Pavement Edge Treatment — Final Report

WA-RD 798.2

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Experimental Feature Report

Final Report
Experimental Feature WA 11-01

Pavement Edge Treatment

Contract 8017, SR 395
Lee Road to Junction I-90

Contract 8116, SR 410
Twin Creek to Mather Memorial Park Pull-Off Paving

Contract 8241, SR 21
Curlew State Park to North of Rin Con Creek

Contract 8271, SR 542
Fossil CR to Wells CR RD Vic Paving

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16. ABSTRACT
Four projects were built over two construction seasons using special devices attached to the paving machine that produces a 30º slope on the outside pavement edge instead of the near vertical drop-off common with conventional paving equipment. This pavement edge treatment allows vehicles that leave the roadway a gentler slope to navigate when remounting the pavement.

The projects used four types of devices; (1) the TransTech Shoulder Wedge Maker™, (2) the Advant-Edge™, (3) the Carlson Safety Edge End Gate, and (4) a contractor built device. All of the devices were able to produce a finished pavement slope that was close to the 30º angle recommended by FHWA.

The cost of adding the pavement edge treatment was minimal for both the Contractor and WSDOT. The safety benefits of the pavement edge treatment could not be measured due to the absence of a statistically significant number of crashes at the test locations.

17. KEY WORDS
Safety Edge℠, Slope, HMA, Advant-Edger™, TransTech Shoulder Wedge Maker™, Troxler Safety *Slope*™, Carlson Safety Edge End Gate, pavement edge treatment

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DISCLAIMER

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Introduction

Safety Edge$_{SM}$ is one of the safety enhancements being promoted through the Federal Highway Administration's (FHWA) Every Day Counts (EDC) program. The Every Day Counts program identifies and deploys innovative technologies that are aimed at shortening project delivery, enhancing safety, or protecting the environment. The Safety Edge$_{SM}$ pavement edge treatment enhances safety through a modification to asphalt paving equipment that result in a sloped edge in place of a vertical edge at the outside shoulder. WSDOT embraced the EDC program by constructing a number of demonstration projects which were monitored for constructability, pavement edge stability and durability, operational characteristics, and collision reduction.

Safety Edge$_{SM}$ Description

If a vehicle leaves the roadway in a location where the pavement edge drops off vertically, a driver may overcorrect as they re-enter the roadway and this overcorrection can cause a loss of vehicle control and lead to a serious collision. When drop offs are in the range of four inches, the potential exists for a vehicle's front tire to scrub against the pavement edge and not be able to return to the road surface (Ivey and Sicking, 1986). In these conditions drivers may increase turning forces in an effort to overcome the pavement edge drop. When the tire overcomes the friction forces created by the tire-pavement interaction, the vehicle may return to the road surface abruptly and with excess angle. Once the vehicle re-enters the roadway the sharp turning angle of the front tires may result in the driver losing control of the vehicle which can cause it to rollover or swerve into oncoming traffic (see Figure 1).

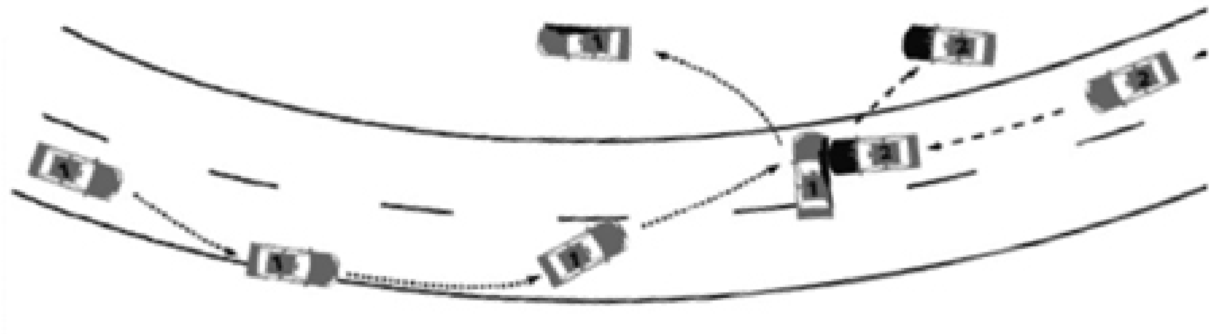

Figure 1. Typical drop-off crash with tire scrubbing. (FHWA)

The Safety Edge$_{SM}$ pavement edge treatment provides a non-vertical wedge at the edge of the pavement which reduces the steering forces needed for re-entering the roadway. With this treatment, the pavement edge is sloped at a 30º angle (see Figure 2). The presence of a slope instead of a vertical face makes it easier for a vehicle to re-enter the roadway. Figures 3 and 4 are diagrams of a pavement edge with and without the pavement edge treatment. Figures 5 and 6 are photos of a pavement with a vertical edge and one with the pavement edge treatment. Figure 7 shows a pavement under construction.

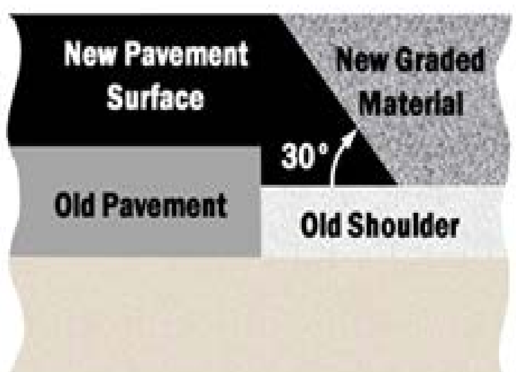

Figure 2. Safety Edge$_{SM}$ detail.
(FHWA Safety Edge PowerPoint)

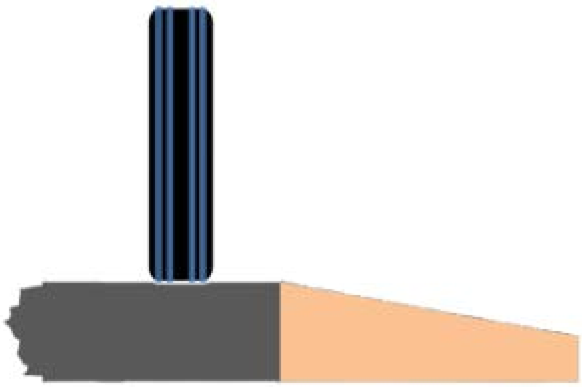

Figure 3. Without a Safety Edge$_{SM}$. (FHWA Safety Edge PowerPoint)

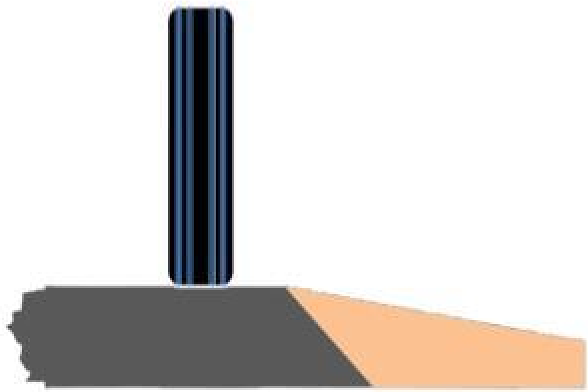

Figure 4. With a Safety Edge$_{SM}$. (FHWA Safety Edge PowerPoint)

Figure 5. Vertical drop off at pavement edge. (FHWA Safety Edge$_{SM}$ PowerPoint)

Figure 6. Sloping edge produced by pavement edge hardware. (FHWA Safety Edge$_{SM}$ PowerPoint)

Figure 7. Pavement edge without the Safety Edge$_{SM}$ in foreground and with the Safety Edge$_{SM}$ in the background. (FHWA Safety Edge PowerPoint)

Need

The Strategic Highway Safety Plan, adopted in 1998 by the American Association of State Highway and Transportation Officials (AASHTO), identified 22 goals to pursue in order to reduce the number of crashes and fatalities on our nation's highways. The goals included minimizing the consequences of leaving the road and reducing head-on and across median crashes (AASHTO, 1998). National Highway Traffic Safety Administration (NHTSA) statistics from 2009 showed that of all the fatal accidents, approximately 53% can be attributed to vehicles leaving the roadway (NHTSA, 2009). A reduction in roadway departures fatalities would significantly impact the total number of annual fatalities, which is the goal of FHWA in promoting the use of the Safety Edge$_{SM}$ (FHWA Safety Edge$_{SM}$ Web Site).

