Federal Highway Administration
Every Day Counts
Innovation Initiative

Safety Edge$_{SM}$ Design and Construction Guide

Final Report
January 5, 2012

U.S.Department of Transportation
Federal Highway Administration

January 5, 2012

FOREWORD

The main focus of this document is to explain the important design, construction, and materials-related considerations for constructing the Safety Edge$_{SM}$. The target audience of this report is pavement design and construction personnel who will specify and construct the Safety Edge$_{SM}$.

1. Report No.	2. Government Accession No	3. Recipient's Catalog No
3. Title and Subtitle Safety Edge$_{SM}$ Design and Construction Guide		5. Report Date January 5, 2012 6. Performing Organization Code
7. Authors Andy Mergenmeier, P.E., Harold Von Quintus, P.E, Jagannath Mallela, and Paul Littleton, P.E.		8. Performing Organization Report No.
9. Performing Organization Name and Address Applied Research Associates, Inc. 100 Trade Centre Drive, Suite 200 Champaign, IL 61820		10. Work Unit No. 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Office of Infrastructure Federal Highway Administration 1200 New Jersey Avenue, SE Washington, DC 20590		13. Type of Report and Period Covered Design and Construction Guide April 2010 – July 2011 14. Sponsoring Agency Code

15. Supplementary Notes
Contracting Officer's Technical Representative: Byron Lord and Mary Huie
Contracting Officer's Technical Manager: Andy Mergenmeier

16. Abstract

In a coordinated effort with highway authorities and industry leaders, the Federal Highway Administration (FHWA) 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 Design and Construction Guide shares the findings from ten demonstration projects in multiple states and other ad hoc projects in which the Safety Edge$_{SM}$ was implemented. This Guide supports the FHWA's efforts to implement the Safety Edge$_{SM}$ technology by providing standards, guidance, and specifications for adopting this treatment as a standard practice on all applicable new and resurfacing pavement projects.

The Guide provides information on the various elements to consider when designing and constructing pavement projects with the Safety Edge$_{SM}$. The Guide provides insights and lessons learned on previously constructed projects, highlighting items that may vary from conventional pavement design and construction.

17. Key Words	18. Distribution Statement
Safety Edge$_{SM}$, slope, asphalt concrete materials, PCC, roadway departure	No restriction.

19. Security Classif.(of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

Form DOT F 1700.7 (8-72)

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 ft	inches	25.4	millimeters	mm
yd	feet	0.305	meters	m
mi	yards	0.914	meters	m
	miles	1.61	kilometers	km
in^2		**AREA**		
ft^2	square inches	645.2	square millimeters	mm^2
yd^2	square feet	0.093	square meters	m^2
ac	square yards	0.836	square meters	m^2
mi^2	acres	0.405	hectares	ha
	square miles	2.59	square kilometers	km^2
fl oz		**VOLUME**		
gal	fluid ounces	29.57	millimeters	mL
ft^3	gallons	3.785	liters	L
yd^3	cubic feet	0.028	cubic meters	m^3
	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
oz		**MASS**		
lb	ounces	28.35	grams	g
T	pounds	0.454	kilograms	kg
	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
°F		**TEMPERATURE (exact degrees)**		
	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
fc		**ILLUMINATION**		
fl	foot-candles	10.76	lux	lx
	foot-Lamberts	3.426	candela per square meter	cd/m^2
lbf lbf/in^2		**FORCE and PRESSURE or STRESS**		
(psi) k/in^2	poundforce	4.45	Newtons	N
(ksi)	poundforce per square inch	6.89	kiloPascals	kPa
	kips per square inch	6.89	megaPascals	MPa
lb/ft^3 (pcf)		**DENSITY**		
	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 ft
m	meters	3.28	feet	yd
m	meters	1.09	yards	mi
km	kilometers	0.621	miles	
		AREA		in^2
mm^2	square millimeters	0.0016	square inches	ft^2
m^2	square meters	10.764	square feet	yd^2
m^2	square meters	1.195	square yards	ac
ha	hectares	2.47	acres	mi^2
km^2	square kilometers	0.386	square miles	
		VOLUME		fl oz
mL	milliliters	0.034	fluid ounces	gal
L	liters	0.264	gallons	ft^3
m^3	cubic meters	35.314	cubic feet	yd^3
m^3	cubic meters	1.307	cubic yards	
		MASS		oz
g	grams	0.035	ounces	lb
kg	kilograms	2.202	pounds	T
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	
		TEMPERATURE		°F
°C	Celsius	1.8C+32	Fahrenheit	
		ILLUMINATION		fc
lx	lux	0.0929	foot-candles	fl
cd/m^2	candela per square meter	0.2919	foot-Lamberts	
		FORCE and PRESSURE or STRESS		lbf
N	Newtons	0.225	poundforce	lbf/in^2 (psi)
kPA	kiloPascals	0.145	poundforce per square inch	k/in^2 (ksi)
MPa	megaPascals	0.145	kips per square inch	

*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)

Table of Contents

Table of Contents

SECTION 1: INTRODUCTION

1.1 Introduction

The Safety Edge$_{SM}$ is a relatively simple but effective solution that can help save lives by allowing drivers who drift off highways to return to the road safely.

During conventional paving processes, the pavement is constructed with vertical or near vertical edges. Instead of a vertical drop-off, the finished Safety Edge$_{SM}$ forms the edge of the pavement with a slope of approximately 30 degrees. Research has shown this "transition from on-roadway surface to shoulder and back is so smooth it defies assignment of any degree of severity." The Safety Edge$_{SM}$ provides a strong, durable transition for all vehicles and helps prevents pavement edge raveling.

