

**Construction of a Safe Pavement Edge:
Minimizing the Effects of Shoulder Dropoff**

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ABSTRACT

Crashes on two-lane undivided highways result in nearly sixty percent of the total fatalities on our nations highways. One major concern for driver safety on these facilities is the interface of the paved surface and the unpaved shoulder. Vertical dropoffs found along the edge of the pavement can lead a driver to overcorrect upon re-entry onto the paved surface. This overcorrection may lead the vehicle to cross into opposing traffic or leave the opposite side of the roadway.

One solution to this problem is to form a thirty-degree tapered transition at the edge of the paved surface called the "safety edge". A safety edge provides an easily traversable transition for an errant vehicle to reenter the travel lane from the unpaved shoulder. The Georgia Department of Transportation constructed a 13.3 mile (26.6 lane miles) asphalt overlay on a rural, two-lane, undivided highway using the safety edge. The objective of this paper is to report on the research conducted on this project. This research studied the construction and the durability of a safety edge placed at the interface of the paved surface and the grassed shoulder.

This report documents the construction of a safety edge using two different devices. Findings of this research indicate that the safety edge can be constructed with no impact to production and at less than one percent additional material costs. Based on field evaluations the safety edge is likely to serve as temporary safety feature while an asphalt overlay is constructed and a permanent safety feature where dropoff locations emerge in the future.

INTRODUCTION

Adopted in 1998, the American Association of State Highway and Transportation Officials (AASHTO's) Strategic Highway Safety Plan identified 22 goals to pursue in order to reduce the number of crashes and fatalities on our nations highways. Two of these goals are to *minimize the consequences of leaving the road* and to *reduce head-on and across median crashes*. (1) Of all the fatal accidents reported in 2002, approximately one-third result from a vehicle leaving the roadway and hitting a fixed object and an additional twenty percent of the fatalities occurred due to vehicle rollover or head-on collisions. These two types of vehicle crashes account for twenty percent of the total crashes, and are among the most severe type of crash responsible for one-half of the total fatalities. (2) According to the same statistical data, the majority (57%) of the fatal accidents occurred on undivided two lane roads. An important goal to achieve a reduction of fatalities on these types of facilities is to keep vehicles in their travel lane.

Vertical pavement edge dropoff has been identified as a significant safety hazard on roadways for half a century and has been related to the two types of crashes mentioned above to some degree. An errant vehicle that has departed the paved surface can experience difficulty reentering the travel way if the tires traverse a vertical or near vertical edge of any appreciable height. This tire to pavement interaction is known as "scrubbing". When a tire(s) scrubs the pavement edge, resulting forces of a vertical pavement edge act on that tire to prevent reentry. As the driver increases the angle of tire reentry, a critical steering angle is ultimately reached. This causes a sudden and steep-angled reentry onto the travel way. Compounding the danger, the rear wheel may catch the pavement edge causing the vehicle to enter the roadway at a steep angle. This resulting steep-angle reentry can lead to over steering and head-on collisions. These erratic actions may cause the vehicle to veer into the adjacent lane, where it has the potential to collide with oncoming traffic or depart the paved roadway on the opposite side of the original departure. (3)

An edge dropoff of four or more inches is considered unsafe if the roadway edge is at a 90-degree angle to the shoulder surface. (4) Near vertical edge dropoffs of less than 4 inches are still considered a safety hazard to the driving public and may cause difficulty upon reentry to the paved surface. The AASHTO Design Guide recommends regular maintenance to provide a flush shoulder recognizing that a dropoff can adversely affect driver control when driving off of the paved surface at any appreciable speed.(5) The Texas Transportation Institute (TTI) conducted research in 1982 that demonstrated the effect of using an angled wedge at the edge of the pavement to effectively reduce this type of uncontrolled reentry to the paved roadway. This research concluded that an angled wedge of 45-degrees or flatter can significantly reduce over-steering upon reentry. (4)

There are six areas where a pavement edge dropoff is often encountered. These areas include:

1. Horizontal curves,
2. Near Mailboxes,

3. Turnarounds,
4. Shaded areas,
5. Eroded Areas,
6. and Asphalt Pavement Overlays.

Horizontal curves have a greater occurrence of edge rutting than tangent roadway sections. This is due to vehicles departing the paved surface more frequently than on straight sections. Similarly, turnarounds, intersection gore areas, and areas near mailboxes exhibit pavement edge drop off frequently due to tire departure.

