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Solar Delineator Trial Project

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Six hundred solar pavement delineators were installed at two different locations along US-169 in southeast Kansas in the fall of 2013. Yellow and white lights were installed in both asphalt and concrete pavements. Six different installations methods were evaluated to determine the best practice for installation.

The solar delineation lights were evaluated after being exposed to two winter seasons. Overall the lights have worked very well in concrete, with all the pull out and damaged lights coming from the asphalt areas. Only 1.2% (seven out of 602) were damaged or pulled out.

A public survey was conducted to obtain the opinion of highway users. Overall the public seemed to respond favorably to the utilization of the solar delineators. While one of KDOT's original hopes was that the lights would offer an effective and efficient alternative to the use of overhead lighting, the fact is that the overhead lights offer a superior illumination area when compared to the solar lights that illuminate the edge of pavement. From a safety point, the overhead lights are superior in illuminating the entire intersection or area, however, in adverse conditions this can lead to washing out of the pavement markings. The solar lights do a superior job of illuminating the pavement markings in adverse weather, such as rain and fog events.

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KDOT will continue to monitor the delineators to evaluate their longevity.

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Abstract

The Kansas Department of Transportation (KDOT) partnered with the Pittsburg State University School of Construction to assess the installation of solar pavement lights at two intersections in southeast Kansas.

Solar pavement lights have been used in several places throughout the United States but have not had favorable results; either they did not stand up to traffic/snow plows or their renewable solar power gave out in 2 to 3 years and went dark. Research as to why these problems existed had not been adequately analyzed. KDOT saw three major concerns with using solar pavement markers: cost, proper installation, and longevity. We hoped to address these concerns with this research project.

Six hundred solar pavement delineators were installed at two different locations along US-169 in southeast Kansas in the fall of 2013. Yellow and white lights were installed in both asphalt and concrete pavements. Six different installation methods were evaluated to determine the best practice for installation.

The solar delineation lights were evaluated after being exposed to two winter seasons. Overall the lights have worked very well in concrete, with all the pull out and damaged lights coming from the asphalt areas. Only 1.2% (seven out of 602) were damaged or pulled out.

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Introduction

The Pittsburg State University (PSU) School of Construction was approached by the Kansas Department of Transportation (KDOT) to investigate best practice methods for the installation of Infinity YH-DD1 solar delineators on two test projects located in southeast Kansas.

The initial discussion with KDOT personnel (Mike Stringer, Chris Pross, and George Dockery) focused on KDOT's interest to install approximately 600 YH-DD1 solar delineators along two exits ramps at Plummer Ave and Old US Highway 169 on US Highway 169 north of Chanute, Kansas. Pittsburg State University School of Construction faculty were asked to submit a proposal to investigate best practice methods for the installation of the YH-DD1 solar delineators along the designated ramps. The proposal needed to address installation methods in existing concrete and asphaltic surfaces along the proposed sites, specifically targeting best practices for anchoring the delineators and for coring the existing surfaces.

The first phase of the project would entail PSU and KDOT jointly producing a best installation practice manual for the lights, included in Appendix A. The next phase would be PSU and KDOT conducting a yearlong evaluation of the performance and survey of the general public's reaction to the solar delineator lighting of the ramps compared to existing lighting methods.

Statistics of Lights in Place

As stated above, there were approximately 600 solar pavement delineators installed at two different locations along US-169. The final totals and their respective locations are listed below.

Fact Sheets:	Total Lights Installed	602 each:	White: 434	Yellow: 168
	Plummer & 169 Exit:	492 lights:	White: 381	Yellow: 111
	Old 169 & 169 Exit:	110 lights:	White: 53	Yellow: 57

Based on our best installation practice estimate, the cost for all materials, equipment, and labor for each delineator ranged from $140 to $165. This brought the total cost of the project to $100,000.