The recommended practice of bringing the adjacent soil or aggregate material (unpaved shoulder or modified soil) flush with the top of the pavement often requires frequent maintenance. When the vertical edge is exposed due to wear/erosion, it can contribute to drivers losing control of the vehicle when attempting to recover from a roadway departure. The Safety Edge$_{SM}$ concept is when drop-offs along the pavement edge occur, the edge will not be vertical, but has a shape that will not induce tire scrubbing. By including the Safety Edge$_{SM}$ detail while paving, this safety countermeasure can be implemented system-wide at little or no cost.

1.2 Purpose of the Guide

The Federal Highway Administration (FHWA) works with States and Industry to accelerate the use of innovative technologies. This Guide supports efforts to implement the Safety Edge$_{SM}$ technology by providing information and guidance to assist agencies in developing standards and specifications for adopting this treatment as a standard practice on all applicable new and resurfacing pavement projects.

The Guide provides information on the various elements to consider when designing and constructing pavement projects with the Safety Edge$_{SM}$. The Guide provides insights and lessons learned on previously constructed projects, highlighting items that may vary from conventional pavement design and construction.

1.3 Scope of the Guide

The information for this Guide draws significantly from experiences obtained from 10 formal construction project evaluations conducted in 2010 and 2011, as well as several ad hoc evaluations. It is expected that significant enhancements in equipment and procedures will be forthcoming as the Safety Edge$_{SM}$ is implemented into standard practice.

The Guide is grouped into four sections, including this introductory section. Section 2 is focused on general design and construction considerations that are applicable to all pavement types and rehabilitation projects. Sections 3 and 4 identify specific considerations for

constructing a Safety Edge$_{SM}$ for asphalt concrete materials (AC) and Portland cement concrete (PCC) pavements, respectively.

SECTION 2: SAFETY EDGE$_{SM}$ – GENERAL DESIGN AND CONSTRUCTION CONSIDERATIONS

In terms of paving operations, there is little difference between the placement and construction of AC and PCC materials (refer to Figure 1) with and without the inclusion of the Safety Edge$_{SM}$. However, there are important considerations that should be accounted for when incorporating the Safety Edge$_{SM}$ into a paving operation. This section of the Guide highlights the general design and construction details when constructing a Safety Edge$_{SM}$ in conjunction with AC or PCC pavements.

2.1 Safety Edge$_{SM}$ Use

The Safety Edge$_{SM}$ provides two important safety related functions. It serves as a mitigating measure to help with pavement edge drop off that occurs after an AC layer is placed, but before shoulders can be reconstructed flush with the paved surface. The Safety Edge$_{SM}$ also serves as a long-term safety feature for areas susceptible to material displacement and/or erosion adjacent to the paved surface.

An additional benefit of the Safety Edge$_{SM}$ is that the density of the AC mat adjacent to the pavement edge was found to be higher in most areas with the Safety Edge$_{SM}$ in comparison to areas without the Safety Edge$_{SM}$. The Safety Edge$_{SM}$ is believed to serve as a restriction to the lateral movement of the AC mat along an unconfined edge. This observation was found from multiple demonstration projects. Visual assessment of many Safety Edge$_{SM}$ treatments have shown that trucks loaded with asphalt do not deform/damage the finished edge.

(a) AC Project. (b) PCC Project.

Figure 1. Safety Edge$_{SM}$ placed on an AC and PCC project.

Where the Safety Edge$_{SM}$ Can Be Placed

The Safety Edge$_{SM}$ can be used in almost every situation to provide a condition towards preventing near vertical lane-shoulder drop offs during construction and over time. It also provides added insurance until such time that maintenance personnel are able to repair eroded areas of the shoulder adjacent to the paved surface.

Where the Safety Edge$_{SM}$ Should Not Be Placed

A site condition where the Safety Edge$_{SM}$ should not be used is where the foreslope/embankment or ground surface has a steeper slope than the slope of the Safety Edge$_{SM}$. This condition may exist for a portion of the road being paved, thus the Safety Edge$_{SM}$ should be considered for use on the remainder of the road. Figure 2 depicts this condition.

Figure 2. Example of where a foreslope/embankment is too steep for the Safety Edge$_{SM}$.

The Safety Edge$_{SM}$ should be excluded in areas where curb and gutter have been or will be placed as the Safety Edge$_{SM}$ is appropriate for the interface of a paved material and an unpaved/unbound material. In areas where there is a restriction for vehicles leaving the paved surface (for example; guardrails and other safety features) whether or not to use the Safety Edge$_{SM}$ must be assessed on a case-by-case situation. The agency may see value in using the Safety Edge$_{SM}$ for its pavement quality benefit, and thus may want to use it in these applications.

2.2 Pre-Construction and Discontinuous Paving Operations

The pre-construction activities for Safety Edge$_{SM}$ projects are to review the paving plan and make sure the Safety Edge$_{SM}$ can be placed in suitable areas along the project. If there are areas with restrictions along the edge of the pavement (for example, guardrails, intersections, and bridges), the width of the roadway and width of paving should be considered so that there is sufficient room for the Safety Edge$_{SM}$ device for resurfacing projects. As an example, narrow bridges along some low volume roadways can result in conditions where the AC paver screed extensions cannot be moved-in sufficiently when using Safety Edge$_{SM}$ devices that are bolted to the paver screed, so the paver operator must steer the paver more towards the center of the roadway during paving operations (center line crown or other cross slope changes need to be considered in these conditions). Other areas where the foreslope is steeper than the Safety Edge$_{SM}$ slope should be noted. These conditions should be discussed in the contractors quality control plan and/or pre-paving meeting and how the condition will be resolved.

Paving across intersections and driveways with the Safety Edge$_{SM}$ device in place is generally no different than when paving without the Safety Edge$_{SM}$. The differences for both AC and PCC paving are noted below. All of these conditions or paving anomalies should be identified and addressed prior to beginning paving operations.