Areas underneath trees or other objects that cast a shadow on the pavement edge for a majority of the day have little or no vegetation on the unpaved shoulder. This lack of vegetation can allow the area to erode away and a pavement edge dropoff may develop over time. (6) Other areas can have excessive erosion due to roadway geometry or soil characteristics.

An asphalt pavement overlay is also a common source of pavement edge dropoff. This situation can be compounded by the existing edge rutting caused by any of the other situations mentioned. Consider a common scenario of a two-inch asphalt overlay on a tree lined two-lane roadway. These types of roadway are prone to having existing edge dropoffs due to the shaded areas. Compound this existing dropoff with the two-inch dropoff due to the overlay and there could be many places along the roadway with a 4 to 6 inch near vertical dropoff.

Construction of a safety edge when a road surface is repaved can serve two important functions. The safety edge serves as a mitigating measure to help with pavement edge dropoff that occurs after a pavement overlay is placed, but before shoulders can be reconstructed flush with the travel way. This temporary exposure may exist for several months depending on the sequence of construction operations. The safety edge also can serve as a permanent safety feature for future areas of edge rutting or soil erosion.

All six of the dropoff conditions noted were found during the pre-construction investigation of the research test sections. These situations are not all inclusive, and significant edge dropoff can be found in other locations. Whatever the cause of a pavement edge dropoff, the result is an unsafe condition for the motorist.

An additional benefit to including the safety edge into the normal paving operation is the reduction of tort liability. Pavement edge dropoff is a common source of tort claims against many highway agencies and it is not unusual to find legal cases in which monetary awards were given to a motorist due to a dropoff condition caused by a pavement overlay. (7,8,9,10) In these cases, the public entity was found guilty of creating an unsafe condition for the motorist and not properly informing them of that condition. The use of the safety edge may aid in such litigation by demonstrating that the public agency or private contractor is proactively taking steps to prevent unsafe pavement edge conditions in workzones.

OBJECTIVE

Although the safety hazards of pavement edge dropoff have been well documented and the benefits of having a tapered transition at the edge of the paved surface are known, there has been little research documenting the construction of a tapered edge. This lack of published data on the construction, material performance, and durability of the safety edge is believed to have inhibited the use of this safety feature by federal, state, and local highway agencies. While public agencies are often aware of the safety implications of pavement shoulder dropoff, they are often unaware of the mitigating effects a safety edge produces.

This report documents a project that incorporated a tapered edge in the construction of a 1.5 inch pavement overlay. The primary objective of this research was to evaluate the feasibility of construction and the performance of two safety edge hardware systems, one fabricated by the Georgia Department of Transportation (GDOT) and a commercial device developed by TransTech Systems, Inc. The durability of the safety edge was also observed and is discussed in this report.

SAFETY EDGE DESIGN AND CONSTRUCTION

The safety edge is designed to create a tapered edge approximately 6 to 8 inches in length between the paved travel way and the unpaved shoulder. Consideration was given to constructing the edge over the existing paved surface. This design would provide more support under the fillet section, but would decrease the width of the travel way. With this design, the benefits of the safety edge during construction would be limited, as it would not correct an existing edge drop-off. For these reasons, the safety edge design should be constructed over the unpaved shoulder as seen in Figure 1.

The safety edge is constructed with the angle break lining up directly over the existing paved surface. Constructing the edge onto the unpaved shoulder does not result in a decrease in lane width. This design will also adjust to the varying height differentials between the paved surface and the unpaved shoulder. The benefits to this design allow for varying dropoff heights existing before construction. The edge is placed in the same paving operation as the asphalt pavement wearing layer and does not require second construction operation.

The safety edge design is not intended to substitute for a shoulder that is flush with the paved travel way. The safety edge is a mitigation of the dropoff created by the asphalt overlay. After the pavement overlay is complete the shoulder should be graded back flush with the paved surface. The safety edge will also serve as a permanent safety feature in areas where edge rutting occurs in the future.

The safety edge can be implemented on any type of roadway facility as an integrated part of the asphalt paving process. Two lane undivided highways typically do not have paved shoulders, have a higher occurrence of shoulder dropoff, and are the location of the majority of highway fatalities. For these reasons incorporation of the safety edge design is likely to have the most impact on this type of facility.

Safety Edge Installation Hardware

Two different devices used to construct the safety edge were evaluated. One device, hereto referred to as the GDOT safety wedge, was fabricated “in house” by the GDOT maintenance department. Several iterations of the GDOT wedge were fabricated and evaluated before a final design was achieved. The GDOT hardware seen in Figure 2, is a steel wedge that is bolted onto the screed end gate. This device has a rounded leading edge that is crucial to providing a smooth finished appearance to the safety edge. Previous GDOT hardware did not include the rounded leading edge and did not produce a smooth finished surface.