Orientation of Lights Through Turning Movements

In the early stages of the research, KDOT and the PSU School of Construction brainstormed different approaches of orientation and offsets, in regards to turning movements and pavement markings, respectively. In terms of turning movement orientation, it was decided to try placing the lights so that the orientation would be transverse with the centerline at all times; this was to delineate the turning movement to oncoming traffic similar to that of what our dashed lines through a turn movement accomplish. The other orientation that was decided upon was to rotate the lights to stay in contact with the vehicle operators eyes at all times; it was felt that this orientation would better delineate the turning movement. The main takeaway from the rotation orientation was that the operator never lost positive guidance through the turning movement, whereas with the transverse orientation, the lights were lost as soon at the driver passed the light. It was quickly realized that rotating the lights to maintain eye contact with the vehicle operator performed exponentially better in comparison to the transverse to centerline observation.

Offset of Lights

As stated above, KDOT and the PSU School of Construction brainstormed different approaches to orientation and offsets in regards to turning movements and pavement markings. When it came to the offset of the lights in terms of pavement marking, many different options were evaluated. Options included placing the lights in the pavement markings themselves, offset to the inside of the pavement markings (in the traveled way), and offset to the outside of the pavement marking; each option had pros and cons. For instance, placing the lights in the pavement marking had the maintenance issue of how to restripe the lines without covering the lights, offsetting the lights in the traveled way would expose them to additional wear and tear yet would solve the restripe issue, and offsetting them outside the pavement marking onto the shoulder would possibly not be cleared as much as the mainline in snow events. In the end it was decided to try all three options, with the intent of covering the lights to be striped over for those in the markings, while offsetting in the mainline would just be objected to the additional wear and tear, and offsetting to the shoulder would require the plow operators to ensure that the lights were cleared off. All three options performed equally. The additional wear and tear was not noticed, except that the lenses were more scuffed from snow removal operations. Observing that the lights were cleared off was not an issue, however, we still had concerns that placing the lights in the pavement marking would have a large maintenance cost in terms of additional man and equipment hours. We recommend that the lights be offset towards the shoulder to mitigate the additional wear and tear and future additional maintenance cost issues. Doing so will sacrifice no performance and will extend the service life of the units.

Performance Findings in Concrete and Asphalt

When we originally started this project, we were going to do our evaluation with one winter cycle to be used to determine performance results, in terms of both installation method durability and performance of the lights themselves. After the first winter cycle, there were five lights that were damaged or came out. This made us revisit the potential of the lights performing well for one year, but uncertain what the performance will be after two or three winter cycles. Therefore, we decided to extend our evaluation period to two winter cycles and one full year minimum. The breakdowns of the failures are as follows: there are two missing lights, placed with a concrete grout method for adhesion. There are also two additional lights that are not working for unknown reasons and will need to be replaced.

The area of old asphalt on the Old US Highway 169 overpass in the southbound lane seems to have been affected the most with the study. The delineator lenses have received heavy damage and three lenses have been totally destroyed. It is our belief that this is due to the rutting of the asphalt in this area. This rutting has caused the light to sit at an elevated position compared to the rest of the road and during snow removal activities they seem to have received a point load and are wearing unevenly when compared to the rest of the lights throughout the study both in concrete or asphalt. Amazingly enough, the light portions of these delineators are still operational with over a year of exposure to the elements. The scraping of the lens is not prevalent on the lights located in more level asphalt areas and does not appear to be happening with the lights in the other ramp areas. All lights that were installed in the concrete sections have performed well and have shown no distress from the wear and tear of snow removal activities.

Best Practices from Findings

The epoxy worked with all types of substrates and withstood the forces received from traffic and the snow plows. This is clearly evident from the delineators that have had their lenses ground off, but are still in place in the asphalt areas mentioned previously. This method also dried and was able to be put into use at a much quicker rate than the grouting option. The drawback to this option was the cleaning of the excess epoxy around the delineator. If left in place the excess epoxy would leave a ridge in front of the light and obscure the light.

The grout method was the cheaper option and preferred for clean up by the crews that placed the delineators. The drawback to this method was that overall it took more time to complete the installation, obtain proper seating, and open for use. This method is also the only method that has had pull out issues to date.