- For AC paving, extra attention from the paver and screed operators may be necessary to accommodate the Safety Edge$_{SM}$ at transitions for intersections, driveways, and changes in longitudinal elevations or profile. The reason for this extra attention is discussed in Section 3 of the Guide. Specifically, Section 3.2 discusses the different Safety Edge$_{SM}$ devices and their attachment to the paver. For devices attached to the screed, the screed operator can keep the Safety Edge$_{SM}$ device lowered or can raise the device above the bottom of the screed so that the Safety Edge$_{SM}$ is not placed through some intersections (refer to Figure 3). The capability for lowering and raising the device allows the paving operation to continue without disruption when discontinuous features or adjacent features are encountered. For devices attached to the end plate, the screed operator needs to monitor the height of the end plate ski to ensure the desired shape is placed.
- For PCC slip-form paving, the PCC material at the intersection or driveway will need to be sawcut to remove the Safety Edge$_{SM}$ (refer to Figure 4) or build up the Safety Edge$_{SM}$ by hand in order to tie into pavement intersections.

Figure 3. Placing an AC overlay at an intersection of a Safety Edge$_{SM}$ project.

Figure 4. Sawcut on a PCC project at an intersection to remove the Safety Edge$_{SM}$.

2.3 Pavement Edge/Shoulder Preparation

The pavement edge should be prepared in accordance with standard agency paving operations for both AC and PCC surfaces (refer to Figure 5).

	Motor grader is used to remove vegetation and soil build-up along the edge of the pavement.
	A motorized broom cleans the surface of the pavement prior to applying the tack coat to the surface of the existing pavement.
	A tack coat is applied to the cleaned pavement surface prior to placing the asphalt overlay.

Figure 5. Surface preparation activities performed prior to placing an AC overlay.

The following items are highlighted to ensure the agency considers them as they have been shown to adversely impact Safety Edge$_{SM}$ construction on some projects.

- If vegetation exists along the pavement edge consideration should be given to removing this vegetation in the area supporting the Safety Edge$_{SM}$ prior to paving. Good asphalt paving practice includes not paving on vegetation as the asphalt will not adequately compact and thus will not perform adequately. Figure 6 shows an example of a Safety Edge$_{SM}$ edge placed over vegetation. For asphalt paving, a clean/clearly visible pavement edge will help the screed operator monitor the material placement along the pavement's edge.
- If the agency removes vegetation/soil from the edge of the pavement (edge clipping), ensure a reasonable grade elevation and slope of the pavement edge/shoulder is established to minimize use of excess pavement material along the edge.
- Edge clipping should extend far enough to accommodate the additional width of the Safety Edge$_{SM}$ which may be a change in standard operating practice. The wedge part of the Safety Edge$_{SM}$ is typically additional width, therefore paving a vertical edge depth of 3 inches will require clipping an additional 6 inches of width to accommodate the Safety Edge$_{SM}$.

Figure 6. Example of Safety Edge$_{SM}$ placed on heavy vegetation – due to lack of adequate compaction the Safety Edge$_{SM}$ will deteriorate.

2.4 Slope Measurement

Including the Safety Edge$_{SM}$ on a new construction or resurfacing project does not impact the agency's material and construction specifications. The only difference in determining the quality between projects with and without the Safety Edge$_{SM}$ is the measurement of slope for the as-built Safety Edge$_{SM}$ itself. This part of the Guide discusses measuring the slope of the Safety Edge$_{SM}$.

Figure 7 illustrates how the slope is measured or determined for an AC resurfacing project. The length of line B is determined as the distance of a vertical virtual line from the edge or toe of the Safety Edge$_{SM}$ to the pavement surface cross slope extended. The toe of the Safety Edge$_{SM}$ can be defined as where a straight line along the surface of the Safety Edge$_{SM}$ contacts the ground surface. This point becomes important for asphalt mixtures with larger nominal maximum sized aggregate where the removal of one coarse aggregate particle can significantly change the measured slope. The length of line A is determined as the distance from the point where there is space between the straight edge placed on the pavement surface at the edge, defined as the break point, and the vertical virtual line through the toe of the Safety Edge$_{SM}$ or vertical line B. The angle, θ, is calculated as $\theta = \arctan B/A$. This angle measurement is the angle that the vehicle tire encounters when the vehicle is attempting to return to the pavement. The slope of a PCC Safety Edge$_{SM}$ is determined in the same manner. The angle measurement is made on the sloped portion of the Safety Edge$_{SM}$ and does not include the vertical portion of the PCC edge.

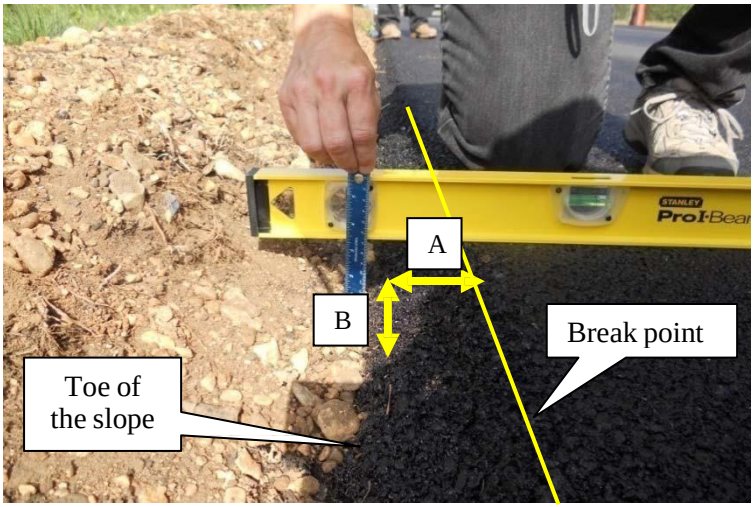


Figure 7. Measurement of Safety Edge$_{SM}$ slope or angle.

