Evaluation of Safety Edge Benefits in Iowa

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Final Report
March 2011

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IOWA STATE UNIVERSITY
Institute for Transportation

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About CTRE

The mission of the Center for Transportation Research and Education (CTRE) at Iowa State University is to develop and implement innovative methods, materials, and technologies for improving transportation efficiency, safety, and reliability while improving the learning environment of students, faculty, and staff in transportation-related fields.

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16. Abstract

Pavement edge drop-off can be a serious safety concern when a vehicle leaves the paved roadway surface and encounters a significant vertical elevation difference between the paved roadway and the adjacent unpaved shoulder. Edge drop-offs are potential safety hazards because significant vertical differences between surfaces can reduce vehicle stability and affect the driver's ability to control a vehicle when inadvertently leaving the paved driving area. In addition, scrubbing between the pavement edge and tire can result in loss of control.

The Federal Highway Administration (FHWA) developed the Safety Edge, based on research results that indicated a sloped pavement edge surface could be more easily traversed by a vehicle leaving its lane and attempting to remount the pavement edge. The Safety Edge is a design feature that creates about a 30 degree fillet along the outside edge of the paved section of a roadway.

This report summarizes the extent of run-off-road (ROR) crashes resulting from pavement edge drop-off, includes information about the effectiveness of the Safety Edge, and describes types of equipment that are commercially available to place the Safety Edge during hot-mix asphalt (HMA) paving.

It also describes the marketing and outreach activities that the research team undertook to inform agencies and encourage use of the Safety Edge in Iowa, primarily through open houses, equipment loans, technical assistance, and trouble-shooting. The team also monitored work to evaluate application of the Safety Edge on both HMA and Portland cement concrete (PCC) projects.

With encouragement from the FHWA, the team and the Iowa Department of Transportation (DOT) worked to develop Safety Edge design standards and specifications for PCC projects. This report also provides estimates for the additional materials to apply the Safety Edge to both HMA and PCC projects.

Finally, this report covers lessons learned and includes conclusions and recommendations.

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EVALUATION OF SAFETY EDGE BENEFITS IN IOWA

Final Report
March 2011

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EXECUTIVE SUMMARY

Pavement edge drop-off can be a serious safety concern when a vehicle leaves the paved roadway surface and encounters a significant vertical elevation difference between the paved roadway and the adjacent unpaved shoulder. Edge drop-offs are potential safety hazards because significant vertical differences between surfaces can reduce vehicle stability and affect the driver's ability to control a vehicle when inadvertently leaving the paved driving area. In addition, scrubbing between the pavement edge and tire can result in loss of control.

The Federal Highway Administration (FHWA) developed the Safety Edge, based on research results that indicated a sloped pavement edge surface could be more easily traversed by a vehicle leaving its lane and attempting to remount the pavement edge. The Safety Edge is a design feature that creates about a 30 degree fillet along the outside edge of the paved section of a roadway.

Because use of the Safety Edge is relatively new to Iowa, the Iowa Department of Transportation (DOT) and the FHWA – Iowa Division commissioned the Center for Transportation Research and Education (CTRE) at Iowa State University (ISU) to:

- Develop educational materials
- Market the Safety Edge to Iowa counties
- Conduct some early analyses of the Safety Edge

This report documents these efforts. Table 1 provides an overview of the report content and structure.

Table 1. Safety edge benefits evaluation report chapters

Chapter	Title
1	Introduction and Literature Review
2	Acquiring Safety Edge Equipment for Loans
3	Inviting Participation of an Advisory Group
4	Marketing and Outreach to State and Local Agencies in Iowa
5	Evaluation of Performance of the Safety Edge
6	Development of Design Standards and Specifications
7	Iowa Safety Edge Projects
8	Lessons Learned
9	Estimating Material Needed for the Safety Edge
10	Conclusions and Recommendations

Chapter 1 summarizes background information on the extent of run-off-road (ROR) crashes resulting from pavement edge drop-off, includes information about the effectiveness of the Safety Edge, and describes project objectives.

Chapter 2 describes types of equipment that are commercially available to place the Safety Edge during hot-mix asphalt (HMA) paving. The chapter also details purchase of two types of Safety Edge equipment that were acquired by the team for loan to contractors to try before investing in the equipment.

The next objective was to form an advisory panel, which is outlined in Chapter 3. Chapter 3 describes panel roles lists members.

Chapter 4 describes the marketing and outreach activities that the team undertook to inform agencies and encourage use of the Safety Edge. The team also provided technical assistance to agencies and contractors before and during construction. This included attendance at pre-construction meetings, trouble-shooting, and monitoring work. The CTRE team also developed, administered, and hosted three open house demonstrations of the Safety Edge.

Chapter 5 outlines the performance evaluation of the Safety Edge. The team measured the Safety Edge slope on 15 projects during the 2010 construction season. Although it appeared that the equipment shaped the Safety Edge slope appropriately, the evaluation found compaction efforts with HMA projects may adversely impact the final achieved slope.

The team carried out an assessment to verify whether compliance with the desired 30 degree slope was occurring. The team measured density of the Safety Edge at several sites to estimate the amount of compaction that was occurring. The team also obtained information from the Freeborn County, Minnesota engineer, Sue Miller, who has been using the Safety Edge on most of their resurfacing projects since 2005.

Minnesota constructed several projects with the Safety Edge on one side of the roadway and a normal pavement edge surface on the other. They have collected pavement edge drop-off data at these paired locations along two roadways for several years. Measurements of drop-off with and without the Safety Edge were compared and it was determined there was no statistically significant difference in performance. The CTRE team also surveyed agencies and contractors to determine their experience and opinions in using the Safety Edge.

The Safety Edge is most commonly used with HMA projects and, as of August 2009, there were no applications of the Safety Edge on Portland Cement Concrete, (PCC) paving projects as far as CTRE researchers or advisory team members were aware. With encouragement from the FHWA, the CTRE team and the Iowa DOT worked to develop PCC Safety Edge design standards and specifications. The Safety Edge was applied on two PCC construction projects. Chapter 6 details development of the design standards and specifications and describes application of the Safety Edge in Jones/Linn and Keokuk counties in Iowa.

Chapter 7 provides a descriptive summary of projects where the Safety Edge was applied in Iowa during the 2010 construction season.

Chapter 8 covers lessons learned. Problems, such as rollover, were noted during construction and various solutions were tried. Concerns from contractors about strict interpretation of the 30 degree slope specification and recommendations were also provided. Finally, Chapter 8 discusses problems that arose with matching the safety edge between HMA lifts.

It has been estimated that the amount of additional material to place the Safety Edge for HMA paving projects would be minimal. However, application of the Safety Edge on PCC projects could increase quantities. The CTRE team estimated the additional material that could be required for several scenarios and describes the results in Chapter 9.

Finally, Chapter 10 provides conclusions and recommendations. In general, it the team found the Safety Edge holds great potential for addressing roadway departure incidents, but several issues of concern must be addressed. These include development of appropriate design standards and specifications, attention to resultant Safety Edge slope obtained during construction activities, especially with HMA pavement, and necessary continued investigation to document actual crash reduction statistics from use of this technology.

1. INTRODUCTION AND LITERATURE REVIEW

1.1 Background

Roadway departure crashes are a serious traffic safety concern. These crashes annually account for 53% of U.S. highway fatalities and 1 million injuries. It is estimated that 24% of highway fatalities occur on two-lane undivided rural roads (Taylor and Meczkowski, 2003). Neuman et al. (2003) also estimated that 39% of national fatal crashes are single-vehicle run-off-road (SVROR) crashes.

Lane (or roadway) departure crashes are the single largest category of fatal and major injury crashes in Iowa. The Iowa Department of Transportation (DOT) estimates that 52% of roadway-related fatal crashes are lane departures and that 39% of Iowa's fatal crashes are SVRORs.

Pavement edge drop-off is a vertical elevation difference between two adjacent roadway surfaces, usually a paved roadway and an unpaved shoulder. Edge drop-offs are potential safety hazards because significant vertical differences between surfaces can reduce vehicle stability and affect the driver's ability to handle their vehicle when inadvertently leaving the paved driving area.

A typical pavement edge drop-off-related crash occurs when the driver attempts an immediate return to the roadway and tire scrubbing occurs. Scrubbing is a condition in which the tire sidewall is forced against a vertical pavement edge, resulting in friction between the tire and pavement. Some drivers compensate for scrubbing by increasing the steering angle. When the right front tire finally remounts the pavement, a sudden decrease in friction between the tire and the surface of the pavement edge occurs resulting in a loss of control (Ivey et al., 1988).

Typical pavement edge faces are shown in Figure 1.1. Both can be difficult to remount after a vehicle has left the paved surface if several inches of the pavement edge is exposed.

Vehicles such as motorcycles, subcompact vehicles, and semi-tractor trailers are more sensitive to pavement edge drop-off than other full-size automobiles. Motorcyclists are prone to lose control on uneven surfaces with even marginal pavement edge drop-offs. Also, large trucks with a high center of gravity are very susceptible to rollovers, especially for 6 in. or higher pavement edge drop-off (NCDOT, 2005).

Typical vertical edge with Portland cement concrete pavement | **Typical rounded edge with hot-mix asphalt pavement**

Figure 1.1. Typical pavement edge faces

The Federal Highway Administration (FHWA) (2010) estimated that 160 fatalities and more than 11,000 injuries occur annually related to unsafe pavement edges. A Georgia Tech study evaluated 150 fatal crashes on rural two-lane roads in Georgia (2004) and found that edge drop-off was present in 55% of the crashes. A study by Hallmark et al. (2006) evaluated crashes in Iowa from 2002 to 2004 and found that pavement edge drop-off may have been a contributing factor in about 18% of rural ROR crashes on paved roadways with unpaved shoulders . The study also found that pavement edge drop-off-related crashes were two times more likely to result in a fatal crash than other crashes on similar rural roadways.

The FHWA (Roche, 2009) indicated drop-offs of three or more inches can be considered potentially dangerous. Hallmark et al. (2006) suggested a similar result with drop-offs of 2.5 inches or more having a higher relationship to edge drop-off-related crashes.

1.2 Solutions to Address Pavement Edge Drop-Off

The FHWA (2009) suggested several treatments to address pavement edge drop-off including:

- Resurface shoulders when roadways are resurfaced
- Previously, the FHWA encouraged a 45 degree angle asphalt fillet as a contract specification in all pavement resurfacing projects; currently, they recommend use of the Safety Edge

Humphreys and Parham (1994) made several recommendations for addressing pavement edge drop-off, based on research, including the following:

- Require that shoulder material be pulled up to the new surface as a non-pay item as part of project work
- Require that appropriate signing remain installed along the roadway to inform the motoring public of the existence of a low shoulder condition, when warranted
- Require that a 45 degree angle asphalt fillet be installed as a part of the roadway resurfacing along the edge of the roadway
- Combinations of the above

The most common solution to the occurrence of pavement edge drop-off is maintenance of unpaved shoulders. However, because rural roads in Iowa commonly feature granular or earth shoulders, maintenance efforts to address a recurrence of erosion and wear along the pavement edge that contribute to edge drop-off require a significant amount of effort and cost for replacement of granular material, particularly given Iowa's relatively short road maintenance season.

1.3 The Safety Edge

The FHWA began a demonstration project of the Safety Edge based on research results that indicated a sloped pavement edge surface could be more easily traversed by a vehicle leaving its lane and attempting to remount the pavement edge. The Safety Edge is a design feature that creates a fillet along the outside edge of the paved section of a roadway.

The Safety Edge is most commonly placed during hot-mix asphalt (HMA) paving using a device that shapes and consolidates the asphalt material at the pavement edge into an approximate 30 degree fillet as shown in Figure 1.2. Figure 1.3 shows the application of the Safety Edge during paving and Figure 1.4 shows the finished pavement edge face after paving.

The Safety Edge shape reduces the likelihood that scrubbing will occur and provides a gradual rather than abrupt transition back to the roadway as an errant vehicle remounts the pavement surface. The Safety Edge provides this benefit before shoulders have been pulled back up after resurfacing, as well as when the unpaved shoulder material migrates away from the pavement edge over time due to wear or erosion.

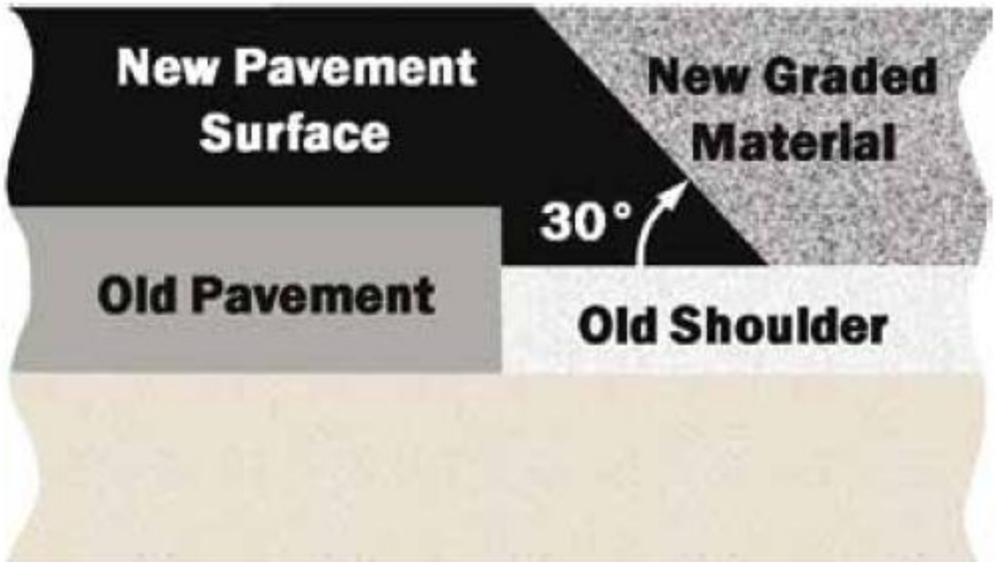


Figure 1.2. Safety Edge (FHWA, 2009)

Figure 1.3. Application of the Safety Edge during paving

Figure 1.4. Pavement edge shape resulting from application of the Safety Edge

1.4 Effectiveness of Safety Edge

Little information is available describing the actual effectiveness of the Safety Edge in reducing crashes, given the feature has not been widely used. However, the concept of a Safety Edge has been suggested by researchers for nearly 20 years.

Humphreys and Parham (1994) suggested that a 45 degree angle asphalt fillet placed at the pavement edge would be useful in addressing over corrections even for unpaved or eroded shoulders. Neuman et al. (2003) also suggested creation of 45 degree wedge during pavement resurfacing in a National Cooperative Highway Research Program (NCHRP) 500 series report, "A Guide for Addressing Run-off-Road Collisions." However, it was also indicated that more data are necessary to determine if the wedge is effective.

Figure 1.5 shows the relationship between pavement edge shape, height, and relative degree of safety per Zimmer and Ivey with the Texas Transportation Institute (TTI) (1982).