The epoxy seat and silicone sealant method was not time efficient or clean. The crew had to come back after the epoxy had cooled so that they could place the silicone on top. It was also difficult to keep the silicone sealant off of the delineators.

It was determined that obtaining the proper pitch of the light on the ramps was very important. It was found that the braces for the lights might sag, causing the lights to set below the rim of the substrate and obscure the light. (This can be viewed on the southbound exit ramp at Old US Highway 169.) This problem was easily fixed with the following lights and was easy to spot in place before the epoxy or grouts had hardened.

Public Survey

We conducted a public survey to help obtain the opinion of the highway users in the area. The survey was advertised via Facebook, KDOT's website, and the Chanute Tribune. 58 persons visited the survey with 57 responding to the survey. Below are the questions and the answers with the percent responding to each answer choice.

Question 1: Did you travel through the targeted area (Plummer Avenue and Old US Highway 169 exit ramps) and did you notice the solar powered lights along the exit ramps?

Traveled through the area and noticed the lights:	68.42%	39
Traveled through the area and did not notice the lights:	8.77%	5
Did not travel through the area but heard about the lights:	5.26%	3
Did not travel through the area and have not heard about the lights:	17.54%	10

Question 2: If you did travel through the targeted area, how would you rate the effectiveness of these solar lights relative to lighting/marking the designated ramp path?

Very effective:	82.50%	33
Somewhat effective:	17.50%	7
Not very effective:	0.00%	0

Question 3 Set:

Marking edges of highway and ramps on Plummer Avenue and Old US Highway 169 exits (yellow and white lights):

Very effective:	82.50%	33
Somewhat effective:	17.50%	7
Not very effective:	0.00%	0
Not effective:	0.00%	0
No response:	14.29%	7

Marking Centerline of Old US Highway 169 at exit ramps (yellow lights):

Very effective:	56.25%	27
Somewhat effective:	16.67%	8
Not very effective:	6.25%	3
Not effective:	0.00%	0
No response:	20.83%	10

Visibility of edge of highway on ramps in fog:

Very effective:	51.02%	25
Somewhat effective:	14.29%	7
Not very effective:	2.04%	1
Not effective:	0.00%	0
No response:	32.65%	16

Visibility of edge of highway and ramps in snow:

Very effective:	22.45%	11
Somewhat effective:	26.53%	13
Not very effective:	10.20%	5
Not effective:	2.04%	1
No response:	38.78%	19

Visibility of edge of highway and ramps in rain:

Very effective:	59.18%	29
Somewhat effective:	14.29%	7
Not very effective:	0.00%	0
Not effective:	0.00%	0
No response:	26.53%	13

Question 4: Do you prefer the use of the solar delineators/markers or the existing overhead lighting for marking or identifying the edge of highway and ramps?

Prefer solar delineators	71.11%	32
Prefer overhead lights	11.11%	5
No difference	17.78%	8

Quotes from Survey

A few of the comments from the survey have been included below. A complete list of quotes and comments can be seen in Appendix D.

- "Awesome lighting for guidance of the ramps love it! Much better than overhead lighting that are too bright and my eyes cannot adjust fast enough."
- "No glare with Solar, more effective in fog, and more environmentally friendly. I drive this route every day from Chanute to Humboldt and it seems to be very effective. I can't think of any negatives other than deep snow, but overhead lights aren't very effective in that scenario either."
- "I am a truck driver and drive these routes daily beginning at 2 am. They have been very effective. I would like to see more of them in Kansas"
- "I think the solar light serve their purpose but I think the overhead lighting serve as more of a safety as far as a motorist needing to get off to and out of the vehicle feeling more safe with the overhead lighting."

Survey Summary

The results show that the lights were viewed positively. The only situation where the lights were not overwhelmingly viewed positively was the visibility in snow, where 49% of respondents viewed it as effective or somewhat effective. The largest percent was no response.

This is probably due to there not being a large amount of snow events over the last year for viewing by the public.

There were some questions and comments that were asked or stated in person, which included that the lights worked very well in fog. Where the overhead lights were not penetrating the fog to the road edges, the delineator lights clearly marked the edges of pavement. This is seen as one of the biggest upsides of the solar delineators when compared to overhead light installations.