2.5 Backing Material Placement

It should be remembered that the Safety Edge$_{SM}$ is a mitigation of the drop off created by the AC or PCC overlay or new paved layer; it is not intended to substitute for a shoulder that is flush with the paved surface. After the paved layer or overlay has been placed, the shoulder or backing material needs to be graded back flush with the paved surface. The shoulder material should be placed in accordance with standard equipment and procedures specified

by the owner agency for both AC and PCC pavements. The only cautionary note is to grade the backing or shoulder material over and along the Safety Edge$_{SM}$ as soon as possible but, in the case of an AC pavement, after the mat has cooled sufficiently so that any scuffing or tearing of the surface from construction equipment is minimized. Similarly, PCC should be allowed to cure and gain sufficient strength so that the construction equipment grading the backing material does not damage the PCC Safety Edge$_{SM}$. After construction is completed, the Safety Edge$_{SM}$ will be covered with the backing material and not seen by the road user as shown in Figure 8.

Figure 8. Safety Edge$_{SM}$ completely covered by shoulder backing material.

SECTION 3: SPECIFIC CONSIDERATIONS FOR CONSTRUCTING THE SAFETY EDGE$_{SM}$ IN CONJUNCTION WITH NEW AC PAVEMENTS OR AC OVERLAYS

This section of the Guide identifies issues that need to be monitored during the placement and compaction operations of the AC pavement.

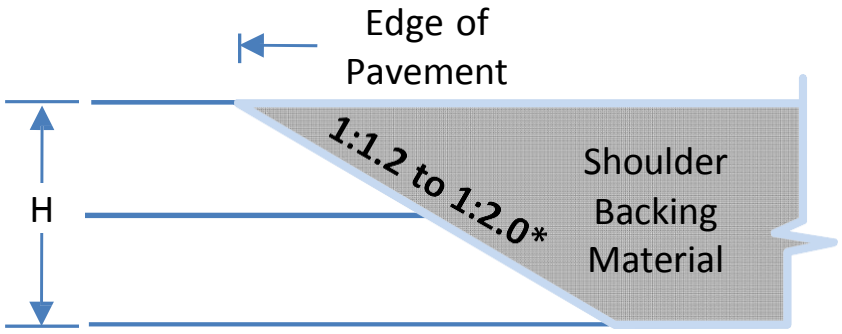
3.1 Design Features and Shape

The paved lane/shoulder width and location of the Safety Edge$_{SM}$ break point should be discussed and established prior to paving. The Safety Edge$_{SM}$ can be constructed on the unimproved or improved shoulder with the break point lining up directly over the existing pavement edge or over any portion of the previously paved surface as shown in Figure 9.

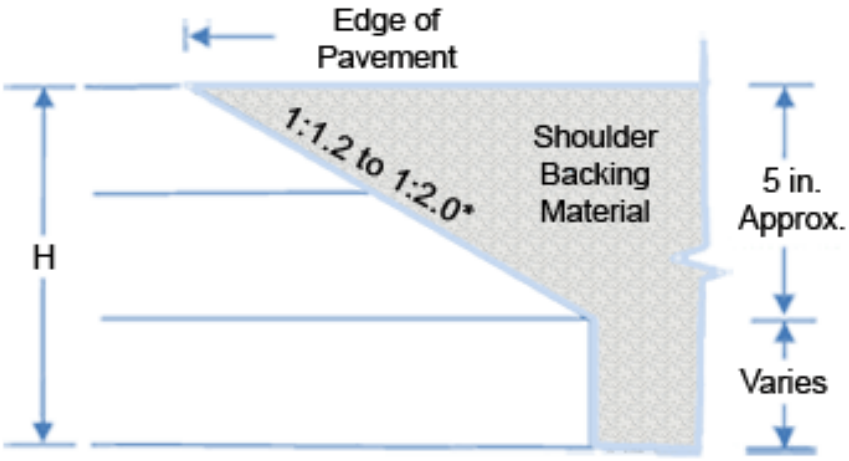
Figure 9. Paver positioned to align the Safety Edge$_{SM}$ break point over the existing pavement.

The intent is not to sacrifice paved lane/shoulder width to construct the Safety Edge$_{SM}$. Constructing the Safety Edge$_{SM}$ onto the unimproved shoulder does not result in a decrease in paved lane/shoulder width.

The Safety Edge$_{SM}$ is designed to create a 30 degree finished angle, relative to the pavement cross slope, on the edge of the pavement. Agency-specific tolerances may vary from those shown in Figure 10 which is from the FHWA guide specification. On projects where multiple AC layers are used, it is recommended each AC layer (except leveling layer) of the final 5 inches of AC receive the Safety Edge$_{SM}$ as shown in Figure 10. For new construction or reconstruction with thicker AC layers, consideration should be given to widening the underlying paved layers to accommodate the Safety Edge$_{SM}$ without decreasing lane width as shown in Figure 10. On projets with multiple AC layers, it is expected the additional volume of AC required to form the Safety Edge$_{SM}$will increase bid quantities.



For H ≤ 5 in.



For H > 5 in.

** Note, Recommended Rise to Run ratio range 1:1.2 to 1:2.0. The range of slope is equal to 26° to 40°.*

Figure 10. Recommended Safety Edge$_{SM}$ configuration for AC pavements and overlays.

3.2 Equipment – AC Safety Edge$_{SM}$ Devices

The current commercial Safety Edge$_{SM}$ devices can be grouped into two categories: (1) devices attached to the paver screed, and (2) modifications or attachments to the paver end plate. The devices listed below do not constitute an approved products list. Highway agencies should evaluate any new Safety Edge$_{SM}$ hardware for compliance with specifications before approving for use on a project.