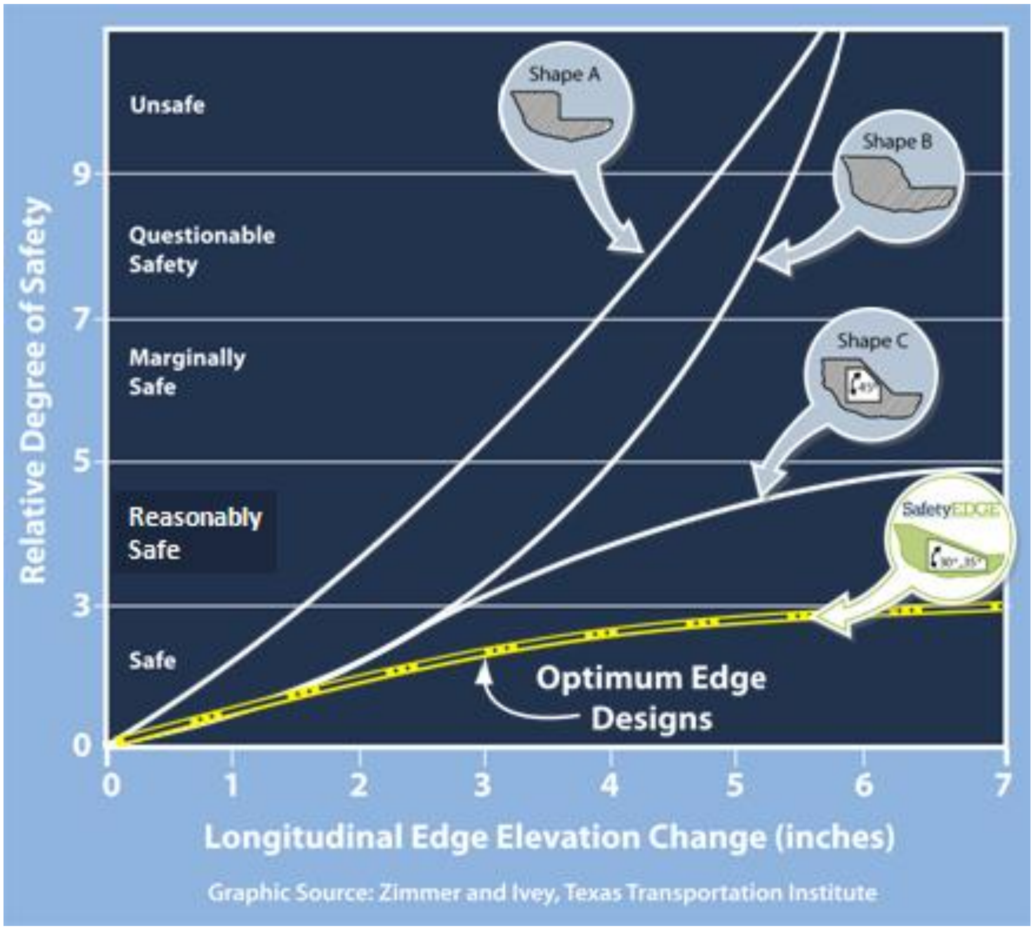


Figure 1.5. Relationship between pavement edge face and safety (Zimmer and Ivey, 1982)

A pooled fund study by the Midwest Research Institute (MRI) et al. (2008) evaluated the effectiveness of using the Safety Edge with pavement resurfacing projects. The study includes two-lane rural roads with less than 4 foot paved shoulders and multilane roads with paved shoulders of 4 feet or less. The study evaluates treatment sites that were resurfaced with a Safety Edge and comparison sites that were paved without the Safety Edge.

The research team evaluated drop-off and conducted a crash analysis after the treatments were in place for one year and plans are to conduct further analyses when more data are available. For the analysis, the roadways were categorized by characteristics and homogenous sections were created. Analyses were conducted in Georgia and Indiana. A total of 242 sites were available in Georgia with 705 miles for all roadway types. Indiana featured 148 sites with 519 miles for all roadway types.

The MRI team measured drop-off along both control and treatment sections before and during the first year after resurfacing in each study state. Drop-offs of 2 inches and greater were noted. A logistic regression was conducted to compare whether a drop-off was less likely to occur with the Safety Edge in place. Results at one year after the sites were resurfaced suggested that resurfacing with the Safety Edge is slightly more effective in reducing the proportion of extreme drop-offs than resurfacing without the Safety Edge.

A crash analysis was also conducted using crash data for five years before resurfacing and one year after resurfacing. A before-and-after analysis using Empirical Bayes (EB) indicated crashes generally increased after resurfacing for all sites, which may be due to higher speeds that are not uncommon when smoother driving surfaces are available. Although the data were limited and a one-year after period is not sufficient to determine statistical significance, results of the analysis suggest that the Safety Edge treatment is effective in reducing crashes. The study also found that the proportion of fatal and injury crashes decreased after resurfacing, but the impact of the Safety Edge on this finding was not determined.

In addition, the MRI researchers obtained costs for resurfacing for sites with and without the Safety Edge and found that the cost of applying the Safety Edge was minimal in actual application.

1.5 Benefits of the Safety Edge

The major benefit of using the Safety Edge is the flatter surface, which is provided, aids vehicle re-entry onto the driving surface before shoulders have been pulled up during construction or when drop-off forms before maintenance has taken place. Other benefits of the Safety Edge (Roche, 2009) include:

- Provides temporary safety during construction while pavement edge face is exposed
- Some states do not require contractors to pull up shoulders immediately after construction, which results in increased production for contractors since shoulder work can be done after overlay is completed
- Provides a permanent solution for pavement edge drop-off
- Can reduce tort liability by showing “due care”
- Minimal hardware, labor, or material costs are required
- Potential increased pavement edge durability

Although a safety benefit is provided, the FHWA emphasized that the Safety Edge should not be considered as an alternative to well-maintained shoulders (Roche, 2009). Routine maintenance of unpaved shoulders should still be conducted on a routine, as-needed basis.

Although data on in-place density verification tests are not available for a statistically-significant conclusion, Safety Edge placement equipment may provide some consolidation of the sloped pavement edge, which may be beneficial in long-term performance, as shown in Figures 1.5 and 1.6. Specific findings on Iowa projects are discussed in Chapter 7.

Pavement edge after resurfacing without Safety Edge | **Pavement edge after resurfacing with Safety Edge**

Figure 1.5. Edge of pavement immediately after HMA resurfacing (Roche, 2009)

Pavement edge after resurfacing without Safety Edge

Pavement edge after resurfacing with Safety Edge

Figure 1.6. Edge of pavement six years after resurfacing (Roche, 2009)

1.6 Early Use of Safety Edge in Iowa

Based on information received from the FHWA and some other states where the Safety Edge has been used, in 2010 the Iowa DOT adopted the Safety Edge as a standard practice for construction and rehabilitation projects, including both hot-mix asphalt, (HMA) and Portland cement concrete (PCC) pavement and overlays. However, initial use of the Safety Edge in Iowa was in September of 2008 on a HMA resurfacing project on County Road (CR) Z36 in Clinton County.

An open house allowed area engineers and officials to learn about the concept and view the work in progress. Additional HMA projects were undertaken and open houses held to showcase the work on CR X99 in Louisa County in May 2009 and on Iowa 143 (a state highway) in Cherokee and O'Brien Counties in September 2009. The latter open house was held with the Asphalt Paving Association of Iowa (APAI), also highlighting the use of a warm-mix asphalt.

The Iowa DOT developed specifications and design standards for state projects, beginning with the October 2010 letting, although the Safety Edge was applied to several construction projects in 2010 by extra work order.

1.7 Evaluation Project Objectives

Because use of the Safety Edge is relatively new to Iowa, the Iowa DOT and FHWA – Iowa Division, commissioned the Center for Transportation Research and Education (CTRE) at Iowa State University (ISU) to develop educational materials, market the Safety Edge to Iowa counties, and conduct some early analyses of the Safety Edge. To accomplish this, the research team completed the following tasks, which are detailed in this report:

- Review literature
- Acquire Safety Edge equipment
- Invite participation of an advisory group
- Market the Safety Edge to state and local agencies in Iowa
- Develop, administer, and host about four open house demonstrations
- Provide technical assistance as needed to agencies on use of Safety Edge
- Investigate the feasibility of expanding the Safety Edge concept to PCC pavement
- Prepare an evaluation report

2. ACQUIRING SAFETY EDGE EQUIPMENT FOR LOANS

One of the project tasks was to acquire different types of Safety Edge equipment that could be loaned to contractors to encourage use of the Safety Edge without their having to invest in the necessary equipment.

2.1 Types of Safety Edge Equipment Available

The team found three types of devices, which could be used to create the Safety Edge during asphalt overlay, that were commercially available.

TransTech Systems Device

TransTech Systems, Inc. from Schenectady, New York worked with the FHWA Resource Center and the Georgia DOT (GDOT) to develop the first device to create the Safety Edge. The device consists of a mounting plate that can easily attach to the screed face of all varieties of asphalt paving machines. The device implements an integral self-adjusting spring that allows the device to follow the roadside surface independent of the other components of the paver. A robust screw allows the adjustment for setting a position below the screed.

The component that makes the Safety Edge includes a curved runner that, in conjunction with the self-adjusting spring, helps the device to adapt to any obstacles it may encounter. The device has an angled surface that pre-compacts the asphaltic material as it enters the device and continues on to the wedge forming surface. The Trans Tech Safety Edge Shoes are side specific to the asphalt paver (left- and right-side shoes). The final angle is created when the roadway is compacted. Figures 2.1 and 2.2 show the Safety Edge device as developed by TransTech Systems.

Figure 2.1. Trans Tech safety wedge shoe (FHWA, 2009a)

Figure 2.2. TransTech Shoulder Wedge Maker™ (TransTech Systems)

Advant-Edger

The Advant-Edger is shown in Figure 2.3 and attached to the paver in Figure 2.4. This device is manufactured by Advant-Edge Paving Equipment, LLC, of Loudonville, New York. The company's product is made in the U.S. of high-quality steel and comes with a one-year guarantee. It is designed primarily to construct a consolidated, tapered mat edge with a final angle after rolling of the lane mat of approximately 30 degrees to the horizontal. The Advant-Edger Universal model can be used on both the right and left side of the paving machine. The purpose of providing both left and right operation in one device is to facilitate creating the lane edge wedge fillet, whether paving in the direction of traffic or paving against the traffic pattern. Therefore, only one unit is required to do both functions. While paving, the Advant-Edger is adjusted to keep the bottom edge of the device in contact with the road shoulder surface to prevent asphalt leakage under the wedge, producing a well-defined wedge fillet.

Figure 2.3 Advant-Edger device (Advant-Edge Paving Equipment)

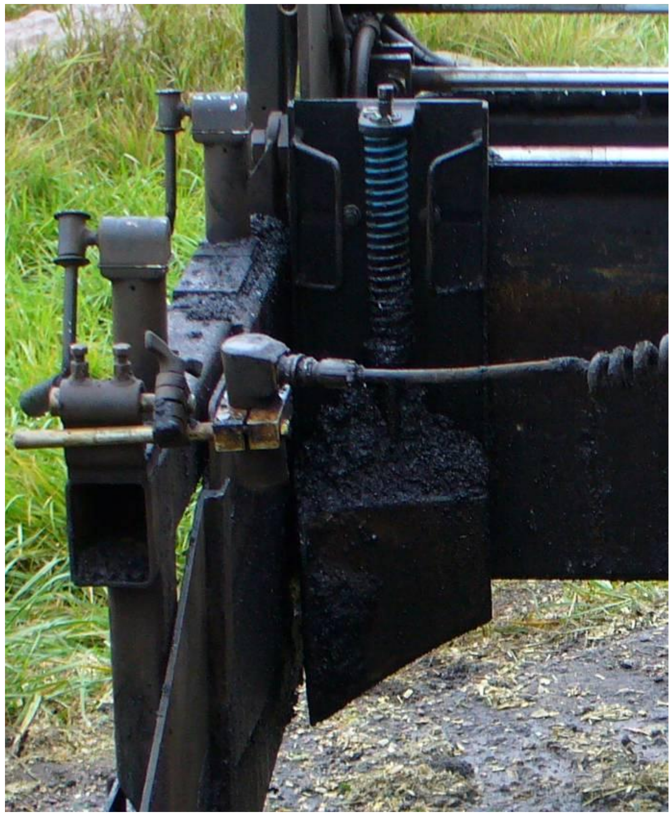


Figure 2.4. Advant-Edger device installed for use

Notched Wedge Joint Maker

The Notched Wedge Joint Maker was designed to create a denser joint between two lanes of asphalt paving. The equipment is not intended to create an exact 30 degree slope, instead being adjustable to any angle. It leaves a notch on the top surface of the asphalt. Figure 2.5 shows one model of the Notched Wedge Joint Maker made by TransTech Systems, Inc. This model has been available for a longer period of time and has been used by contractors (especially in other states) for several years in the construction of centerline joints on HMA projects. However, the flatter edge slopes that this model produces make it a very desirable alternative for areas of narrow shoulders and in subdivisions where additional shoulder material is not planned to be used.

Figure 2.5 Notched Wedge Joint Maker (TransTech Systems)

2.2 Acquisition and Loaning of Safety Edge Equipment

It was anticipated that contractors may be more inclined to use the Safety Edge technology if purchase of the equipment wasn't required. As a result, the CTRE team purchased a TransTech Shoulder Wedge Maker and an Advant-Edge Paving Equipment Advant-Edger and made them available for loan to contractors.

The cost of the TransTech Systems Shoulder Wedge Maker was $4,800 for the set (left- and right-side shoes and shipping cost). The Advant-Edge Paving Equipment shoe cost was $4,090 for the single shoe and shipping. One difference between the two shoe designs is the shoulder wedge makers from TransTech Systems are screed-side specific for use on HMA pavers and can only be attached on the proper side. The Advant-Edger can be attached to either side of the of the paver screed.

When contractors requested a loan of the equipment, the CTRE team facilitated transportation of the equipment to and from the sites. The TransTech Shoulder Wedge Maker shoes were loaned to Jasper County for use on the CR F62 project. Another set of TransTech shoes was borrowed from the FHWA – Iowa Division Office and loaned to the contractor in Webster County for use on three projects on CR D14, D46, and P59. The Advant-Edger was loaned to a contractor in Clinton County for use on CR Z30.

It was anticipated that the equipment purchased by the CTRE team would be used significantly throughout the 2010 construction season. Possibly in reaction to the adoption of Safety Edge use by the Iowa DOT, many contractors elected to purchase shoes, resulting in fewer loans of the CTRE equipment.

3. INVITING PARTICIPATION OF AN ADVISORY GROUP

To provide guidance and advice as the study proceeded, the CTRE team invited a group of experienced and knowledgeable professionals to serve on an advisory committee to work with CTRE researchers in completing this evaluation. Service on the committee involved participating in a series of project meetings throughout 2010, attending open houses as available, and reviewing/commenting on research proposals and evaluation documents.

The team extended invitations to serve as advisors to staff in both asphalt and PCC paving associations, industry, the FHWA, the Iowa DOT, academia, and interested county engineers in Iowa. The county engineers on the advisory committee all agreed to allow the use of the Safety Edge on projects for evaluation and some hosted open houses for those projects.

