Federal Highway Administration
Every Day Counts
Innovation Initiative

Safety Edge$_{SM}$
PCC Demonstration Project
County Highway E34
Fairview, Iowa

Field Report
June 10, 2011

U.S.Department of Transportation
Federal Highway Administration

FOREWORD

The purpose of this field report is to provide a summary of observations made during the construction of the portland cement concrete (PCC) Safety Edge$_{SM}$ project near Fairview, Iowa, east of Cedar Rapids. These observations and data are to be used with similar information from other Safety Edge$_{SM}$ projects to facilitate the development of standards and guidance for Safety Edge$_{SM}$ construction and long-term performance.

This field report is a summary of the observations and field data measured during construction on May 14, 2010 to evaluate the use of the Safety Edge$_{SM}$ during paving, determine the slope of the Safety Edge$_{SM}$, recommend design adjustments, and identify benefits and complications with the use of the edge device

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16. Abstract

In a coordinated effort with highway authorities and industry leaders, the Every Day Counts initiative serves as a catalyst to identify and promote cost effective innovations to bring about rapid change to increase safety of our nations highway system, decrease project delivery time, and protect our environment. The Safety Edge$_{SM}$ concept is an example of one such initiative in which the edge of the road is beveled during construction for the purpose of helping drivers who migrate off the roadways to more easily return to the road without over correcting and running into the path of oncoming traffic or running off the other side of the roadway.

This field report documents the observations made on the construction of the Safety Edge$_{SM}$ on a two lane highway PCC overlay project on County Highway E34 (a.k.a. Fairview Road) in the vicinity of Fairview, Iowa. Details regarding the fabrication and performance of a custom device used to shape the Safety Edge$_{SM}$ along with the shape and physical properties of the finished Safety Edge$_{SM}$ are presented for the purpose of understanding what processes and techniques were most successful in forming the Safety Edge$_{SM}$.

The findings from this overlay project and other similar ongoing projects form the basis for understanding the construction process and material performance necessary to bring this innovation into common highway practice and make our Nation's highways safer.

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SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
(none)	mil	25.4	micrometers	μm
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	millimeters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela per square meter	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	Newtons	N
lbf/in^2 (psi)	poundforce per square inch	6.89	kiloPascals	kPa
k/in^2 (ksi)	kips per square inch	6.89	megaPascals	MPa
		DENSITY		
lb/ft^3 (pcf)	pounds per cubic foot	16.02	kilograms per cubic meter	kg/m^3
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
μm	micrometers	0.039	mil	(none)
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela per square meter	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	Newtons	0.225	poundforce	lbf
kPA	kiloPascals	0.145	poundforce per square inch	lbf/in^2 (psi)
MPa	megaPascals	0.145	kips per square inch	k/in^2 (ksi)

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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Topic *Page*

Summary of Observations

This section of the field report provides a summary and listing of important observations made during the paving operations, interview with paving personnel and findings from the field measurements taken during paving that are expected to have a significant impact on the performance of the Safety Edge$_{SM}$.

Overall Opinion of the Safety Edge$_{SM}$

- The Safety Edge$_{SM}$ does not appear to have a major impact on the contractor's paving operation during mainline open paving. Some minor issues were encountered by the contractor and the construction method may require some refinement to resolve these issues, however.

Slope of Safety Edge$_{SM}$

- The average slope of the Safety Edge$_{SM}$ was found to be 31.5° with a maximum value of 34.0° and a minimum value of 28.5°.

Placement

- The sloped face of the Safety Edge$_{SM}$ was slightly concave or convex at some locations. This condition may be caused by either flex in the device during paving or due to issues during finishing. The deviation from flat surface is generally considered to be minor and is not expected to have a significant impact on the performance of the Safety Edge$_{SM}$.
- The fixed nature of the Safety Edge$_{SM}$ device lead to additional labor needed to form the Safety Edge$_{SM}$ at locations where the mainline crosses existing roads.
- Sawcutting of the transverse joints stopped at the sloped face of the Safety Edge$_{SM}$. Joints were observed forming at the proper location through the Safety Edge$_{SM}$ where the sawcut ended.
- The contractor experienced minor difficulty placing the tie bars at the lane to shoulder joint but this turned out to be an equipment issue rather than the design of the Safety Edge$_{SM}$.
- Minor random cracking was observed but was not directly related to the Safety Edge$_{SM}$.

Shoulder Construction

- The thickness at the outside edge of Safety Edge$_{SM}$ varied due to variability of the concrete overlay thickness and shoulder base material grading and was not due to Safety Edge$_{SM}$ construction.

PCC and Safety Edge $_{SM}$

- The results of the air voids and modulus testing of the hardened concrete indicate that the quality of the concrete is reasonably uniform between the Safety Edge$_{SM}$ and away from the Safety Edge$_{SM}$.

This Safety Edge$_{SM}$ project should be monitored over time to determine its long-term performance and the frequency of any required maintenance operations, as well as the life cycle cost of the Safety Edge$_{SM}$ and its effectiveness over time. Attention should be given to how well the granular shoulder dressing remains in place.

FIELD EVALUATION OF PCC OVERLAY WITH SAFETY EDGE$_{SM}$

Introduction

The project was located along County Highway E34 (a.k.a. Fairview Road) in the vicinity of Fairview, Iowa. The objective of this study was to evaluate the quality of Safety Edge$_{SM}$ constructed as well as that of the in-place concrete material. The location of the project is shown in Figure 1. The length of the project was approximately 14,055 ft between Quaker Lane and Fairview Road.

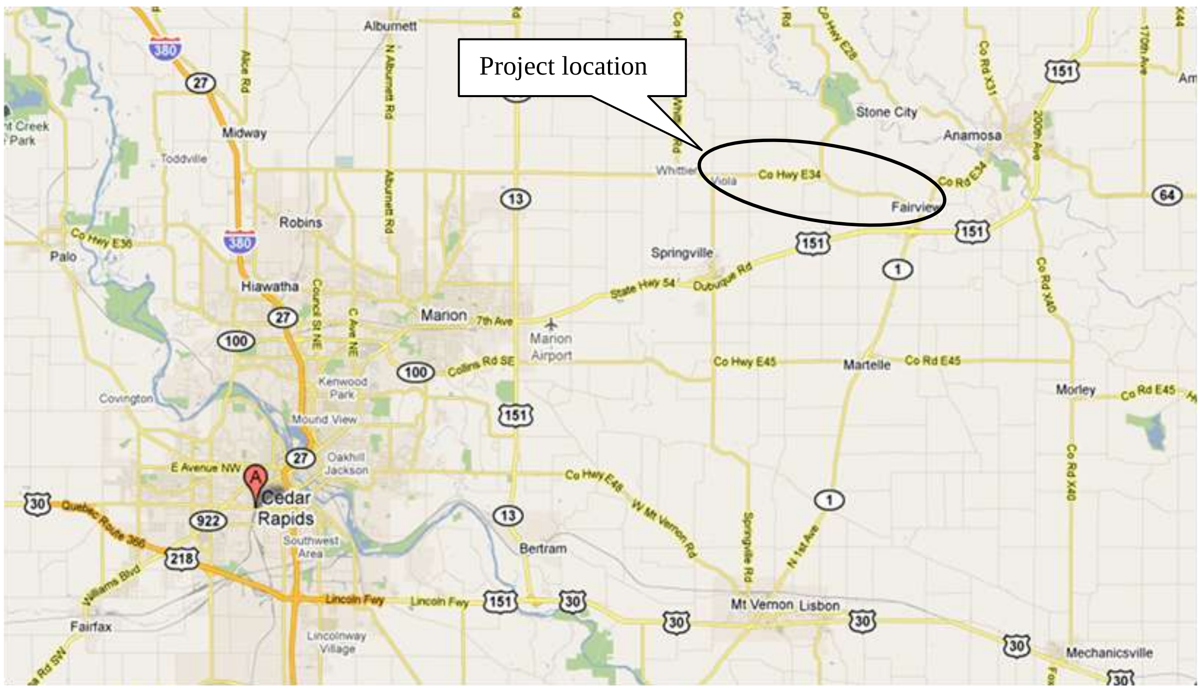


Figure 1. Location of site.

