TECH BRIEF
March 2011

Evaluation of Safety Edge Benefits in Iowa

Authors

Shauna L. Hallmark
Director, Midwest Transportation Consortium, Iowa State University;
Associate Professor of Civil, Construction, and Environmental Engineering, Iowa State University
515-294-5249, shallmar@iastate.edu

Tom McDonald and Bob Sperry
Iowa Local Technical Assistance Program, Iowa State University

Evan Vencil
Research Assistant, Midwest Transportation Consortium, Iowa State University

Sponsors

Federal Highway Administration
Iowa Department of Transportation
Midwest Transportation Consortium
(MTC Project 09-358)

For More Information
www.intrans.iastate.edu/mtc/

MTC
Iowa State University
2711 S. Loop Drive, Suite 4700
Ames, IA 50010-8664
515-294-8103

MTC
MIDWEST TRANSPORTATION CONSORTIUM

ctre
Center for Transportation Research and Education

IOWA STATE UNIVERSITY
Institute for Transportation

Background

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 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 their 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, 2010) estimated that 160 fatalities and more than 11,000 injuries annually are related to unsafe pavement edges. A Georgia Tech study evaluated 150 fatal crashes on rural two-lane roads in Georgia and found that edge drop-off was present in 55% of the crashes (Dixon, 2004). A study by Hallmark et al. (2006) evaluated crashes in Iowa and found that pavement edge drop-off may have been a contributing factor in 18% of rural run-off-road (ROR) crashes on paved roadways with unpaved shoulders.

The study also found that pavement edge drop-off-related crashes were twice as likely to result in fatal crashes as other crashes on similar rural roadways.

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

The Safety Edge

The FHWA developed the Safety Edge based on results of research indicating that a sloped pavement edge surface could more easily be traversed by the driver of 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 outermost edge of the paved section of the 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 about a 30 degree fillet.

Portland cement concrete (left) and hot-mix asphalt (right) pavement edge drop-off without the Safety Edge

The shape created by the Safety Edge reduces the likelihood that tire scrubbing will occur, providing a gradual, rather than an abrupt, transition back to the roadway as drivers of errant vehicles remount 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.

The major benefit of using the Safety Edge is the flatter, angled drop-off surface aids vehicle re-entry onto the driving surface or lane. A pooled fund study by the Midwest Research Institute (MRI) indicates that the Safety Edge on rural two-lane roads has a crash reduction factor of 5.7 percent and a benefit-cost ratio of 4:44 for roadways with paved shoulders and 4:63 on roadways with unpaved shoulders (MRI, 2008).

Other benefits of the Safety Edge include:

- Provides temporary safety during construction while pavement edge face is exposed
- Increases production for contractors in states that don't require shoulder pull up immediately after construction (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 (Roche, 2009)

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). Unpaved shoulder maintenance should still be conducted on a routine, as-needed basis.

Although in-place density verification test data are not available for a statistically-significant conclusion, Safety Edge placement equipment may also provide some consolidation of the sloped pavement edge, which may be beneficial in pavement edge maintenance over the long term.

Marketing and Outreach

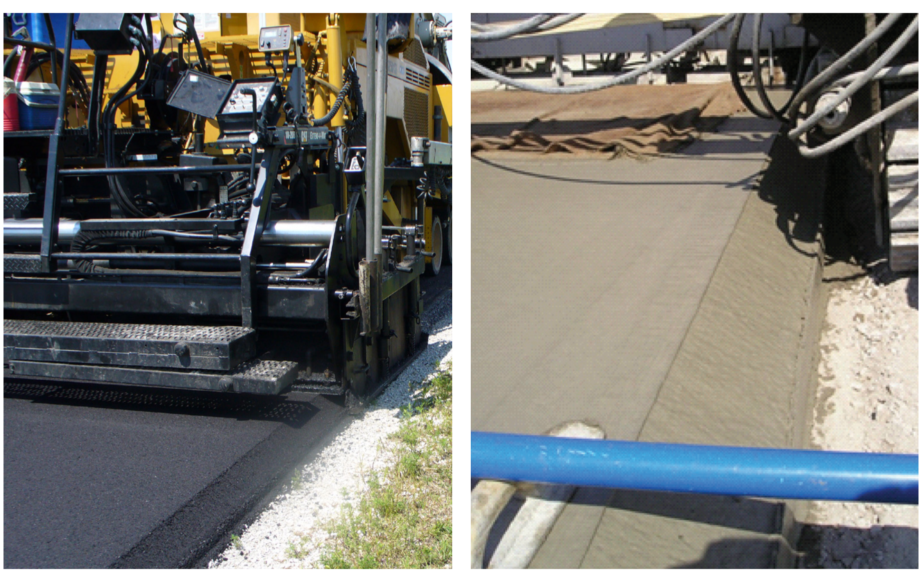
Because use of the Safety Edge was relatively new to Iowa, the Iowa Department of Transportation (DOT) and the FHWA – Iowa Division commissioned the Center for Transportation Research and Education (CTRE) at Iowa State University (ISU) to develop educational materials, market the Safety Edge to Iowa counties, and conduct some early analyses of the Safety Edge.