The committee provided valuable advice and suggestions for evaluation topics, design and specification recommendations, and beneficial input at open houses. Review and comments for the project report were most worthwhile and appreciated by the research team. Below is a list of advisory committee members and the agencies they represented.

- Bill Roesner, Asphalt Paving Association of Iowa (APAI)
- Larry Mattusch, APAI
- Gordon Smith, Iowa Concrete Paving Association (ICPA)
- Jason Schaben, Oldcastle® Materials (OMG) Midwest
- Jeremy Delaney, Henningsen Construction, Inc.
- Jerry Roche, FHWA
- Kevin Korth, FHWA
- Chris Williams, ISU
- Cathy Nicholas, Black Hawk County Engineering
- Christy Van Buskirk, Keokuk County Engineering
- Mike McClain, Jones County Engineering
- Randy Will, Webster County Engineering
- Troy Jerman, Iowa DOT
- Deanna Maifield, Iowa DOT
- LeRoy Bergmann, Iowa DOT
- Darwin Bishop, Iowa DOT
- Jeffrey Schmitt, Iowa DOT
- Jeremey Vortherms, Iowa DOT
- Jim Armstrong, Iowa DOT
- Bryan Bradley, Iowa DOT
- Eric Johnson, Iowa DOT

4. MARKETING AND OUTREACH TO STATE AND LOCAL AGENCIES IN IOWA

One of the project objectives was to encourage use of the Safety Edge by marketing it to state and local agencies in Iowa.

With input from the advisory group, a list of potential projects where the Safety Edge could be applied was developed. A survey of counties identified planned projects for the 2010 construction season. These counties were then contacted to determine interest in using the Safety Edge concept. Participating Iowa counties added the Safety Edge to projects by contract plans or extra work orders, depending on project letting dates.

4.1 Provide Technical Assistance

When requested, the CTRE team provided various types of technical assistance including project design recommendations, attendance at pre-construction meetings, suggestion of open houses, loan of Safety Edge shoes, troubleshooting, and monitoring of work. Table 4.1 lists projects where assistance was rendered.

Where extra work orders were employed on HMA projects, contractors agreed to use the Safety Edge for mutual benefit, given the sloped pavement edge did not require placement of a temporary granular rock fillet to eliminate a drop-off to the adjacent shoulder. Potential additional costs incurred from the Safety Edge are discussed later in this report.

Table 4.1. CTRE assistance to local agencies

	Pre-Letting Assistance	Attended Pre-Construction Conference	Open House	Construction Site Visits	Slope Measurement
	Black Hawk	Cedar	Clinton – October 2008	Black Hawk	Black Hawk
	Buchanan	Jasper	Louisa – August 2009	Delaware	Cedar
	Cedar	Keokuk		Iowa DOT – IA 148	Clinton
	Jasper	Kossuth	Iowa DOT Marcus 2009	Iowa DOT – US 20	Delaware
	Keokuk	Union (H24)	Jones (E34)	Jasper	DOT – US 20
	Kossuth	Webster (P59)	Union (H24)	Jones (E34)	Jasper
	Marion		Webster (P59)	Keokuk	Jones (E34)
	Page			Kossuth	Keokuk
	Union (H24)			Union (H24)	Kossuth
				Webster (P59)	Sac
					Union (H24)
					Webster (P59)
Total	**9**	**6**	**6**	**10**	**12**

The pre-construction meetings that CTRE researchers attended (as listed in Table 4.1) provided an opportunity for the researchers to meet the contractors who would be working on the projects, as well as to answer questions and offer information about the Safety Edge. If requested, Safety Edge shoes were transported to the pre-construction meeting and loaned to the contractor to allow ample time for examination and attachment of the equipment.

The CTRE research team also provided technical assistance as needed to agencies where the Safety Edge was used. This advice included contract document recommendations, such as plan notes and specifications, as well as proper procedures for use of equipment and construction of the Safety Edge. A slope-measuring tool was provided to county technical staff for use in checking final Safety Edge slopes. The CTRE team developed the device using a protractor and ruler as shown in Figure 4.1. A more sophisticated measuring device was acquired later and this was used to document Safety Edge results.

Figure 4.1. Slope-measuring tool developed by CTRE

Whenever possible, the research team made project site visits to measure and record Safety Edge slopes. Monitoring of results and advice at the project site was also offered during these visits and, when problems were observed, the team worked with the agency and contractor to resolve the issue.

4.2 Develop, Administer, and Host Open Houses

The CTRE team developed, administered, and hosted open house demonstrations of the Safety Edge technique on selected projects around Iowa to promote the concept to state and local agencies Table 2.2 provides a list of the locations. About 49 people attended the early open houses in 2008 and 2009 and 108 people attended the three events in 2010. The Jones County event was especially popular because that project was thought to be the initial proper use of the Safety Edge on a PCC project.

Table 4.2. Open House locations

County	Project	Date	Location
Clinton	County Road Z36	October 8, 2008	Clinton County Engineer's Office
Louisa	County Road X99	August 5, 2009	Louisa County Engineer's Office
Cherokee/O'Brien	State Highway IA 143	September 21, 2009	Hometown Motel Lobby in Marcus
Jones/Linn	County Road E34	May 11, 2010	Anamosa Public Library
Webster	County Road P59	August 3, 2010	Webster County Conservation Bldg.
Union	County Road H24	November 5, 2010	Green Valley Park Conference Center

The CTRE researchers organized the three 2010 open houses and two or more members of the team attended. Invitations were developed in coordination with the local agencies and contractors. Initiations were distributed electronically to engineers from the FHWA, counties, cities, and the Iowa DOT, as well as contractors. Figure 4.2 shows a typical open house invitation. In some cases, telephone calls were also made to encourage attendance.

Open House Format

A general meeting at a location near the job site was held for each open house. Following a welcome by CTRE staff, the host agency gave a short review of the project details and reasons for electing to use the Safety Edge. A representative from the FHWA provided a presentation describing the need for and value of the Safety Edge. The project contractor also related experiences and offered opinions on the benefit of the Safety Edge technology. A question and answer period for the open house participants was also offered.

Following the presentations, a lunch was provided and attendees were invited to participate in a project site visit to view the equipment and application of the Safety Edge on the project roadway. At the Jones County and Union County open houses, inclement weather prevented any actual paving work, so attendees could only review work already completed. At the Webster County open house, paving was in progress and participants were able to view the HMA overlay and compaction process, as well as examine completed work.

4.3 Provide Resources through the Iowa Local Technical Assistance Program

Further conversation with the Iowa Local Technical Assistance Program (LTAP) indicated a need for resources that could be used to provide training for local agencies. Consequently, a set of outreach materials were developed.

These included a PowerPoint presentation that can be used for training and a Technical Brief. The materials can be used by any LTAP or roadway agency for training and they include this information:

- Description of why pavement edge drop-off is a problem
- Description of the Safety Edge
- Quality assurance during construction
- Contractor benefits
- Lessons learned
- Estimating additional cost of materials
- Recommendations

Figure 4.2. Typical Open House invitation

5. EVALUATION OF PERFORMANCE OF THE SAFETY EDGE

Although the ultimate measure of the effectiveness of the Safety Edge is reduction in crash frequency and/or severity, neither could be assessed at this point given that a statistically-valid safety analysis requires several years of crash data after a treatment is applied, especially on lower-traffic-volume roadways. Several measures were available, however, which can be used to assess initial performance of the Safety Edge, as described in the following sections.

5.1 Measurement of Safety Edge Slope

The team measured the Safety Edge slope on as many construction projects during the 2010 construction season as was feasible. Although the equipment places the Safety Edge slope appropriately, actual application may vary in the field. The assessment was carried out to verify whether compliance with the desired 30 degree slope was occurring.

The final Safety Edge slopes were measured with the SmartTool™ smart level (except in Delaware County, which used a protractor/ruler combination) as shown in Figure 5.1. The SmartTool was furnished by the FHWA for CTRE team use.

For most projects, measurements on each side of the road were taken at approximate 0.2 mile intervals, so that a minimum of 10 measurements per mile was achieved for projects longer than one mile. For shorter length projects, sampling was made at 0.1 mile intervals. The measurements were initiated at the beginning of each project and extended to the end of paving. The level was held flush against the sloped edge of Safety Edge surface, and after a short period of waiting for the digital angle reader to stabilize, a reading was obtained. Final slope measurements were taken and recorded following paving completion and before final shoulder construction.

CTRE research staff ascertained from the contracting agency the anticipated completion date for overlay work, HMA or PCC. Staff then scheduled a project visit prior to initiation of shouldering activities, if possible, to obtain a sampling of Safety Edge results at a minimum frequency of 5 per mile per side. For shorter projects, a frequency of 10 per mile per side was used with the intent of obtaining a minimum of 20 samples per project. Slope measurements at each location were recorded and, on some projects, sampling sites were marked with spray paint to allow a determination of comparative shoulder deterioration at those locations periodically in the future. All results are documented in this report. These data can be used in future crash analyses.

Figure 5.1. Measurement of Safety Edge slope with SmartTool

Results of the final measurements for all sites where slope measurements were taken are shown in Table 5.1. Readings at each site were averaged for the entire project for both sides of the project. No adjustments to the recorded angles were made for the cross slope of the pavement, as that consistently ranged from about 0.5 to 2.0%.

Table 5.1. Final slope measurements

Site	Average Slope (degrees)
Blackhawk County D46	26
Cedar County Y26	40
Clinton County Z30	39
Delaware County D34*	52
Jasper County F62	37
Jones County E34	30
Keokuk County V63	31
Kossuth County A21	36
Kossuth County P20	35
Sac County M50	36
Union County H24	18
Union County Green Valley Road	18
Webster County D46	30
Webster County P59	31
Ida-Sac County US 20	31

* Measured with protractor and rule assembly instead of SmartTool

5.2 Density

When the Safety Edge is used on HMA projects, the edge itself is not directly compacted except for the consolidation that is provided by the paver and Safety Edge shoe itself. Because density from compaction is necessary for desired pavement edge durability, estimating the resultant density of the in-place Safety Edge material could be valuable information for agencies that plan to implement this technique. This assessment could provide an approximation of the durability of the Safety Edge.

Some concern has been expressed that HMA material forming the Safety Edge may not perform over long periods if in-place density is low. The researchers didn't find any literature that indicated an evaluation of compaction and/or density of the Safety Edge had ever been undertaken. The team found only one anecdotal example that assessed how the edge had worn over time.

It is generally assumed that about 80% of desired compaction is obtained from the lay-down machine during the process of placing the HMA; then, a series of rollers is used to achieve the specified final compaction and density. Because the Safety Edge slope is not compacted with the rollers, it was expected that about 80% compaction should be achieved in the Safety Edge and density testing should bear this out.

Figure 1.6 shows a site in Georgia that was examined six years after installation and the Safety Edge appeared to be in similar condition as when it was constructed. Although the durability of the Safety Edge has apparently not been evaluated, it is anticipated that even if the Safety Edge eventually deteriorates or "breaks off," the resulting pavement edge face would present no worse safety condition than had the Safety Edge not been placed.

Because no other information was available regarding durability of the Safety Edge, the CTRE team developed a method to assess in-place density (compaction) after consultation with a pavement materials specialist (Chris Williams with the Department of Civil, Construction, and Environmental Engineering at ISU).

Contractors in Iowa are normally required to take 5 to 7 cores per day on HMA projects to test compaction results. Cores are randomly taken along the recently compacted section. A density test is conducted on the core samples to determine the percentage of optimum laboratory density that is achieved in the field, to be compared with the minimum percentage density target of the specifications.

The CTRE team solicited two contractors to take additional cores from the Safety Edge during regular field sampling. Contractors record the core locations as part of the normal sampling procedure, so it would only be necessary to match the regular cores with the Safety Edge samples for comparison of results. Each contractor was requested to obtain a density core from the Safety Edge simultaneously with regular core sampling for any two days and test those cores for density results. Sampling at the same location provided a paired test. The contractors were asked to label the cores for later identification. Because the Safety Edge produced an irregularly shaped core, “shrink wrap” tests were also subsequently conducted by Dr. William’s staff at ISU.

When possible, density tests were also taken in the outside foot of pavement, which was compacted with the final roller only for some projects (due to “rollover,” as explained in section 8.1). For this evaluation study, rollover is defined as distortion of the outside HMA pavement edge that can result during the compaction process, adversely impacting the final slope of the Safety Edge.

Table 5.2 shows density testing results. The compaction for normal cores ranged from an average of 97.1 to 97.9%. Density tests performed on cores within the outer foot of pavement shows that average compaction was in the range of 87.8 to 95.0. For the Jasper County sites, this was 2.3% lower and for the Webster County sites, this was 2.1 and 3.5% lower than the density recorded for the core samples taken from adjacent HMA pavement, which had been compacted with standard methods.

Table 5.2. Field densities measured on projects

	Normal Cores		Cores from Outside Foot		Change between normal and outside foot	Cores from Safety Edge		Change between normal and outside foot
County	**Range (%)**	**Average (%)**	**Range (%)**	**Average (%)**		**Range (%)**	**Average (%)**	
Jasper 7/22	96.8 to 98.3	97.1	94.8	94.8	2.3	82.8 to 85.7	84.3	12.8
Jasper 7/26	96.1 to 97.9	97.1	NA	NA	NA	80.6 to 86.3	84.1	13.0
Jasper- by Chris Williams	NA	NA	NA	NA	NA	73.8 to 84.9	79.8	17.3
Webster 7/13	95.5 to 98.9	97.1	95.0	95.0	2.1	NA	NA	NA
Webster 7/14	97.0 to 98.5	97.9	94.4 to 94.5	94.5	3.5	NA	NA	NA
Union	NA	NA	87.2 to 88.8	87.8	NA	NA	NA	NA

Some concern was raised about reducing roller passes along the outer foot of pavement surface during compaction to avoid rollover of the Safety Edge. Without the initial compaction, the outside edge may not have the same uniform density and may perform differently than the remainder of the pavement surface. Two field evaluation tests indicated that final compaction was indeed slightly lower when less compactive effort was expended along the outer edge of pavement.

Tests were performed on the sloped Safety Edge at the Jasper and Union County sites with contractor results ranging from 84.1 to 84.3%. As a result, density was 12.8 to 13.0% lower than for normal cores.

The CTRE team obtained the core samples and had Dr. Williams perform an independent test on the cores, which resulted in an average of 79.8% compaction. This was somewhat lower than what was reported by the contractor and was 17.3% lower than for the adjacent cores using a different test method. However, caution should be used in this comparison, given the core samples were not verified by the independent test and may have been different than what was reported in the field.

The cores samples are shown in Figure 5.2. Some of the cores deteriorated soon after density tests were performed. The use of modified safety shoes, which tended to "extrude" HMA material, visually appeared to produce the best results in producing a uniform finished look.

Figure 5.2. Deterioration of Safety Edge core samples from Jasper County

It was expected that the Safety Edge would have approximately 80% compaction due to the lay-down machine and Safety Edge equipment. The field density and independent tests for the Jasper County project indicated that approximately 80% compaction had occurred, confirming the initial assumption.