Figure 2 presents a view of a completed section of the roadway. The construction included a 6 inch overlay of unbonded PCC over an existing 6 inch PCC pavement. The overlay included a tied 9-inch thick shoulder 2.75 ft wide, with a 30° sloped Safety Edge$_{SM}$ in both the westbound and eastbound direction. A schematic of the cross section of the pavement is shown in Figure 3.

Figure 2. General view of the project showing the Safety Edge$_{SM}$.

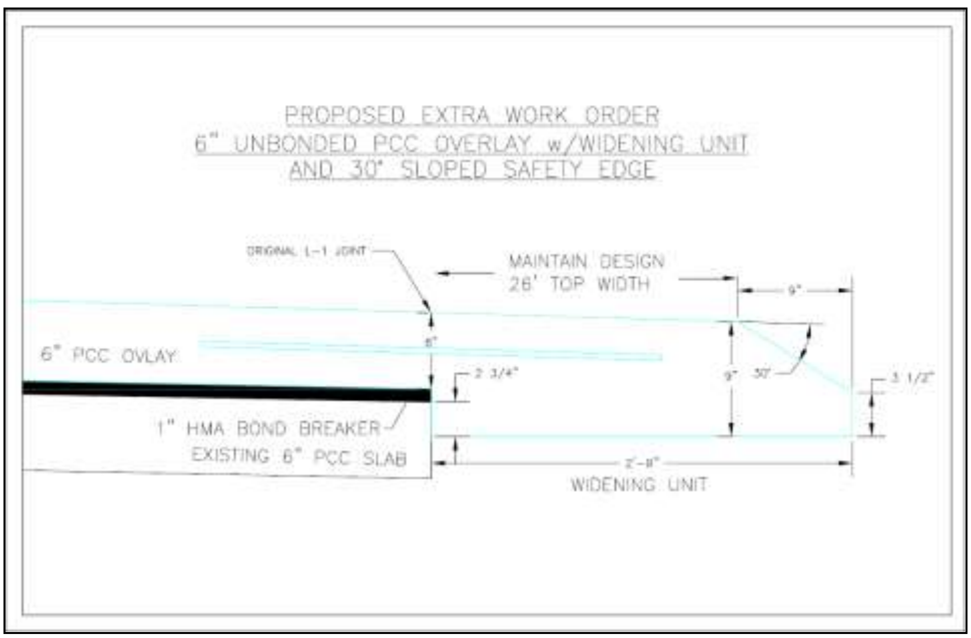


Figure 3. Cross section of concrete pavement overlay.

Field Evaluation

Field evaluation of this pavement included:

- Safety Edge$_{SM}$ slope measurements.
- Testing the modulus of the concrete within the Safety Edge$_{SM}$ and away from the edge using the portable seismic pavement analyzer (PSPA).
- Free-free resonant column (FFRC) testing conducted to compare the moduli measured in the field with the PSPA.
- Core samples taken to analyze the compressive strength, unit weight, and air void content of the hardened concrete within the Safety Edge$_{SM}$ and away from the edge.

Construction of the Safety Edge$_{SM}$ was observed over two days to record the paving process and any peculiarities associated with the inclusion of the Safety Edge$_{SM}$.

<u>Slope Measurements</u>

Measurements were taken along the length of the Safety Edge$_{SM}$ in both directions for the first two days of paving at 50-ft intervals. The pavement was placed and saw cut prior to the field evaluation crew arriving on site. The edge of the pavement was generally found to be well formed. The slope of the Safety Edge$_{SM}$ varied along the length of the pavement due to curve elevations, flexing of the paver device that forms the Safety Edge$_{SM}$, and other related issues; however, the slope was generally found to be within a reasonable range. The average slope measured was 31.5° with a maximum value of 34.0° and a minimum value of 28.5°.

Some deviation in the flatness of the slope face was observed. The flatness was measured by placing a straightedge on the face as shown in Figure 4. The face was found to be concave in some cases and convex in other cases. This condition may be caused by either flexing of the device or issues during finishing. The deviation from flat is generally considered minor and is not expected to have a significant impact on the performance of the Safety Edge$_{SM}$.

Similarly, the vertical edge face of the pavement was found to have defects from forming. The Safety Edge$_{SM}$ device did not always seal tightly against the end gate, leaving a ridge in the face. Figure 5, shows an example of this. The vertical face is bowed and the marks created by the end of the device and the end gate can be clearly observed.

Figure 4. Measuring the slope and flatness of the Safety Edge$_{SM}$.

Figure 5. Slope face showing ridge and bow.

Portable Seismic Pavement Analyzer

The PSPA was utilized to provide a measure of quality by determining the variation in modulus with depth of the concrete in the field. Details of this nondestructive test procedure are explained in Appendix A. PSPA testing was conducted on the sloped edge, at 1 ft from the edge, and on the right wheelpath as illustrated in Figure 6. This was done to compare the quality of the concrete within the edge and at points gradually moving towards the interior of the pavement.

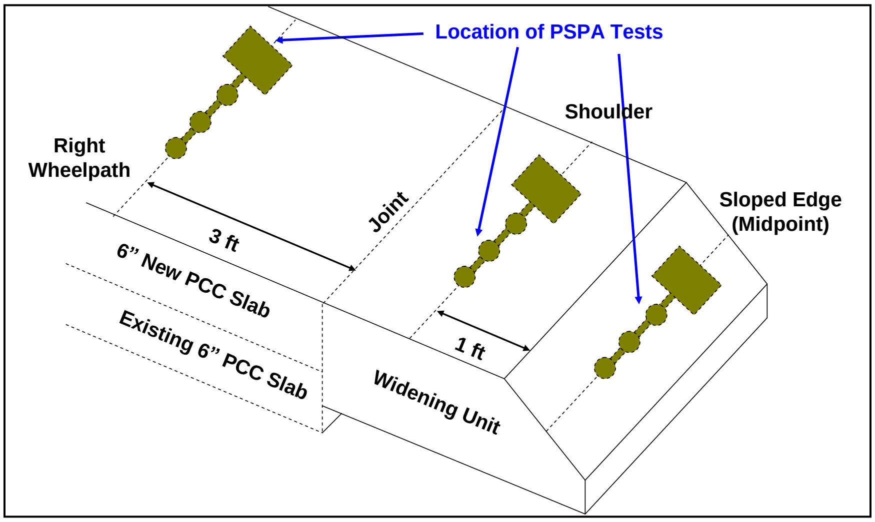


Figure 6. Location of PSPA test points.

PSPA tests were conducted on the westbound and eastbound lanes from Stations 19+00 to 53+00 of Linn County and from Stations 11+00 to 19+00 of Jones County. Spacing between stations was 100 ft. This portion of the project was paved over two days. The first section that was tested was paved on May 5 and tested on May 10 (Day 1 of testing) and included stations 19+00 to 36+00. The second section that was tested was paved on May 6 and tested on May 11 (Day 2 of testing) and included station from 11+00 to 19+00 and from 37+00 to 53+00. In total, tests were conducted at 44 stations. In addition to the PSPA tests, nine cores were obtained at three different locations for laboratory analysis of the concrete's modulus for comparison with the PSPA results.

Moduli for the 44 stations investigated in each direction and representative statistics are summarized in Table 1. The full set of data are presented in Appendix A. The section that was paved on Day 1 exhibited an average modulus of 4,200 k/in^2, slightly higher than the section constructed on Day 2 (4,050 ksi). Coefficients of variation (COV) of the modulus for all stations were small and between 3 and 6 percent. Figure 7 and Figure 8 graphically present the variation of moduli at the three lateral points tested along the project.

Table 1. PSPA statistical results.