The hardware is connected to the end gate of the paver screed. The shoe of the end gate rides on the shoulder of the pavement and is able to freely move vertically allowing it to continually adjust to height differentials. It is important that this steel wedge is able to free float with the end gate in order for the safety wedge to be able to adapt to differing shoulder dropoff heights and pavement overlay thicknesses. The GDOT safety wedge is connected with a simple two-bolt connection allowing it to be easily attached and removed. The hardware should fit closely to the screed (approximately 1/4”) to prevent asphalt material from falling behind the device. However, the triangle should not contact the screed in order to insure that it is not affecting the angle of attack of the screed or limiting the device from moving vertically. The GDOT safety wedge demonstrated the ability to create the safety edge from a dropoff depth of 0 to 6 inches.

A proprietary device developed by TransTech Systems, Inc was also evaluated. TransTech Systems, Inc describes their Safety Edge Maker™ (SEM) hardware as a mounting plate that easily attaches to all varieties of paving machines with a self-adjusting spring that allows the device to follow the roadside surface. The adjusting screw allows for setting the initial height and the edge-making component itself includes a radius edge that helps the device to adapt to obstacles it may encounter. The unit provides a compound angled surface that pre-compacts the asphalt as it enters the device. As the asphalt continues under the 30-degree edge it is then smoothed, as it would be under the screed bottom, to create a better surface finish on the angled mat.

Figure 3 shows a technical drawing of the device along with the mounting plate. It should be noted that the SEM used in this research was a prototype device and that additional refinements to the SEM are being made and evaluated by TransTech Systems, Inc.

Both of these devices force the HMA material under the hardware. In essence this action extrudes the material into the tapered edge shape. This extrusion process allows for some reorientation of the aggregate particles and compaction of the material.

SCOPE

A 13.3-mile (26.6 lane miles) section of roadway on Georgia State Route 88 was chosen to evaluate the constructability of the safety edge. The project consisted a 1.5-inch asphalt overlay of a two lane undivided highway. The project was located just south of August,

Georgia. This area of Georgia is located in a temperate climate with an average rainfall of 45 inches per year. Soils at the project location consisted of a sandy clay. During the preconstruction investigation it was observed that this type of soil was susceptible to erosion where grassing was not established.

The typical cross section of the pavement includes two 12-foot lanes with two foot paved shoulders. Adjacent to the paved surface the roadway had grassed shoulders of varying width. A total of 11 miles (22 lane miles) were constructed with a tapered edge at the transition of the paved surface and the grassed shoulder. A control section of two miles in length was constructed without the safety edge. An additional two-mile section of the project had in place concrete curb and gutter and therefore did not incorporate the safety edge.

Two different devices were evaluated along with two different asphalt mix designs. The first section included hot mix asphalt (HMA) designed using the Marshall mix design procedure. This HMA mix design procedure results in a higher asphalt content, a smaller nominal maximum aggregate size (in this case 9.5 mm), and a finer aggregate gradation. This type of mixture typically has greater workability and is therefore more easily extruded under the safety wedge hardware. The second section incorporated a 12.5 mm HMA designed to meet superpave design criteria. Superpave HMA designs typically have a lower percentage of asphalt and a coarser aggregate gradation as compared to Marshall mix designs. The resulting superpave mixes are typically less workable. (11) These two HMA designs were chosen to study a range of different mixtures that are typically specified in resurfacing low volume roadways in Georgia.

Research Plan

This research was conducted to answer critical questions about the constructability, performance, and durability of the safety edge. As stated, the safety benefits of a tapered edge have been proven through previous research efforts and therefore no measurements of vehicle dynamics or crash data analysis were conducted for this research.

The most critical question that this research plan was designed to address is the constructability of the safety edge. Before this research project was undertaken no efforts had been taken to construct this type of tapered pavement edge in Georgia. Qualitative information was gathered from field visits before, during, and after construction to determine the impact of using the safety edge design on production and to document the finished appearance of the safety edge. This evaluation included input from the project personnel on the performance of the hardware and the ease of implementation of the safety edge.

An initial site investigation was made to locate areas where dropoffs were present. These locations were measured, photographed, and located with Global Positioning System (GPS) instrumentation.