5.3 Monitoring Drop-Off

Several conditions contribute to the wear of granular shoulders, resulting in edge ruts. Jahren et al. (2011) concluded that edge ruts likely develop from a combination of vehicles leaving the roadway surface (off-tracking) and the time between shoulder maintenance cycles.

When a vehicle leaves the paved roadway surface and encounters a granular or earth shoulder, the force of the tire can dislodge the larger particles. With a normal vertical or rounded pavement face that commonly exists, the force of the tire is mostly vertical, which can cause a rut to form near the pavement edge as shown in Figure 5.3.

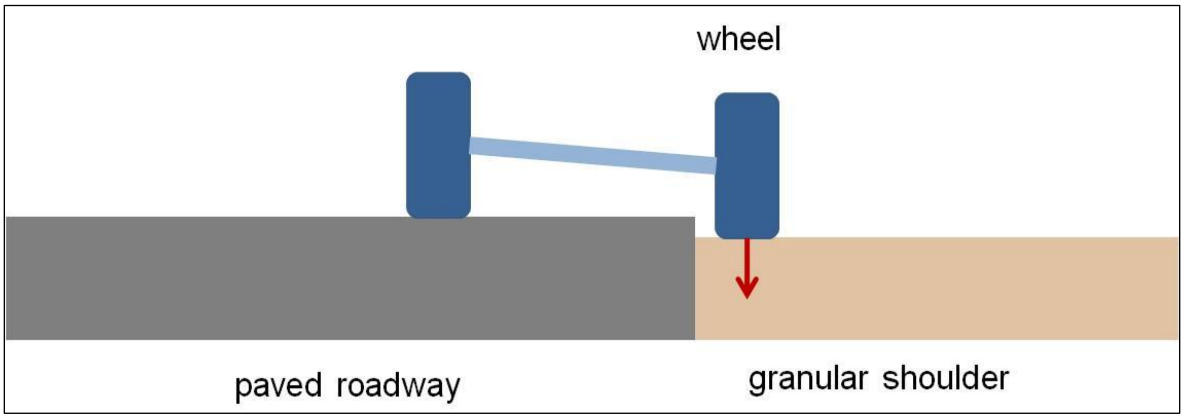


Figure 5.3. Wheel impacting granular shoulder with regular resurfacing pavement edge face

With the Safety Edge, the tire may push the loose material down the sloped edge as illustrated in Figure 5.4. As a result, there may be a slightly greater tendency for pavement edge drop-off to form.

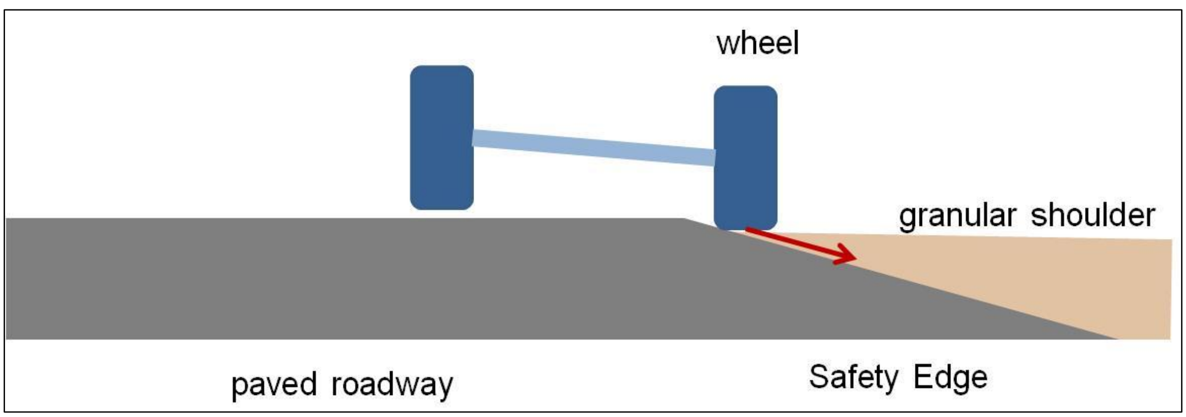


Figure 5.4. Wheel impacting granular shoulder with Safety Edge

As indicated in section 1.4, a pooled fund study evaluated pavement edge drop-off one year after resurfacing on a number of HMA roadway sections with and without the Safety Edge. Results at one year after the sites were resurfaced suggested that resurfacing with the Safety Edge is slightly more effective in reducing the proportion of extreme drop-offs than resurfacing without the Safety Edge (MRI, 2008).

Due to the relatively short timeframe for this project, it wasn't possible to extensively evaluate pavement edge drop-off formation for any of the Iowa sites. However, to explore the issue further, the research team contacted and visited with the Freeborn County, Minnesota engineer, Sue Miller, who has been using the Safety Edge on most of their resurfacing projects since 2005.

Beginning with 11.3 miles of work on two projects in 2005, as an experiment, one side of the roadway was overlaid with HMA normally and the other side featured the Safety Edge. To evaluate the possible impacts of the Safety Edge on edge rutting, Miller began monitoring several locations on one of the 2005 projects, along with another project that was completed in 2006. Initial observations were made and recorded in August 2007, measuring the vertical elevation difference from a horizontal projection of the pavement edge and the shoulder surface at a distance of 3 inches and 1 foot horizontally from the edge of the pavement on both sides of the road.

Following a shoulder reclamation project on these road sections, similar reviews were made in May 2008 and September 2009. The CTRE team also repeated these measurements during a July 2010 site visit, so considerable information was gathered and recorded.

Following good experience with the Safety Edge on these projects, the feature was added as a requirement to all resurfacing projects in Iowa. Through the 2010 construction season, more than 65 miles of resurfacing have now been installed with the Safety Edge.

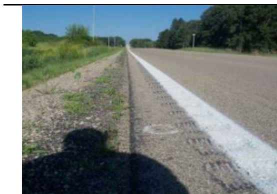
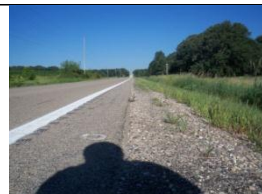
Table 5.3 shows results for Minnesota CSAH Highway #18. The road was last maintained shortly after September 2009 measurements. The Safety Edge is located on the east side (northbound lane) and no Safety Edge is present on the west side (southbound lane). The average drop-off depth for the west side (no Safety Edge) was 0.984 inches and the average for the east side (with Safety Edge) is 1.13 inches. A paired t-test was used to compare the mean pavement edge drop-off for the side with and without the Safety Edge. There was no statistically significant difference (p=0.189) between the average drop-off.

Table 5.3. Drop-off measurements along Minnesota CSAH #18 (ADT 280 to 395 vpd)

Westside	**Eastside**		**Aug. 2007**	**May 2008**	**Sept. 2009**	**July 2010**
		**North of State Line 1/2 mile – Pipeline post on west side**				
		West	1.25	1.25	0.75	0.0
		East	1.50	1.50	0.75	0.0
		Difference	-0.25	0.25	0.0	0.0
		**North of State Line 1 mile – No Pass on east side**				
		West	1.25	1.50	1.0	0.125
		East	1.50	1.375	1.0	0.0
		Difference	0.25	0.13	0.0	0.125
		**North of State Line 1.5 mile Intake on west side**				
		West	1.0	1.0	1.0	0.0
		East	1.75	1.75	0.75	0.0
		Difference	-0.75	-0.75	0.25	0.0
		**North of State Line 2 miles – Pipeline post on west side**				
		West	1.25	1.5	1.0	1.175
		East	1.5	2.0	1.0	1.0
		Difference	-0.25	-0.5	0.0	0.175
		**North of State Line 2.4 miles – Power box on east side**				
		West	1.25	1.5	1.0	0.875
		East	2.0	2.0	1.175	0.0
		Difference	-0.75	-0.5	-0.175	0.875

Information for Minnesota CSAH #5 is shown in Table 5.4. Average daily traffic (ADT) volumes are 350 vehicles per day (vpd) along the roadway. The average drop-off for the west side of the road without the Safety Edge was 1.07 inches, while the average for the east side was 1.19 inches (with a Safety Edge). A paired t-test was used to compare the mean pavement edge drop-off with and without the Safety Edge. There was no statistically significant difference (p=0.18) between the average drop-offs.

Table 5.4. Drop-off measurements along Minnesota CSAH #5 (ADT 350 vpd)

Westside	**Eastside**		**Aug. 2007**	**May 2008**	**Sept. 2009**	**July 2010**
		**0.3 Miles West of #18 South – Intake on both sides of road**				
		West	2.00	2.25	1.50	0.875
		East	1.50	2.00	1.25	0.625
		Difference	0.50	0.25	0.25	0.25
		**1/2 Mile North of # 5 – No Pass on east side of road**				
		West	1.50	1.75	1.0	0.0
		East	1.875	2.0	1.25	0.0
		Difference	-0.375	-0.25	-0.25	0.0
		**1 Mile North of #5 – 82 route marker on east side of road**				
		West	1.375	1.50	0.675	0.0
		East	1.75	1.75	0.75	0.0
		Difference	-0.275	-0.25	-0.075	0.0
		**1.3 Miles North of #5 – 85 route marker on east side of road**				
		West	1.00	1.25	0.50	0.0
		East	1.75	1.75	0.75	0.0
		Difference	-0.75	-0.5	-0.25	0.0

5.4 Agency and Contractor Feedback

In an effort to obtain additional information from counties and the Iowa DOT about the 2010 Safety Edge projects, the following questions were sent to all 12 of the participating agencies and contractors on these projects, in addition to comments received throughout the summer. A compilation of the responses from eight counties and four contractors follows.

Please name the type of safety shoe that you used and note the degree of difficulty that you had mounting it, as well as adjusting it vertically as you paved.

Most respondents used the TransTech shoe, one was fabricated; only one noted a mounting problem and slow adjustment of the shoe only when it needed to be fully raised or lowered. The problem was resolved by using an electric drill to turn the screw adjustment. One suggested mounting the Safety Edge to the end gate, rather than the paver, to minimize mix accumulation behind the shoe when changing the width laid for fillets.

Did the shoe leave a beveled edge of the proper angle (30 degrees) coming out of the paver?

The shoes shaped a consistent 30 degree angle out of the paver; for the fabricated unit, the exit slope was 22 degrees, which seemed to allow more roller tolerance to maintain the desired final slope.

If multiple lifts were involved, did paving a proper width and alignment on the base course cause any problems?

Paving proper widths and alignment seemed more difficult, especially if more than two lifts were involved.

Were you able to develop a rolling pattern that kept the slope near 30 degrees? If so, what pattern and thickness of lift were you laying?

The pattern required seemed to change with various mixes, but most eliminated the rubber tire roller on the outer foot of paving and some rolled it only with the final roller. Rollover problem seemed less with thin lifts (one and a half to two inches).

Were there any new complications noted with shouldering on the Safety Edge?

Responses varied from "no problems" to "hard to get rock to stick to the wedge." Problems were also noted when thickness variations occurred along a segment.

In an effort to get a broader view of the any functionality problems with the Safety Edge on PCC pavements, the following questions were asked of the counties and contractors working on PCC projects.

Were the pan modifications that were made difficult to accomplish?

Neither contractor expressed any concern over their ability to conform to the shape desired.

Other than requiring additional width for the paver pads, were any complications encountered that should be mentioned and resolved in the future?

Having sufficient shoulder width and stability to support the paver was the only concern of counties and contractors.

What was the most successful method of tying in intersections and radii?

Paving through the intersection, then sawing off the Safety Edge before placing tie bars was the most labor intensive, but appeared to produce satisfactory results. Contractors should be allowed the option of using this procedure or forming a "box-out" to restrict placement of the Safety Edge during the paving operation.

Were there any new complications noted with shouldering on the Safety Edge?

No new or unique problems were noted when shouldering adjacent to the Safety Edge by contractors or agencies.

6. DEVELOPMENT OF DESIGN STANDARDS AND SPECIFICATIONS

When this evaluation study began in August 2009, the Iowa DOT and local agencies had no formal specifications or design standards for use of the Safety Edge; early project applications were accomplished with special drawings and extra work orders. Use of the Safety Edge on HMA projects had been accomplished in other states with guidance from the FHWA and sample contract requirements from those projects were available for reference in developing design requirements for HMA projects in Iowa.

However, there were no properly designed applications of the Safety Edge on PCC paving projects, nationally, as far as CTRE researchers or advisory team members were aware. With encouragement from the FHWA, the CTRE team and the Iowa DOT worked to develop PCC Safety Edge design standards and specifications.

6.1 Iowa DOT Guidance on Use of the Safety Edge

In April 2010, the Iowa DOT issued design guidance that was finally adopted for the October 2010 letting on use of the Safety Edge. Currently (as of January 2011), the Safety Edge is required on all primary highways unless one of the following is met:

- Roadway is an interchange ramp or loop
- Roadway or shoulder has curbs
- Paved shoulder width is 4 or more feet

The standards apply to both new construction, as well as rehabilitation. The Iowa DOT further specifies that the beveled edge should be 30 degrees with an equivalent rise over run ratio of 10.5 to 6 and that the 30 degree angle does not account for surface slope. Additional information and plan details are provided in the Iowa DOT Design Manual (Iowa DOT, 2010).

6.2 HMA Design Standards

The Iowa DOT design standard for use of the Safety Edge in HMA paving and overlays is shown in Figure 6.1. The design prescribes a 30 degree Safety Edge beginning at the edge of the original pavement width extending the full-depth of the paving.

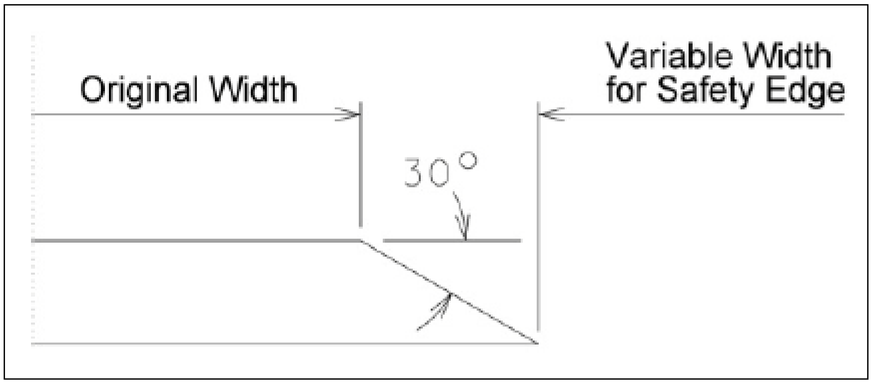


Figure 6.1. HMA Safety Edge dimensions from the Iowa DOT Design Manual

6.3 PCC Design Standards

The Iowa DOT design staff began developing design standards and specifications for application of the Safety Edge to both HMA and PCC projects following adoption of the safety feature in Iowa in late 2009. However, formal DOT requirements were not available until later in 2010.

In addition, PCC pavements and overlays for county roads are normally thinner (5 to 8 inches) than for Iowa DOT designed projects, so the team was concerned that a thinner outer PCC Safety Edge could break off when subjected to loading. As a result, the CTRE team worked with Keokuk County staff to develop design standards and specifications for county projects independent of the Iowa DOT. Jones County staff developed these requirements on their own.