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

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.

As requested, the CTRE team provided various types of technical assistance, including project design recommendations, attendance at pre-construction meetings, open houses to demonstrate the Safety Edge, loan of equipment for actual roadway construction with the Safety Edge, troubleshooting, and monitoring of work. The CTRE research team also provided focused technical assistance as needed to agencies where the Safety Edge was used. 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.

Sixteen Iowa counties currently have projects where the Safety Edge was used. The Safety Edge was implemented at 19 sites on county roads and 16 state projects during the 2010 construction season (when the project was active).



Hot-mix asphalt (left) and Portland cement concrete (right) applications of the Safety Edge

Design Standards for HMA Projects

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 and 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.

In April 2010, the Iowa DOT issued Safety Edge design guidance, which was adopted for the October 2010 letting on use of the Safety Edge. Currently (as of March 2011), the Safety Edge is required on all primary highways unless the roadway is an interchange ramp or loop, curbs are present, or the paved shoulder width is 4 or more feet.

The standards apply to new construction and rehabilitation projects. 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), which is available online at http://www.iowadot.gov/design/dmanual/03C-06.pdf.

Lessons Learned on HMA Projects

Safety Edge Equipment

Several types of equipment are available for formation of the Safety Edge on HMA projects. Most agencies in Iowa reported they did not have problems with installation or use of the equipment during the 2010 season. The equipment can be removed and installed on multiple pavers.

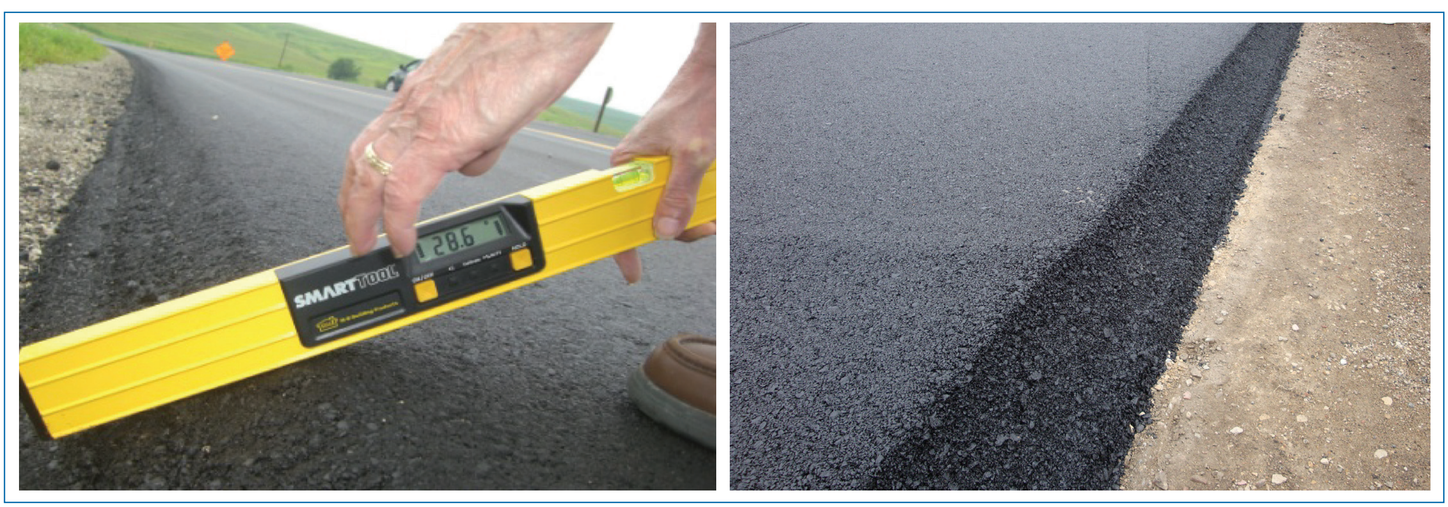
Durability of Safety Edge

Some concern had been expressed about the long-term durability of the Safety Edge, given the only compaction in the edge itself is from the paver and the Safety Edge shoe.