Pavement density measurements were taken at three places transversely across the pavement cross section. These measurements were taken at the center of the lane, at the edge line, and

on the wedge section itself. The density measurements were performed on core samples taken from the mainline and from saw cut specimens taken from the safety edge. Three sets of samples were taken longitudinally for one lot, which is equal to one day's production.

The center of the lane cores were used as a baseline comparison and are considered the maximum density achieved on the cross section. Achieving compaction at the edge of a pavement can be difficult due to the lack of edge confining pressure. Density measurements were taken at the edge line of the pavement to determine the degree of compaction that was achieved due to the lateral confining pressure of the safety edge hardware. This measurement was taken on the sections that included the use of the safety edge and the control sections. A comparison of density measurements was made to determine the effect of the confining pressure applied by the edge hardware on the edge of the pavement section. Also, a comparison of the relative compaction between the edge of pavement and the center of the lane was made.

An important assumption made in this research is that the pavement density at the edge of the pavement would be affected by the addition of the safety edge device due to the lateral confinement provided by the additional paving material and the extrusion forces applied by the hardware. Also, the edge density is assumed to be an indicator of the compaction performance of each of the devices used.

Smoothness measurements for a six-mile segment of roadway were obtained before and after the pavement overlay was constructed. These measurements were taken for both the control section(s) and the section incorporating the safety edge. Statistical comparisons of control and test sections were evaluated to determine the effect of using the safety edge on roadway smoothness. These measurements were made using calibrated South Dakota Profiler equipment and are reported as an International Roughness Index (IRI).

EVALUATION OF PAVEMENT DENSITY MEASUREMENTS

Bulk specific gravity and density values were determined on all of the core samples taken by both the AASHTO T-166 method and the ASTM D6752-03 standard using the automatic vacuum sealing method. Unfortunately, the sawn wedge section samples did not survive transportation and testing. This was due to the irregular shape of the triangular wedge sections. For this reason, density measurements of the safety edge are not available.

In order to determine the effectiveness of the safety edge hardware, the density measurements near the edge of pavement were used as an indicator of compaction effort. The assumption made is that the lateral confining pressure of the hardware will be reflected in the density of the edge of pavement.

A density ratio of the edge of pavement measurements to the center of the lane measurements (ρ_{EP} / ρ_{CL}) was determined. By using this ratio in the analysis the effects of other variables that effect density are minimized. The intent is to not to compare the raw density value, but to look at the relative compaction as compared to the center of the lane. This statistic was

then used to evaluate the effects of mix type and device on the density of the pavement edge. The average values of the test sections were also calculated and the results are discussed below.

As expected, the average densities at the center of the lane are higher than corresponding average densities at the edge of pavement in all of the six test sections (Figures 4 and 5). This is due to the lack of confining pressure at the edge of the pavement. A comparison of the density ratios of the different test sections was conducted to determine the differences in compaction levels by the two different devices and for the two different mix types.

As seen in Figures 4 and 5, the average densities of sections using the SEM are lower than the densities of the control section and GDOT wedge section at both of the center of lane and the edge of pavement for the 9.5 mm Marshall HMA. A comparison of the density ratios of the three sections was conducted in order to determine if these two sections were different. The results shown in Table 1 indicate that there is no statistical difference between the control section and the GDOT section or the SEM section. It is worth noting that the density ratios were calculated for only 4 of the 9 locations (see Table 2) in the SEM section built with the 9.5 mm Marshall HMA. This is due to the degradation of the pavement cores during shipping and testing.

The density measurements obtained from the 12.5 mm Superpave HMA sections were considerably higher and had less variability than those samples taken from 9.5 mm Marshall HMA sections for both of the devices. Similar conclusions can be drawn from the analysis of the Superpave test sections as compared to 9.5 mm Marshall test sections. The density ratios and the average densities of both the center of the lane and the edge of the pavement are similar for all three of the test sections. The conclusion can be made that the sections that did not have the safety edge had no significant difference in density at the edge of the pavement than the test sections that included the safety edge.

An outlier observation analysis was conducted on two values (Test Lot 1, Location 6; and Test Lot 5, Location 3). Based on this analysis these values were found to be outliers and therefore excluded in the calculation of the averages, standard deviations, and density ratios.

Based on the analysis of the density measurements taken at the pavement edge, it is unclear as to whether this measurement properly identifies the compaction of the tapered edge section. The results discussed the post construction observations section may be a better indicator of the durability of the safety edge.