Literature Review

Texas Transportation Institute (TTI) did pioneering work in the 1980's on an improved pavement edge configuration. Their research found that drivers rated a 45º wedge as a much easier pavement edge to remount than either the vertical or rounded edge normally found on pavement edges. The TTI study was criticized as not being representative of real world conditions because the participants were instructed to drive off the pavement edge rather than collecting data from drivers unknowingly putting themselves in the position of remounting a vertical pavement edge (Zimmer and Ivey, 1983).

A Federal Highway Administration (FHWA) pooled fund project was formed to implementation construction of Safety Edge$_{SM}$ demonstration projects. Eight states (California, Colorado, Georgia, Indiana, Mississippi, New York, North Carolina and Utah) constructed projects with the Safety Edge$_{SM}$ and participated in a multiyear performance evaluation. The effort focused on rural two-lane roadways with paved and unpaved shoulders. A total of 377 sites in Georgia and Indiana were selected and accident data was collected over a three year period. The researchers looked at the effectiveness, cost, and benefit-cost of the Safety Edge$_{SM}$ treatment (FHWA, 2011).

The analysis of the crash data determined that the use of the safety edge resulted in approximately a 5.7 percent reduction in total crashes. This result was not statistically significant; however, the results obtained were in a positive direction. The statistical analysis of fatal and injury crashes were too variable to draw conclusions. Overall project costs and the overall cost of asphalt resurfacing materials did not increase for the projects with the treatment as compared to projects without the treatment. Computations based on the volume of asphalt material used to form the safety edge suggest added costs in the range of $536 to $2,145 per lane mile for both sides of the roadway. Benefit-cost analysis based on the estimated 5.7 percent crash reduction effectiveness found that the low cost of the safety edge treatment makes it highly cost-effective for application to a broad range of two-lane highways (FHWA, 2011).

Eleven FHWA sponsored demonstration projects were constructed in ten states under the EDC program in 2010 and 2011. The individual field reports from these demonstration projects can be seen by clicking here. A brief summary of the field reports follows with more complete information tabulated in Appendix A.

Device Used

Five different devices were used on 11 projects to construct the Safety Edge$_{SM.}$

- TransTech Shoulder Edge Maker (7 projects)
- Avant-Edger (3 projects)
- Carlson End Gate (2 projects)
- Troxler SafeT*Slope* (1 project)
- Home Made Devices (2 projects, one Iowa, one North Carolina)

Device Operation

The major complaint with the devices, with the exception of the Carlson End Gate, center on the difficulty in quickly raising or lowering the devices when paving across intersections or in areas with higher or lower longitudinal profiles. Contractors and state inspection personnel recommended the development of automated devices to eliminate this problem. Most of the devices now employ a spring mechanism that allows the device to move vertically when encountering obstacles. The Carlson End Gate moves with the screed and therefore does not need to be adjusted.

Slope Angle

The end product of the use of the safety edge devices is a sloped edge. The average slope produced by each device was measured to be as follows:

- TransTech (37°) on seven projects
- Avant-Edger (50°) on three projects
- Troxler (28°) on one project
- Carlson (31°) on two projects
- NCDOT contractor built device (36°) on one project

Compaction

Densities and air void contents immediately adjacent to the Safety Edge$_{SM}$ are compared to the same measurements three feet away from the safety edge to determine the degree of compaction of the treated pavement. The results are as follows:

- Higher densities and lower air voids near the Safety Edge$_{SM}$ (4 projects).
- Slightly higher densities and lower air voids near the Safety Edge$_{SM}$ (2 projects).
- Densities and air voids no difference near the Safety Edge$_{SM}$ (2 projects).
- Lower densities and higher air voids near the Safety Edge$_{SM}$ (1 project).

The higher densities and lower air voids were directly correlated to the amount of compactive effort applied to the Safety Edge$_{SM}$. On the one project that recorded lower densities the roller operators were instructed to avoid rolling the edge because it caused the slope angle to substantially increase.

Pavement Segregation

Segregation was noted in the safety edge treatment pavement as follows:

- No segregation (6 projects)
- Minor segregation (2 projects)
- Interior segregation (1 project)

Pavement Thickness

The thicker the pavement the easier it is to create the safety edge treatment, however, a thicker lift also requires more compactive effort to achieve maximum density. The thickness of the pavement for each of the projects was as follows:

- 1.5 inches (4 projects)
- 2.0 inches (4 projects)
- Multiple lifts (1 project)

Summary of Demonstration Projects

The demonstration projects used all of the available Safety Edge$_{SM}$ devices with the TransTech Shoulder Edge Maker used on the most projects. Two projects used home-made devices developed by the paving contractor. The major complaint on the devices was the difficulty in quickly adjusting the device when encountering changes in longitudinal profile of the pavement or intersections and as a result automation of the devices was recommended. The edge formed by the various devices varied in slope angle from 28 to 50º with the Avant-Edger producing the highest average angle at 50º and Troxler the lowest average at 28º. The TransTech device, used on seven projects, produced an average slope angle of 37º. The compaction of the pavement at the safety edge was higher or slightly higher than the pavement in the remainder of the mat in six of the nine projects, the same in two of the nine, and lower in one of the nine projects. Segregation of the asphalt material in the Safety Edge$_{SM}$ area was not found in a majority of the projects (7 out of 9) and only a minor amount in two of the nine projects. The depth of the pavement places on the nine projects was equally split between 1.5 inches and 2.0 inches, with four projects in each category. The remaining project had multiple lifts with the top lift being 1.5 inches.

Montana Department of Transportation (MDT) participated in the demonstration projects by reviewing 25 years of constructing tapered edges on their roadways. The tapered edge is typically constructed at a 6:1 (9.5° angle) and is formed by attaching a strike-off plate to the paver that strikes off the edge and pulls the excess material back into the screed. The review determined that their practice performs very well and produces pavement edges that are durable with no significant edge breakup. Opportunities were identified for the selective use of the Safety Edge$_{SM}$ on narrow roads, steep grades and curve widening. The conclusion arrived at by the reviewers was that the MDT tapered edge practice should be acknowledged as being an acceptable alternative to the Safety Edge$_{SM}$.

Application

WSDOT typically paves the shoulder on state highways to improve the driving surface for errant vehicles. The widths of paved shoulders on WSDOT highways vary between one and ten feet depending on route and location. Surfacing material is then used to finish the shoulder slope flush with the top of the paved surface, which mitigates shoulder pavement edge drop-offs. However, over time a vertical edge may be present due to erosion of the shoulder materials or wheel encroachment, especially along curves. FHWA has determined that the Safety Edge$_{SM}$

treatment is particularly beneficial on two-lane roads with unpaved shoulders. It allows drivers who drift off the highway to return to the road safely. It is expected that as a result the number of crashes and fatal collisions will be reduced. Its benefits are highlighted below:

- Reduces crashes and saves lives by mitigating pavement edge drop-off
- Is a low cost, systematic improvement applied during paving
- Improves durability by reducing edge raveling

Devices Used to Construct Pavement Edge Treatment

A number of manufacturers make hardware that forms the sloping pavement edge. All of these devices are adjusted manually; however, the size and coarse threads of the cranking mechanism do not facilitate quick adjustments. Contractors have been making modifications to these devices to better fit their equipment and to simplify the operation of this device. One modification has been to mount an electric drill on the device to quickly adjust the shoe height at driveways, mailboxes and other obstacles. Contractors worry about the adjustment speed because if the toe of the shoe is not above the driveway or other obstacle, the force of the paver will rip the shoe off the paver and likely disrupt the screed alignment. It is a good idea for the operator to give himself a buffer space initially until he gets more familiar with the speed of the crank in relation to the speed of the paver (FHWA Safety Edge$_{SM}$ Web Site).