The designs used by both Keokuk and Jones Counties varied from the final design adopted by the Iowa DOT in width and minimum vertical edge dimension. Because PCC pavement is measured and paid by square yards of placement in Iowa, this type of design variation impacts the final cost to the administrating agency.

The PCC design standard used for the two county projects resulted in a thicker section at the outer edge. This design also results in a narrower final pavement width and thereby fewer square yards for payment than what would result from using the measurement method in the new Iowa DOT specification. In areas where the design thickness is less than the 8 inches shown, it is anticipated that a minimum depth of 8 inches will be attained by undercutting the shoulder material to uniformly provide the additional depth needed. The two county designs are shown in Figure 6.2 and 6.3.

The Iowa DOT Design Manual (2010) for PCC paving and overlays prescribes a 1 foot widening to accommodate the Safety Edge. The specified depth for the Safety Edge is 6 inches with a minimum 1 inch vertical face as shown in Figure 6.4.

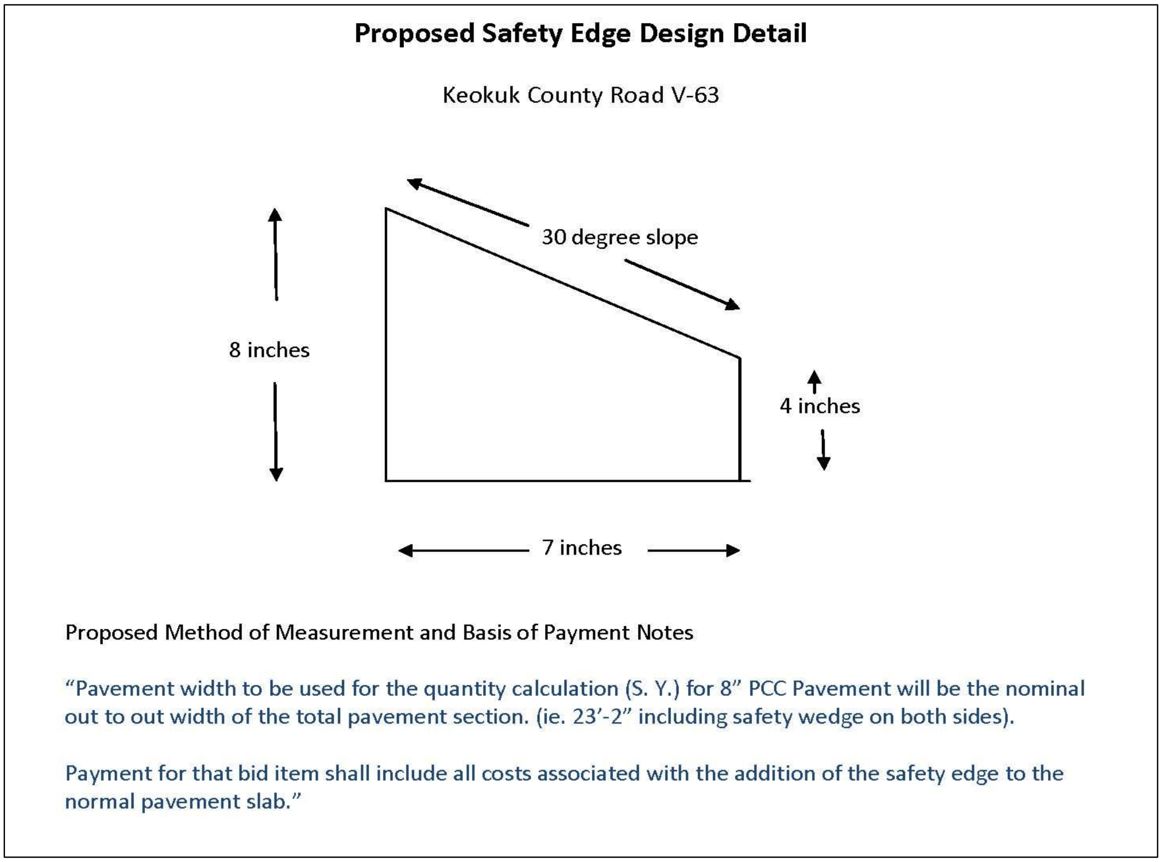


Figure 6.2. CTRE PCC Safety Edge design used in Keokuk County

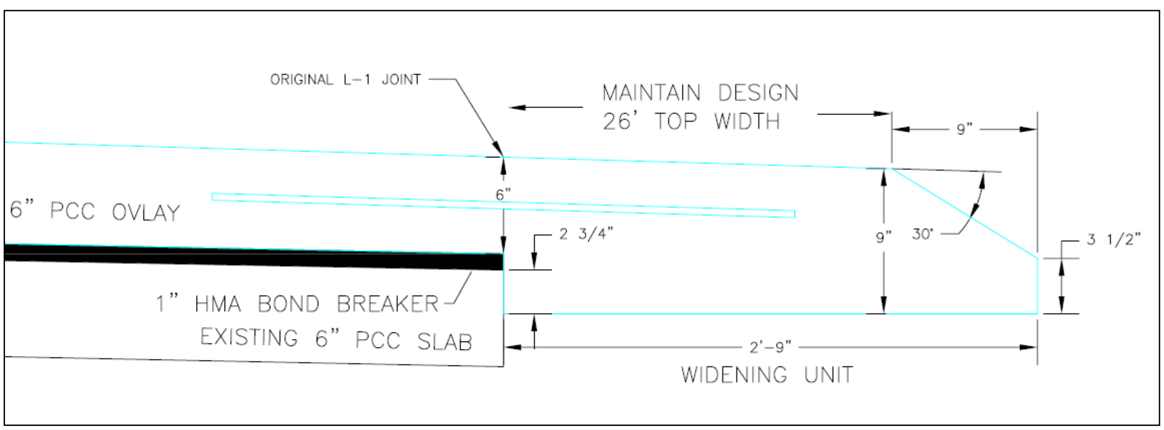


Figure 6.3. Jones County PCC Safety Edge design

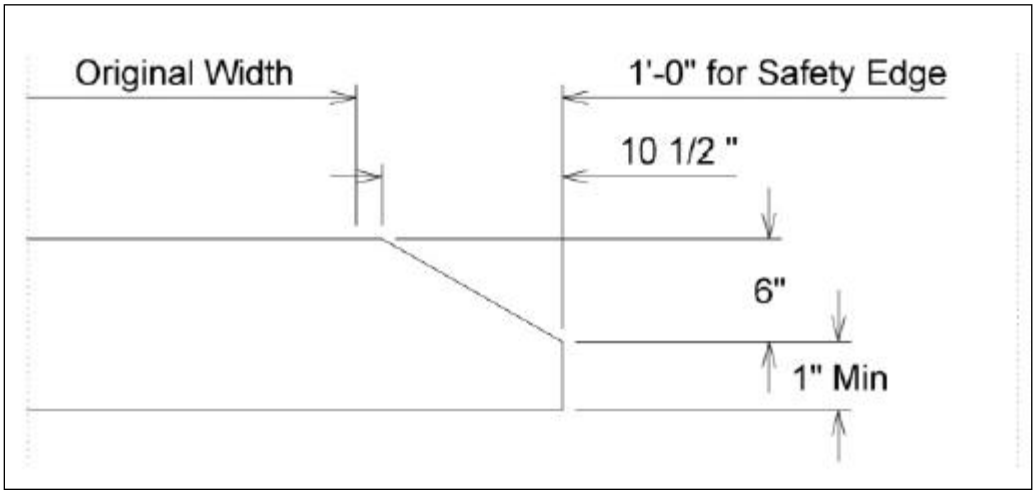


Figure 6.4. PCC Safety Edge dimensions from the Iowa DOT Design Manual

6.4 Adapting the Safety Edge to Portland Cement Concrete Pavement

Two counties agreed to test the use of the Safety Edge for PCC projects. The Jones/Linn Counties project used a slightly modified version of the CTRE design, but Keokuk County incorporated the edge as designed by the research team for their project. The Jones/Linn Counties project was the first to implement the Safety Edge. As of February 2011, the new Iowa DOT design had not yet been used on a project. The latest Iowa DOT design drawings and specifications became effective October 2010 and will be the required standard for any future PCC projects let under the DOT Standard Specifications, unless noted otherwise.

Design and Fabrication of Equipment

The contractor for Jones/Linn Counties, Horsfield Construction, Inc. from Epworth, Iowa fabricated a device to form the Safety Edge slope by welding an angled steel plate and shoe assembly to the outside edges of the paver pan. Unlike the Safety Edge shoes for HMA lay-down machines, Safety Edge modifications to a PCC paver might not be as easily mounted and removed. As designed for this project, the Safety Edge assembly can be removed by cutting from the pan using a torch or similar tool. Touch-up of the pan may be required to return the paver to service for standard PCC pavements.

The contractor indicated there may be additional benefit to use of the Safety Edge versus a conventional vertical face, expecting a more workable concrete mix can be used, which would facilitate improved concrete quality. Figure 6.5 shows the modified equipment and paving with the Safety Edge on the Jones/Linn County PCC project.

Safety Edge assembly

Start of construction

Extrusion of the Safety Edge

Finished section

Figure 6.5. Constructing the Safety Edge with PCC pavement in Jones County

The contractor for Keokuk County, Wicks Construction of Decorah, Iowa also fabricated an extension to the paver pan to form the Safety Edge, working with Gomaco Corporation, the equipment manufacturer, to design and build the proper assembly shape to achieve the desired Safety Edge shape. Figure 6.6 shows the device that was fabricated for the Keokuk County project.

Figure 6.6. PCC paver modification for the Keokuk County Safety Edge

Modifications at Paved Side Road Intersections

The sloped Safety Edge face of the mainline pavement poses a concern when constructing a durable interface joint at PCC paved road intersections. In Iowa, a reinforced joint is constructed to adequately tie the intersecting pavements together and this is accomplished with a vertical pavement edge, not sloped. To accomplish the desired connection effectively, it is necessary to remove or eliminate the Safety Edge through intersections with paved roads. The contractor would be required to either saw-cut and remove the Safety Edge, as shown in Figure 6.7, or construct a formed “box-out” to prevent placement of the sloped edge when the mainline was paved.

Figure 6.7. Safety Edge modifications at a paved road intersection

Final Pavement Edge Characteristics

Depending on the design of the Safety Edge forming assembly and thickness of the pavement section, the shape of the pavement edge will vary significantly. As shown in Figure 6.8 and with the Iowa DOT design details previously shown, the vertical dimension of the Safety Edge might vary from 4 to 6 inches with any remaining edge exhibiting a typical vertical pavement face for the remaining slab thickness.

Pavement with 3 inches of vertical toe	**Pavement with significantly more vertical toe**

Figure 6.8. Placement with various dimensions of vertical toe

Figure 6.8 shows a placement with 3 inches of vertical face and a thicker slab with a greater vertical dimension and material spill out from below the Safety Edge paving assembly. No detrimental impacts to the Safety Edge or pavement, in general, are anticipated from this occurrence.

An assessment by the FHWA (2011) indicated the average slope for the Jones/Linn County Safety Edge applications was 31.5 degrees with a range of 28.5 to 34.0 degrees. The report also indicated the face of the Safety Edge was slightly concave or convex in some locations, which may have resulted from flex in the paving pan or from issues during finishing (as shown in Figure 6.9). Results of an air voids and modulus test indicate that the quality of the concrete was uniform for both the normal pavement section and the Safety Edge.

Figure 6.9. Edge of PCC Safety Edge showing ridge and bow (FHWA, 2011)

Saw Cutting of Transverse Joints

To control random cracking in a newly-placed PCC pavement, full-width saw-cutting for transverse joints at approximate 20 foot intervals is required before hardening of the pavement material. To avoid challenges from operating a saw on a sloped surface, it was decided not to extend the saw cut down the Safety Edge slope. It was anticipated that a near vertical random crack would eventually occur from the saw cut through the remaining pavement thickness. As shown in Figure 6.10, the predicted random crack did occur, thus negating the necessity for extending the saw cut through the Safety Edge section.


Figure 6.10. Saw cut transverse joint with the Safety Edge

7. IOWA SAFETY EDGE PROJECTS

7.1 Portland Cement Concrete Projects

Prior to commencement of this evaluation project, the Iowa DOT and some local agencies had constructed projects using a sloped edge design. Most improvements were constructed of HMA, but one PCC pavement was completed by the Iowa DOT on I-29 in Woodbury County in 2008.

Interstate 29 in Woodbury County

The designed new pavement section consisted of 9 inches of PCC pavement with 7 inch thick paved shoulders (See Figures 7.1 and 7.2). The contractor was allowed the option of selecting the paving material for the shoulders and PCC was chosen as the preferred material. A sloped outer edge was part of the design to eliminate the need for additional shoulder material there. For various reasons, the desired shoulder top width was not attained with the sloped edge as designed. This experience pointed out the need for carefully-devised design standards and specifications to achieve the desired results.