EVALUATION OF SMOOTHNESS DATA

Smoothness measurements using a high-speed inertial profiler were made in both wheelpaths to determine if the addition of the safety edge had an effect on the smoothness of the finished pavement. The results of the smoothness data presented in Table 3 indicate that there is no degradation in smoothness profile due the addition of the safety edge.

The one-mile safety edge test section has an IRI value less than all but one of the segments tested for both wheel paths. This data suggests that the safety edge can be constructed without an adverse effect on pavement smoothness. No additional irregularities were noticed

by project personnel that would indicate any effect on smoothness by the addition of the safety edge hardware.

POST CONSTRUCTION PERFORMANCE OBSERVATIONS

A field investigation the safety edge test sections was made in July 2004, approximately one year after the project was constructed. This field investigation consisted of a visual inspection of the areas where dropoffs were documented before the pavement overlay was constructed. Ten sites were located where dropoffs were initially measured in June 2003. After one year, these sites had remarkably similar dropoffs as were found before the pavement overlay. This can be expected because many of these sties were located in areas of shade where it is difficult to reestablish grassing. At these sites the safety edge was visible and still in “like new” condition. No visible distress was seen along any of the observed sections of the safety edge. This evaluation was made for both sections made with the SEM and the GDOT hardware. In contrast, the control sections paved without the safety edge exhibited a near vertical edge where the dropoffs had re-emerged. Over the majority the length of the project grass had been successfully re-established and the shoulders remain flush with the paved surface. There were no observations made that indicate that the safety edge will contribute to shoulder erosion or that the safety edge will substantially deteriorate over time.

CONCLUSIONS AND RECOMMENDATIONS

The safety edge was constructed on a two lane undivided highway in rural Georgia. Both the GDOT Safety Edge Hardware and the Safety Edge Maker hardware successfully produced the safety edge with little impact on production and at negligible cost in materials or equipment. The safety edge was produced successfully for both a 9.5 mm Marshall HMA design and a 12.5 mm Superpave HMA, which are the typical HMA designs for this type of roadway. Neither the GDOT safety wedge nor the SEM hardware had a significant effect on the relative density at the edge of the pavement. However, based on the field observations conducted one year after construction the safety edge has no visible signs of deterioration. Both edges placed by the GDOT wedge and the TransTech SEM are performing adequately and there is no evidence to suggest that the safety edge will deteriorate over time. Long term evaluation of the test site is planned in order to observe the durability of the safety edge over an extended period of time. On Georgia highways the safety edge can be readily constructed as an integral part of the paving operation.

This research did not attempt to quantify the safety benefits of the safety edge. Other projects should be constructed to evaluate the construction, durability, and performance of the safety edge under several different highway conditions and at several locations throughout the country. The crash data of these sites should be monitored for several years in order to quantify the benefits of the safety edge design.

The safety edge shows promise as a low cost solution to mitigate pavement shoulder drop off. Federal, State, and Local Highway Agencies should pursue implementation of the safety edge design as a low cost means to mitigate shoulder dropoff. The implementation of the

safety edge design would be most applicable to asphalt resurfacing projects on two lane undivided roadways with limited paved shoulders.

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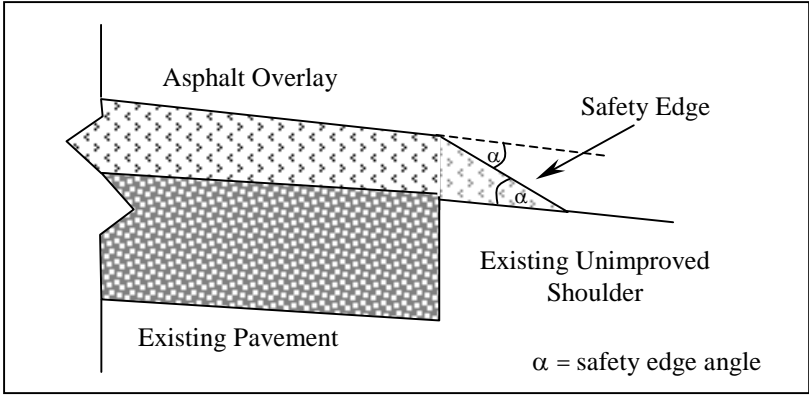