TransTech Systems, Inc.

The TransTech Shoulder Wedge Maker™ (SWM) mounts directly on the paver screed extension against the end gate (see Figure 8). An internal spring holds the device down on the road surface and this pressure in combination with the compound angled face compacts the mat as the paver moves forward. The SWM is delivered as a pair with both right-hand and left-hand versions for paving with traffic or against traffic. TransTech also markets a notched wedge device for longitudinal joint formation.

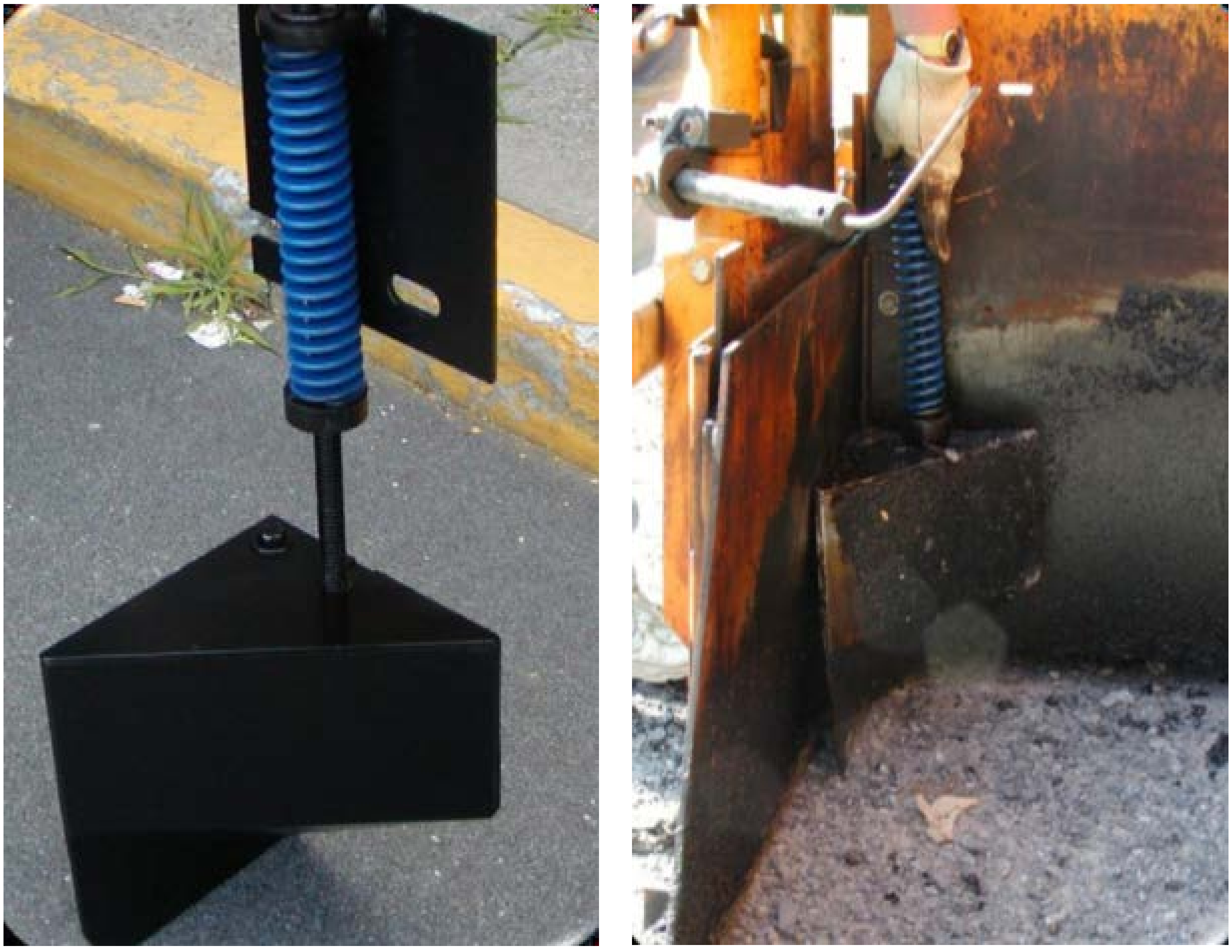

Figure 8. TransTech Shoulder Wedge Maker™ (SWM). Note compound angle of the wedge face. (FHWA, Madison Co., WI)

Troxler

The Troxler SafeT*Slope*™ Edge Smoother is mounted on the paver screed extension against the end gate (see Figure 9). A guide rail with a two-inch radius allows the device to ride along the surface of the road shoulder following its contour. The two-inch radius helps the transition when the device encounters an obstacle such as a driveway cut or road intersection. A self-adjusting internal spring provides downward force to keep the guide rail in contact with the shoulder surface. A 30º forming edge produces the smooth wedge fillet. A 45º compound angle surface forces more asphalt mix under the device. An extended smoothing surface acts as a trowel to smooth the surface of the wedge fillet. Both left and right-hand devices are available for paving with or against traffic.

Figure 9. Troxler SafeT*Slope*™ Edge Smoother.

Carlson Paving Products, Inc.

The Carlson Safety Edge End Gate features a spring loaded and heated end gate for the paving screed (see Figures 10 and 11). It utilizes the length of the end gate to apply compaction to the slope face of the pavement edge treatment. The screed operator's normal end adjustments automatically control the edge. The end gate ski is flat in the front and transitions to 30º at the back of the ski. The relatively long length of the end gate ski results in a smooth/sealed slope face.

Figure 10. Carlson Safety Edge End Gate hardware. (FHWA, Madison Co., WI)

Figure 11. Carlson Safety Edge End Gate in use. (FHWA, Menominee, WI)

Advant-Edge Paving Equipment

The Advant-Edger™ attaches to the screed extension and shapes the edge to a 30º tapered angle (Figures 12 and 14). It automatically adjusts to changes in shoulder elevations (i.e. driveways) via its internal spring. The Advant-Edger™ is reversible so that it may be attached to either side of the paving machine. A new model called the Ramp Champ™ is designed to create either a safety edge or a tapered longitudinal center lane joint (Figure 13). It is also spring loaded to automatically adjust for changes in shoulder elevation. The slope of the safety edge is adjustable from 5º to 30º and its forming surfaces (shoes) are detachable permitting the same unit to create a variety of edge profiles.

Figure 12. The Advant-Edger™ creates a tapered 30° safety edge along the shoulder of the road.

Figure 13. The Advant-Edger Ramp Champ™ forms a tapered safety edge or a longitudinal center lane joint.

Figure 14. Advant-Edger™ mounted on a paver. Unit is designed to automatically adjust to shoulder elevation changes (driveways and intersections).

(Note: The Safety Edge$_{SM}$ will be referred to as the "pavement edge treatment" from this point on in the report.)

WSDOT Projects

WSDOT built 4 projects that incorporated the pavement edge treatment device. Each of the projects used a different device to create the pavement edge treatment. The projects and the type of devices used on each are listed in Table 1:

Table 1. WSDOT Projects with pavement edge treatment.