Figure 7.1. Sloped edge on I-29 in Woodbury County

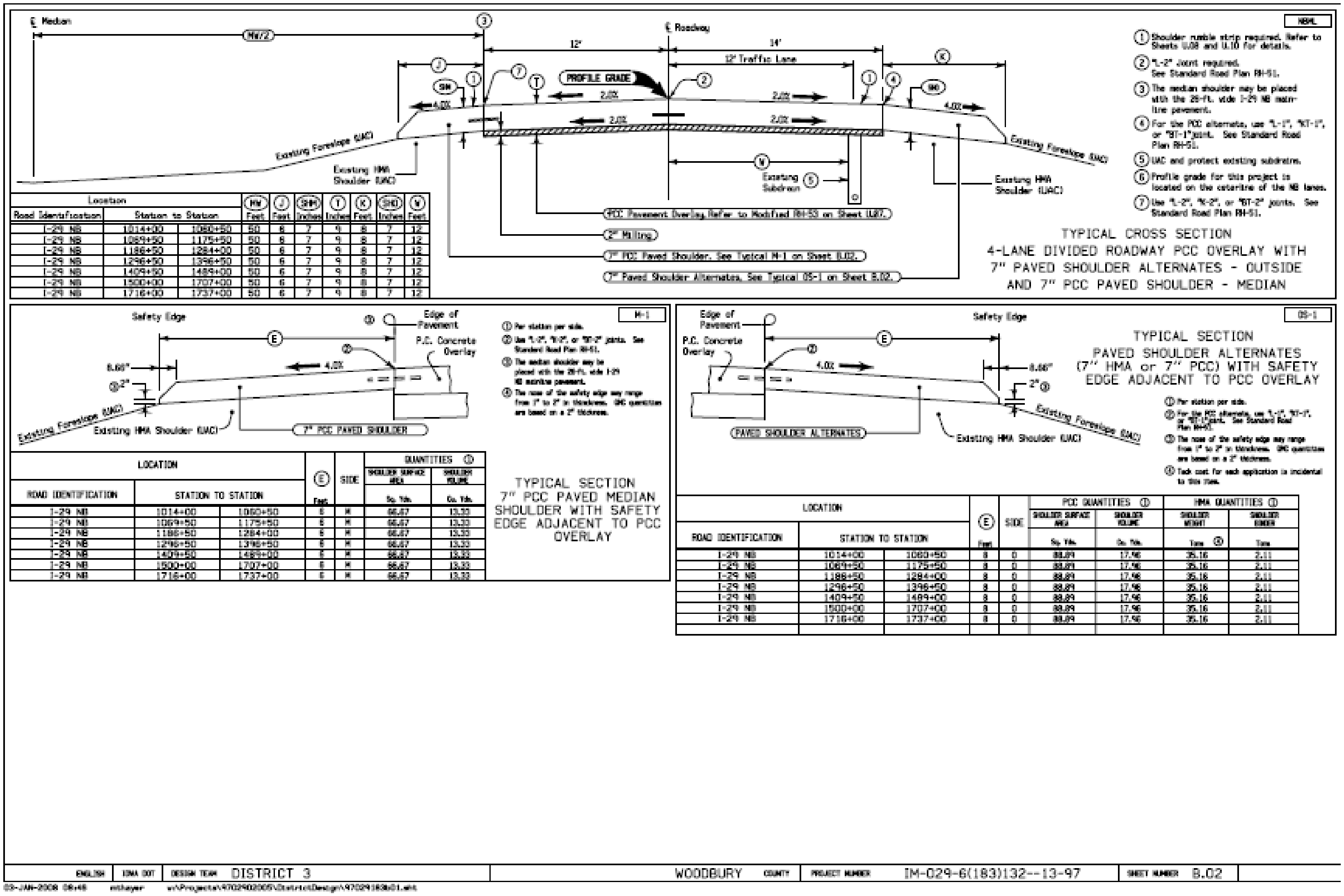


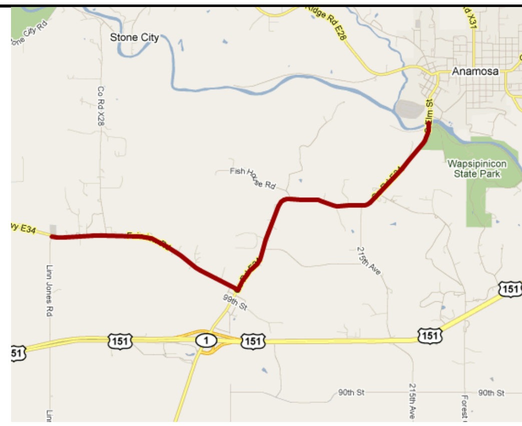
Figure 7.2. Woodbury County I-29 typical sections

County Road E34 in Jones/Linn Counties

Jones County Engineer Mike McClain, a member of the advisory group, suggested CR E34 as a candidate project for the Safety Edge evaluation. The project was funded by the American Recovery and Reinvestment Act (ARRA) with a letting date of August 18, 2009. The Safety Edge was added to the project by extra work order. Jerry Roche from the FHWA – Iowa Division was instrumental in obtaining Federal funding for the cost of this project addition. The contactor, Horsfield Construction, Inc. of Epworth, Iowa also contributed to the successful results through the fabrication and installation of the necessary equipment modifications and undertaking of a new construction method. This project was the site of an open house demonstration in May 2010. Table 7.1 provides a project summary and Figure 7.3 shows the finished PCC Safety Edge.

Table 7.1 PCC project summary for CR E34 in Jones/Linn Counties

Project	**E34, Jones/Linn Counties**
Surface Material	Unbonded 6 inch PCC overlay over an existing 6 inch PCC pavement with a 1 inch HMA bond breaker
Paved Width (not including Safety Edge)	26 feet
Project Length	2.5 miles
Letting Date	August 18, 2009
Open House	May 11, 2010
Construction Start/End	May 1 – July 20, 2010



Project Extents (Google image)

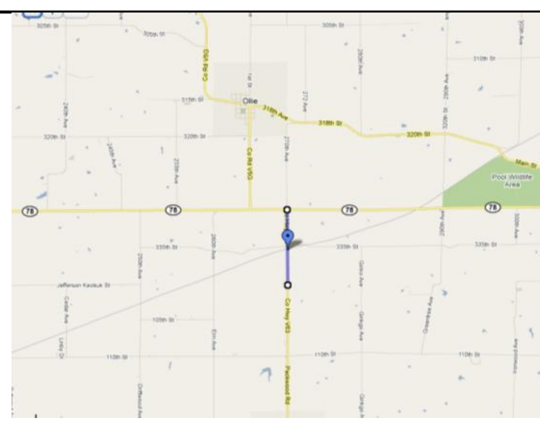
Figure 7.3. Finished PCC Safety Edge for CR E34 in Jones/Linn Counties

County Road V63 in Keokuk County

The CR V63 project in Keokuk County was the second PCC pavement to be evaluated for the Safety Edge in Iowa. The contractor, Wicks Construction, worked with the paver manufacturer, Gomaco Corporation of Ida Grove, Iowa, to develop a differently designed Safety Edge adaptation from that used on the Jones County project. The Safety Edge portion was about one mile in length on CR V63, south of Iowa Highway 78, on this 2.7 mile long combination project. Table 7.2 provides a project summary.

Table 7.2 PCC project summary for CR V63 in Keokuk County

Project	**V63, Keokuk County**
Surface Material	PCC
Paved Width (not including Safety Edge)	24 feet
Project Length	1 mile (SE) segment of 2.7 miles of work
Letting Date	3/16/2010
Open House	None
Construction Start/End	May 17 – November 2010



Project Extents (Google image)

The CTRE team attended the preconstruction meeting May 12, 2010 and shared many photos and details learned from the Jones County open house with both the engineering staff and the contractor.

This project included some grading and the extension of and new construction of box culverts on other portions of the work. The project schedule was expanded many times due to heavy area rainfalls. A short section less than a tenth of mile in length omitted the Safety Edge due to a railroad crossing.

Site visits were made during and following work completion to observe the work in progress and measure the Safety Edge slope, using a smart level (See Figure 7.4). The project inspector stated that the whole construction process went smoothly and seemed like any other PCC paving project. The county is also hoping that the Safety Edge will help with future edge rutting problems on the road.

Figure 7.4. Safety Edge on Keokuk CR V63

7.2 Hot-Mix Asphalt Projects (County and Local)

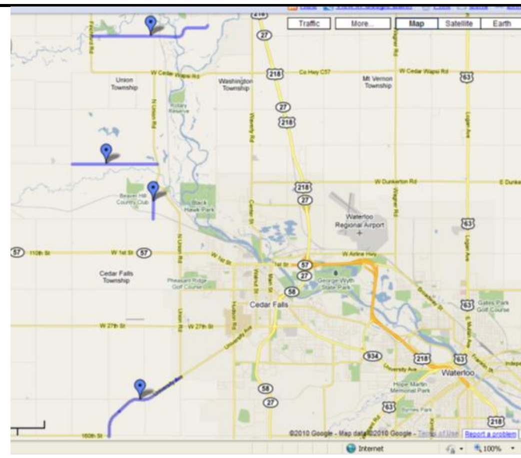
The majority of projects for the 2010 construction season that utilized the Safety Edge were HMA projects. The CTRE team only worked with county and local agencies to adopt the Safety Edge.

University, Winslow, and Beaver Valley/Skyline in Blackhawk County

Three HMA projects were identified as candidates for the Safety Edge by Catherine Nicholas, the Blackhawk County engineer and a member of the advisory committee. These projects were funded by Blackhawk County Secondary Roads. Table 7.3 provides a project summary.

Table 7.3 HMA project summary for University, Winslow, and Beaver Valley/Skyline in Blackhawk County

Projects	**University Avenue, Winslow Road, and Beaver Valley Road/ Skyline Road, Blackhawk County**
Surface Material	HMA overlay, 2 lifts with a 2.5 inch intermediate and a 2 inch surface
Paved Width (not including Safety Edge)	24 feet
Project Length	8.6 miles (total)
Letting Date	April 1, 2010
Open House	None
Construction Start/End	May – June 11, 2010



Project Extents (Google image)

The contractor for the project was Aspro, Inc. of Waterloo, Iowa. Aspro used the TransTech Notch Wedge Joint Maker equipment to construct the Safety Edge. It was necessary for the contractor to estimate the height of vertical notch needed in the freshly laid mix to achieve a smooth and level pavement surface after compaction. As seen in Figure 7.5, the contractor was fairly successful in achieving a desirable slope, while not leaving a vertical notch at the surface.

Measurements taken with the smart level indicated an average of 26 degrees. The Blackhawk County inspector, Chad Wurzer, stated that challenges in achieving the desired Safety Edge slope were encountered with varying lift thickness. The design of the Notch Wedge Maker includes two adjustment screws, but the fixed width of shoe results in steeper Safety Edge slopes with the thicker courses, while thinner lifts exhibit a safety edge with quite flat slopes. In addition, the resultant slope sometimes presents a coarse, possibly permeable surface texture because little downward pressure on the sloped edge is imparted as the mix is extruded.

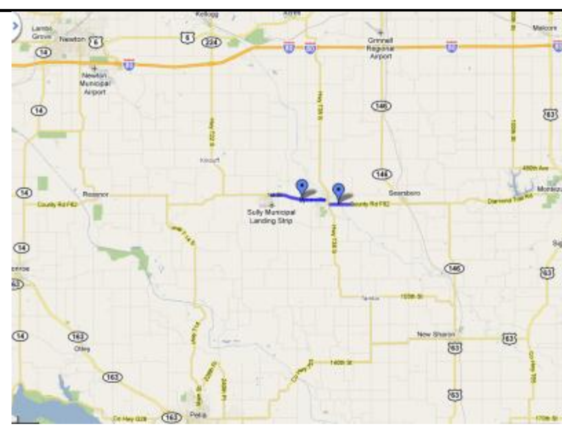
Figure 7.5. Safety Edge on Skyline Road in Blackhawk County

County Road F62 in Jasper County

Jasper County Road F62 was identified as a candidate for the Safety Edge technology. The contractor for the project was Manatt's, Inc. of Brooklyn, Iowa. The project included two sections: a 2.8 mile segment between the communities of Sully and Lynnville and a 1.7 mile section from Lynnville to the Poweshiek County Line. Table 7.4 provides a project summary.

Table 7.4 HMA project summary for CR F62 in Jasper County

Project	F62, Jasper County
Surface Material	Cold In-Place Recycled HMA, 5 inches new HMA, 3 lifts 2+1.5+1.5 inches
Paved Width (not including Safety Edge)	24 Feet
Project Length	4.5 miles
Letting Date	March 16, 2010
Open House	None
Construction Start/End	July 6, 2010 –



Project Extents (Google image)

Members of the CTRE team attended the preconstruction meeting to offer advice and answer questions from the contractor and county about the Safety Edge.

A pair of TransTech Shoulder Wedge Maker shoes were loaned to the contractor for use on the project. At the request of CTRE, the contractor agreed to sample and test cores from the Safety Edge for density. Density testing was performed by the contractor and later by ISU. Results of those tests were presented in section 5.2.

The Safety Edge slope was measured throughout the project using the smart level and recorded to the nearest degree, with an average reading of 37 degrees. The contractor experienced some initial problems with rollover of the Safety Edge during compaction. The issue was addressed by delaying compaction of the pavement edge with the initial roller passes. Figure 7.6 shows the typical edge produced on this project.

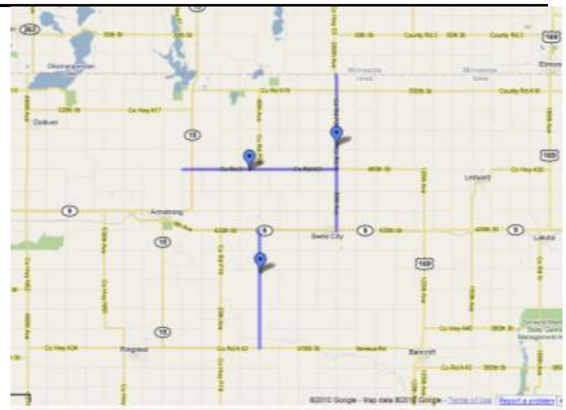
Figure 7.6. Safety Edge on CR F62 in Jasper County

County Roads A21, P20, and B20 in Kossuth County

CTRE researchers worked with Kossuth County Engineer Doug Miller and identified three projects for Safety Edge treatment. The CR A21 project was about 7 miles long, the CR P20 project was about 6 miles long, and the CR B20 project was 1 mile long. Table 7.5 provides a project summary.

Table 7.5 HMA project summary for CR A21, P20, and B20 in Kossuth County

Projects	**A21, P20, and B20, Kossuth County**
Surface Material	HMA: A21 with two 1.5 inch lifts, P20 with one 2 inch lift, and B20 with two 1.25 inch lifts
Paved Width (not including Safety Edge)	26 feet total with 11 foot lanes and approximate 2 foot wide shoulders
Project Lengths	7 miles, 6 miles, and 1 mile, respectively
Letting Date	March 16, 2010
Open House	None
Construction Start/End	August 10 – August 31, 2010



Project Extents (Google image)

All projects featured the same HMA mix design, but with differing thickness. The contractor was Manatt’s, Inc. using the same crew from the CR F62 project in Jasper County described earlier.

CTRE staff visited the projects following construction to view the completed work and obtain Safety Edge slope edge measurements. Some rollover of the Safety Edge was observed at the beginning of the CR P20 project, but this was corrected within 0.2 mile. Slope measurements taken every 0.2 mile along the sides of both projects with the smart level yielded average readings of 36 and 35 degrees for CR A21 and P20, respectively. No measurements were taken along CR B20 because the other two projects provided 13 miles of data and no difference in performance was anticipated. Figure 7.7 shows the completed Safety Edge construction achieved on CR P20.

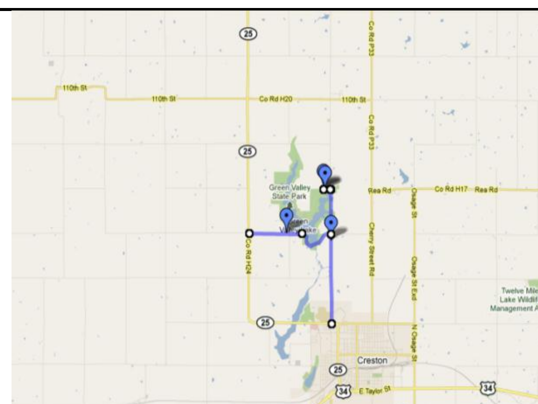
Figure 7.7. Safety Edge on CR P20 in Kossuth County

County Roads H24, P27, and 130th in Union County

County Engineer Steve Akes suggested three projects in Union County for the Safety Edge treatment. All three projects were designed for removal/reconstruction of the existing pavement and replacement with 6 inches of HMA. Table 7.6 provides a project summary. Henningsen Construction, Inc. of Atlantic, Iowa was the contractor.