Contractors in Iowa are normally required to take five to seven cores per day on HMA projects to test compaction results. Cores are randomly taken along the recently-compacted section and a density test is conducted on the core samples to determine the percentage of optimum laboratory density that is achieved in the field.

Sufficient compaction is necessary for long-term durability, so the CTRE team requested Safety Edge cores on two projects during normal density testing. About 80 percent of compaction occurs from the lay-down machine, so the Safety Edge compaction was expected to exceed that. Results indicated that compaction for the normal cores was 96.1 to 98.3 percent, while the cores from the Safety Edge were 80.6 to 86.3 percent.

Advant-Edger installed and in use (left) and Safety Edge applied (right)



Safety Edge slope measurement (left) and warm-mix asphalt Safety Edge application (right)

Quality Assurance of the Safety Edge Slope

The Safety Edge shoes place the fillet angle at about 30 degrees. The CTRE team monitored the slope for 15 sites and found a variation in final slope angle. The slope was measured using a SmartLevel™ and slopes ranged significantly from 18 to 52 degrees. The team also found that some distortion of the slope was occurring during compaction. This problem was termed rollover and was noted by Minnesota and other states as well.

Although the causes are unknown, the team speculated that rollover could be caused by roller pattern, magnitude of vibration material, and being pushed toward the edge during compaction. The team discussed the problem with local agencies, contractors, the advisory team, and an HMA materials expert. 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, including 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.

The rollover problem underscores the need for quality assurance during paving. The slope can be easily checked during paving and problems resolved in the field. Several solutions were tried during the course of this project.

Several contractors tried only using the final roller on the outside foot of pavement to avoid distorting the Safety Edge. There were some concerns about reduction in durability of the outside foot, so other options should be explored first. The CTRE team had core tests conducted in the outside foot at two sites where the contractor used only the final roller. Normal cores ranged from 95.5 to 98.9 percent and cores for the outside foot ranged from 94.4 to 95.0 percent, so some reduction in compaction had occurred, although only minor.

The CTRE team also estimated that contractors who did not have problems with rollover were using mixes with total asphalt cement (AC) content from 5.7 to 6.5 percent with a higher percentage of coarse aggregates. It was also felt that temperature of the mix may have contributed. As a result, quality assurance of the mix may also resolve problems with rollover.

To address the problem of rollover, two contractors made modifications to the Safety Edge shoe for their HMA projects. 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, one modified shoe 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.

Matching the Safety Edge Between Lifts

Another problematic issue noted during field reviews was that the Safety Edge did not always consistently align horizontally between lifts (layers). To avoid this, the nominal base width to accommodate succeeding lifts of HMA resurfacing must be determined as accurately as possible before beginning work.

With Portland cement concrete (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 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 necessary. Where multiple lifts are designed, prior planning and proper paver operation are needed to avoid excess (and unused) base width with lower lifts and/or insufficient width to support the subsequent layer(s). 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.

Pavement edge six years after resurfacing without the Safety Edge (left) and with the Safety Edge (right) (Roche, 2009)

Drop-Off Performance with the Safety Edge

The Safety Edge provides a significant benefit when drop-off occurs because drivers are better able to remount the pavement surface with a sloped surface. However, some concerns have been raised that drop-off may form differently for the sloped Safety Edge than for the more typical pavement edge face without it.

When a vehicle leaves a paved roadway surface and encounters a granular or earth shoulder, the force of the tire can dislodge loose material at the pavement/shoulder interface.

With a traditional vertical or rounded pavement face, the force of the tire is mostly vertical, which can cause a rut to form near the pavement edge. With the Safety Edge, the tire may push the loose material down the sloped edge and, as a result, there may be a slightly greater tendency for edge drop-off to form.