Year	Contract No.	SR	Project	Device Used
2011	8017	395	Lee Road to Junction I-90	Contractor built screed and roller hardware
2011	8116	410	Twin Creek to Mather Memorial Park Pull-Off Paving	TransTech Shoulder Wedge Maker™ and contractor built roller hardware
2012	8241	21	Curlew State Park to North of Rin Con Creek	Advant-Edger™
2012	8271	542	Fossil Cr. To Wells Cr. Rd. Vic. Paving	Carlson Safety Edge End Gate

Contract 8017, SR 395, Lee Road to Junction I-90

Contract 8017 improved 22.50 miles of southbound SR 395 from MP 72.36 to MP 94.85 between Connell and the junction of I-90 at Ritzville, Washington as shown in the project location map (Figure 15). The pavement edge treatment was added to the project via a change order. The Contractor (Central Washington Asphalt Inc.) electing to build a special screed with edge rolling hardware. The outside, passing lane was planned 0.15 ft. prior to the placement of an equal amount of HMA Class 1/2 inch. The roadway was then paved shoulder to shoulder with 0.15 ft. of HMA Class 1/2 inch using the pavement edge treatment on both shoulders except where there was guardrail or curbing. The paving occurred in the spring of 2011.

Figure 15. SR 395, Lee Road to Junction I-90, location map.

Figures 16 through 25 show the roadway prior to construction, the construction operation and formation of the pavement edge treatment, and the finished product.

Figure 16. SR 395 before overlay. Note wide stable shoulder.

Figure 17. Paver forming and compacting pavement edge treatment.

Figure 18. Close-up of paver screed.

Figure 19. Close-up of roller hardware.

Figure 20. Close-up of sloped pavement edge showing top of slope at existing pavement edge.

Figure 21. View of rolled pavement edge treatment.

Figure 22. Distant view of paver with edge rolling hardware.

Figure 23. Angle of sloped pavement edge. Note the uniform compaction.

Figure 24. Finished pavement with shoulder material in place.

Figure 25. Finished pavement with shoulder material in place.

Measurements were taken of the pavement edge angle at various locations before and after compaction of the edge. The results are summarized in Table 2. The average final slope angle of the compacted slopes at 23º misses the 30º goal on the positive side since it is a much flatter slope and would be easier to mount then by a 30º. The FHWA Design and Construction Guide states that the recommended range for the slopes is 26 to 40 degrees (FHWA Safety Edge Web Site).

One of the advantages of this particular roadway was a very firm stable shoulder area that extended well beyond the pavement edge. This allowed the Contractor to retain the full width of pavement by placing the pavement edge treatment on the shoulder area. Figures 37-39 show the pavement edge treatment on top of the stable gravel shoulder area.

Table 2. SR 395 edge treatment slope angle before and after compaction.					
Uncompacted Slopes			Compacted Slopes		
Height (in)	Length (in)	Slope (º)	Height (in)	Length (in)	Slope (º)
3.15	7.50	23	1.84	4.25	23
2.90	7.50	21	2.61	5.25	26
2.63	6.50	22	2.09	4.50	25
3.15	7.50	23	2.10	5.00	23
2.65	7.50	19	2.37	6.00	22
2.65	7.25	20	2.11	5.25	22
3.39	7.00	26	1.86	5.50	19
3.14	6.75	25	2.34	4.50	27
-	-	-	2.00	4.75	23
Average		22	Average		23

Note: Heights have been adjusted for the slope of the pavement surface.

Contract 8116, SR 410, Twin Creek to Mather Memorial Park Pull-Off Paving

The second project using the pavement edge treatment was located on SR 410 between Enumclaw and the junction of SR 123 with its center roughly around Greenwater, Washington. The project limits extended for 9.2 miles; however, two large paving exceptions reduced the total mileage to 5.32 miles. The roadway was paved shoulder to shoulder with 0.15 ft. of HMA Class 1/2 inch using the pavement edge treatment on both shoulders except where there was guardrail or curbing. The pavement edge treatment was added as a Special Provision (Appendix B). The Contractor, Tucci and Sons Inc., used a TransTech Shoulder Wedge Maker™ and a home-made edge roller to form the pavement edge treatment. The treatment was only used between MP 35.50 and MP 37.00. The Contractor started without the roller but the slope was unacceptable so they added the roller to improve compaction of the slope. The paving occurred in the summer of 2011.

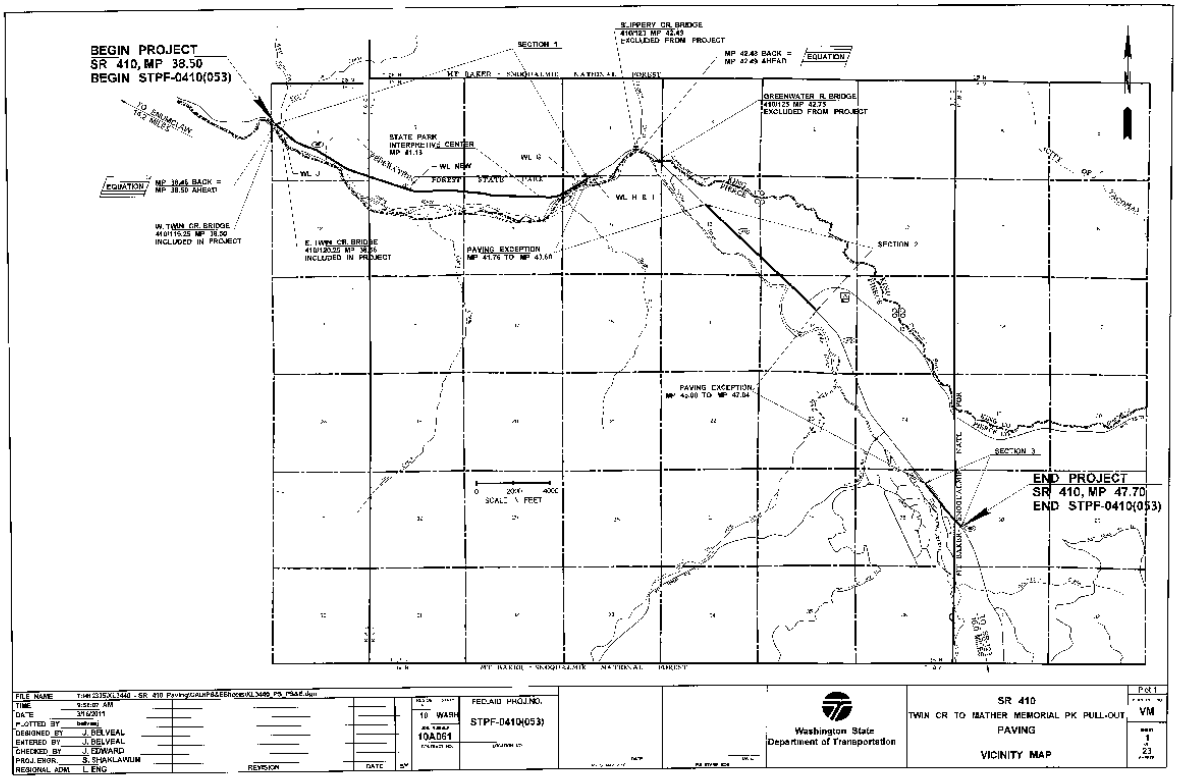

Figure 26. SR 410, Twin Creek to Mather Memorial Park Pull-Out Paving location map.

Figures 27 through 36 show the roadway prior to construction, the construction operation and formation of the pavement edge treatment, and the finished product.

Figure 27. SR 410 prior to construction.

Figure 28. Side view of TransTech hardware.

Figure 29. End view of TransTech pavement edge hardware without the roller.

Figure 30. Pavement edge formed by the TransTech hardware prior to adding the roller. Note open texture of the HMA.

Figure 31. Pavement edge treatment after addition of a roller behind the paver.

Figure 32. Roller added to compact the vertical edge at the top of the slope.

Figure 33. Roller added to compact the vertical edge at the top of the slope.

Figure 34. Finished pavement with dressed shoulders.

Figure 35. Dig out showing slope of pavement edge.