Devices Attached to the Screed

Currently, there are three devices available from two different manufacturers, which are the "Shoulder Wedge Maker" manufactured by TransTech, www.transtechsys.com and the "Advant-Edger" and "Ramp Champ" manufactured by the Advant-Edge Paving Equipment LLC, www.advantedgepaving.com . Each manufacturer provides detailed installation instructions for attaching their devices to the paver screed. The devices can be easily attached to and removed from the paver screed with a simple two-bolt connection. The Safety Edge$_{SM}$ device should fit closely to the end plate to prevent AC from getting between the device itself and end plate. The Ramp Champ can be set to a range of angles, while the other devices have a fixed angle.

End Plate Modifying Devices

The end plate modification devices are available from Carlson Paving Products, Inc. (Safety Edge End Gate) http://www.carlsonpavingproducts.com, and Willow Designs LLC, http://www.willowdesignsllc.com/. The ski of the devices form the slope of the Safety Edge$_{SM}$ and can be set to a range of angles. The screed operator can adjust the angle of the ski while paving to ensure the final angle of the Safety Edge$_{SM}$ after rolling is close to 30 degrees.

3.3 Asphalt Concrete Materials

The Safety Edge$_{SM}$ can be placed with all dense-graded AC materials that have been properly designed in accordance with existing mixture design methods, including: Hot Mix Asphalt (HMA), Warm Mix Asphalt (WMA), HMA with high amounts of Recycled Asphalt Pavement (RAP), HMA with Recycled Asphalt Shingles (RAS), polymer modified asphalt (PMA), rubberized gap graded and open graded mixes, and other specialty mixtures. The demonstration projects included HMA, RAP, RAS, WMA, and PMA mixtures.

There are two critical material issues in terms of placing a Safety Edge$_{SM}$ for AC mixtures: (1) lateral movement of the AC mix during compaction and (2) the size or amount of coarse aggregate in the AC mixture.

- Most AC mixtures exhibit some lateral movement under the rollers during compaction and that movement is mixture and application dependent. Lateral movement of the AC mix should not prevent the contractor from achieving an acceptable Safety Edge$_{SM}$ slope after final rolling. Ensure that after rolling is

completed the Safety Edge$_{SM}$ break point lines up directly over the existing pavement edge or over any portion of the previously paved surface. If the break point is over the unimproved shoulder (i.e. different support structure) the potential of a longitudinal crack forming is greater (Figure 11). This material related issue is discussed in more detail in Section 3.4 - Safety Edge$_{SM}$ Construction, under Rolling.

- The maximum nominal size aggregate of the mixture or amount of coarse aggregate can affect the surface texture or appearance of the Safety Edge$_{SM}$ and measurement of the slope. Fine-graded AC mixtures were observed to have a tighter surface appearance and texture along the edge. Rough surface texture makes the measurement of the slope more difficult to quantify – increasing variability in slope measurements.

Figure 11. Longitudinal crack due to Safety Edge$_{SM}$ break point located on unimproved shoulder.

3.4 Safety Edge$_{SM}$ Construction

This section discusses items of interest to asphalt paving projects when a Safety Edge$_{SM}$ is to be placed as part of the new construction or rehabilitation project.

Safety Edge$_{SM}$ Device Installation

Manufacturers of commercially available devices provide detailed instructions for attaching the Safety Edge$_{SM}$ devices to the paver. Proper installation of the devices was discussed in a previous part of this section (Equipment – AC Safety Edge$_{SM}$ Devices). A key issue for devices attached to the screed without guide rails is to ensure close installation to the end plate so loose mix does not get trapped between the device and end plate during paving operations. At the beginning of the day's production, when pulling off a transverse joint, the screed operator needs to monitor the position of the device as the auger chamber and extension are being charged to ensure the device is in contact with the end plate. These issues do not affect the end gate type device.

AC Placement

The Safety Edge$_{SM}$ can be placed with normal paving procedures, and no changes to the operation of the paver need to be made. More importantly, the Safety Edge$_{SM}$ device has no impact on how the paver operates, whether paving on an embankment or crushed stone layer, recently placed AC, existing AC or PCC layers, or milled surface.

For those agencies that require trial or control sections as part of standard AC paving operations, the slope of the Safety Edge$_{SM}$ should be measured after all rolling has been completed to ensure the Safety Edge$_{SM}$ slope did not "stand up" (substantial increase in the slope). Trial sections provide an opportunity for the screed operator to make adjustments to the Safety Edge$_{SM}$ and screed before high production paving begins. For example, to obtain the 30^{o} finished angle, the target angle to be achieved behind the paver by the Safety Edge$_{SM}$ device may need to be shallower for a given mix, e.g., 25 degree. Trial sections can also be used to assess if the edge will "stand up" during the AC rolling operation. The issue of maintaining the slope of the Safety Edge$_{SM}$ is discussed under the next subsection – Rolling.

The screed operator needs to watch and adjust three items during the paving operation when using a Safety Edge$_{SM}$ device attached to the screed, described in Section 3.2: (1) the Safety Edge$_{SM}$ device itself, (2) the end plate, and (3) the screed (refer to Figure 12). If the Safety Edge$_{SM}$ device with too much downward pressure rides on the AC or other stiff base material that has been previously placed, this can result in undesirable paving results, as described below.