Day	Average Modulus (ksi)					
	Eastbound			Westbound		
	Slope	Shoulder	Wheelpath	Slope	Shoulder	Wheelpath
May 10	4,238 (4)*	4,185 (3)	4,169 (3)	4,192 (4)	4,222 (5)	4,215 (5)
May 11	4,046 (5)	4,036 (4)	4,059 (5)	3,999 (6)	4,111 (5)	4,012 (5)

**Numbers in parentheses are the COV of the 44 points.*

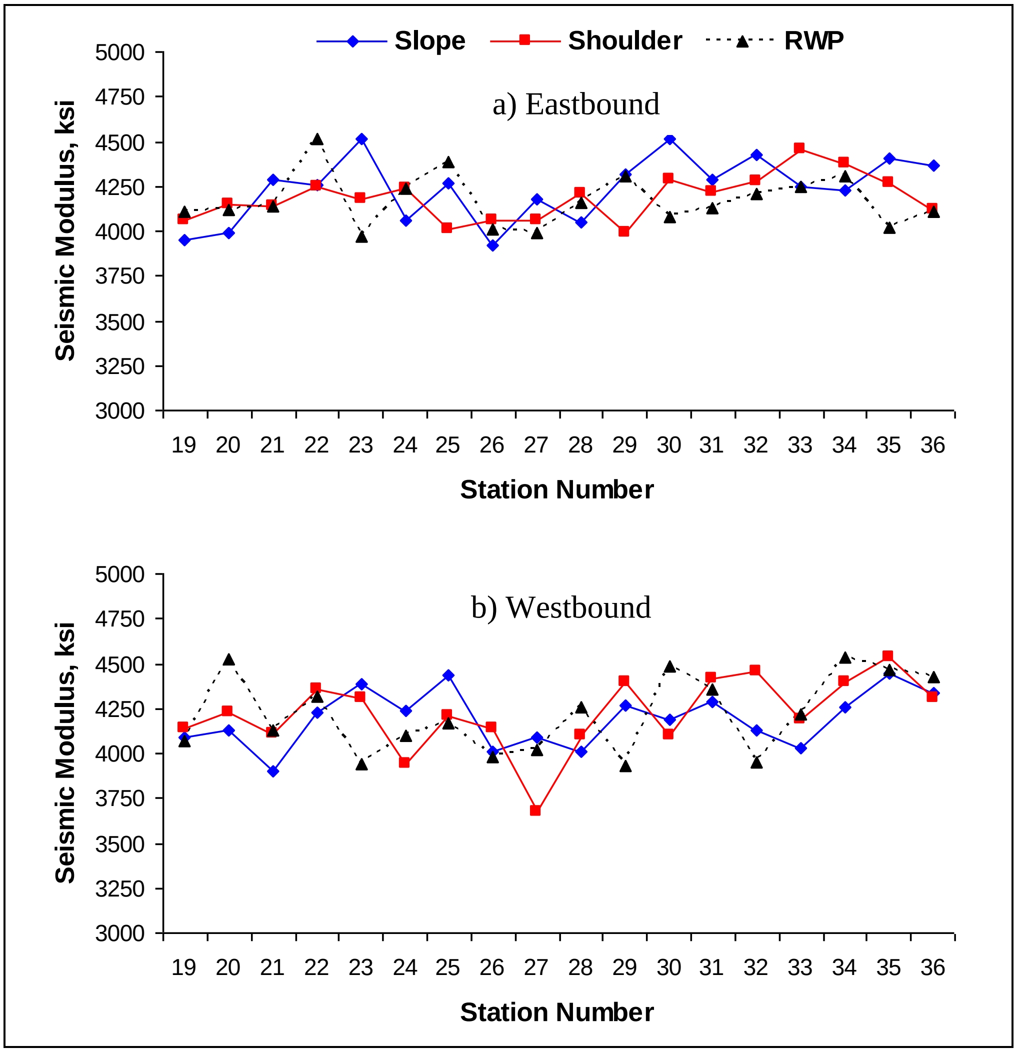


Figure 7. Variations of the moduli for the sections tested on Day 1.

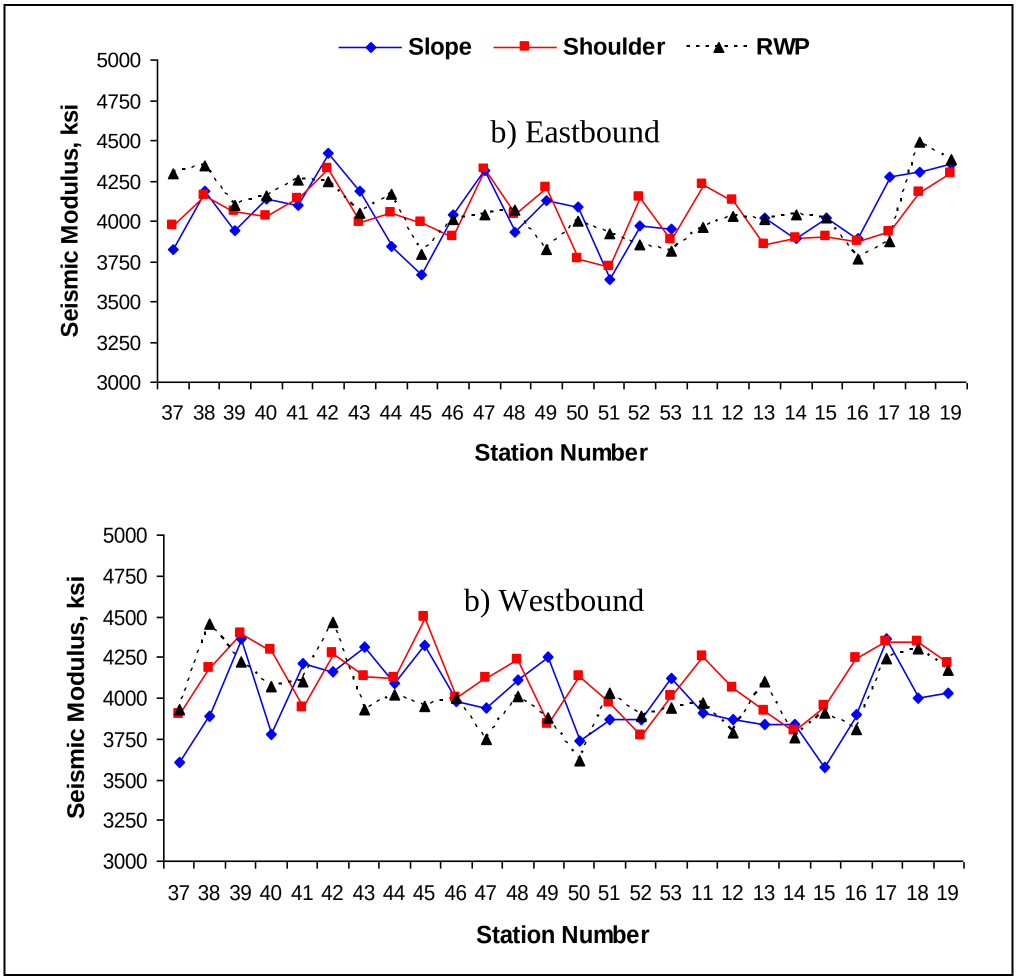


Figure 8. Variations of the moduli for the sections tested on Day 2.

Table 2 through Table 4 present the results of a paired t-test and a single factor analysis of variance (ANOVA) on the test data from the eastbound direction, westbound direction, and pooled east and westbound directions. There are no statistical differences among different data groups as indicated by the statistical analysis with one exception. The calculated t-value for westbound slope versus shoulder data pairs is higher than the critical t-value indicating that there exists significant difference between the two groups. However, this difference is caused by the variations in the "westbound shoulder" data rather than the "westbound (Safety Edge$_{SM}$) slope" data. Note that the paired t-value for westbound slope vs right wheelpath (RWP) is -0.48, whereas the t-value for the westbound shoulder vs RWP is 1.73. The results of the statistical analysis therefore indicates that the concrete across the pavement is uniform suggesting that the Safety Edge$_{SM}$ concrete is no different than interior concrete.

Table 2. Paired t-test and ANOVA results for the eastbound dataset.

	Eastbound		
	Slope	Shoulder	RWP
Mean	4128.6	4093.6	4104.2
Std dev.	215.6	170.3	180.9
	Slope vs	Shoulder vs	Slope vs
t Stat	1.32	-0.24	0.57
P(T<=t)	0.20	0.81	0.57
t Critical	2.02	2.02	2.02

Anova: Single Factor

F	P-value	F crit
0.36	0.70	3.07

Table 3. Paired t-test and ANOVA results for the westbound dataset.