Figure 36. Shoulder material put back in place.

This project had some areas where the pavement edge treatment could be placed outside of the existing paved surface; however, there were some areas that the slope began immediately at the edge of existing slope so this required a slight narrowing of the roadway surface. Measurements were taken to determine the angle of pavement edge treatment at various locations before and after compaction of the edge. The results are summarized in Table 3. The measurements on the uncompacted edge averaged 30º with a range of values between 27 and 33º. Two sets of measurements were made on the compacted slopes. The first set at unknown mileposts averaged 40º with a range of 34 to 43º. The second set taken between MP 40.20 and 40.59 averaged 29º with a range of 26 to 31º.

Table 3. SR 410 edge treatment slope angle before and after compaction.					
Uncompacted Slopes (MP 41.55 - MP 41.69)			Compacted Slopes (milepost unknown)		
Height (in)	Length (in)	Slope (º)	Height (in)	Length (in)	Slope (º)
3.50	7.00	27	2.05	2.50	39
3.00	5.00	31	2.05	2.25	42
3.25	5.00	33	2.31	2.75	40
3.5	6.75	27	2.31	3.00	38
2.5	4.00	32	2.06	2.75	37
Average		30	2.30	2.50	43
			2.06	2.75	37
			2.56	3.00	40
			2.06	3.00	34
			2.30	2.50	43
			2.06	2.75	37
			2.30	2.50	43
			2.05	2.25	42
			Average		40

Table 4. SR 410 edge treatment slope angle after compaction MP 40.30 to 40.59.					
Slope Top Surface (º)	Edge Slope (º)	Effective Edge Slope (º)	Slope Top Surface (º)	Edge Slope (º)	Effective Edge Slope (º)
1	30	29	4	32	28
1	30	29	4	30	26
1	30	29	3	30	27
1	30	29	3	30	27
1	30	29	3	30	27
1	30	29	3	30	27
1	30	29	2	30	28
1	30	29	2	30	28
1	30	29	2	30	28
1	30	29	2	30	28
2	30	28	2	30	28
2	30	28	2	30	28
2	30	28	1	32	31
2	30	28	1	32	31
2	30	28	1	32	31
2	30	28	1	32	31
3	30	27	1	32	31
3	32	29	1	32	31
3	32	29	1	32	31
3	32	29	1	32	31
				Average	29

Figures 37 through 40 show the SR 410 pavement edge treatment one year after construction. Some erosion can be seen of the shoulder material exposing the pavement edge treatment.

Figure 37. Pavement edge treatment close-up one year after construction.

Figure 38. Pavement edge treatment on SR 410 one year after construction.

Figure 39. Another photo of the SR-410 pavement edge treatment one year after construction.

Figure 40. Close-up of pavement edge treatment on SR 410 one year after construction. Shows some exposure of pavement edge treatment.

Contract 8241, SR 21, Curlew State Park to N of Rin Con Creek Rd - Paving

The third project was located on SR 21 between Republic, Washington and the border with Canada. The project limits extended from MP 168.58 to MP 183.80 a distance of 15.22 miles. The roadway was preleveled and then paved shoulder to shoulder with 0.15 ft. of HMA Class 3/8 inch. The pavement edge treatment was added as a Special Provision in the contract (Appendix B). The Contractor, Poe Asphalt Paving Inc., used an Advant-Edger™ and a homemade edge roller to form the pavement edge treatment. The paving occurred in the summer of 2012. Figures 42 through 51 show the roadway prior to construction, the construction operation and formation of the pavement edge treatment, and the finished product.

Figure 41. SR 21, Curlew State Park to North of Rin Con Creek location map.

Figure 42. Advant-Edger™ used to produce the pavement edge treatment.

Figure 43. Pavement edge treatment produced by the Advant-Edger™.

Figure 44. Pavement edge treatment on SR 21.

Figure 45. Close-up of edge treatment slope.

Figure 46. Side view of edge treatment.

Figure 47. Another view of the edge treatment.

Figure 48. Edge treatment and shoulder area.

Figure 49. Close-up of edge treatment slope.

Figure 50. Slope of edge treatment across a road approach.

Figure 51. Closer view of slope of edge treatment.

Measurements were taken at three locations to determine the angle of pavement edge treatment after compaction of the edge. The results are summarized in Table 5. The average of 20º is well below the target value of 30º indicating the slopes are flatter making it easier for vehicles to re-enter the roadway.

Table 5. After compaction slope measurements for SR 21.		
Height (in.)	Length (in.)	Degrees (°)
4	15.5	15
5	13	23
3	8.5	21
	Average	20

Contract 8271, SR 542, Fossil Cr to Wells Cr Rd Vic - Paving

The fourth project was located on SR 542, the Mt. Baker Highway, between Glacier and the end of the route. The project limits extended from MP 38.65 to MP 41.55 a distance of 2.90 miles, however, the first 0.43 miles were a paving exception; therefore, the total length of paving was only 2.47 miles. The entire roadway was planed 0.15 inches shoulder to shoulder in preparation for the paving. The pavement section consisted of 0.15 ft. of HMA Class 3/8 inch over 0.08 inches of HMA Class 3/8 inch pre-leveling. The pavement edge treatment was added as a Special Provision in the contract (Appendix B). The contract was awarded to Granite Construction Inc. with paving scheduled for August of 2012. The Carlson End Gate was used to form the pavement edge treatment on this project.

Figure 52. SR 542, Fossil Creek to Wells Creek Road Vicinity location map.

Figures 53 through 60 show the construction operation and formation of the pavement edge treatment, and the finished product.

Figure 53. Side view of Carlson end gate.

Figure 54. Mix passing through the end gate.

Figure 55. Pavement edge treatment produced by the Carlson end gate.

Figure 56. Slope indicator device on the edge treatment. Slope does not appear to be compacted.

Figure 57. Close-up of slope indicator.

Figure 58. View showing uniform appearance of edge treatment.

Figure 59. Pavement edge treatment next to guardrail.

Figure 60. Pavement edge treatment next to guardrail.

Table 6 lists the slope measurement made of the finished pavement using a slope indicator gauge (Figures 56 and 57). The average of 28º meets the pavement edge goal of 30º and none of the slopes fall out of FHWA's 26 to 40º recommended range.

Table 6. Slope measurements on the finished pavement on SR 542.

Station	Milepost	Slope (º)
121+50	40.75	24.0
122+50	40.77	25.0
123+50	40.79	39.0
124+50	40.81	27.0
125+50	40.82	35.0
126+50	40.84	31.0
127+50	40.86	27.0
129+50	40.90	26.0
131+50	40.94	23.0
133+50	40.98	24.0
	Average	28.0

Summary of Findings

All of the pavement edge devices were capable of producing a finished pavement that met the FHWA's goal of 30º (Table 7). The slope angles produced on the four WSDOT projects which ranged from 20 to 30 degrees are generally lower and, in the case of the Avant-Edger™ and TransTech devices, significantly lower than those reported on the FHWA demonstration projects. As previously noted, pavement edges produced by the Advant-Edger™ had an average slope angle of 50º, by the TransTech an average of 37º, and by the Carlson End Gate an average of 31º on the trial demonstration projects built by other states. It would appear that perhaps the design of the first two devices has changed since the demonstration projects were built, or that contractors have become more adept at using the devices to produce the desired slope angle.

Table 7. Average compacted slope angle for each project.		
Project	**Average Slope Angle (º)**	**Device Used**
SR 395, Lee Road to Junction I-90	**23**	**Contractor built**
SR 410, Twin Creek to Mather Memorial Park Pull-Off Paving	**31**	**TransTech Shoulder Wedge Maker™**
SR 21, Curlew State Park to North of Rin Con Creek	**20**	**Advant-Edger™**
SR 542, Fossil Cr. To Wells Cr. Rd. Vic. Paving	**28**	**Carlson Safety Edge End Gate**

Evaluation of the Process and the Devices

On the first two projects the Contractors and project personnel were asked to evaluate the use of the edge forming devices, its effect on rates of production, possible added cost, possible improvement in the quality of the finished pavement edge, challenges in using the devices, and any recommendations that might improve the process. On the last two projects the same questions were posed only to the WSDOT project engineers.