- When the Safety Edge$_{SM}$ device rides on a base with a rough positive surface texture (e.g. coarse aggregate protruding upward such as in a chip seal) in some cases it may cause the screed to vibrate or jerk. The toe of the Safety Edge$_{SM}$ can get caught on larger aggregate particles and when the particle breaks loose, the screed jerks. The screed operator will need to monitor the downward pressure of the Safety Edge$_{SM}$ device so this does not happen in extreme cases.
- When the Safety Edge$_{SM}$ device rides on a base with a varying longitudinal profile, the screed operator will need to monitor the downward pressure of the Safety Edge$_{SM}$ device to keep the screed functioning as designed within the free-floating principle. The spring around the shaft of the Safety Edge$_{SM}$ is designed to keep a relatively uniform pressure on the mixture being placed under the Safety Edge$_{SM}$ – assuming the vertical operational limit of the Safety Edge is not exceeded.
- The screed operator also needs to monitor the downward pressure of the Safety Edge$_{SM}$ device when it rides on soft surfaces. The leading edge of the device can dig into the soft shoulder pulling soil/aggregate into the asphalt wedge of the Safety Edge$_{SM}$. This is the same condition experienced in conventional paving when the paver end plate ski digs into the soft shoulder.

Figure 12. Safety Edge$_{SM}$ adjustment for raising and lowering the device.

When paving begins the screed operator should pay close attention to the following items when using a Safety Edge$_{SM}$ device attached to the screed.

- In charging the auger chamber with AC, the screed operator should ensure that the device is in close contact with the end plate so that mix does not get between the device and end plate and that there is sufficient material surrounding the device to keep it held against the end plate.
- After the paving operation begins and the full AC lift thickness has stabilized, the screed operator should adjust the Safety Edge$_{SM}$ device by lowering the device into contact with the underlying surface. This adjustment should not be made prior to the paver moving off the shims at the start of a day's paving operation. The screed operator should look behind the paver to ensure that the slope of the edge will produce a slope of about 30 degrees after rolling.

- The paver end plate ski needs to remain in contact with the surface being paved over. AC can extrude out under the end plate ski if not in contact with the existing surface which can reduce the amount of AC available for the Safety Edge$_{SM}$ – affecting the slope and density of the wedge itself.
- When placing an AC overlay, the Safety Edge$_{SM}$ can ride on the underlying layer. However, the screed operator should closely monitor the downward force on the Safety Edge$_{SM}$ device relative to underlying hard surfaces with variable longitudinal profiles, which can change the forces on one side of the screed (free floating screed principle or mode). This concern is heightened at intersections or areas of increased variation of longitudinal profile. The spring around the shaft of the Safety Edge$_{SM}$ is designed to keep a relatively uniform pressure on the mixture being placed under the Safety Edge$_{SM}$ – assuming the vertical operational limit of the Safety Edge is not exceeded.
- The operator needs to be aware that the height adjustment screw can be bent from paving with too much downward force, especially if the shoe is in contact with a variable elevation of a hard surface. The height adjustment screw can also be bent from or hitting objects while in transport.
- The screed operator should monitor the surface texture and condition of the Safety Edge$_{SM}$.
- When drawing in the hydraulic extension, the screed operator needs to closely monitor the process to ensure that the Safety Edge$_{SM}$ device does not come in contact with the cross feed auger. If this occurs, it can damage both the Safety Edge$_{SM}$ device and auger.
- If the hydraulic extension of the screed is extended during mainline paving, the amount of mix in the extension can be reduced near the paver end plate. When this occurs the screed operator should monitor the amount of mix to ensure it is not getting between the end plate and Safety Edge$_{SM}$ device itself, as the screed moves out.
- The flow of AC material to the Safety Edge$_{SM}$ device should be closely monitored to make sure enough material is available to form a continuous edge and that the material feed augers are properly positioned.
- Paver manufactures commonly recommend material feed augers be no greater than 18 inches from the end plate.
- When the paver is being moved, the Safety Edge$_{SM}$ device should be removed or raised to its mounting height or uppermost position. This will ensure that the bottom of the device will not strike/get caught on any obstruction.

When using a Safety Edge$_{SM}$ device the screed operator needs to continually be aware of the position of the break point of the Safety Edge$_{SM}$ slope and keep the break point on the structural base or existing pavement.

At the beginning of the project, it is recommended that slope measurements be made immediately behind the paver and after each roller pass. The focus is on the final Safety Edge$_{SM}$ slope angle after all rolling to determine how rolling impacts the final slope angle.

The contractor may want to periodically make these measurements as part of the quality control process.

Rolling

No special rollers are required for compacting the AC mix along and adjacent to the Safety Edge$_{SM}$ (refer to Figure 13).

Figure 13. Rolling the Safety Edge$_{SM}$ with standard rollers – No special rollers are required.

Most AC mixtures exhibit some lateral movement under the rollers during compaction. Lateral movement of the AC mix should not prevent the contractor from achieving an acceptable Safety Edge$_{SM}$ slope after final rolling. For some of the demonstration projects, the contractor did change or revise the standard rolling pattern to maximize the density of the AC mat, while retaining an appropriate Safety Edge$_{SM}$ angle. Just like for any AC paving project, the optimum rolling pattern is AC mixture specific. A rolling pattern used to compact a low stiffness mix and high stiffness mix may be different to meet the density requirements.

The following recommendations are made based on the findings from multiple demonstration projects.

- The contractor should roll the AC mat and pavement edges based on normal or standard compaction operation. This should ensure adequate density along and near the pavement edge. Multiple demonstration projects have been constructed successfully where the pavement edge was rolled with the contractor's standard rolling pattern.
- After final rolling, the slope of the Safety Edge$_{SM}$ should be measured. If the slope of the edge is too steep, the contractor should determine if the slope of the edge was steepened because of excessive rolling, the use of a mix that exhibits tenderness, or the AC mixture is simply too soft to retain the targeted slope angle. A variable angle Safety Edge$_{SM}$ device can be used to place the Safety Edge$_{SM}$ at an angle less than 30 degrees behind the paver, which should assist the contractor in achieving 30 degrees after rolling.
- Delaying the rolling of the edge of the mat should be the last resort taken to retain the slope of the Safety Edge$_{SM}$. This becomes a decision between durability along and near the pavement edge and retaining a slope of the Safety Edge$_{SM}$.
- Continually monitor the slope of the Safety Edge$_{SM}$ after final rolling. The slope of the Safety Edge$_{SM}$ varied between 30 to 40 degrees on multiple demonstration projects without delaying the rolling of the Safety Edge$_{SM}$.