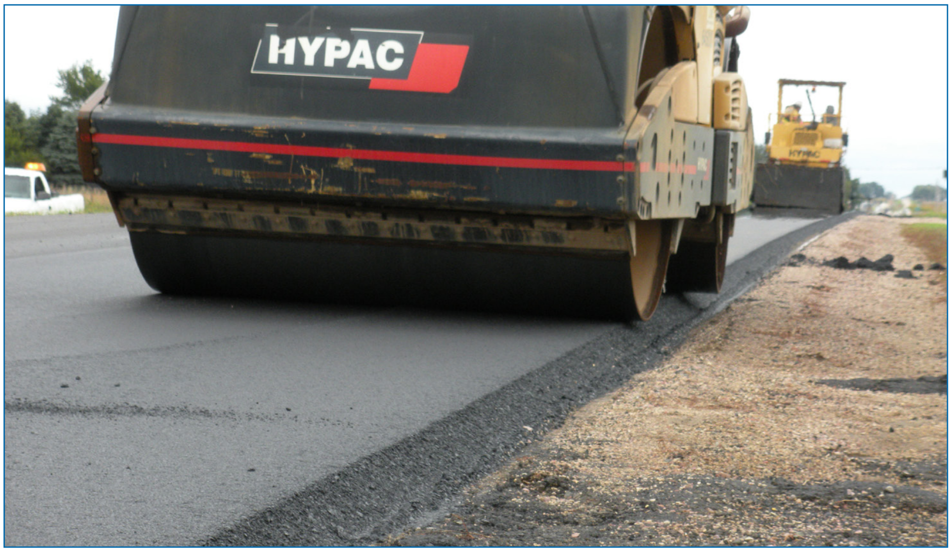
The MRI study evaluated pavement edge drop-off after resurfacing on a number of HMA roadway sections with and without the Safety Edge. Results at one year suggested that resurfacing with the Safety Edge is slightly more effective in reducing the proportion of extreme drop-offs than resurfacing without the Safety Edge.

Due to the relatively short timeframe for this project, it wasn't possible to extensively evaluate edge drop-off formation for any of the sites. However, to explore the issue further, the research team worked with Freeborn County, Minnesota, where they have been using the Safety Edge on most of their resurfacing projects since 2005.

Freeborn County monitored drop-off for several years after construction at several locations on both a 2005 and a 2006 project, where one side featured the Safety Edge and the other side did not. Freeborn County provided data to the CTRE researchers, who also measured drop-off at the two sites and compared the sides with and without the Safety Edges to each other.

The researchers used a paired t-test to compare the mean pavement edge drop-off for the side with and without the Safety Edge. They found no statistically-significant difference between the average drop-off for either site.

The researchers concluded it's not likely that formation of pavement edge drop-off will be more problematic with the Safety Edge.



Quality assurance during paving includes slope measurement, as well as monitoring for rollover

Additional Material for HMA Projects

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, the specified design of and measurement methods for the Safety Edge, along with typical unit prices for the materials need to be considered. Only additional material was computed, since costs will vary over time.

Calculating the additional cost requires an assumption of additional material outside the pavement top width with non-Safety Edge construction procedures. For the calculations shown here, the team assumed 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.

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%

Application on PCC Projects

When this project began in August 2009, there were no properly-designed applications of the Safety Edge on PCC paving projects nationally, as far as CTRE researchers and advisory team members were aware. With encouragement from the FHWA, the team and the Iowa DOT worked to develop PCC Safety Edge design standards and specifications.

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 feature in Iowa in late 2009. However, formal DOT requirements were not available until later in 2010.

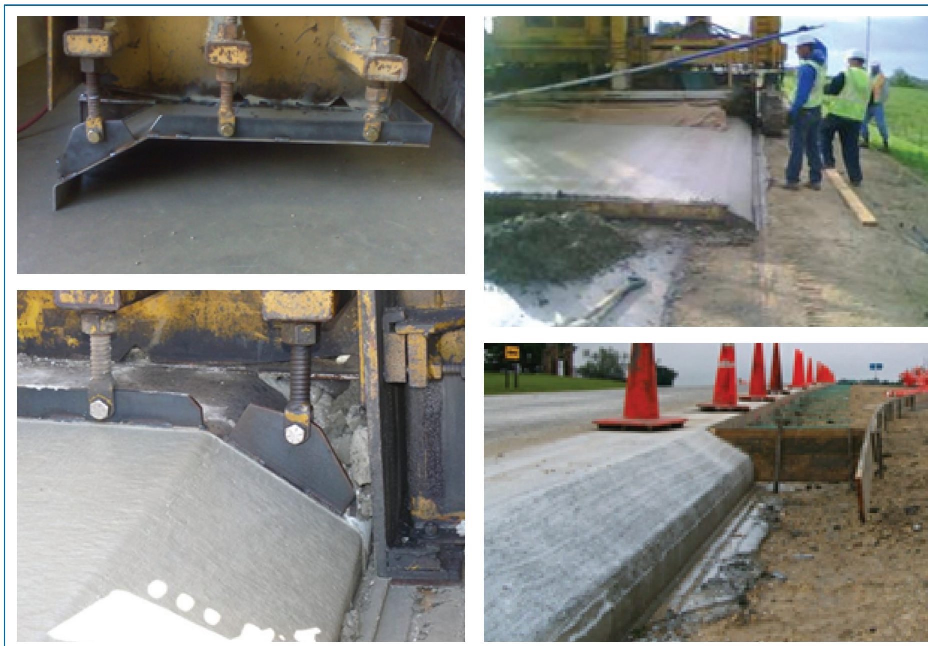
In addition, PCC pavements and overlays for county roads are normally thinner (5 to 8 inches) than for DOT-designed projects, so the team was concerned that a thinner outer PCC Safety Edge could break off when subjected to loading.