	Westbound		
	Slope	Shoulder	RWP
Mean	4077.9	4156.6	4095.4
Std dev.	218.3	203.7	231.0
	Slope vs	Shoulder	Slope vs
t Stat	-2.47	1.73	-0.48
P(T<=t)	0.02	0.09	0.63
t Critical	2.02	2.02	2.02

Anova: Single Factor

F	P-value	F crit
1.58	0.21	3.07

Table 4. Paired t-test and ANOVA results for the combined east and westbound dataset.

	Both lanes		
	Slope	Shoulder	RWP
Mean	4102.7	4125.8	4102.1
Std dev.	217.2	189.7	208.1
	Slope vs Shoulder	Shoulder vs RWP	Slope vs RWP
t Stat	-1.07	1.03	0.02
P(T<=t)	0.29	0.31	0.98
t Critical	1.99	1.99	1.99

Anova: Single Factor

F	P-value	F crit
0.37	0.69	3.03

Free-Free Resonant Column Testing

Three random stations tested with the PSPA were selected for core extraction. At each station, three samples were obtained—one on the sloped edge, one on the shoulder and one on the wheelpath. The three stations were:

- Eastbound 21+00 (samples 1 to 3).
- Westbound 50+00 (samples 14 to 16).
- Eastbound Station 18+00 (samples 19 to 21).

As an example, the cores from station 21+00 are shown in Figure 9. The cores were first trimmed to remove either the rough ends (if needed) or the sloped portions.

Figure 9. Cores retrieved from station 21+00.

The seismic moduli of the cores were determined by measuring the resonant frequency of vibration (standing waves) according to the FFRC test for comparison with the moduli measured in the field with the PSPA. Details of the FFRC test procedure are included in Appendix A. At the time of FFRC testing, the specimens had cured for approximately seven days. The comparisons of the lab and field moduli for the nine cores are presented in Figure 10. The results of the PSPA and FFRC testing were similar with the average difference of 7 percent and a range of 1 to 13 percent.

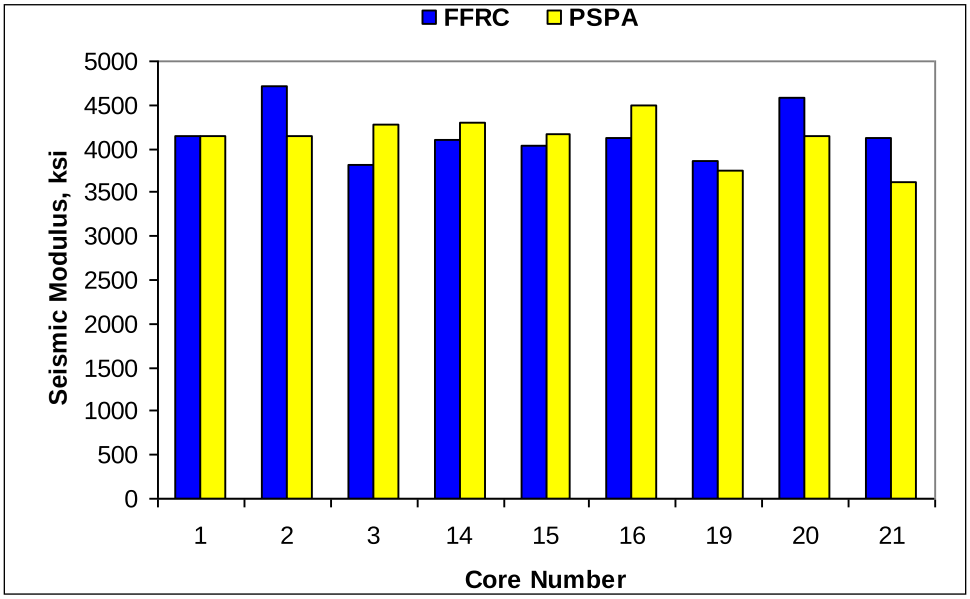


Figure 10. Comparison of the moduli obtained with PSPA and FFRC.

Compressive Strength Testing

The nine cores tested for seismic modulus were further tested to measure their compressive strengths (ASTM C39) approximately 22 days after construction. The compressive strengths of the cores are summarized in Table 5. Because cores had different length-to-diameter ratios (L/D), adjustment factors were applied to convert the strengths to those for L/D ratios of 2 as per ASTM C39/C39M. The average compressive strength was 6,200 lbf/in^2 with a COV of 12 percent. Similarly, the average seismic modulus was 4,368 k/in^2 with a COV of 6 percent. Considering the low COV for both parameters, the concrete can be considered to be relatively uniform.

Table 5. Compressive strength and FFRC modulus results.

Core No. and Location	**Station Number and Bound**	**Raw Compressive Strength,** lbf/in^2	**Length/ Diameter**	**Adjustment Factor**	**Adjusted Compressive Strength,** lbf/in^2
1 (wheelpath)	21+00 (EB)	6,250	1.47	0.958	5,987
2 (shoulder)	21+00 (EB)	6,738	2.00	1.000	6,738
3 (edge)	21+00 (EB)	5,682	1.20	0.920	5,229
14 (edge)	50+00 (WB)	5,394	1.90	0.991	5,343
15 (shoulder)	50+00 (WB)	5,891	2.01	1.001	5,897
16 (wheelpath)	50+00 (WB)	5,963	1.72	0.977	5,827
19 (edge)	18+00 (EB)	6,976	1.23	0.926	6,459
20 (shoulder)	18+00 (EB)	7,592	2.01	1.001	7,600
21 (wheelpath)	18+00 (EB)	7,189	1.28	0.934	6,717
				Average	6,200
				COV	12

Eastbound (EB), Westbound (WB)

Before conducting strength tests, the cores longer than 8 inches were further trimmed to 8 inches and all cores were tested again with the FFRC. The comparisons of the FFRC moduli at ages of 7 and 22 days are shown in Figure 11. On average, the moduli increased by 5 percent in that time frame.

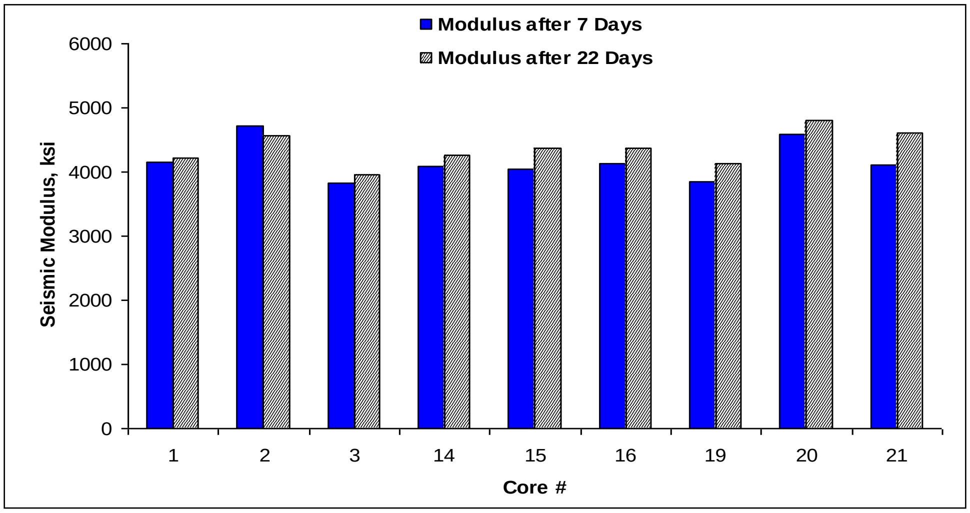


Figure 11. Comparison of the FFRC Moduli.

Unit Weight and Air Void Analysis

A total of six pairs of additional cores were taken (each pair containing one core from the edge and one core from the shoulder) to determine if there were any differences in unit weight or air voids that could lead to differences in their respective durability performances over the life of the pavement. The shoulder concrete was supposed to be representative of the mainline pavement. ASTM C457 standard test procedures were followed to determine the parameters of the air-void system in the cores.

