material left by the Safety Edge$_{SM}$ device with pressure applied in an attempt to increase the slope.

Mark on HMA base material left by the Safety Edge$_{SM}$ device with pressure applied in an attempt to increase the slope.

Figure 18. Gouges in the HMA left by the Safety Edge$_{SM}$ device riding on the surface of HMA base mix.

Localized area where the slope of the shoulder was steeper than the slope of the Safety Edge$_{SM}$ for an extended distance past the roadway's edge.

Figure 19. Area where the slope of the shoulder was steeper than the Safety Edge$_{SM}$ slope.

Localized area where the screed was extended to place the overlay at intersections and an insufficient amount of material was retained in the extension area to restrain movement of the Safety Edge$_{\text{SM}}$ device.

During mainline paving, sufficient amount or head of material was retained in the extension area so that Safety Edge$_{\text{SM}}$ device was restrained and could not move.

Figure 20. Photographs showing where a sufficient and insufficient amount of head of HMA was retained in the extended auger chamber area.

Compaction Operations

Figure 21 shows the two rollers that were used to compact the HMA 9.5 mm mixture. The breakdown roller was a Dynapac CC422VHF and the finish roller was an Ingersoll-Rand DD90.

Vibratory steel wheel roller used in the breakdown position for compacting the 9.5 mm HMA overlay mix.

Steel wheel roller used in the finish position for compacting the 9.5 mm HMA mixture (operated in the static mode).

Figure 21. Two steel wheel rollers used to compact the 9.5 mm HMA mix.

The Dynapac steel wheel roller was operated in the high frequency, low amplitude vibratory mode, while the Ingersoll-Rand roller was operated in the static mode. The breakdown roller was operated close behind the paver. The finish roller was operated right behind the breakdown roller along most of the areas. The following summarizes the number of passes and coverage used by both rollers.

- Dynapac steel wheel roller; high frequency, low amplitude; primary or breakdown roller:
    - First pass along and extended over the shoulder edge by about 2 to 6 inches with vibration.
    - Second pass; same location as for first pass but in reverse without vibration.
    - Third pass along the center of the mat in low amplitude with vibration.
    - Fourth pass along the centerline with the edge of the drum extended over the edge about 2 to 6 inches with vibration.
    - Fifth pass same as location for the fourth pass but without vibration.

- Ingersoll-Rand steel wheel roller; static mode; finish roller:
    - First pass along the shoulder edge with the edge of the steel wheel roller extended over the edge about 2 to 6 inches.
    - Second pass; same location as for the first pass.
    - Third pass down the center of the mat.
    - Fourth pass along the center of the roadway with the edge of the steel drum extended over the edge by about 2 to 6 inches.
    - Fifth pass; same location as for the fourth pass.

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 readings and the densities of the cores found that an insufficient density level was obtained for this mixture.

One possible explanation for this low density is that the breakdown roller was being operated in the low amplitude and the thickness of the mat was less than 1.5 inches in many areas of the project. HMA lifts less than 1.5 inches in thickness may need to be compacted using the static mode of a steel wheel roller.

No visual signs of shoving or tearing of the mixture were noted or observed during the compaction operation. In addition, the Safety Edge$_{SM}$ slope did not shove out or become more vertical, during the compaction operation. In a couple areas of the project, the mixture was easily depressed after compaction. It is expected that the supporting layers are soft. In addition, only localized areas exhibited broken aggregate under the vibratory rollers and most of these areas were along the confined longitudinal joint – on the cold side of the joint.