One respondent brought up the intensity of the yellow delineators compared to the white delineators. The comment was that the yellow lights do not illuminate as well as the white lights and thus are not as effective in marking the roadway.

Another respondent that liked the lights asked, "If on the long straight lane areas could we lengthen the spacing? The lights are very clear from a distance, spacing them could save additional money." We felt that this was a very good observation and actually something that we pondered on during the evaluation period.

Summary of Findings

As stated above, the evaluation period was extended to address the concern of the life expectancy and performance of the lights. Overall, the lights have worked very well in concrete, with all the pull out and damaged lights coming from the asphalt areas. Only 1.2% (seven out of 602) were damaged or pulled out. Two lights have pulled out, one at each exit, using concrete grout as the adhesive to the substrate. There are two lights that have failed as they do not illuminate anymore. There are three lights on the Old US Highway 169 overpass that have received heavy damage to the surface lens but are still operating. They have been in this condition for a year and the moisture has not affected the performance of the lights. There are additional lights in this area on which the surface lens has been scratched but not to the extent of these three.

Of the three methods employed to install the lights the least effective was the use of the combination of epoxy and silicone. This method created a large mess and was time consuming as the installation crew had to return to install the silicone after the epoxy cooled. The complete epoxy method was believed to be the method of choice by the investigators. This method, while being the most expensive option, worked best in all substrates and was the easiest to install. The complete grouting method was favored by the installation crew. They believed this method to be the fastest method and resulted in little to no clean up.

Overall the public seemed to respond favorably to the utilization of the solar delineators. While one of KDOT's original hopes was that the lights would offer an effective and efficient alternative to the use of overhead lighting, the fact is that the overhead lights offer a superior illumination area when compared to the solar lights that illuminate the edge of pavement. From a safety point, the overhead lights are superior in illuminating the entire intersection or area; however, in adverse conditions this can lead to washing out of the pavement markings. The solar lights do a superior job of illuminating the pavement markings in adverse weather such as rain events. From feedback and observations taken from the evaluation period, it is our belief that spacing of the lights could be lengthened on the straightaways. This would reduce overall installation costs. Furthermore, when considering the upfront cost and potential maintenance cost of failed delineators, either by poor installation practices or electronic failure, the savings may be limited to the yearly electric cost of the overhead lights. In general, the solar delineators work very well to delineate the roadway and provide adequate direction to motorists. They are well suited for locations that would not currently meet our overhead lighting policy based on traffic volumes, geometrics, etc., and from the responses received could be a potential solution to the issues that present themselves on these rural exits.

Appendix A: Installation Manual

KDOT-PSU Solar Delineator Trial Project: Best Practices Recommendations for Installation

Introduction

The Pittsburg State University School of Construction (PSU SOC) was approached by the Kansas Department of Transportation (KDOT) to investigate best practice methods for the installation of Infinity YH-DD1 solar delineators on two test projects located in southeast Kansas.

The initial discussion with KDOT personnel (Mike Stringer, Chris Pross, and George Dockery) focused on KDOT's interest to install approximately 600 YH-DD1 solar delineators along two exit ramps at Plummer Ave and Old US Highway 169 on US Highway 169 north of Chanute, Kansas. Pittsburg State University School of Construction faculty were asked to submit a proposal to investigate best practice methods for the installation of the YH-DD1 solar delineators along the designated ramps. The proposal needed to address installation methods in existing concrete and asphaltic surfaces along the proposed sites, specifically targeting best practices for anchoring the delineators and for coring the existing surfaces.

As part of the proposal, PSU and KDOT will jointly conduct a yearlong survey of the general public's reaction to the solar delineator lighting of the ramps compared to existing lighting methods. A final report of all findings will be submitted to KDOT.

Investigation Procedures

PSU SOC initially proposed two primary methods for installation of the solar delineator lights. The two categories were the use of epoxy and non-shrink grouts for the anchoring of the YH-DD1 units. Within each of these main categories we developed a number of adhesive combination methods for comparison.