Observations of the surface of the cores suggested that the concrete in the Safety Edge$_{SM}$ was of good quality but had inconsistent consolidation that resulted in differences in the entrapped air contents. Two of the shoulder cores appear to have not been vibrated sufficiently because entrapped air voids are distributed throughout the core sample. In most of the other cores, the entrapped air occurs in higher concentrations several inches from the top surface and slightly below the bottom surface. This distribution of entrapped air was likely the result of the paver's vibrator penetrating to a fixed depth slightly above the granular base. The entrapped air is the lowest at the top because of vibration inherent to the screeding process. The vibrator did not seem to be contacting the granular base because there is no apparent incorporation of foreign materials into the bottom of the concrete.

Two of the cores at the Safety Edge$_{SM}$ contained irregular air-void channels (or tears during placement) that may lead to lower durability if they didn't occur a couple of inches below the surface. The location of these defects, inches below the surface, suggests that they will have no effect upon the durability of the concrete because they are protected by a layer of denser concrete.

Generally, laboratory testing revealed that the air void systems in the edge cores had both a greater percentage of entrapped air voids greater than 1.0 mm and more air void chords greater than 0.5mm in comparison to the shoulder cores (Figure 12).

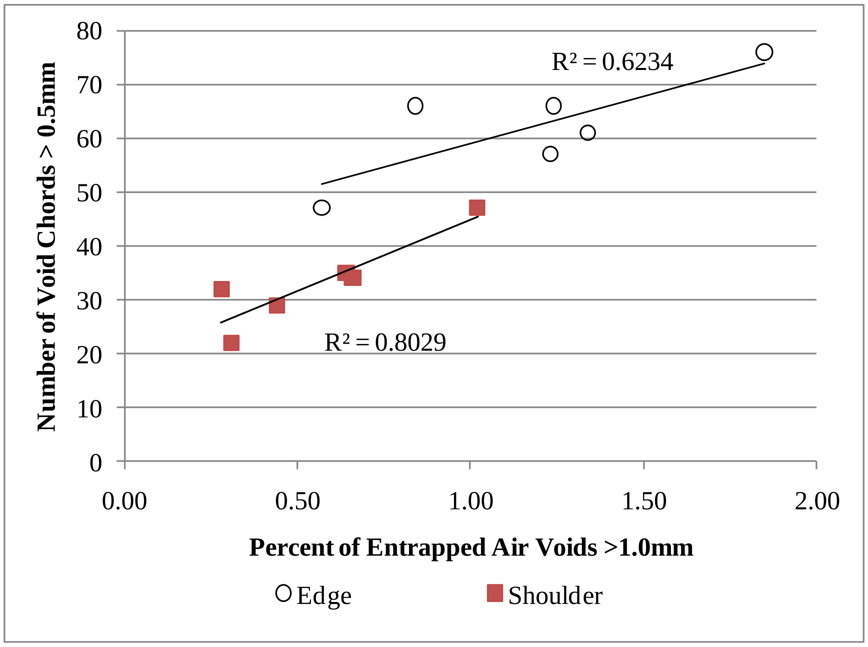


Figure 12. Comparison of the percentage of entrapped air and the number of void chords greater than 0.5mm.

The only consistent difference found in the pairs of cores is that the Safety Edge$_{SM}$ cores had a somewhat greater amount of entrapped air voids in regards to the spacing factors as compared to the shoulder cores (Figure 13). This observation appears in both the amount of entrapped air voids as determined by both the linear traverse method (where the length of all traverse chord across air voids was observed) and the point count method.

On average, the edge cores had a lower unit weight, a higher air content, a slightly higher spacing factor, and more air voids over 0.5mm. Despite the differences, however, the spacing factors and other parameters were reasonable and the concrete at the edge as well as from the shoulder appears to be durable. Table 6 summarizes these results.

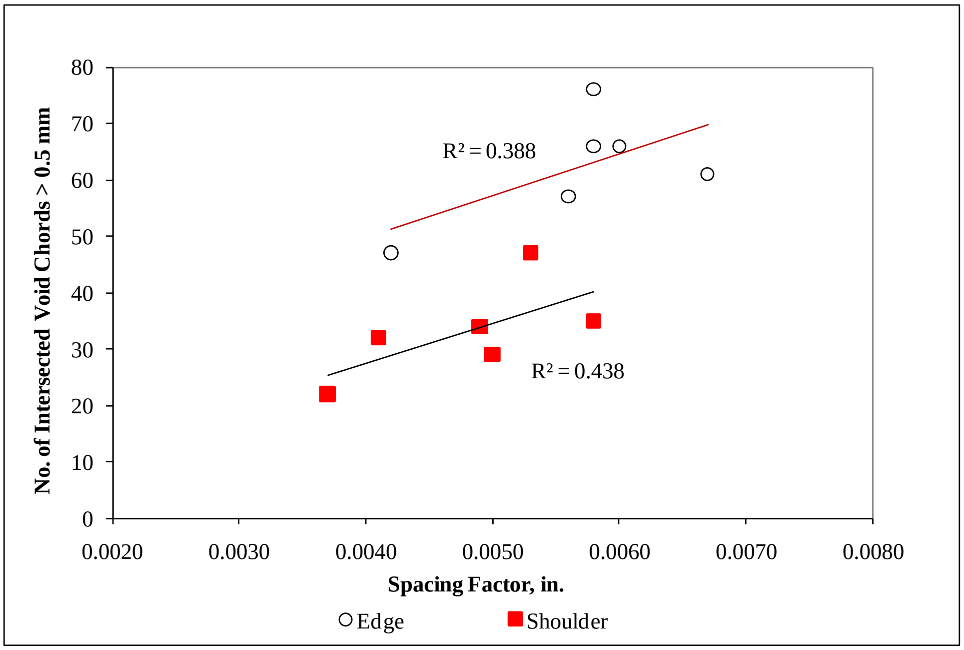


Figure 13. Comparison of the number of large air voids (> 0.5 mm) and the spacing factors.

Table 6. Results of the air voids analysis.

Core	Position	Unit Weight, pcf		Avg. Hardened Air,		Spacing Factor,		No. of Chords	
		Shoulder	Edge	Shoulder	Edge	Shoulder	Edge	Shoulder	Edge
1	Edge		135.6		6.4		0.0042		47
	Shoulder	137.3		6.3		0.0053		47	
2	Edge		138.7		6.6		0.0058		66
	Shoulder	138.2		6.0		0.0037		22	
3	Edge		138.6		6.4		0.0060		66
	Shoulder	139.1		4.5		0.0041		32	
4	Edge		139.7		6.4		0.0067		61
	Shoulder	140.9		5.1		0.0058		35	
5	Edge		138.6		6.0		0.0056		57
	Shoulder	139.9		6.4		0.0049		34	
6	Edge		136.5		7.6		0.0058		76
	Shoulder	139.0		5.8		0.0050		29	
	Average	**139.1**	**138.4**	**5.7**	**6.6**	**0.0048**	**0.0060**	**33.2**	**65.2**
	COV	**0.89**	**1.13**	**13.05**	**8.22**	**16.14**	**13.73**	**24.8**	**15.0**

Observations Made During Paving with the Safety Edge$_{SM}$

This section provides an overview of the observations made during the paving operations.