FIGURE 1: Safety Edge Detail

TABLE 1: Statistical Test of the Means of the Density Ratios

Test Sections	t-statistics	Degree of Freedom	t-critical with 5% significance level	p-value	Significant Difference?
[F mix – control] to [F mix – GDOT wedge]	0.676	10	2.228	0.514	No
[F mix – control] to [F mix – TT wedge]	0.051	5	2.571	0.961	No
[SP mix – control] to [F mix – GDOT wedge]	1.279	9	2.262	0.233	No
[SP mix – control] to [F mix – TT wedge]	0.856	9	2.262	0.414	No

TABLE 2: Density Measurements

Test Lots	Mix Type	Wedge Maker	Location Number	Density at Center of Lane (ρ_{CL} , pcf)	Density at Edge of Pavement (ρ_{EP} , pcf)	Density Ratio (ρ_{EP} / ρ_{CL})
1	9.5 mm Type F	No Wedge (Control Section)	1	139.5	126.5	0.907
			2	143.8	131.4	0.914
			3	140.2	132.3	0.943
			4	138.2	131.8	0.954
			5	138.7	133.9	0.965
			6	139.3	139.4*	1.001*
			Average	140	131.2	0.9
Std. Dev.	2.0	2.8	0.025			
2, 3, 4	9.5 mm Type F	GDOT Wedge	1	138.4	125.3	0.905
			2	138.5	129.8	0.937
			3	139.5	124.5	0.892
			4	135.9	131.5	0.967
			5	142.4	N. A.	N. A.
			6	139.6	128.9	0.923
			7	140.5	135.9	0.967
			8	142.4	128.9	0.905
			9	139.5	N. A.	N. A.
			Average	139.6	129.3	0.926
Std. Dev.	2	3.8	0.03			
8, 9, 10	9.5 mm Type F	TransTech Wedge	1	131.9	125.6	0.952
			2	135.8	N. A.	N. A.
			3	134.2	N. A.	N. A.
			4	138.0	127.2	0.922
			5	137.4	122.0	0.888
			6	130.8	N. A.	N. A.
			7	N. A.	129.0	N. A.
			8	N. A.	124.2	N. A.
			9	127.6	124.9	0.979
			Average	134.15	125.5	0.935
Std. Dev.	3.9	2.4	0.039			
6	12.5 mm Superpave	No Wedge (Control Section)	1	146.3	133.0	0.909
			2	144.1	132.3	0.918
			3	145.5	134.8	0.927
			4	141.1	132.5	0.939
			5	142.3	136.1	0.957
			6	145.4	136.3	0.938
			Average	144.1	134.2	0.931
Std. Dev.	2.1	1.8	0.017			
5	12.5 mm Superpave	GDOT Wedge	1	143.3	133.5	0.932
			2	141.5	134.6	0.952
			3	145.9	126.4*	0.866*
			4	142.3	135.1	0.949
			5	145.3	138.7	0.954
			6	147.1	136.2	0.926
			Average	144.2	135.6	0.943
Std. Dev.	2.2	2.0	0.013			
7	12.5 mm Superpave	TransTech Wedge	1	148.6	135.1	0.909
			2	144.2	135.5	0.94
			3	145.2	137.3	0.946
			4	144.3	138.6	0.96
			5	144	132.4	0.919
			6	140.4	136.7	0.974
			Average	144.4	135.9	0.941
Std. Dev.	2.6	2.2	0.024			

*values were determined to be outliers and not included in the average and standard deviation