As part of the investigation an estimate of material costs and equipment needed to drill the holes was conducted. PSU investigated the equipment, materials, and estimated costs of materials needed to drill and fill holes with a core diameter of 6 and 8 inches to a depth not to exceed 2.5 inches. For estimating purposes we used a hole depth of 2.5 inches to calculate needed materials. The calculated volumes of materials, associated cost, and sequence methods can be found in Appendix B. Due to excessive cost of additional materials and KDOT already owning the equipment needed to core 6-inch holes, we elected to eliminate the option to core 8-inch holes. Materials needed to fill an 8-inch hole versus a 6-inch hole are nearly three times the volume. We also factored into this decision the manufactures recommended gap from substrate to edge of solar light which would have been exceeded on the 8-inch cores.

Once we settled on the 6-inch diameter coring method, we evaluated six methods of adhesion and two methods of coring. The six methods of adhesion are:

- Method 1: This is Infinity Inc.'s recommended method modified. This method is recommended by the manufacturer's specification. Although this method only inserts the light halfway into the substrate material. See Appendix C for this method.
- Method 2: PSU's Modification of manufacturer's recommendation. This method includes the placement of epoxy fill in the bottom of the hole with an upper level of silicone around the edges.
- Method 3: Complete epoxy encasement placement technique 1. This method includes the placement of epoxy fill in the bottom of the hole, placement of light, then filling around edges with epoxy.
- Method 4: Complete epoxy encasement placement technique 2. This method fills the hole with the needed amount of epoxy to completely encase the light when inserted.
- Method 5: Epoxy spot placement at bottom with an upper level of silicon. This method requires the placement of epoxy in four spots, placement of the light, then filling around edges with epoxy.
- Method 6: Non-shrink cementitious grout full depth. This method fills the hole with the needed amount of non-shrink cementitious grout to encase the light when inserted.

The methods investigated for coring the 6-inch holes included the use of either a diamond tip bit or a carbide bit to the desired depth. Then a 30-lb electric jack hammer was used to break large pieces of the core out of the hole followed by using an electric hammer drill with a chipping hammer bit to level the bottom of the hole.

Findings/Results

Core Drilling of Concrete and Asphaltic Surfaces

To core the holes we followed the proposed method for coring a 6-inch hole. Drilling the concrete to a depth of 2.5 inches took an average of 4 minutes. The clearing and cleaning of the hole took an average of 3 minutes. The clearing of the hole was completed using a 30-lb electric jack hammer. The bottom of the hole cleaned up very nicely with the use of a chipping hammer to form a relatively uniform depth across the area. When we returned the diamond bit to the rental store, they noted that we had not put any noticeable wear on the bit.

Drilling at the KDOT office was performed to test the coring of asphaltic surfaces. The diamond core bit did not perform well in the asphalt. We took over 15 minutes to complete the second hole. The rental salesperson believed that the binder in the asphalt stuck to the bit causing the teeth to cut. Given this experience, we would recommend a carbide bit for the asphalt areas only.

Anchoring of Lights

Table A.1 compares the estimated costs of materials to fill the holes per the tested methods. A comparison estimate per hole and an overall estimated cost to complete 600 holes is given. A pop out test using the bucket of a skid steer dragged against the lights demonstrated that all adhesive methods resisted pop out in the short term. Further testing needs to be conducted for long-term results impacted by weather, vibration, and other environmental changes.

Table A.1: Cost Comparison of Methods 1-6

Method for 6-inch coring to a depth of 2.5 inches	Estimated material cost per hole	Total estimated material cost for 600 holes
Method 1	$17.96	$10,770.00
Method 2	$15.77	$9,462.00
Method 3	$24.25	$14,550.00
Method 4	$24.25	$14,550.00
Method 5	$11.32	$6,792.00
Method 6	$3.00	$1,800.00

Method 1

Method 1 is the method recommended by the solar light manufacturer. This method places silicon in the bottom of the hole to form a leveling agent with epoxy around the exterior edge of the light. This method required the most time to position the delineator within the hole. As the epoxy was placed around the edge of the fixture, the fixture's alignment was altered slightly. However, the delineator was easily moved back into the desired position. We completed the other test methods before placing the epoxy into this hole and found the silicon was still very workable after that time.