Paver/Placement Operations

The contractor made a custom Safety Edge$_{SM}$ device or profile for their Gomaco paver. A discussion of the fabrication process is provided by the contractor as follows:

> As far as the fabrication process on a Gomaco machine, there is an insert section on the end drive portion of the pan that allows the use of different profiles, such as curb profiles, flat sections, or in this case a Safety Edge$_{SM}$ profile….
>
> One idea we had was to weld the Safety Edge$_{SM}$ profile to the bottom of the existing profile section, after much discussion we decided against this as we felt we may get tearing of the finished product at the welds. Also with this method we would not have any edge slump adjustment as the adjusting bolts would be in the wrong location.
>
> The second idea [and the idea used on this project] was to cut out the existing profile and fabricate in the Safety Edge$_{SM}$ profile. This method seemed the best because we were able to incorporate some adjustment into the profile, and all edges would be smooth to hopefully eliminate any tearing of the finished edge. We were also able to fabricate in the edge slump adjustments to the new section. Although the inserts would only be able to be reused as a Safety Edge$_{SM}$ profile in the future or a complete rebuild would have to be done again, unlike if we welded the profile beneath the existing profile, we still felt this was the best way to go.
>
> After the decision was made to rework the existing profile, our fabricator cut the profile out of rigid cardboard first to get the correct dimensions. He then removed the portions of the existing profile needed to fit in the new Safety Edge$_{SM}$ profile. He then took the cardboard template and cut out and rolled the new profile into shape. He then made the same profile out of stainless steel for the finish portion of the pan. We decided to leave a 2 inch finish tail on the stainless steel profile to help finish the portion of the edge where it goes from slope to vertical. When he was done with the profile fabrication, he then made the adjusting bolts fit where we thought the adjusting points needed to be. One spot was on the sloped section itself as this way we had some adjustment if the edge was not finishing properly.
>
> When the first side was complete, and all measurements were checked we mirrored the same process for the other side….

When the time came to setting up the paver, we made sure that the vibrators were positioned in the correct locations for proper consolidation at the point where the slope angled at the top. One thing that benefited us on this project was the fact that we had done a lot of urban paving also, so we had previous experience with vibrator placement on different profile types.

We encountered a few challenges as we progressed down the road. One was the two inch tail we had left at the point on the profile where it went from slope to vertical. When going through existing intersections, drives, or if the grade was not exact on the very outside edge, this would drag. We eventually cut one inch off of this and it still performed well. I believe a half inch would work also.

With the use of the Safety Edge$_{SM}$ on an overlay, one consideration that has to be taken into account is the outside edge thickness of the pavement. This thickness must be as thick or thicker than design. Once the Safety Edge$_{SM}$ [profile] is attached to the paver there is no way of reducing the outside thickness as the profile is stationary on the machine.

Another challenge with the use of the Safety Edge$_{SM}$ [profile] was paving through intersections or drives that required a vertical edge. The first intersection we went through we decided to pave through and come back and saw off 9 inches to create a vertical edge. This method worked but wasted concrete. Another option would be to box out the intersections before we went through. We decided at the drives to place forms, fill in and consolidate the sloped edge with fresh concrete right behind the paver. This worked well, so before we went through the next intersection we laid out forms and did it the same as we had done the drives.

Another thing that we had to watch out for was the profile protruded beneath the main pan section. This created extra height to the machine when moving to, and on the job. The operator had to make sure the machine was in the right location or the edges could be damaged. If width adjustments on the main pan needed to be done, the inserts had to be removed first unlike other profiles.

We had good luck using the Safety Edge$_{SM}$ profile and believe the level of difficulty of using it is low, if you do the preparation ahead of time.

The Safety Edge$_{SM}$ device can be seen in Figure 14. The device in Figure 15 is shown welded to the back of the pan and sits closely to the end gate. It is evident that the device has been bent. The contractor indicated the device was bent during transport operations. This bend in the device can be seen in the pavement as a bow in the exposed vertical face of the pavement edge.

The contractor indicated there may be a benefit to using the Safety Edge$_{SM}$ versus a conventional vertical face. It is expected a more workable concrete mix can be used that would facilitate improved concrete quality.

Figure 14. View of the Safety Edge$_{SM}$ device from front of paver.

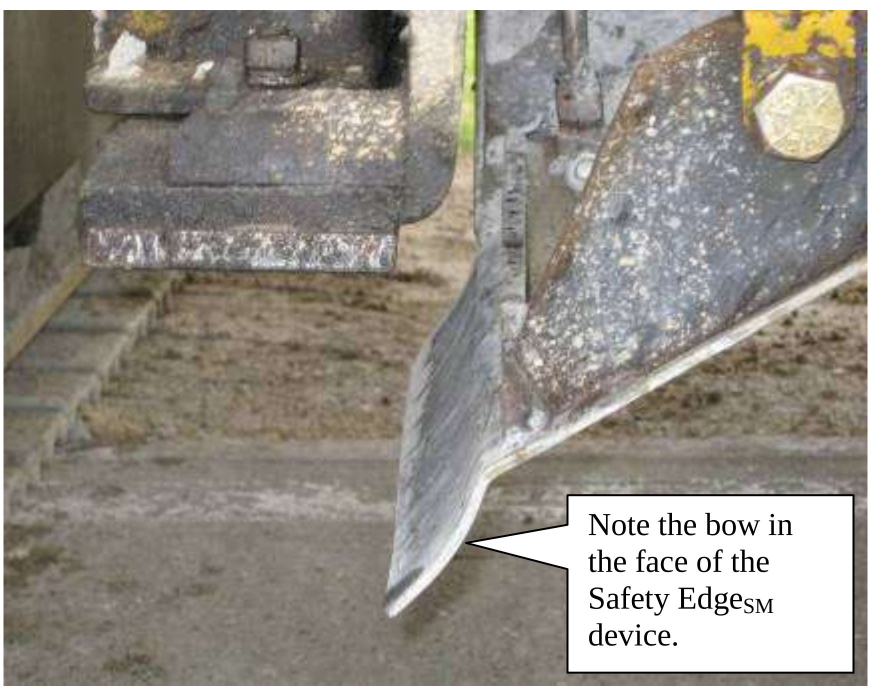


Figure 15. Viewed from the rear of paver showing the bend in the Safety Edge$_{SM}$ device.

An example of saw cutting and removing the Safety Edge$_{SM}$ at an intersection is shown in Figure 16. The alternative was to build up the Safety Edge$_{SM}$ by hand (see Figure 17) in order to tie into pavement intersections.

Figure 16. Saw cut edge at an intersection.

Figure 17. Edge formed and prepared for intersection paving.

Shoulder Construction

The plan for the Safety Edge$_{SM}$ called for a nominal 9 inch thickness for the widened shoulder section. Measurements revealed that the average thickness of the shoulder over the first two days of paving was 11.0 inches. The additional concrete thickness in the shoulder may benefit the performance of the pavement, but indicates that the shoulder preparation was not as precise as the contractor or engineers may have wished. Additional material costs may be reflected in the final payout. This issue is more likely due to the widening of the roadway than the presence of the Safety Edge$_{SM}$ itself.

Material/Structural Performance Issues of the Safety Edge$_{SM}$

The primary concerns for failure from a structural aspect of the Safety Edge$_{SM}$ will be material issues such as segregation or under-consolidation in the Safety Edge$_{SM}$, and lack of support under the widened roadway, which may cause the Safety Edge$_{SM}$ and shoulder to break away from the mainline pavement.

Unlike with hot mix asphalt (HMA), which requires a rolling operation to produce material density, the PCC Safety Edge$_{SM}$ achieves density, or consolidation through the vibration and extrusion process. While a vibrator was not placed within the steeply sloped portion of the Safety Edge$_{SM}$, the nearest vibrator is still quite close the edge. No obvious signs of consolidation issues were observed at either the exposed edge face or in the surface of the cores cut from the Safety Edge$_{SM}$. Laboratory and nondestructive testing of the in-place concrete confirmed that consolidation was not a major issue.

Tie Bar Placement

The contractor experienced problems with one of the tie bar launchers for the tie bar located between the shoulder and mainline pavement. The launcher repeatedly failed to release the bars inside the pavement resulting the bars being bent and partially removed from the pavement. The net result when a bar was misplaced is that the bar was removed and not replaced. The contractor resolved this issue by placing a laborer on the bridge of the paver to manually pause the launcher with the bar at depth. Once the paver moved past the bar, the laborer would restart the launcher and reload the device. This significantly reduced, but did not completely eliminate, the problem. Several misplaced bars were observed during a few hours of paving.

Random Cracking

A decision was made to saw cut only the top of the pavement and not saw cut the slope of the Safety Edge$_{SM}$ as shown in Figure 18. The reason for not saw cutting the slope was that it would be easier to retain the joint sealant with only the sawcut on top. Another reason was the joint would crack straight down which was what was observed. Figure 18 also shows that the joint formed properly at this location.

Figure 18: Photo of saw cut and formed joint.