3.5 Quality Measurement

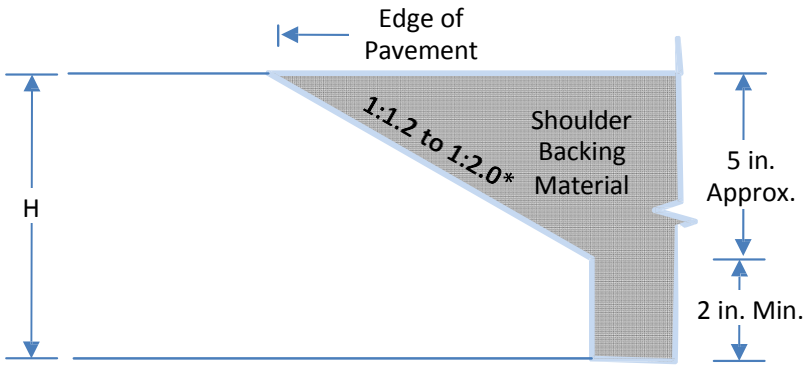
The same properties used or identified by the owner agency to measure the quality of AC pavement layers for acceptance should also be used on projects that include the Safety Edge$_{SM}$. The acceptance plan should not be modified for projects that include the Safety Edge$_{SM}$. More importantly, the density, strength, and/or smoothness requirements appropriate for a typical project should not be relaxed simply because the Safety Edge$_{SM}$ is added to a resurfacing or new construction project. Thus, the only difference between projects with and without the Safety Edge$_{SM}$ is the slope of the edge itself.

SECTION 4: SPECIFIC CONSIDERATIONS FOR CONSTRUCTING THE SAFETY EDGE$_{SM}$ IN CONJUNCTION WITH NEW CONCRETE PAVEMENTS OR CONCRETE OVERLAYS

This section identifies issues that need to be monitored during the construction of PCC pavements. All of the PCC demonstration projects that were used for preparing this Guide included the use of slip-form paving to form the Safety Edge$_{SM}$. A benefit of forming the Safety Edge$_{SM}$ during PCC slip-form paving is the sensitivity to edge slump is reduced.

4.1 Design Features and Shape

The Safety Edge$_{SM}$ is designed to create a 30 degree finished angle relative to the pavement cross slope as shown in Figure 14 and should be constructed on a similar structural base as the adjoining monolithically placed lane/shoulder. During design, the structural base width needs to account for the Safety Edge$_{SM}$ width.



** Note, Recommended Rise to Run ratio range 1:1.2 to 1:2.0. The range of slope is equal to 26° to 40°.*

Figure 14. Recommended Safety Edge$_{SM}$ configuration for PCC pavements and overlays.

4.2 Equipment – PCC Safety Edge$_{SM}$ Devices

This part describes the modifications that must be made to a slip form concrete paver to form a Safety Edge$_{SM}$. It also notes the essential attributes of a concrete paver that are necessary to create an effective Safety Edge$_{SM}$. When a slip form paver is not being used, the Safety Edge$_{SM}$ needs to be manufactured or created as part of the forms – one side of the forms will have an angle of 30 degrees rather than being vertical.

Currently, there are no commercially available Safety Edge$_{SM}$ devices for PCC pavers or forms. Custom devices, however, can be fabricated by modifying the finishing pan of the paver (refer to Figure 15). The pan is essentially configured to form an inverted curb under the pan close to the end gate. The steel components of the assembly need to be robust in order to resist bending during paving operations from the force of the plastic PCC. The following provides a description of the modifications that were made to a Gomaco paver that

was used on one of the PCC demonstration projects and identifies some of the issues or items that should be considered in fabricating the Safety Edge$_{SM}$ profile.

- A template was created for the Safety Edge$_{SM}$ profile to ensure correct dimensions. The template was used to manufacture a stainless steel profile pan of the desired shape and dimensions. Portions of the existing profile pan were removed to fit in the new Safety Edge$_{SM}$ profile.
  [Note: The contractor decided against welding the Safety Edge$_{SM}$ profile to the bottom of the existing profile section or pan because of a concern that the welds might tear the finished PCC.]

- A 2-inch finish tail on the stainless steel Safety Edge$_{SM}$ profile was fabricated to help finish the portion of the edge where it goes from slope to vertical. When going through existing intersections, driveways, or where the grade is not exact on the outside edge, the 2-inch finish tail did drag in some locations. For the demonstration project, the contractor cut one inch off of this tail and it performed well, but cutting 0.5 inches from the tail would have also worked well.

- Adjusting bolts were fitted to the Safety Edge$_{SM}$ profile pan. One adjustment bolt was on the sloped section in case an adjustment had to be made if the edge profile was not finishing properly.

- In setting up the paver, care was taken to position the vibrators in the specific locations for proper consolidation of the Safety Edge$_{SM}$–near the breakpoint.

Unlike the Safety Edge$_{SM}$ attachments for AC layers or overlays, the modifications made to the concrete paver cannot be easily removed and replaced. The modifications can be removed, but the parts must be cut from the pan using a torch or grinder. Touchup of the pan is required to return the unit to service on standard PCC pavements.

4.3 Concrete Mixtures

Demonstration projects completed to date have used standard concrete mixes. No changes to the mix were needed to accommodate the SE.

4.4 Safety Edge$_{SM}$ Construction

This part of the Guide discusses items of interest to PCC paving projects when a Safety Edge$_{SM}$ is to be placed as part of the new construction or rehabilitation project.