On the first two projects the interviews with WSDOT and the Contractor's personnel both revealed that the pavement edge treatment was very easy to install and that it resulted in very little to no additional effort. One paving foreman felt that it was a stronger edge by his observations of loaded trucks driving off the edge compare with the traditional edge. On the last two projects, the project engineers reported that the cost to the contractors of acquiring the edge devices were minor and the actual use of the devices resulted in no additional cost nor did it slow down production. The project engineer on the SR 21 project indicated that the pavement edge treatment provided an improvement since the shoulders were very narrow and the existing slopes were often 3:1 or steeper. The PE on the SR 542 project did not see the benefit of the pavement edge treatment due to the fact that most of SR 542 is winding and narrow and protected by guardrail. It was his opinion that the project did not prove to be a good selection for a trial use of the pavement edge treatment. In fact, the pavement edge treatment turned out to be a liability in that there was slightly less depth of pavement where there should have been full depth at the edge of the guardrail. The project engineer recommended that future project selection should be based on roadways that have a history of overtracking where the pavement edge and shoulder material are being frequently disturbed by vehicles.

Crash Analysis

The Safety Analysis Section of the Traffic Operations Division performed an analysis of three of the four locations to determine what effect the installation of the safety edge treatment had on run-off-the-road accidents. The project on SR-20 could not be analyzed due to the large amount of the guardrail. The target crashes were drop-off related crashes except ice and snow road surface conditions. Table 8 summarizes the measured crash statistics and Table 9 the predicted and observed crash frequency data for the three locations. Based on the analysis, the SR-410 segments are anticipated to experience more crashes and the SR-21 and SR-395 fewer crashes than segments with similar roadway characteristics and traffic volumes. Quoting Izawa Kumiko, Safety Analysis Section, "due to the limitations of data, the results are inconclusive with regard to the safety effectiveness of the safety edge treatment." Appendix D contains the complete reports for the three projects.

Table 8. Measured crash statistics.

SR	Years of Analysis	Total Crashes		Total Fatal and Injury Crashes	
		Before	After	Before	After
21	4	8	10	7	6
410	5	6	4	5	3
395	5	14	13	8	6

Table 9. Predicted crash frequency data

SR	Total Crashes			Fatal and Injury Crashes		
	Average Predicted Crash Frequency (crashes/year/mile)	Observed Crash Frequency (crashes/year/mile)		Average Predicted Crash Frequency (crashes/year/mile)	Observed Crash Frequency (crashes/year/mile)	
		Before	After		Before	After
21	0.61	0.39	0.43	0.23	0.21	0.16
410	0.97	2.00	1.73	0.32	1.07	0.53
395	0.91	0.40	0.67	0.23	0.13	0.16

Conclusions

The following conclusions are reached with regard to the use of the pavement edge treatment.

- The cost of adding the pavement edge treatment on a roadway was minimal for both the Contractor and the WSDOT.
- The safety benefits of the pavement edge treatment could not be measured due to the absence of a statistically significant number of crashes at the test locations.

References

AASHTO Strategic Highway Safety Plan, A Comprehensive Plan to Substantially Reduce Vehicle-Related Fatalities and Injuries on the Nation's Highways, American Association of State Highway and Transportation Officials, Washington, D.C., 1998.

Ivey, Don L. and Dean L. Sicking, (1986). *Influence of Pavement Edge and Shoulder Characteristics on Vehicle Handling and Stability*. Transportation Research Record 1084, TRB, National Research Council, Washington D.C., 1986.

Highway Safety Information System (HSIS) 2011. *Safety Evaluation of the Safety Edge Treatment: Summary Report,* Report No. FHWA-HRT-11-025, Federal Highway Administration, McLean, VA.

Satterfield, Cathy., Carol Tan, and Andy Mergenmeier. *Safety Effects of the Safety Edge[SM] Technical Summary of Crash Modification Factors*, FHWA-SA-17-044, U.S. Department of Transportation, Federal Highway Administration, Washington D.C., 2017.