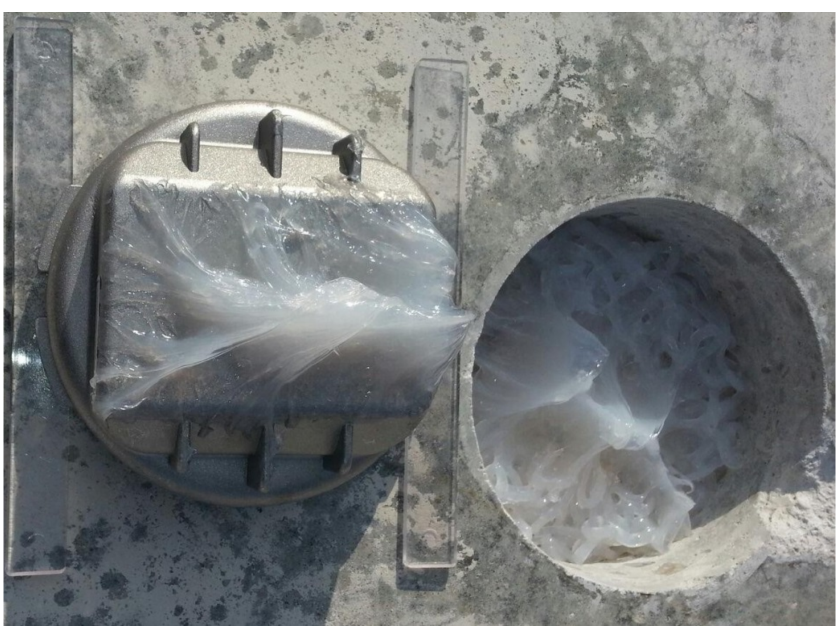

Figure A.1: Method 1 Silicone Coverage of Base

Method 2

This method incorporated an epoxy-filled bottom with an upper level of silicon. This method had a completion time of approximately 10 minutes and gave good epoxy coverage to the bottom of the delineator. Within 10 minutes the epoxy was hard and the light was not able to be moved. We then finished the placement of silicon around the light. After two weeks the silicon receded into around the edges of the hole. This may allow water to pool and cause problems in the future.