Table 7.6 HMA project summary for CR H24, P27, and 130th in Union County

Project	**H24, P27, and 130th, Union County**
Surface Material	6 inch HMA Grade and Pave project with HMA put on in three 2 inch lifts
Paved Width (not including Safety Edge)	22 feet
Project Length	6.5 miles combined
Letting Date	June 9, 2010
Open House	November 5, 2010
Construction Start/End	Paving: October 25 – November 18, 2010



Project Extents (Google image)

Two CTRE researchers attended the preconstruction meeting to provide information and answer questions about the Safety Edge. The contractor furnished the equipment (self-fabricated) for installation of the Safety Edge. An open house was conducted for these projects at Green Valley State Park Meeting Center on November 5, 2010. A site visit was made a week later by CTRE staff to obtain measurements of the Safety Edge slope, which averaged 18 degrees. Figure 7.8 shows the completed Safety Edge slope.

Figure 7.8. Finished Safety Edge Slope on CR H24 in Union County

County Roads D14, D46, and P59 in Webster County

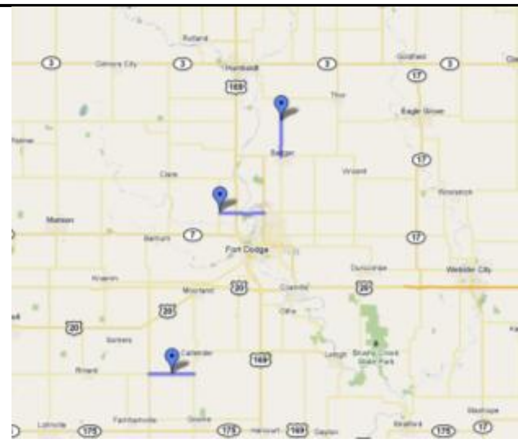
These projects were identified by Webster County Engineer and advisory committee member Randy Will as candidates for the Safety Edge. Table 7.6 provides a summary.

CTRE researchers attended the preconstruction meeting to provide information and answer questions about the Safety Edge and equipment. CTRE loaned the contractor, Ft. Dodge Asphalt Company of Ft. Dodge, Iowa, a set of TransTech Shoulder Wedge Maker shoes.

The CR D14 project included a 2 inch lift over the top of rubblized PCC, addition of 4 foot paved shoulders, and, then, overlaying with another 2 inches and adding the Safety Edge to the outside. The CR D46 project featured a two-lift HMA overlay of 1.5 inches each over the existing HMA pavement. The CR P59 project consisted of a 4 inch HMA overlay in two 2 inch lifts over the existing PCC pavement, which was rubblized in place.

Table 7.7 HMA project summary for CR D14, D46, and P59 in Webster County

Project	D14, D46, P59 , Webster County
Surface Material	Rubblization and two 2 inch HMA overlay lifts on D14 and P59, two 1.5 inch overlay lifts on D46
Paved Width (not including Safety Edge)	D14 – 32 feet D46 – 22 feet P59 – 22 feet
Project length	2.4 miles, 4 miles, and 2 miles, respectively
Letting Date	June 15, 2010
Open House	August 3, 2010
Construction Start/End	July 5 – August 2010



Project Extents (Google image)

Some problems with edge rollover of the Safety Edge were encountered on the first project and CTRE staff suggested that the initial roller avoid compaction along the outside edge of the overlaid pavement. To completely eliminate the rollover occurrence, the outside edge was not compacted until the final roller passes. Although this did seem to correct damage to the Safety Edge, lower in-place densities were also noted during later testing. It was surmised that the high ambient temperatures (+90 degrees F) may have contributed to the rollover occurrence, as this problem was not noted on the other two projects.

The completed work on CR D46 and P59 was measured with the smart level, with average readings of 30 and 31 degrees, respectively. Webster County and the contractor were recognized with a smoothness award by APAI in 2010 competition for their work on the CR P46 overlay.

An open house for CR P59 provided an opportunity for participants to review completed, as well as work in progress, with excellent results. Figure 7.9 shows a sample of the finished Safety Edge on CR P59.

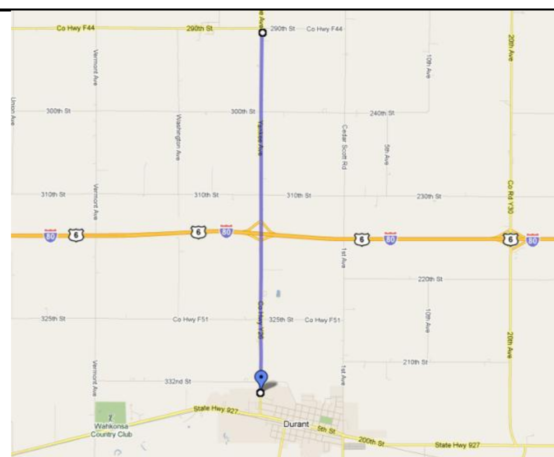
Figure 7.9. Completed Safety Edge on CR P59 in Webster County

County Road Y26 in Cedar County

This project was identified by Cedar County Engineer Robert Fangmann as a good candidate for the Safety Edge. He had planned to use the Safety Edge on another project that was postponed, so then contacted the contractor about the possibility and advantages of using it on the CR Y26 project. Table 7.8 provides a project summary.

Table 7.8 HMA project summary for CR Y26 in Cedar County

Project	Y26, Cedar County
Surface Material	Cold in Place Recycling with two 1.5 inch lifts of HMA overlay
Paved Width (not including Safety Edge)	24 feet
Project Length	4.1 miles
Letting Date	July 21, 2009
Open House	None
Construction Start/End	June 21 – mid-August 2010



Project Extents (Google image)

A member of the CTRE research team attended the preconstruction meeting, answered questions, and provided information about the process. The Safety Edge requirement was added by extra work order to the contract. The contractor for this work was IlIowa Investments, Inc. of Blue Grass, Iowa. TransTech shoes were used to construct the Safety Edge. Some initial problems with Safety Edge rollover were encountered early, but corrected as the work proceeded.

CTRE researchers made a site visit to measure the angle of the Safety Edge using the smart level with an average angle of 40 degrees recorded. However, only about 75% of the total project length was represented by these measurements, as the project was not totally completed when measurements were taken. Figure 7.10 shows a sample of the completed Safety Edge on CR Y26.

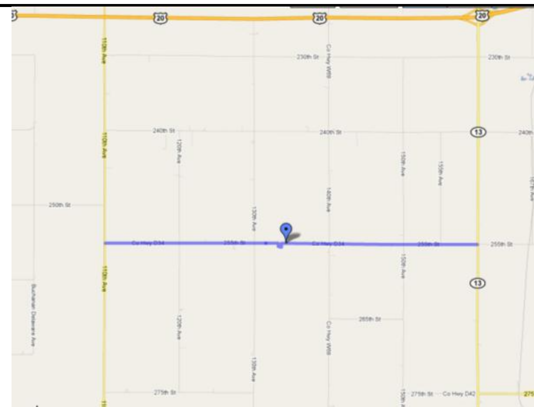
Figure 7.10. Completed Safety Edge on CR Y26 in Cedar County

County Road D34 in Delaware County

The CR D34 project was identified by the CTRE research team as a candidate for the Safety Edge. The project design consisted of a 3 inch cold in place recycling of the existing pavement as a base with two 1.5 inch lifts of HMA overlay. Table 7.9 provides a project summary.

Table 7.9 HMA project summary for CR D34 in Delaware County

Project	**D34, Delaware County**
Surface Material	Cold in Place Recycling with a 3 inch HMA overlay
Paved Width (not including Safety Edge)	22.5 feet
Project Length	5 miles
Letting Date	March 22, 2010
Open House	None
Construction Start/End	June 1 – June 30, 2010



Project Extents (Google image)

The contractor, Mathy Construction Co. of Onalaska, Wisconsin, furnished the Advant-Edger shoe to construct the Safety Edge; however, the equipment was not received until the day construction began, so about 1,200 feet of the first lift was placed without the Safety Edge.

Possibly due to unfamiliarity with use of the Safety Edge equipment, the contractor experienced problems in achieving a desired 30 degree angle, both during the paving process but also with roll over of the edge. Even when the initial roller passes avoided the pavement edge by 8 to 12 inches, the rollover problem continued. The narrow width of the existing roadway also contributed to challenges during the paving process.

CTRE researchers were not available to visit the project during construction work. However, the CTRE team did obtain measurements of the completed Safety Edge following completion using a plastic protractor and ruler. The average angle reading was 51 degrees. Figure 7.11 shows the Safety Edge achieved on the project.

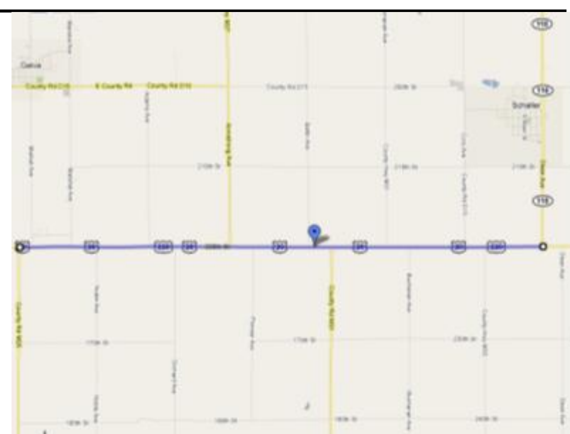
Figure 7.11. Typical Safety Edge on CR D34 in Delaware County

US Highway 20 in Sac and Ida Counties

This Iowa DOT project was suggested for evaluation of the Safety Edge during an advisory committee meeting by members of the group. It was a HMA widening and resurfacing project on US Highway 20 from US 59 to IA 110, for which Oldcastle® Materials (OMG) Midwest/Tri-State Paving, of Estherville, Iowa was the contractor. Table 7.10 provides a project summary.

Table 7.10 HMA project summary for US 20 in Sac and Ida Counties

Project	**US 20, Sac and Ida Counties**
Surface Material	HMA
Paved Width (not including Safety Edge)	About 28 feet
Project Length	6 miles
Letting Date	NA
Open House	None
Construction Start/End	August – September 2010



Project Extents (Google image)

CTRE researchers visited the site to observe the HMA overlay work and obtain completed Safety Edge measurements. The contractor had used three different shoes during the work, TransTech's, the Advant-Edger, and a modified version of the Advant-Edger, which appeared to achieve excellent results, both in appearance and final Safety Edge slope. CTRE researchers obtained slope measurements using the smart level with readings averaging 30 degrees. Figure 7.12 shows the typical finished Safety Edge on the US 20 project.

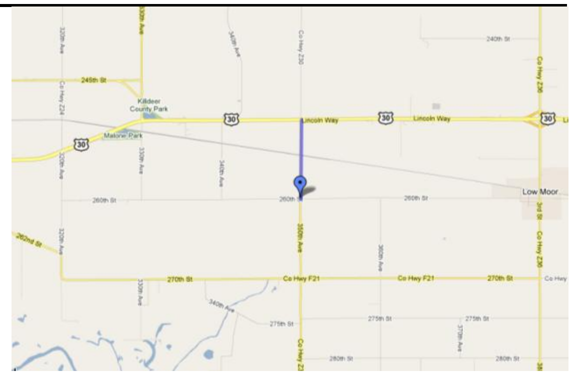
Figure 7.12. Typical Safety Edge Slope on US 20

County Road Z30 in Clinton County

Although the CR Z30 project was not identified earlier by the CTRE research team as a candidate for evaluation of the Safety Edge, County Engineer Todd Kinney requested the loan of some safety shoes to add the edge to his project. TransTech shoes were delivered to a nearby maintenance facility for him to pick up. Table 7.11 provides a project summary.

Table 7.11 HMA project summary for CR Z30 in Clinton County

Project	Z30, Clinton County
Surface Material	Full-Depth HMA
Paved Width (not including Safety Edge)	22 feet with 4 foot granular shoulders
Project Length	4.2 miles with 0.9 miles HMA
Letting Date	May 28, 2010
Open House	None
Construction Start/End	July 12 – September 15, 2010



Project Extents (Google image)

Although this project was a total of 4.2 miles long, only about 0.9 miles were constructed using HMA. The contractor, Flynn Company, Inc. of Dubuque, Iowa paved the remainder with 7 inches. of PCC pavement. Use of the safety shoes by the HMA paving subcontractor, Determann Asphalt Paving, LLC of Comanche, Iowa allowed them to incorporate the Safety Edge into the HMA portion of the project.

Three lifts were placed: a 3.5 inch base course, a 3 inch. intermediate course, and a 2.25 inch surface course. Following completion of the paving, the CTRE team was able to measure the slope of the Safety Edge along this project using the smart level and obtained an average slope using the smart level of 39 degrees. Figure 7.13 shows the typical finished Safety Edge on the CR Z30 project.

Figure 7.13. Safety Edge on CR Z30 in Clinton County

7.3 Hot Mix Asphalt Projects (State)

One of the objectives of this evaluation project was to inform county and local agencies about the Safety Edge and to encourage adoption of the Safety Edge by these agencies. Although the team did not work directly with the Iowa DOT, state projects where the Safety Edge was used were recorded so that future crash analyses and evaluations could be conducted. Known state projects for the 2010 construction season are shown in Table 7.12.

Table 7.12. State projects where Safety Edge implemented during 2010 construction season

Dist.	RCE Office	Contract ID	County	Project Number	Location	Contractor
1	Marshalltown	86-0211-703	Tama/Benton	MP-21-1(703)57--76-86	IA 21 from north corporate limits of Belle Plaine to US 30	Manatt's, Inc.
2	Britt	32-0094-043	Emmet	STP-9-4(43)--2C-32	IA 9 from 0.15 miles east of Estherville to the Kossuth County line	Duininck, Inc.
2	Britt	55-0094-044	Kossuth/Winnebago	STPN-9-4(44)--2C-55	IA 9 from east junction of US 169 to CR R20	Mathy Construction Co.
3	Cherokee	18-0032-054	Cherokee/Buena Vista	STPN-3-2(54)--2J-18	IA 3 from 0.27 miles west of IA 7 to 0.25 miles west of CR M31	Henningsen Construction, Inc.
3	Cherokee	43-0301-127	Harrison/Crawford	NHSN-30-1(127)--2R-43	US 30 from Dunlap to Dow City	Manatt's, Inc.
3	Cherokee	47-0202-070	Ida/Sac	NHSN-20-2(70)--3H-47	US 20 from east junction of US 59 to IA 110	OMG Midwest/Tri-State Paving
3	Sioux City	84-0101-070	Sioux/O'Brien	STP-10-1(70)--2C-84	IA 10 from IA 450 (Old IA 60) to east of Maple Street in Paullina	OMG Midwest/Tri-State Paving
3	Sioux City	97-0311-030	Woodbury	STPN-31-1(30)--2J-97	IA 31 from IA 141 in Smithland to south junction of CR D54	Knife River Midwest, LLC
4	Creston	39-0254-033	Guthrie	STPN-25-4(33)--2J-39	IA 25 from Guthrie Center to IA 141	OMG Midwest/Tri-State Paving
4	Creston	73-0022-043	Page/Taylor	STPN-2-2(43)--2C-73	IA 2 from US 71 to 3 miles east of Taylor County line.	Henningsen Construction, Inc.
4	Creston	80-1692-038	Ringgold	ESP-169-1(38)--2S-80	US 169 from Mount Ayr to Union County line	Henningsen Construction, Inc.
4	Creston	88-1692-021	Union	ESP-169-2(21)--2S-88	US 169 from Ringgold County line to Afton	Henningsen Construction, Inc.
4	Creston	87-1481-020	Taylor	STPN-148-1(20)--2C-87	IA 148 from Missouri state line to Bedford	Henningsen Construction, Inc.
5	Chariton	26-0028-034	Davis/Van Buren	STPN-2-8(34)--2J-26	IA 2 from east junction of US 63 to near CR V64 (near Cantril)	Henningsen Construction, Inc.
6	Davenport	52-0067-080	Johnson/Muscatine	HSIPX-6-7(80)--3L-52	US 6 from east corporate limits of Iowa City to west corporate limits of West Liberty	LL Pelling Co., Inc.
6	Manchester	23-1361-058	Clinton/Jones	STPN-136-1(58)--2C-23	IA 136 from Lost Nation to west junction of IA 64	Mathy Construction Co.