PCC Placement

Normal paving procedures are usually sufficient for forming the Safety Edge$_{SM}$ on mainline sections of the roadway using slip form paving operations and equipment. Material

properties of the hardened concrete from the edge and the interior of the pavement have been demonstrated to be similar.

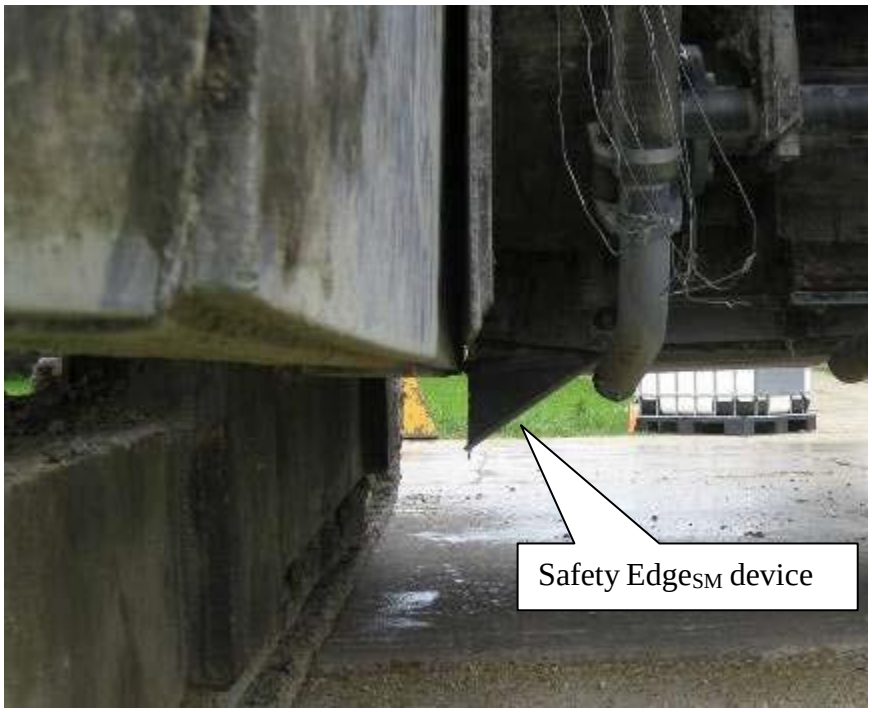


Figure 15. View of the Safety Edge$_{SM}$ device from front of paver.

Transitioning Between Different Edge Profiles

It is recommended to have a transition from a no Safety Edge$_{SM}$ section to a Safety Edge$_{SM}$ section to avoid a vertical edge perpendicular to traffic (i.e. similar to beginning section of bridge concrete rail/parapet where the bottom of the rail/parapet is modified to reduce the probability of vehicle tire snagging).

An important issue to be addressed is the intersection of cross roads where a vertical edge is required. Due to the fixed nature of the edge and shoe assembly, the contractor can consider different options depending on the number and extent of sections with different edge profiles. In either case, additional labor should be anticipated to tie into intersections or other areas requiring different edge profiles when paving using the Safety Edge$_{SM}$ concept. The following provides an overview of the two options that were used on some of the demonstration projects.

- If there are only a few intersecting roadways, driveways or limited areas where a vertical face is required along the edge of the pavement, the contractor can consider placing the safety edge using normal paving operations. The Safety Edge$_{SM}$ is sawcut

and removed to create a vertical edge. The sawing of the Safety Edge$_{SM}$ can be completed at the same time the transverse joints are sawed. This option has worked fine, but does waste some PCC and requires additional sawing.

- Another option is to box out the areas requiring different edge profiles and place forms. The PCC in these limited areas is placed by hand using normal construction practices in order to tie into pavement intersections, driveways, and other features.

Vibration

Generally, the standard spacing of the vibrators are sufficient to properly consolidate the fresh concrete at the Safety Edge$_{SM}$. Consolidation of the material within the Safety Edge$_{SM}$ should be checked at the start of any project. If slip form pavers are not being used, hand vibrators need to be used to ensure that the PCC flows into the lower part of the Safety Edge$_{SM}$. As noted at the beginning of this section, all demonstration projects included the use of slip form pavers in construction the Safety Edge$_{SM}$.

Curing

Care should be taken to insure the specified curing procedures are properly followed for all surfaces at the edge of the pavement, including the Safety Edge$_{SM}$. The Safety Edge$_{SM}$, however, does not require any special curing requirements beyond that for typical PCC layers.

Sawcutting

Transverse control joint sawcutting can be stopped at the breakpoint of the Safety Edge$_{SM}$ and not continued through the sloped surface of the edge. Experience shows the contraction cracks normally form at the end of the sawcut and extend through the Safety Edge$_{SM}$ as planned (refer to Figure 16).

Figure 16. Sawcut and crack at the formed joint on one of the Safety Edge$_{SM}$ demonstration projects.

4.5 Quality Measurement

The same properties used or identified by the owner agency to measure the quality of PCC pavement layers for acceptance should also be used on projects that include the Safety Edge$_{SM}$. The acceptance plan should not be modified for projects that include the Safety Edge$_{SM}$. More importantly, the air void content, strength, and/or smoothness requirements appropriate for a typical project should not be relaxed simply because the Safety Edge$_{SM}$ is added to a PCC overlay or new construction project. Thus, the only difference between projects with and without the Safety Edge$_{SM}$ is the slope of the edge itself.

REFERENCES

EDC Safety Edge$_{SM}$ field reports can be found at:
http://www.fhwa.dot.gov/everydaycounts/technology/safetyedge/field_reports.cfm

APPENDICES

Safety Edge$_{SM}$ guide specification can be found at:
http://www.fhwa.dot.gov/everydaycounts/technology/safetyedge/specs.cfm