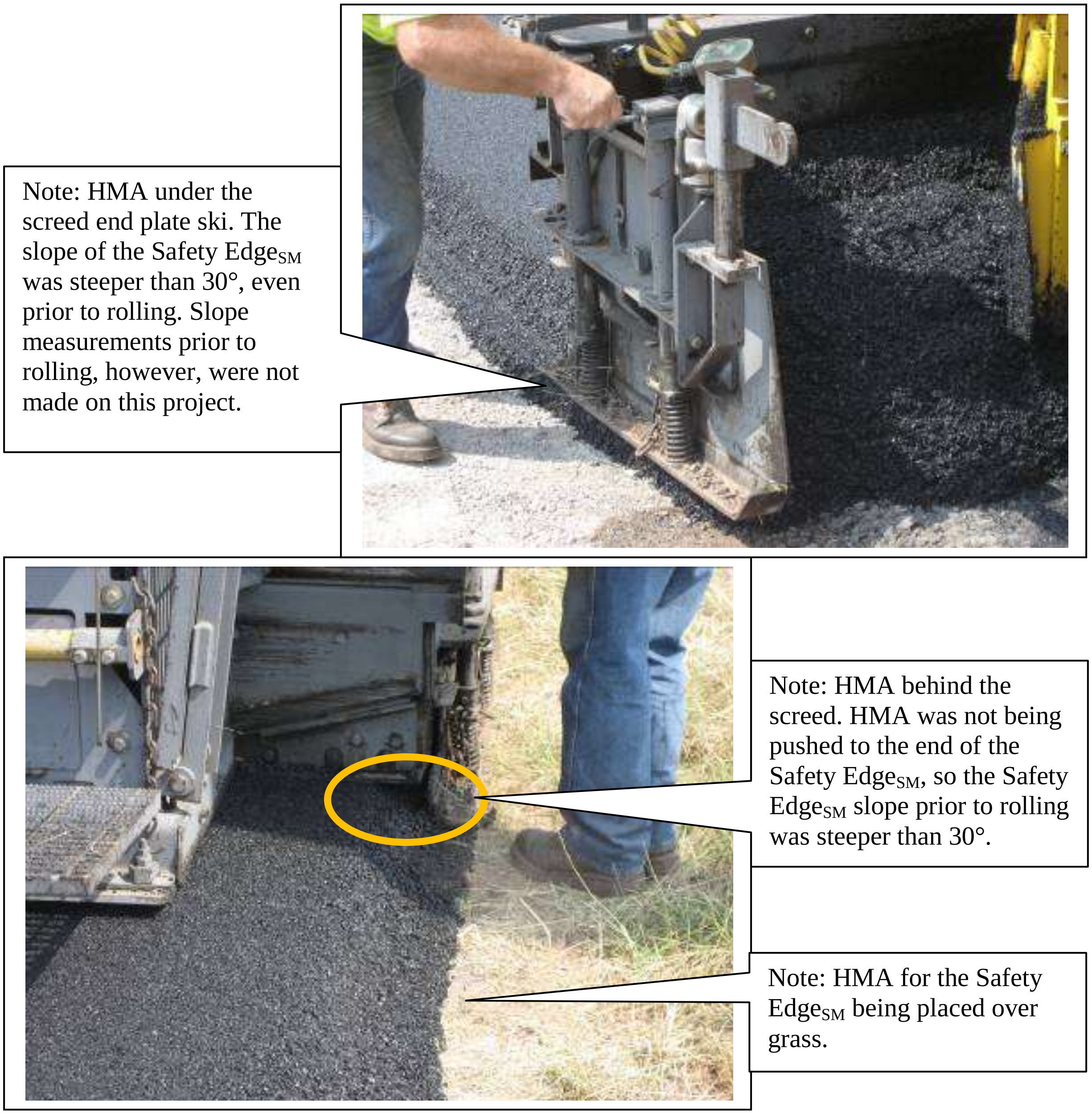
The Safety Edge$_{SM}$ was rolled inconsistently during the project. The majority of the rolling pattern, however, was that the first pass of the breakdown roller was along the Safety Edge$_{SM}$ with the roller extended over the edge of the pavement by about 4 to 6 inches (refer to Figure 22).

Figure 22. Vibratory steel wheel roller used in the breakdown position shown compacting the Safety Edge$_{SM}$ – first pass overhung the edge about 4 inches.

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

The HMA mixture design data was obtained from the Pennsylvania DOT. The HMA mixture design parameters are documented in the Field Evaluation Form, which is a separate document to this field report.

Observations made during paving showed that the HMA mixture was not being pushed to the end of the Safety Edge$_{SM}$ device. Figure 23 shows HMA behind the screed and the Safety Edge$_{SM}$ slope prior to rolling. The slope of the Safety Edge$_{SM}$ was steeper than planned prior to rolling because the mix was not being pushed to the end of the Safety Edge$_{SM}$. The specific reason for the HMA not being pushed to the end of the Safety Edge$_{SM}$ device is unknown for this project. The only mixture design parameter that might have an impact on the slope of the Safety Edge$_{SM}$ and surface texture, however, was voids in the mineral aggregate (VMA). The design VMA was reported to be 17.4 and is considered high for this HMA mixture. It is unknown whether the higher VMA resulted in the steeper slopes measured along this project.



Note: HMA under the screed end plate ski. The slope of the Safety Edge$_{\text{SM}}$ was steeper than 30°, even prior to rolling. Slope measurements prior to rolling, however, were not made on this project.

Note: HMA behind the screed. HMA was not being pushed to the end of the Safety Edge$_{\text{SM}}$, so the Safety Edge$_{\text{SM}}$ slope prior to rolling was steeper than 30°.

Note: HMA for the Safety Edge$_{\text{SM}}$ being placed over grass.