Figure 19 shows one of two locations along the project where random cracking was observed parallel to the sawed joint. It is unknown if the Safety Edge$_{SM}$ contributed to the formation of these cracks, however, given the location and orientation it appears unlikely that the Safety Edge$_{SM}$ contributed to these cracks.

A mid-panel crack was also observed in a slab at approximate station 52+40. The cause of the crack is not believed to be related to the presence of the Safety Edge$_{SM}$. Saw cut timing may have played a role in this.

Figure 19. Random crack formed near joint.

Findings and Conclusions

As previously stated, the objective of this field study was to evaluate the quality of the in-place PCC pavement and Safety Edge$_{SM}$ by investigating three features.

1. Correct use of the Safety Edge$_{SM}$ device during paving.
2. PCC properties at the Safety Edge$_{SM}$.
3. Slope of the Safety Edge$_{SM}$.

This section of the field report summarizes the findings and conclusions made during the paving operations.

- The slope was generally found to be appropriate. The average slope was 31.5° with a maximum value of 34.0° and a minimum value of 28.5°.
- A slight hump or bow in the slope face was produced by the Safety Edge$_{SM}$ device. Modifications to the device and a more robust design should be considered to prevent this problem on future projects. Unlike the Safety Edge$_{SM}$ attachments for asphalt pavers, the PCC device on the concrete paver requires more time and effort to install or modify once paving begins.

- Additional labor was required to cut and remove the Safety Edge$_{SM}$ or form the Safety Edge$_{SM}$ to tie into connecting pavements.
- The results of field and laboratory test results indicate the quality, as indicated by PCC modulus and compressive strength testing, is reasonably uniform throughout the pavement.
- Laboratory test results of cores taken at the Safety Edge$_{SM}$ show, on average, a lower unit weight, a higher air content, a slightly higher spacing factor, and more 0.5 mm air voids in comparison to cores taken from the shoulder. Despite the differences, however, the concrete within the edge appears to be as durable as that in the mainline pavement.

The pavement should be inspected after the final shoulder backing material has been placed to determine if the Safety Edge$_{SM}$ promotes the retention of the backing material. Monitoring of this site would be beneficial in evaluating the long-term performance of the Safety Edge$_{SM.}$

APPENDIX A. DATA TABLES FROM FIELD MEASUREMENTS

The Portable Seismic Pavement Analyzer

The PSPA, shown in Figure 20, consists of two ultrasonic sensors or transducers and a hammer or source packaged into a hand-portable system, which can determine the variation in modulus of the material with depth using the Ultrasonic Surface Wave (USW) method (Nazarian et al., 2006). The PSPA is operable from a laptop computer tethered to the hand-carried transducer unit through a cable that carries power to the hammer and transducers and returns the measured signals to the data acquisition board in the computer. To collect data the user initiates the testing sequence through the computer. The high-frequency source is activated four to six times. The outputs of the two transducers from the last three impacts are saved and averaged (stacked). The other (pre-recording) impacts are used to adjust the gains of the pre-amplifiers to optimize the dynamic range.

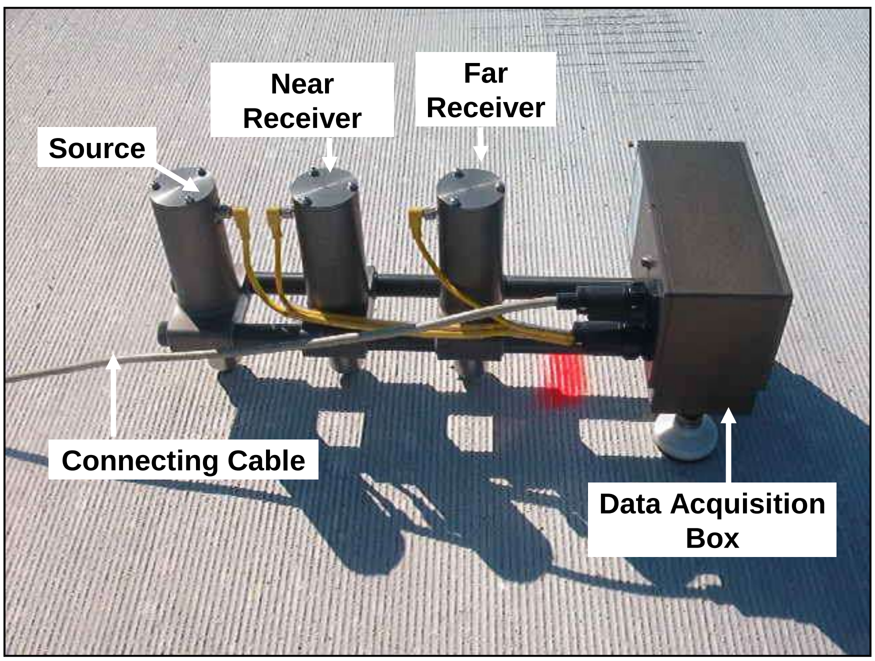


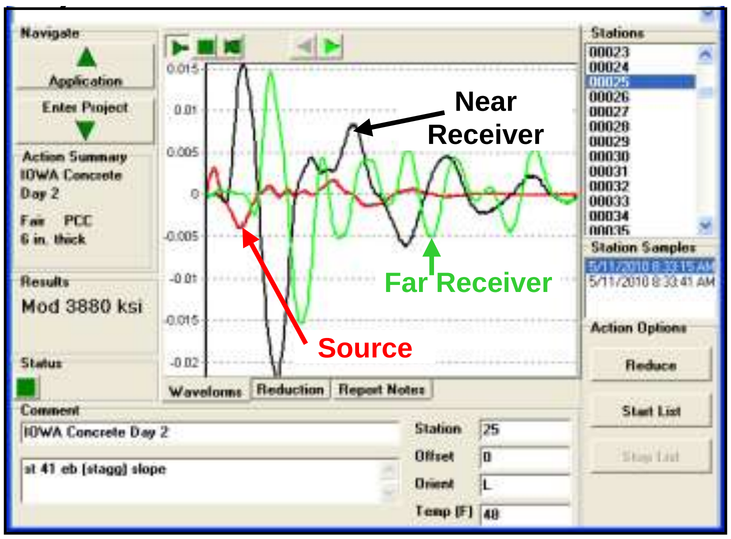
Figure 20. Portable seismic pavement analyzer.

The time records collected are subjected to signal processing and spectral analyses. In the USW method, the surface or Rayleigh wave velocity, V_R, is measured without an inversion algorithm. After V_R is measured, the modulus of the top layer, E_{field}, can be determined from (Nazarian et al., 2002):

$$E_{field} = 2\rho\left[V_R(1.13-0.16)\right]^2(1+\nu) \quad (1)$$

where ρ is mass density, and ν is Poisson's ratio.

Typical time records of the receivers are shown in Figure A-3. These records are analyzed to obtain a dispersion curve, a plot of the modulus vs. wavelength (or depth), as shown in Figure A-3. At wavelengths less than or equal to the thickness of the uppermost layer, the travel time and velocity of surface waves is independent of wavelength, as long as the modulus of the layer is constant. If the pavement structure is composed of several layers, voids are present or poorly-constructed layers exist, the velocity will vary with wavelength in the dispersion curve. In that manner, the operator of the PSPA can get a qualitative feel for the variation in modulus with depth. In Figure A-3 the modulus remains constant for the top 5 inches, and slightly decreases below that depth and remains constant below 6 inches. To obtain the average modulus, the moduli from a wavelength of about 2 to 6 inches (nominal thickness of the overlay) is used. The results of the PSPA testing are in Table A-1.