As a result, the CTRE team worked with Keokuk County to develop design standards and specifications for county projects. Jones County staff also developed requirements.

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 dimensions. Because PCC pavement is measured and paid by square yards of placement in Iowa, this type of design variation impacts the final cost.

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 results using the measurement method in the new Iowa DOT specification. In areas where the design thickness is less than 8 inches, 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.

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, and Keokuk County incorporated the edge as designed by the research team. The Jones/Linn Counties project was the first to implement the Safety Edge.



Angled plate and assembly welded to the paver pan (upper left), Safety Edge extrusion (lower left), start of project paving (upper right), and "box-out" and re-bar for intersection (lower right)

As of February 2011, the new Iowa DOT design had not yet been used on a project. The DOT design drawings and specifications became effective in October of 2010 and are 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 are not 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 that a more workable concrete mix can be used, which would facilitate improved concrete quality.

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 the equipment manufacturer, Gomaco Corporation of Ida Grove, Iowa, to design and build the proper assembly to achieve the desired Safety Edge shape.

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 a sloped edge.

To accomplish the desired connection effectively, it is necessary to remove or eliminate the Safety Edge through intersections with paved roads, requiring either a saw-cut to remove the Safety Edge or construction of a formed “box-out” to prevent placement of the sloped edge during paving.

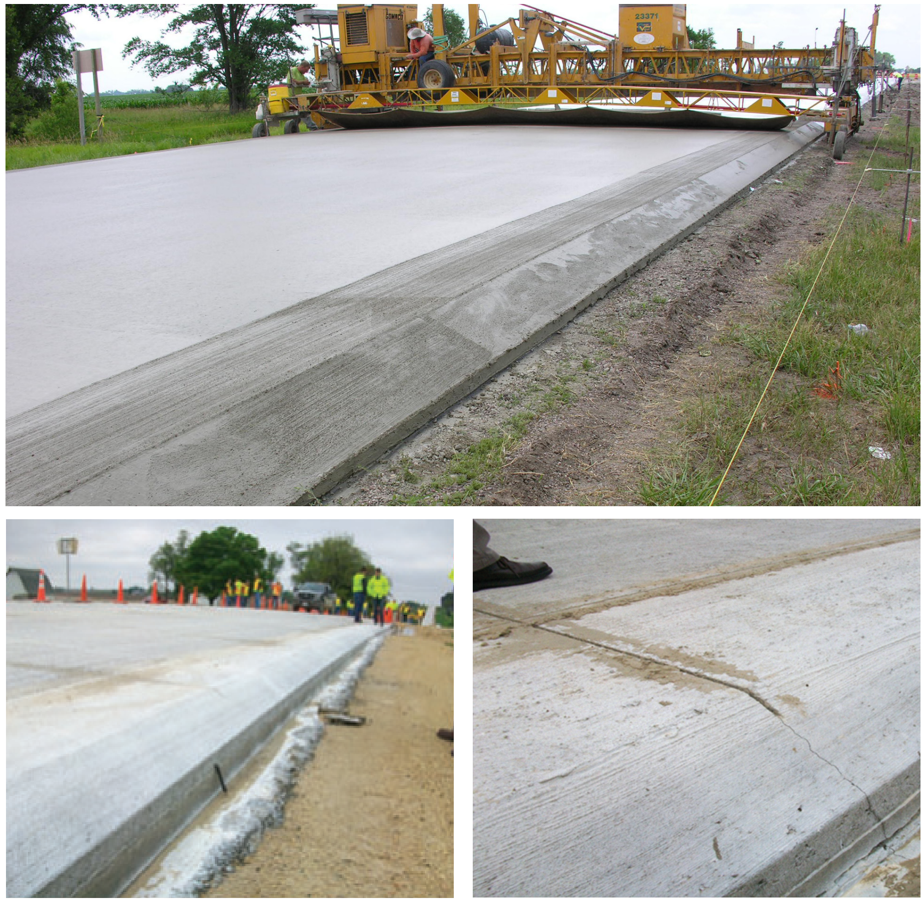
Final Pavement Edge Characteristics

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 the Iowa DOT design details, 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.