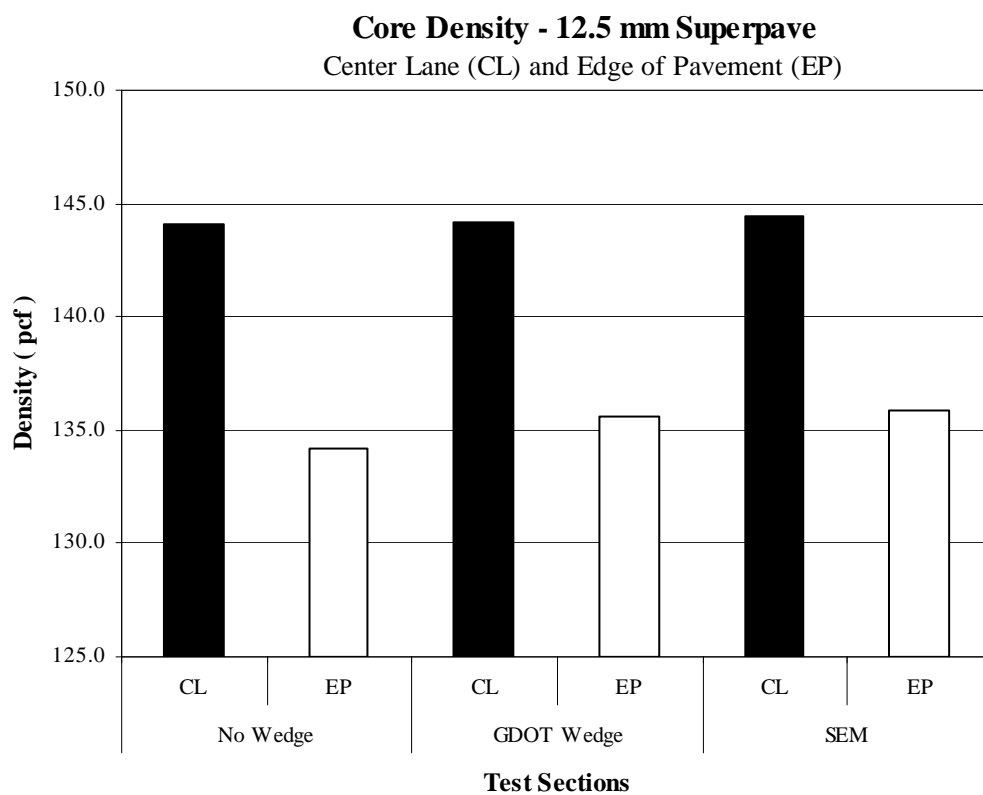


FIGURE 4: Core Density – 12.5 mm Superpave

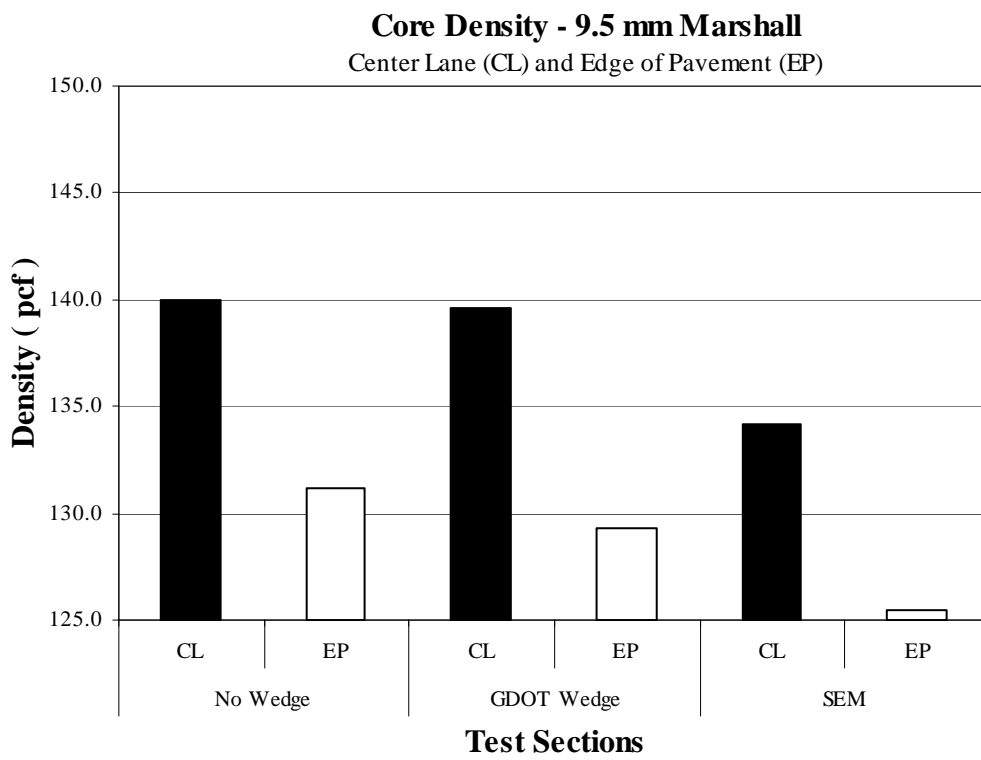


FIGURE 5: Core Density – 9.5 mm Superpave

TABLE 3: Smoothness Data

From (mile)	To (mile)	Left Wheelpath IRI (in/mile)	Right Wheelpath IRI (in/mile)
0.437	1	71	73
1	2	73	73
2*	3*	67	66
3	4	80	73
4	5	70	66
5	6	67	63