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Appendix A

FHWA Demonstration Projects
Summary Data

Safety Edge$_{SM}$ Demonstration Projects

Date	Project Name	Device(s) Used	Placement Comments	Slope of the Safety Edge	Compaction	HMA Mixture	Pavement Section
May 2010	Fairview, IA	Contractor made device	Sloping face was slightly concave or convex at some locations, but it was generally not considered a issue with respect to performance of the SE. Additional labor was needed where mainline crossed existing roads.	Average slope 31.5° with a minimum value of 28.5° and maximum value of 34.0°.	Results of air voids and modulus testing of the hardened concrete indicate that the quality of the concrete is reasonably uniform between the SE and away from the SE.	N.A.	6.0 inches of unbonded PCC over 6 inches of existing PCC. 9.0 inches of PCC shoulder 2.75 feet wide with a 30 degree SE.
May 2010	Elizabethtown, PA	Advante-Edger	Problems adjusting four things at once, Safety Edge device, screed and plate, extending or retracting screed extension, and adjusting height of screed for intersections, driveways, and changes in longitudinal elevations or profiles. Automated system needed to raise and lower the device. Downward pressure on Safety Edge device needs to be monitored so that the device does not hang up on the underlying surface and cause the screed to vibrate and jerk.	Average slope 48°. The 9.5 mm HMA mix behind the screed appeared similar in shape with and without the Safety Edge device.	Compaction **higher** and air voids lower adjacent to the edge of mat for the SE sections as compared to the non-SE section. However, the air void content of the entire mat was higher than desirable for long term performance.	No segregtion in any areas of the mat or SE. Planned for 1.5 inches, got 1.2 to 2.4 inches along the outside edge of the project.	1.5 inches 9.5 mm HMA
July 2010	Kearney, NE	TransTech Shoulder Wedge Maker	Spring stiffness is too high and the travel length too short which results in the device raising the screed in paving across intersections or in areas with higher longitudinal profile. Construction personnel recommended that an automated system be developed to raise and lower the Safety Edge device.	Average slope 34°. Opinion of construction personnel that the slope of the Safety Edge device would need to be flattened to about 20 to 25° to meet the desired 30° desired slope.	Compaction of the non-SE section was **same** as for the SE section, however a different roller patter reversed the results when the roller overhung the SE.	No segregtion in any areas of the mat or SE. Planned 2.0 inches, got 1.5 to 2.1 inches.	Exisiting milled 2.0 inches, 2.0 inches 12.5 mm HMA
July 2010	SR 182, Columbus, MS	TransTech Shoulder Wedge Maker	Automated system needed to raise and lower the Safety Edge device.	Average slope 37°. Rolling did not steepen the slope of the Safety Edge on this project.	Density **higher** and air voids lower adjacent to the mat of the SE sections (average air voids of 10.6%) in comparison to the non-SE section (average air void of 12.3%). Air voids of the interior HMA had a mean value of about 6.5% for both the SE and non-SE sections. Air voids along the edge of the mat were high (9-15%) which is not good.	No segregation in any areas of the mat or SE. Planned 1.5 inches, got 2.0 on the SE sections and 2.75 inches on the non-SE sections.	Exisiting milled 1.5 inches, 1.5 inches 9.5 mm HMA
Aug. 2010	Turner, ME	Avante-Edger, TransTech Shoulder Wedge Maker and Notched Wedge Joint Maker	Construction personnel suggested putting a sleeve around the Safety Edge spring to keep HMA material out of the this area so it does not get into the threads and make it difficult to adjust the device. Also suggested that adding vibration to the Safety Edge device would probably make it better.	Average slope 54° using the Avante-Edger and 45° with the TransTech. Both devices produced the 30° angle slope behind the screed, but both increased after rolling. HMA mix was not too tender or stiff.	Density **slightly higher** and air voids lower adjacent to the edge with the SE sections as compared to the non-SE sections, however, the statistical difference was no significant. Percent compaction of the interior mat averaged 93% while the SE and non-SE mat averaged 84%.	No segregation reported.	Existing milled, 3.0 inches of 19 mm HMA base, 2.0 inches 12.5 mm HMA wearing course.
Aug. 2010	Jasper County, IA	TransTech Shoulder Wedge Maker	Automated adjustment system recommended. Suggest making the angle of the Safety Edge device shoe adjustable so that it can be decreased when using HMA mixtures for which the slope angle tends to increase when compacted.	Average slope 38°. Face of slope had a coarse/open texture. Large aggregates could be removed by hand without much difficulty. Safety Edge used on all three lifts in some sections which resulted in an increased tonage of HMA used.	Rolling of the mat near the SE was discontinued due to the increasing slope caused by the rolling. As a result the density was 6% **lower** adjacent to the SE as compared to the non-SE mat. Air voids adjacent to the SE were high (average 13.6%).	Slight segregation observed at the longitudinal joint and at the edge of the mat. Planned 1.5 inches, got 1.2 to 2.4 inches.	5.0 inches Cold In-Place Recycling of exising, 2.0 inches 19 mm HMA base, 1.5 inches 19 mm HMA intermetiate, 1.5 inches 19 mm HMA wearing course.
Aug. 2010	Seaford, DE	Advante-Edger, TransTech Shoulder Wedge Maker	Project superintendent indicated that was no difference in the performance between the two devices, but the screed operator said that the Advante-Edger seemed to work better, resulting in a smoother edge condition. Concern was expressed by both Contractor and Agency personnel that the device raises the screed relative to the profile set by the longitudinal ski when paving across intersections or in areas with higher longitudinal profile.	TransTech 37°, Advante 45-50°. Opinion of construction personnel that the slope of the Safety Edge device would need to be flattened to about 20 to 25° to meet the desired 30° desired slope.	WMA density of SE sections **higher** than the non-SE sections. Air voids of interior WMA were 7.3 to 8.9% of the SE section 8.6 to 13.5%.	Longitudinal segregation observed along the edge of each slat conveyor of the paver. Planned overlay thickness was 2.0 inches, got 2.0 to 2.7 inches.	2.0 inches 9.5 mm HMA
Sept. 2010	Menominee Co., WI	TransTech Shoulder Wedge Maker, Carson End Gate	The Carlson's end gate device proved to be the least intrusive in that the screed operator's typical end adjustments automatically controlled the edge. The TransTech device required periodic vertical adjustment.	Average slope 35° for TransTech, 33° for the Carlson, and 36° for the Prototype #2 and #3.	Density **sligntly higher** and air voids slightly lower adjacent to the <u>non-SE</u> section as compared to the SE section. Reason for the reverse of the pattern from other projects is unknown since the roller pattern was the same for the non-SE and SE sections.	No segregation. SE covered the edge of the existing pavement preventing a true measurement of the mat thickness at the SE.	Mill existing 0.5 inches, 2.0 inches 12.5 mm HMA.
April 2011	Brogden Road, NC	Troxler SafeT*Slope* and NCDOT device	Service life of 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. Vertical adjustment screw is easily bent during normal use and should be made of stronger material and/or improved design.	Average slope 28° for Trolxer, and 26° for the NCDOT device. Slopes from both devices increased 1 degree or less during compaction operations.	Densities **higher** and air voids lower adjacent to the edge with the SE as compared to the non-SE section. Roller overhung the edge. Contractor said that the edge of pavement with the SE was not damaged by trucks driving over the edge.	Minor segregation. Lateral movement under the roller at the edge was insignificant.	1.5 inches 9.5 mm WMA
April 2011	Little Divine Road, NC	Carlson Paving Products, Inc.	Carlson device was simple to operate and the Contractor was able to produce a uniform and stable edge.	Average slope 29° and decreased by 1 degree during compaction.	Statistical analysis suggest the density of the SE test section is **no different** than the control section either adjacent to the edge or 3 feet from the edge.	Mix behaved normally with no tearing or shoving. Lateral movement of the mat was minor under the passes of the roller.	1.5 inches 9.5 mm HMA

Appendix B

Contract Special Provisions
(Retyped from original)

Section 5-04.3(21) is supplemented with the following:

(******)

Pavement Edge Treatment

A Pavement Edge Treatment shall be constructed to the dimensions shown and at locations designated in the plans. This edge treatment shall not be used along curbing, barrier, or guardrail sections.

The Pavement Edge Treatment device shall provide a sloped and compacted HMA wedge that is constructed monolithically with the pavement. Short sections of handwork will be allowed when necessary for transitions and turnouts or as approved by the Project Engineer.

The Contractor shall submit for approval to the Project Engineer a Pavement Edge Treatment device. An approved device may be available at the Engineer's project office and the Contractor may call the project office to check on availability. Other acceptable devices are the TransTech Shoulder Wedge Maker and the Advant-Edge. Contact information for these devices is the following:

1. TransTech Systems, Inc.
1594 State Street
Schenectady, NY 12304
1 -800-724-6306
www.transtechsys.com

2. Advant-Edge Paving Equipment LLC
P.O. Box 9163
Niskayuna, NY 12309-01 63
Ph. 518-280-6090
Contact: Gary D. Antonelli
Cell 518-368-5699
email: garya@nycap.rr.com
Website: www.advantedgepaving.com

If an alternate device is submitted for approval the Contractor shall provide proof that the device has been used on projects with acceptable results or construct a test section at the beginning of the Pavement Edge Treatment Work and demonstrate to the satisfaction of the Project Engineer that it meets these requirements.

All cost in the Pavement Edge Treatment shall be included in the prices for other Work.

Appendix C

Experimental Feature Work Plan

Washington State Department of Transportation

WORK PLAN

Evaluation of the Pavement Edge Treatment

SR 395 Lee Road to Junction I-90 Decreasing
MP 72.36 to MP 94.85

and

SR 410 Twin Creek to Mather Memorial Park Pull-Off Paving
MP 38.50 to MP 47.70

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Introduction

Vehicles leaving the roadway in locations of vertical pavement drop offs may overcorrect when re-entering the roadway which can lead to serious collisions. The overcorrection occurs when a vehicle leaves the roadway and uses sharp steering maneuvers to return to the road surface. The potential exists, when drop offs are in the range of 4 inches[1] that a vehicle's front tire will scrub against the pavement edge and not immediately be able to return to the road surface. In these conditions drivers may increase turning forces in an effort overcome the pavement edge drop. When the tire overcomes the friction forces created by the tire-pavement interaction the vehicle will return to the road surface abruptly and with excess angle. Once the vehicle re-enters the roadway the sharp turning angle of the front tires may result in the vehicle losing control which can cause it to rollover or swerve into oncoming traffic. The pavement edge treatment provides a non-vertical wedge at the edge of the pavement which reduces the forces needed in steering for re-entering the roadway in comparison to a near vertical face.

The pavement edge treatment is a wedge of pavement placed by a device bolted to the screed of the paving machine (Figure 1). FHWA recommends an angle of 30° to 35° between the roadway slope and the slope of the wedge (Figure 2). After completion of paving the gravel is graded back flush with the new pavement just as when a conventional vertical pavement edge is constructed.

[1] Transportation Research Record 1084 "Influence of Pavement Edge and Shoulder Characteristics on Vehicle Handling and Stability" by Don L. Ivey and Dean L. Sicking

Figure 1. Pavement edge “shoe” bolted to paving machine screed (FHWA).