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. Results of an air voids and modulus test indicate that the quality of the concrete was uniform, comparing the traditional pavement section to the Safety Edge.

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 crack would eventually occur from the saw cut through the remaining pavement thickness, and the predicted cracks did occur, thus negating the necessity for extending the saw cut through the Safety Edge section.



Safety Edge application (top), pavement with significantly more vertical toe (lower left), saw-cut transverse joint and expected Safety Edge crack (lower right)

Additional Material for PCC Projects

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, the specified design of and measurement methods for the Safety Edge, along with typical unit prices for the materials, need to be considered. Only additional material was computed, since costs will vary over time.

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. When using Iowa DOT specifications for PCC pavements, the method of measurement requires that the out-to-out width of the paved area shall be used to calculate the quantity for payment in square yards or meters. Depending on the design used, a significant increase in materials might result.

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%

Conclusions and Recommendations

1. Expectations for the Safety Edge on a particular project should be thoroughly reviewed with the contractor at a pre-construction 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 design standards and specifications are developed and adopted.
3. Several contractors expressed concerns about interpretation of the 30 degree slope standard. Some equipment intentionally creates a slope less than 30 degrees, which does not pose any safety concerns, although a flatter slope may be more prone to deterioration under loading. Additionally during construction, the slope is not likely to be uniform. Strict interpretation requiring a precise 30 degree slope would require contractors to repair or replace the edge. As a result, the CTRE team recommended using a range of values for the slope angle or using the term "approximate.
4. 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.
5. 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.
6. In recognition of the potential benefit, paved shoulders should also be considered for inclusion of the Safety Edge.
7. 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.
8. 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.
9. Project results provided valuable information that should be translated into material that can be used by organizations, such as the Iowa Local Technical Assistance Program (LTAP), to train state, county, and local agencies.

References

Dixon, K. The Pavement Edge Drop-off Crash Problem in Georgia. Paper presented at the Federal Highway Administration Workshop, February 11, 2004.

FHWA. Field Report PCC Pavement Safety Edge Project Linn/Jones County Highway A34 Project – East of Cedar Rapids, Iowa. Draft. January 2011.

FHWA. The Safety Edge. Preventing crashes caused by unsafe pavement edge drop-off. http://www.fhwa.dot.gov/resourcecenter/teams/safety/saf_12TSE.pdf. Accessed July 2010.

Hallmark, Shauna L., David Veneziano, Tom McDonald, Jerry Graham, Rushi Patel, and Forrest Council. Safety Impacts of Pavement Edge Drop-off. June 2006. AAA Foundation for Traffic Safety. http://www.intrans.iastate.edu/research/detail.cfm?projectID=2073651291

Iowa DOT. "Safety Edge." Iowa DOT Design Manual, Chapter 3, Cross-Sections. Section updated. June 2010. http://www.iowadot.gov/design/dmanual/03C-06.pdf

Midwest Research Center. Safety Evaluation of the Safety Edge Treatment. Year 1 Interim Report. MRI project No. 110495.1.001. April 2008.

Roche, Jerry. FHWA Iowa Division. Safety Edge. Minimizing the Effects of Pavement Edge Drop-off. Presented at the Iowa County Engineers Association. December 2009.

About the Midwest Transportation Consortium

The Midwest Transportation Consortium (MTC) is a Tier 1 University Transportation Center (UTC) that includes Iowa State University, the University of Iowa, and the University of Northern Iowa. The mission of the UTC program is to advance U.S. technology and expertise in the many disciplines comprising transportation through the mechanisms of education, research, and technology transfer at university-based centers of excellence. Iowa State University, through its Institute for Transportation (InTrans), is the MTC's lead institution.

About the Center for Transportation Research and Education

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, reliability, and sustainability while improving the learning environment of students, faculty, and staff in transportation-related fields.