** safety edge test section*

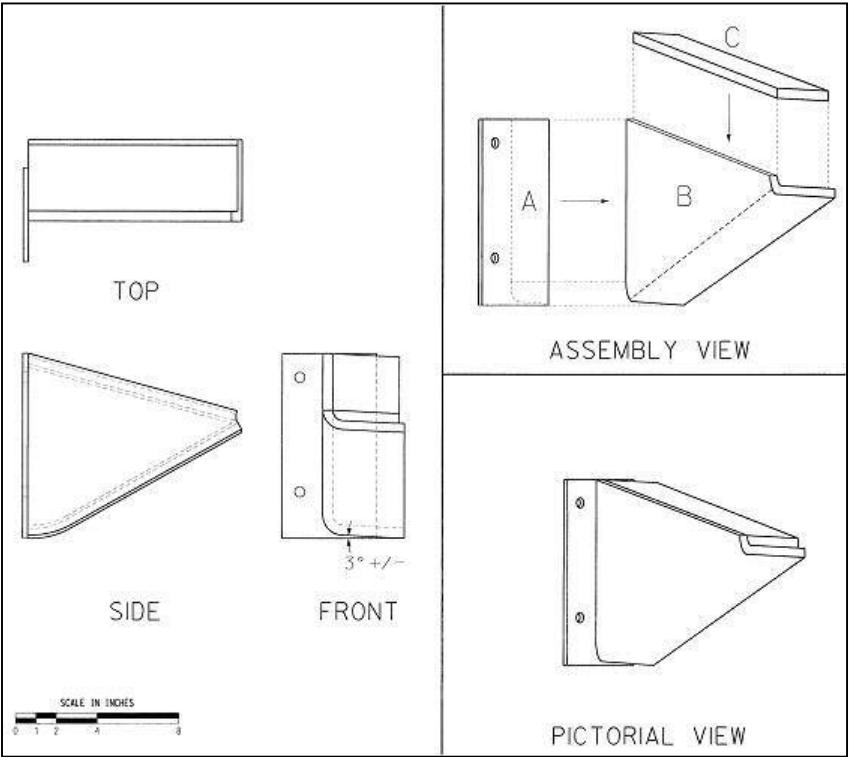


FIGURE 2: GDOT Safety Wedge Technical Drawing

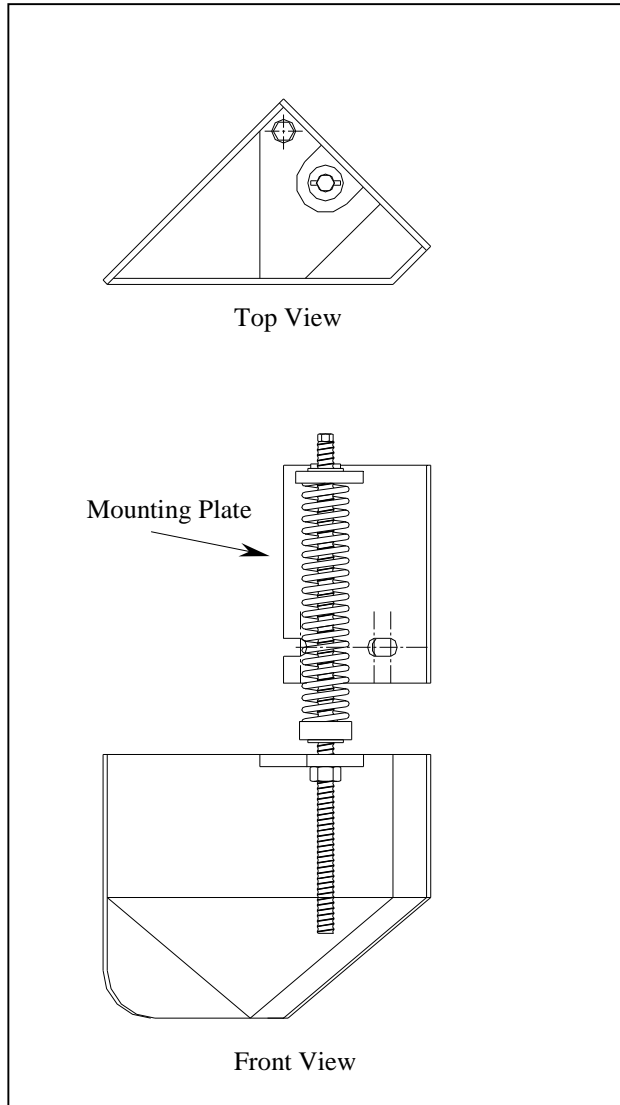


FIGURE 3: Trans Tech Systems Inc. SEM