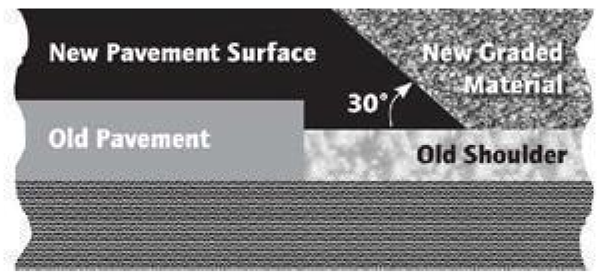

Figure 2. Pavement edge treatment (FHWA)

Scope

The pavement edge treatment will be constructed at the edge of paved shoulder in accordance with the attached plan detail. Unlike the FHWA detail (Figure 2) the pavement edge treatment will be placed over the existing paved surface and will result in a minor reduction in shoulder width. This is to avoid the need to construct a stabilized flat area outside the existing edge of paved shoulder. In areas where there is an existing stabilized flat area outside the existing pavement, the pavement edge treatment may be placed so that the top of the slope is equal to the edge of the existing pavement.

Staffing

These installations will be constructed as a Region programmed pavement rehabilitation projects. Therefore the assigned Region project office will coordinate and manage all construction aspects. Representatives from the WSDOT Materials Laboratory (1 – 2 people) and WSDOT HQ Design will also be involved with the process.

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Testing

No testing other than that normally conducted on a paving project will be required for the pavement edge treatment.

Reporting

A "Post Construction Report" will be written following completion of the demonstration projects. This report will include construction details, cost of the treatment, and other details concerning the overall process. Annual summaries will also be conducted over the next five years. At the end of the five-year period, a final report will be written which summarizes the performance characteristics and future recommendations for use of this process.

Cost Estimate

Construction Costs

Providing the pavement edge shoe is estimated at $3,000. The pavement edge will result in a slight reduction in HMA use which should result in a very minor cost savings.

Testing Costs

No additional testing will be required

Report Writing Costs

Initial Report – 16 hours = $1,600

Annual Report – 4 hours (1 hour each) = $400

Final Report – 32 hours = $3,200

Schedule

Construction: Spring/Summer 2011

Date	Post Const. Report	Annual Report	Final Report
Fall 2011	X		
Fall 2012		X	
Fall 2013		X	
Fall 2014		X	
Fall 2015		X	
Fall 2016			X

Appendix D

Crash Analysis Reports

				Installation Year (2012, highlighted)
SR 21 MP 168.58-183.8	Rural two lane highway			
Total				
	Average predicted crash frequency	0.61	crashes/year/mile	
Before	Observed crash frequency	0.394218	crashes/year/mile	
After	Observed crash frequency	0.42707	crashes/year/mile	

Fatal and Injury

	Average predicted crash frequency	0.23	crashes/year/mile
Before	Observed crash frequency	0.21	crashes/year/mile
After	Observed crash frequency	0.16	crashes/year/mile

Total crashes

	2008	2009	2010	2011	2012	2013	2014	2015	2016	Grand Total
Dead at Scene		1								1
Serious Injury		2	1		1					4
Evident Injury	1	3	1		1	2	1	1	1	11
Possible Injury		2		2	1	3	2			10
PDO	4	2	2	1	8	6	2	2	2	29
Unknown		1	1			2	1	1		6
Grand Total	**5**	**11**	**5**	**3**	**11**	**13**	**6**	**4**	**3**	**61**

Target Crash only - drop-off related crashes except ice and snow road surface conditions.

	2008	2009	2010	2011	2012	2013	2014	2015	2016	Grand Total	Target crash divide by Total crash
Fatal										0	0%
Serious Injury		1	1		1					3	75%
Evident Injury	1	2	1				1		1	6	55%
Possible Injury				1		3	1			5	50%
PDO				1					1	2	7%
Unknown						1	1	1		3	50%
Grand Total	**1**	**3**	**2**	**2**	**1**	**4**	**3**	**1**	**2**	**19**	

Total	4 years before	8	4 years after	10
Fatal & I	4 years before	7	4 years after	6

Do not compensate for regression-to-the mean bias.

Based on the analysis, this segments are anticipated that the segments will experience fewer crashes than segments with similar roadway characteristics and traffic volumes. For the target crashes, the number of total crashes increased from 8 to 10, however, the number of fatal and all injury crashes decreased from 7 to 6 after the treatment.

SR395 MP72.36-94.85	**SB Only**	**Rural -4 lane Freeway**		

Total

	Average predicted crash frequency	0.91	crashes/year/mile
Before	Observed crash frequency	0.40	crashes/year/mile
After	Observed crash frequency	0.67	crashes/year/mile

Fatal and Injury

	Average predicted crash frequency	0.23	crashes/year/mile
Before	Observed crash frequency	0.13	crashes/year/mile
After	Observed crash frequency	0.16	crashes/year/mile

Total crashes

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Grand Total
Fatal	1					1				1		3
Serious Injury		1							1		1	3
Evident Injury	1	1	2	2	2	2	2	1	2	1		16
Possible Injury	2	2	1				2		1	4	2	14
No Injury	5	3	8	7	7	6	15	7	15	12	8	93
Grand Total	**9**	**7**	**11**	**9**	**9**	**9**	**19**	**8**	**19**	**18**	**11**	**129**

Target Crash only - drop-off related crashes except ice and snow road surface conditions.

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Grand Total	crash divide by
Fatal										1		1	33%
Serious Injury		1							1		1	3	100%
Evident Injury		1	1		1	1	1	1				6	38%
Possible Injury	1	2	1				1					5	36%
No Injury	1	1	2	1	1			2	3	1	1	13	14%
Grand Total	**2**	**5**	**4**	**1**	**2**	**1**	**2**	**3**	**4**	**2**	**2**	**28**	

Total	5 years before	14	5years after	13
Fatal & I	5 years before	8	5 years after	6

Do not compensate for regression-to-the mean bias.

Based on the analysis, this segments are anticipated that the segments will experience fewer crashes than segments with similar roadway characteristics and traffic volumes. For the target crashes, the number of total crashes decreased from 14 to 13. The number of fatal and all injury crashes decreased from 8 to 6 after the treatment.

SR 410 MP35.5-37.0	Rural Two Lane Highway			
Total				
	Average predicted crash frequency	0.97	crashes/year/mile	
Before	Observed crash frequency	2.00	crashes/year/mile	
After	Observed crash frequency	1.73	crashes/year/mile	

Fatal and Injury			
	Average predicted crash frequency	0.32	crashes/year/mile
Before	Observed crash frequency	1.07	crashes/year/mile
After	Observed crash frequency	0.53	crashes/year/mile

Total crashes

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Grand Total
Fatal					1							1
Serious Injury		1		1								2
Evident Injury				1	1		2	1	1			6
Possible Injury			2	1		2						5
PDO		1	2	1	3		6	1		2		16
Unknown												0
Grand Total	**0**	**2**	**4**	**4**	**5**	**2**	**8**	**2**	**1**	**2**	**0**	**30**

Target Crash only - drop-off related crashes except ice and snow road surface conditions.

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Grand Total	Target crash divide by Total crash
Fatal					1							1	100%
Serious Injury		1		1								2	100%
Evident Injury				1	1		1	1	1			5	83%
Possible Injury												0	0%
PDO				1			1					2	13%
Grand Total	**0**	**1**	**0**	**3**	**2**	**0**	**2**	**1**	**1**	**0**	**0**	**10**	

Total	5 years before	6	5years after	4
Fatal & I	5 years before	5	5 years after	3

Do not compensate for regression-to-the mean bias.

Based on the analysis, this segments are anticipated that the segments will experience more crashes than segments with similar roadway characteristics and traffic volumes. For the target crashes, the number of total crashes decreased from 6 to 4. The number of fatal and all injury crashes decreased from 5 to 3 after the treatment.