Figure 23. HMA shown under and behind the screed; the HMA was not pushed to the end of the Safety Edge$_{\text{SM}}$ resulting in a steeper slope prior to rolling.

It was also observed that the HMA mixture was not moving above the Safety Edge$_{\text{SM}}$ device – near the screed end plate assembly. HMA mixture was observed to be stationary above the Safety Edge$_{\text{SM}}$ device. The distance between the end of the auger and screed end plate was about 18 to 24 inches. This distance should be less than 18 inches. The reason for the mixture bridging at the surface and not being transferred under the screed is unknown. However, this may also explain the HMA mix not being pushed to the end or edge of the Safety Edge$_{\text{SM}}$ device. The temperature of the HMA being delivered to the project site was reported to be 313 to 327 °F, so it is expected that the temperature of the mix was not a factor for the mix being held in the corner of the screed extension.

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.

- This project is considered an anomaly because of the edge condition along many sections of the roadway. The purpose of this project was to maximize the roadway width, which caused the Safety Edge$_{SM}$ to be placed over loose soil and grass in some areas of the project. The project was not designed with the concept of using the Safety Edge$_{SM}$. In addition, the Safety Edge$_{SM}$ device was used randomly along the project. Those areas included in this field study were observed during paving to ensure that the Safety Edge$_{SM}$ was being used. For the other areas, it is unknown whether the Safety Edge$_{SM}$ was used or was raised during paving.
- Although the 9.5 mm HMA mixture is considered a relatively fine aggregate mixture, the surface texture of the mixture and along the Safety Edge$_{SM}$ was coarse. More importantly, the coarse aggregate were loose along the bottom of the Safety Edge$_{SM}$ and could be easily removed. As noted in the field report, this could be one of the reasons why the width of the Safety Edge$_{SM}$ was so narrow – resulting in a much steeper slope than expected.
- The density of the HMA mixture adjacent to the Safety Edge$_{SM}$ was found to be higher than along the unconfined edge in the areas placed without the Safety Edge$_{SM}$ – a positive benefit from the Safety Edge$_{SM}$ device.
- Many areas along this project were excluded from the field study because the thickness of the HMA lift was less than 1.5 inches. The thicknesses, densities, and slopes are only representative of those areas where the HMA thickness near the edge of the pavement was near or greater than 1.5 inches.

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

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.

Section Identifier	Core/Section ID	Station	Safety Edge		
			Width of Taper	Thickness of Taper	Slope
Location relative to the cores taken and to the intersection between Bellaire Road and Maple Dale Road.	1	984.8	1.25	1.25	45
	1	934.8	1.5	1.875	51
	1	884.8	2.5	2.375	44
	1	834.8	1.5	1.75	49
	3	747	1	1.5	56
	3	697	1.625	2.25	54
	3	647	1.625	1.375	40
	3	597	1.75	2	49
	3	547	1	1.25	51
0+35 for this section is at the culvert and center of the PCC pipe (identified by a delineator). This section is north of the intersection with Maple Dale Road in the northbound lane and south of 365 Bellaire Road. This section looked the best.	No core	0+00	2.875	2.25	38
	No core	0+25	1.5	2	53
	No core	0+50	1.5	1.75	49
	No core	1+00	1.5	2.125	55
	No core	1+25	1.5	1.5	45
	No core	1+50	1.5	1.375	43
	No core	1+75	2.25	2.125	43
Mean Value			1.648	1.797	47.813
Standard Deviation			0.500	0.382	5.431
Coefficient of Variation, %			30.4	21.2	11.4

Table A-2. Core thickness measurements.

Area/Location	Core #	Lane Direction	Station	Type of Section	Core Thickness, in.	
					A – Adjacent to Edge	B – 3 feet from Edge
Areas south of intersection between Bellaire Road and Maple Dale Road	1	Southbound	884.8	Safety Edge	1.25	1.5
	2	Northbound	886.4	Non Safety Edge	1.5	1.75
	3	Southbound	597	Safety Edge	1.25	1.5
	4	Southbound	515	Non Safety Edge	1.5	1.5
	5	Southbound	429.6	Non Safety Edge	1	1.25
Areas north of intersection between Bellaire Road and Maple Dale Road	6	Southbound	1125	Non Safety Edge	1.75	1.75
	7	Southbound	782.5	Safety Edge	2	2
				Mean, in.	1.464	1.607
				Standard Deviation, in.	0.336	0.244
				Coefficient of Variation, %	22.97	15.18