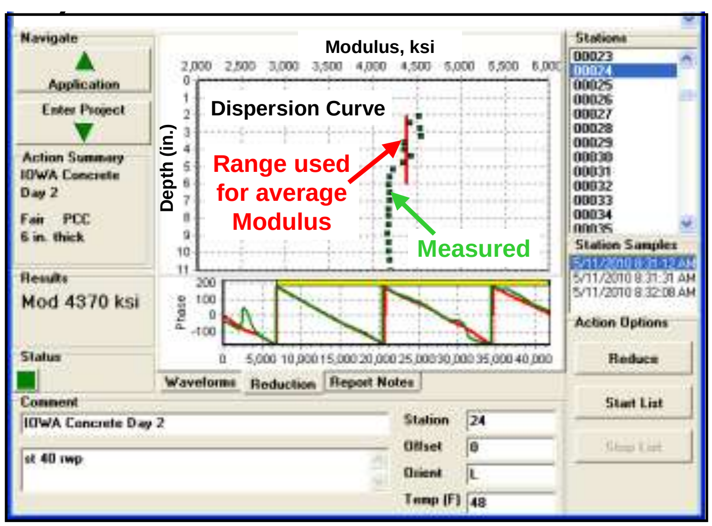


Figure A-3. Reduced data shown on the PSPA interface screen.

Table A-1. PSPA test results.

Station		Eastbound Slope	Eastbound Shoulder	Eastbound RWP
19+00	Day 1	3955	4060	4113
20+00		3995	4150	4115
21+00**		4287	4140	4135
22+00		4257	4250	4510
23+00		4517	4177	3967
24+00		4063	4235	4240
25+00		4263	4013	4385
26+00		3925	4060	4013
27+00		4180	4055	3990
28+00		4050	4210	4160
29+00		4317	3987	4310
30+00		4517	4288	4077
31+00		4290	4217	4133
32+00		4430	4273	4210
33+00		4250	4460	4245
34+00		4227	4380	4310
35+00		4405	4267	4023
36+00		4365	4117	4110
37+00	Day 2	3825	3973	4297
38+00		4187	4153	4345
39+00		3940	4055	4100
40+00		4135	4027	4160
41+00		4100	4135	4255
42+00		4420	4325	4250
43+00		4185	3988	4045
44+00		3843	4045	4170
45+00		3665	3995	3790
46+00		4040	3903	4013
47+00		4315	4320	4040
48+00		3935	4040	4073
49+00		4123	4210	3823
50+00		4085	3763	4000
51+00		3635	3713	3925
52+00		3975	4143	3855
53+00		3950	3883	3815
11+00		N/A	4230	3965
12+00		N/A	4125	4033
13+00		4020	3850	4005
14+00		3890	3893	4040
15+00		4020	3903	4020
16+00		3895	3877	3763
17+00		4273	3928	3875
18+00**		4300	4173	4495
19+00		4353	4297	4387

Station		Westbound Slope	Westbound Shoulder	Westbound RWP
19+00	Day 1	4085	4137	4073
20+00		4125	4230	4523
21+00		3897	4110	4130
22+00		4230	4355	4320
23+00		4390	4305	3940
24+00		4237	3940	4100
25+00		4437	4203	4165
26+00		4007	4140	3980
27+00		4090	3678	4020
28+00		4013	4095	4260
29+00		4270	4400	3927
30+00		4190	4097	4490
31+00		4287	4420	4358
32+00		4125	4458	3947
33+00		4025	4190	4217
34+00		4260	4400	4530
35+00		4447	4535	4465
36+00		4340	4305	4430
37+00	Day 2	3607	3897	3933
38+00		3890	4180	4453
39+00		4363	4395	4220
40+00		3780	4295	4070
41+00		4210	3937	4105
42+00		4165	4270	4467
43+00		4315	4127	3927
44+00		4095	4120	4023
45+00		4327	4490	3946
46+00		3980	3995	4005
47+00		3940	4125	3747
48+00		4113	4230	4010
49+00		4253	3833	3877
50+00**		3740	4135	3620
51+00		3870	3970	4030
52+00		3873	3767	3885
53+00		4120	4010	3938
11+00		3910	4250	3965
12+00		3865	4065	3790
13+00		3840	3917	4103
14+00		3835	3800	3760
15+00		3580	3953	3913
16+00		3900	4243	3810
17+00		4368	4340	4247
18+00		4005	4340	4300
19+00		4030	4210	4177

*** Core Location*

Free-Free Resonant Column

The FFRC test (ASTM C215) measures the resonant frequency of vibration (standing waves) and thus the modulus of a cylindrical or prismatic specimen in the laboratory. In recent years, the test has been simplified and enhanced (Nazarian et al., 2006) and a setup example is shown in Figure A-4. A typical system includes an instrumented hammer that is connected to a load cell and a broadband receiving transducer (accelerometer) that detects waves propagating inside the specimen. To conduct a test, the specimen is placed on a pedestal and impacted on one end with the instrumented hammer. The accelerometer is securely placed on either end of the specimen to measure the time records of the compression wave (or P-wave) and the reflections inside the specimen generated by the impact. The signals collected from the accelerometer and load cell are used to determine the resonant frequency of the reflecting wave inside the specimen, *f*. An example of time records and the resonant frequency obtained of a typical sample are illustrated in data plots in Figure A-4. The Young's modulus (E_{lab}) can be obtained from:

$$E_{lab} = \rho(2fL)^2 \quad (2)$$

where ρ, is mass density and L, is the length of the specimen.

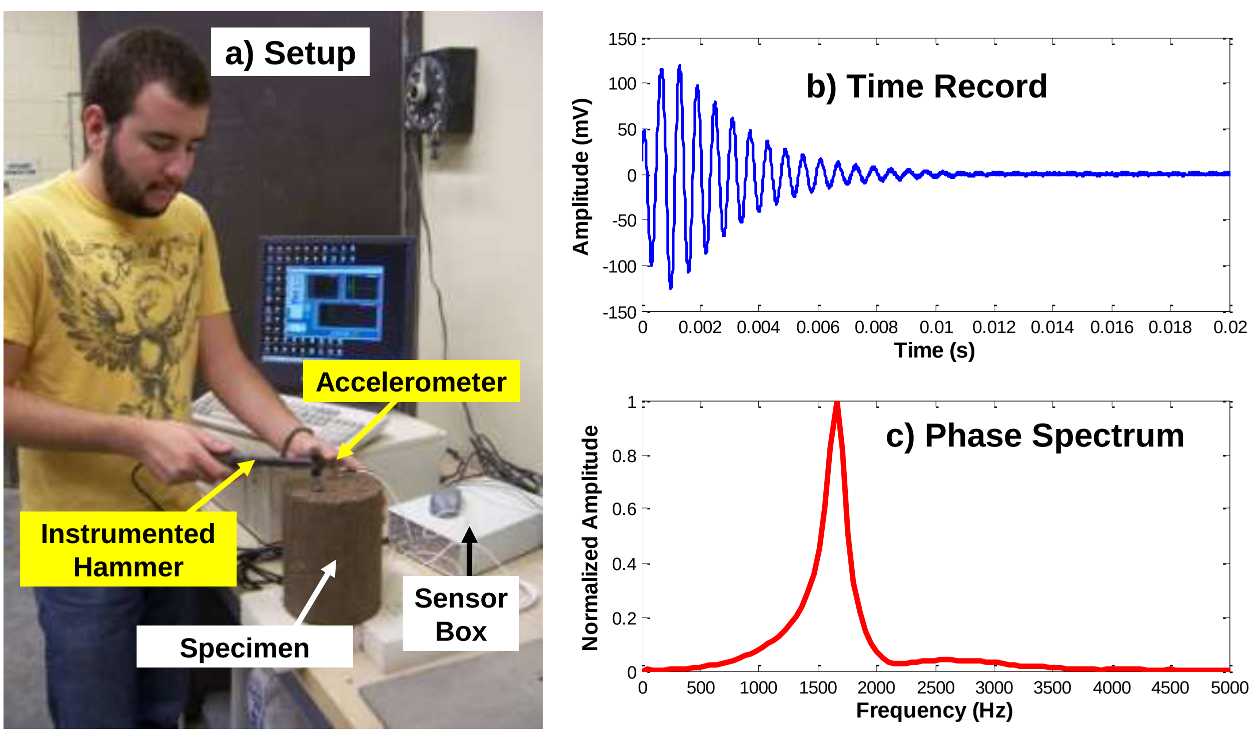


Figure A-4. FFRC setup and example of the time records output.

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ASTM C215 - 08. Standard Test Method for Fundamental Transverse, Longitudinal, and Torsional Resonant Frequencies of Concrete Specimens. ASTM International, West Conshohocken, PA, 2008.

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