RCE = Resident construction engineer

8. LESSONS LEARNED

Safety Edge application was new to Iowa contractors, so a few issues arose, which the CTRE team attempted to address with local agencies and contractors.

8.1 Rollover During Compaction

Agencies and contractors on some HMA projects indicated that rollover of the Safety Edge during the compaction process had occurred or the CTRE team noted the problem during site visits. Rollover occurred when the desired 30 degree slope of the Safety Edge was distorted during compaction of the asphalt material. In most cases, rollover resulted in a slope that was steeper than 30 degrees, although one contractor suggested that it could also cause flattening of the slope.

In a few instances, rollover resulted in significant distortion of the Safety Edge face to the extent that the final pavement edge face resembled a standard overlay without use of the Safety Edge. Rollover typically occurred for at least a minor portion of most projects during the 2010 construction season and was a major occurrence for a few projects. However, all of the final average slope measurements shown in Table 5.1 are considerably better than the angle that results from conventional HMA paving and rolling.

The team discussed the problem with local agencies, contractors, the advisory team, and an HMA materials expert (Professor Chris Williams, Civil, Construction, and Environmental Engineering at ISU). It was surmised that susceptibility to edge rollover was not due entirely to the compaction process, but may have been related to several factors inherent with HMA projects: mix design, support from underlying base, temperature of delivered mix, ambient temperature, roller patterns and magnitude of vibration, lift thickness, and, possibly even, latent moisture content in the mix prior to compaction.

Only one warm-mix HMA project was reviewed (IA 143 in Cherokee/O'Brien Counties) and that lower temperature mix seemed to exhibit less tendency for rollover. The late fall project completed in Union County under cooler ambient temperatures also seemed to exhibit less tendency for slope distortion during compaction, but some edge rollover still occurred.

Several contractors addressed rollover by only using the final roller on the outside foot of the pavement (measured from the pavement edge). Roller pattern changes were tried in Webster and Union Counties, where it was concluded that the revised procedure did help retain the desired edge slope. However, some reduction in density was noted on samples taken from those areas.

There is some concern that reducing compaction for the outside foot of pavement could affect performance and consequently is not an ideal solution. The potential loss of density along the outside edge of the pavement may be slight (about 4 to 5% compacted density loss), but all other options to resolve the rollover problem should be attempted before this option is selected as a solution. The edge of a pavement is normally the most-vulnerable area to distress and purposely reducing density could result in reduced durability and early deterioration.

To address the problem of rollover, two contractors made modifications to the Safety Edge shoe for their HMA projects. The modifications are shown in Figure 8.1.

Modified shoe A

Fabricated shoe B

Figure 8.1. Safety Edge shoes modified to address rollover

Both design revisions intended to slope the entrance and exit of asphaltic material through the shoe to approximate an extrusion process and thereby provide some degree of consolidation to the sloped edge. However, the modified shoe A also flattened the edge slope to about 22 degrees (instead of the desired 30 degrees) to provide more tolerance for potential rollover during the compaction process. Finished edge slopes after application of the modified shoes are shown in Figure 8.2.

Figure 8.2. Improved safety edge resulting from modified shoes

The team also made a site visit to a Minnesota county where the Safety Edge had been used for several years. Measurement of the slope on several projects in this Minnesota county indicated that rollover had also occurred at many locations. Other agencies have also indicated that they have experienced similar results.

The rollover issue should be discussed with Safety Edge shoe manufacturers to determine if a modified design would increase consolidation of the Safety Edge during HMA paving operations, which could be more likely to resist deformation during compaction. Inspectors should also be aware of this potential problem and provide necessary oversight during the rolling process to assure desired results.

8.2 Investigation of Mix Design on Edge Rollover

A review of mix designs that were provided by contracting agencies, as shown in Table 8.1, was made in an attempt to identify a correlation between any mix characteristics (individually or in combination) and the increased potential of edge rollover. The table shows considerable variation in the measured Safety Edge following work completion; however, most is well within what could be considered substantial compliance with desired slope for an effective Safety Edge. This review was undertaken to identify possible mix design characteristics that might be common where excessive edge rollover was observed.

As described earlier, the CTRE research team was unable to visit the Delaware County project during construction and no experimentation with rolling patterns was initiated or other possible contributing factors investigated before the project was completed. Although the gradation of the recycled asphalt pavement (RAP) for this project is not known, the mix appears to be finer in gradation than most of the other project designs, which may have been a factor in the resultant higher slope angle measurements.

Although the Delaware County project mix shares the lower asphalt cement (AC) content with those mixes having the lowest slope angle, more specific differences are noted in the film thickness and filler/bitumen ratio of the mixes. A comparison of the mixes from Union and Delaware Counties, both containing RAP, reveals similar film thicknesses, but a significantly higher filler bitumen ratio in Union County. The mix design in Webster County has a significantly lower film thickness and filler bitumen ratio, possibly due to the higher percentage of crushed rock that was incorporated.

The most consistently performing mixes in terms of stability during rolling appear to be those that have total AC content in the 5.7 to 6.5% range and incorporate a higher percentage of coarse aggregates. However, because the cost effectiveness of using locally available materials is normally a major factor in mix designs, these options are not normally available to all agencies, nor do they need to be used on all types of projects.

Table 8.1. HMA mix design summary for Safety Edge projects

County	Average Top Lift Slope Angle (degrees)	Lift Thickness (inches)	Mix Design Properties															
			Total AC Content	Film Thickness (inches)	Fill/Bit Ratio	1" Clean	3/4" Stone	3/4" Grvl	5/8" Clean	1/2" Stone	1/2" Grvl Scrngs	1/2" Chips	3/8" AC Stone	3/8" Chips	Con-crete Sand	Nat-ural Sand	Manf Sand	RAP
Delaware	52*	Unknown	5.8%	11.25	0.61				25%			15%	15%		35%			10%
Jasper	37	2+1.5+1.5	7.4%	12.1	0.76	11%	14%							20%		5%	30%	20%
Kossuth	36/35	1.5+1.5	6.5%					70%						15%			15%	
Sac	36	1.5 surface	6.4%	11.64	0.6					25%	40%			10%			25%	
Sac	NM	1.5 binder	5.4%							42%				8%		35%	5%	10%
Union	18	2+2+2	5.7%	11.72	0.72		35%								37%		13%	15%
Webster	30	1.5+1.5	5.8%	9.7	0.96			25%		40%				10%	25%			
Webster	31	2+2	5.8%	9.7	0.96			25%		40%				10%	25%			

* Measured with protractor and rule assembly instead of SmartTool
AC = asphalt cement
RAP = recycled asphalt pavement
NM = no measurement

It appears the current mix design practices should be continued as they exist. However, when mix designs with high asphalt content and/or lower percentages of crushed particles are used, contractors and agencies should be alert to the possible higher potential of pavement edge rollover during compaction and take appropriate steps to avoid damage to the Safety Edge slope.

8.3 Concern for Interpretation of a Safety Edge Design Standard

Field experience demonstrated the not uncommon difficulty of constructing a Safety Edge with a final slope that was consistently close to the desired 30 degree angle. As noted earlier, several contractors purchased or fabricated shoes that intentionally formed a slope flatter than the desired 30 degrees. No safety problems are expected with a slope that is flatter than 30 degrees; given drivers should find it less difficult to negotiate these flatter slopes. However, it could be surmised that the thinner edge of a flatter slope may be more prone to deterioration under loading and that the adjacent granular or earth shoulders may be more prone to edge rutting (which will be evaluated following exposure to Iowa winter conditions).

Rollover during compaction may also occur as discussed in section 8.1. In many cases, rollover may result in a slope that is steeper than the desired 30 degrees, at least in isolated areas. While slopes that are significantly greater than 30 degrees should be noticed by inspectors and resolved during construction, a slope that is only slightly steeper than 30 degrees would not be expected to produce any detrimental issues from a safety perspective.

Although no adverse safety results are expected if a Safety Edge slope varies somewhat from 30 degrees, especially in isolated locations, an exact description of desired Safety Edge design details and specifications could be interpreted by some engineers and inspectors to require a precise 30 degree slope, with no variation, and contractors would be unnecessarily required to repair or replace edge slopes that varied from 30 degrees.

After a discussion with the advisory board, the team recommended that design details and specifications should allow some degree of variation from a desired 30 degree edge slope, perhaps with a range of acceptable values or by including “approximate” to describe the desired final edge slope, with a maximum slope toleration.

8.4 Matching the Safety Edge Between HMA Lifts

Another problematic issue noted during field reviews was that the Safety Edge did not always consistently align horizontally between lifts (layers). Figure 8.3 shows a large gap between the second and third lifts observed on one project. To avoid this occurrence, the nominal base width to accommodate succeeding lifts of HMA resurfacing must be determined as accurately as possible before beginning work.

Excess width in base for second and third lifts

Excess base and insufficient second width for third lift

Figure 8.3. Illustrations of improperly matched lifts

With PCC pavement, the base width should be determined by the applicable project design specifications and by using a modified pan on the paver to shape the Safety Edge as desired. With multiple lift HMA overlays, the lower lift width determination may require computation by the engineer or inspector if multiple lifts are designed, to assure that all lifts will exhibit sufficient width to provide base for subsequent layers including the Safety Edge.

In addition to adequate base width, maintaining the proper horizontal alignment of each course is also necessary. Where multiple lifts are designed, prior planning and proper paver operation will be needed to avoid excess (and unused) base width with lower lifts and/or insufficient width to support subsequent layer(s) as shown in Figure 8.3. Depending on agency maintenance policies and practices, the Safety Edge probably only needs to be included on the top lift or two (3 to 5 inches if possible) for adequate performance.

9. ESTIMATING MATERIAL NEEDED FOR THE SAFETY EDGE

The research team computed quantity comparisons to estimate the relative additional materials associated with application of the Safety Edge. To evaluate an actual additional cost difference for the Safety Edge on PCC and HMA projects, the specified design of and measurement methods for the Safety Edge, along with typical unit prices for the materials need to be considered. This evaluation compares *only* the additional material that could be required when a Safety Edge is specified.

When using Iowa DOT specifications for PCC pavements, the method of measurement requires the use of the out-to-out width of the paved area to calculate the quantity for payment in square yards or meters. Depending on the design specification used, a significant increase in materials might result, as shown in Table 9.1. (Refer to Chapter 6 for a discussion of Safety Edge design specifications.)

Table 9.1. Additional square yards needed for PCC Safety Edge

Design Specs	Additional Material per Station for Both Sides (square yds)	Additional Material per Mile for Both Sides (square yds)	Additional Square Yards per Mile for 22 ft Wide Pavement (%)	Additional Square Yards per Mile for 24 ft Wide Pavement (%)
CTRE	12.963	684.444	5.30%	4.86%
DOT	22.222	1173.333	9.09%	8.33%

Calculating the additional costs for HMA construction of the Safety Edge requires an assumption of additional material outside the pavement top width with non-Safety Edge construction procedures. For the calculations shown in Table 9.2, it was assumed that the additional material required is the difference between an 80 degree (non-Safety Edge) slope and a 30 degree (Safety Edge) slope. The calculations include additional material for both sides of the roadway. As the calculations show, additional material required for a Safety Edge with HMA pavements is minimal.

Table 9.2. Additional material needed for HMA Safety Edge

Total Depth All Lifts (inches)	Additional Area for 30 vs. 80° (in^2)	Material in Slope (ton/mile)	Additional Material per Mile for 22 ft Wide Pavement (%)	Additional Material per Mile for 24 ft Wide Pavement (%)
1.0	1.56	4.1	0.6%	0.5%
1.5	3.50	9.3	0.9%	0.8%
2.0	6.22	16.5	1.2%	1.1%
2.5	9.72	25.8	1.5%	1.4%
3.0	14.00	37.2	1.8%	1.6%
4.0	24.89	66.2	2.4%	2.2%
5.0	38.89	103.4	2.9%	2.7%

10. CONCLUSIONS AND RECOMMENDATIONS

Based on the experience and knowledge gained during this evaluation study, the following conclusions can be drawn and recommendations proffered.

1. Expectations for the Safety Edge on a particular project should be thoroughly reviewed with the contractor at a preconstruction conference and procedures verified (and/or adjusted) as necessary at the beginning of construction to assure that satisfactory results are achieved. Monitoring alignment and setting base (and subsequent lift) widths should be the contractor's responsibility, but also need periodic review by the engineer and inspection team.

2. Specifications and design details for the addition of the Safety Edge can have a significant impact on project costs. State and local agencies should consider potential costs as a standard design and accompanying specifications are developed and adopted.

3. Specifications or plan notes that state, "No additional compensation will be allowed for costs associated with the construction of the Safety Edge other than additional material," would seem to be appropriate.

4. Although a Safety Edge can be constructed with minimal variance from the desired slope with PCC pavement, maintaining a consistent slope with HMA is much more difficult due to variations in the base, mix design, mix and air temperatures, percentage of moisture in the fresh HMA, and especially the roller patterns used. Because of this, a range of acceptable values for the finished slope is recommended in the specifications for HMA projects. Based on the Iowa results from this evaluation, 30 degrees plus or minus 10 degrees would seem to be an appropriate target. As contractors gain experience with the shoes and as the design of the equipment is improved, perhaps this target range could be tightened, possibly to plus or minus five degrees.

5. As an incentive to producing a quality product, specifications should allow HMA contractors to omit placement of a temporary granular fillet along the shoulders adjacent to new paving each day, providing the Safety Edge is constructed to design requirements.

6. On PCC pavement projects, the contractor should be given the option of sawing the Safety Edge off to achieve a vertical pavement edge or forming a "box-out" to restrict placement of the Safety Edge when constructing a tie to a PCC paved side road intersection.

7. In recognition of potential benefit, paved shoulders should also be considered for inclusion of the Safety Edge.

8. Vendors and equipment manufacturers should study the improved performance of an extruded Safety Edge and consider a modified “shoe” for HMA pavements that will provide this feature.

9. Preliminary evaluation results did not indicate an adverse impact on the development of pavement edge drop-off, either rate or magnitude of rutting, with use of the Safety Edge design; however, additional long-term assessment of this potential should be undertaken.

10. The ultimate benefit from use of the Safety Edge is an anticipated reduction in the frequency and severity of roadway departure crashes. However, a minimum of three to five years of crash data would be needed for a statistically-valid conclusion. The team recommends that projects featuring a Safety Edge be evaluated over this period of time to assess this presumed safety improvement.

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