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

Area/Location	Core #	Lane Direction	Station	Type of Section	Density of Cores		Nuclear Density Values		Adjustment Ratio	
					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
Areas south of intersection between Bellaire Road and Maple Dale Road	1	Southbound	884.8	Safety Edge	128.2	139.0	139.75	139.75	0.917	0.995
	2	Northbound	886.4	Non Safety Edge	129.8	139.7	128.85	139.00	1.007	1.005
	3	Southbound	597	Safety Edge	135.7	135.0	138.60	137.15	0.979	0.984
	4	Southbound	515	Non Safety Edge	131.4	141.4	136.65	146.60	0.962	0.965
	5	Southbound	429.6	Non Safety Edge	133.4	139.0	134.55	137.90	0.991	1.008
Areas north of intersection between Bellaire Road and Maple Dale Road	6	Southbound	1125	Non Safety Edge	133.8	143.2	132.90	138.50	1.007	1.034
	7	Southbound	782.5	Safety Edge	140.3	142.8	140.45	141.85	0.999	1.007
Summary Values	Mean Value, pcf				133.23	140.01	135.96	140.11	0.980	1.000
	Standard Deviation, pcf				4.0178	2.8026	4.1608	3.2339	0.0322	0.0217
	Coefficient of Variation, %				3.02	2.00	3.06	2.31	3.28	2.17

Table A-4. Density readings made with a nuclear density gauge (Troxlor gauge 3440).

Maximum Specific Gravity of Mix:		2.543	Max. Density:	158.7
Adjustment Ratios for Nuclear Gauge:	A=	0.980		
	B=	1.000		

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
Areas south of intersection between Bellaire Road and Maple Dale Road	1	Southbound	984.8	Safety Edge					1.25		
	1	Southbound	934.8	Safety Edge	139.60	145.75	136.81	145.75	1.875	13.79	8.16
	1	Southbound	884.8	Safety Edge	139.75	139.75	136.96	139.75	2.375	13.70	11.94
	1	Southbound	834.8	Safety Edge	139.40	141.45	136.61	141.45	1.75	13.92	10.87
	3	Southbound	747	Safety Edge					1.5		
	3	Southbound	697	Safety Edge					2.25		
	3	Southbound	647	Safety Edge	137.35	135.60	134.60	135.60	1.375	15.18	14.56
	3	Southbound	597	Safety Edge	138.60	137.15	135.83	137.15	2	14.41	13.58
	3	Southbound	547	Safety Edge	141.90	140.90	139.06	140.90	1.25	12.37	11.22
Areas north of intersection between Bellaire Road and Maple Dale Road	7	Southbound	712.5	Safety Edge	138.30	136.05	135.53	136.05		14.60	14.27
	7	Southbound	782.5	Safety Edge	140.45	141.85	137.64	141.85		13.27	10.62
	7	Southbound	812.5	Safety Edge	143.55	143.40	140.68	143.40		11.36	9.64
Average Value					139.878	140.211	137.080	140.211	1.736	13.623	11.650
Standard Deviation					1.895	3.422	1.857	3.422	0.421	1.170	2.157
Coefficient of Variation					1.35	2.44	1.35	2.44	24.27	8.59	18.51
Areas south of intersection between Bellaire Road and Maple Dale Road	2	Northbound	986.4	Non-Safety Edge							
	2	Northbound	936.4	Non-Safety Edge	136.65	139.25	133.92	139.25		15.62	12.26
	2	Northbound	886.4	Non-Safety Edge	128.85	139.00	126.27	139.00		20.43	12.41
	2	Northbound	836.4	Non-Safety Edge							
	4	Southbound	515	Non-Safety Edge	136.65	146.60	133.92	146.60	1.625	15.62	7.62
	4	Southbound	465	Non-Safety Edge	138.45	147.80	135.68	147.80	1.75	14.50	6.87
	5	Southbound	429.6	Non-Safety Edge	134.55	139.45	131.86	139.45	1.75	16.91	12.13
	5	Southbound	379.6	Non-Safety Edge	136.50	137.90	133.77	137.90	2.25	15.71	13.11
	5	Southbound	329.6	Non-Safety Edge					1.5		
Areas north of intersection between Bellaire Road and Maple Dale Road	6	Southbound	1075	Non-Safety Edge	132.25	136.05	129.61	136.05		18.33	14.27
	6	Southbound	1125	Non-Safety Edge	132.90	138.50	130.24	138.50		17.93	12.73
	6	Southbound	1175	Non-Safety Edge	134.75	141.05	132.06	141.05		16.79	11.12
Average Value					134.617	140.622	131.924	140.622	1.775	16.872	11.391
Standard Deviation					2.923	3.971	2.864	3.971	0.285043856	1.805	2.502
Coefficient of Variation					2.17	2.82	2.17	2.82	16.0588088	10.70	21.97