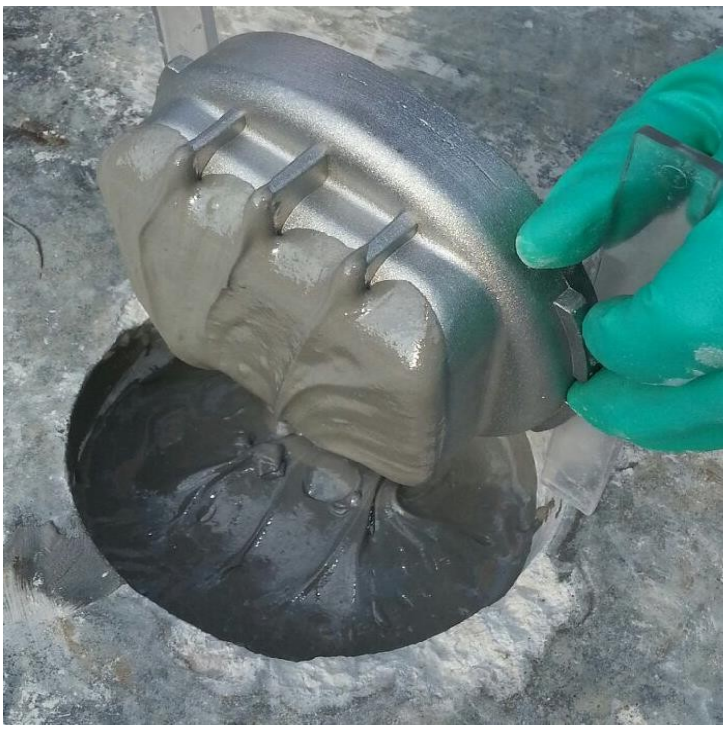

Figure A.2: Method 2 Picture of Epoxy Base Coverage

Methods 3 and 4

Method 3 used epoxy to fill the entire hole so that when the delineator was placed into the hole, the epoxy was pushed up and around the delineator fixture. Method 4 utilized an epoxy base material and then filled the remainder of the cored hole with epoxy after the delineator fixture was placed in the hole. The delineator fixture easily pushed into the epoxy on both methods and had very good coverage around the casement which we believe would create a good bond. The drawback to Method 4 was once we pulled the unit out of the epoxy, we could not reinsert the light into the hole as we did with the others. The epoxy set very rapidly and we believe this was due to the epoxy mass generating a high curing heat. Placing the amount of material needed by hand took approximately 5 minutes from the time the first epoxy was placed in the hole. The manufacturer representative agreed with our assessment. Both methods required the addition of epoxy at the top to completely fill the voids. Cleanup of any overruns is best left until the epoxy has hardened. This method will be difficult with uneven surfaces.

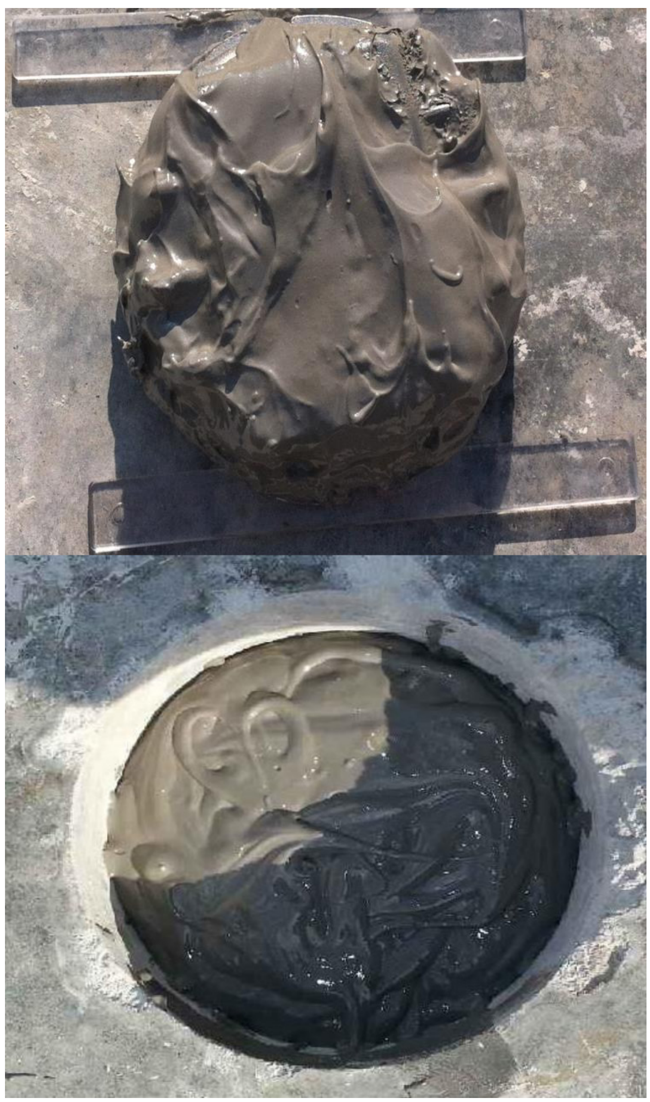

Figure A.3: Picture of Full Depth Epoxy Coverage of Delineator

Method 5

Method 5 used epoxy spot placement at the bottom of the fixture with an upper level of silicon. This method was not recommended as it was difficult to accurately place the spots needed for adhesion to occur while keeping the fixture in the proper orientation.

Method 6

Method 6 used non-shrink grout at full depth around the delineator fixture. The required material for full encasement was mixed by hand in a 5-gallon bucket and poured into the hole at one time. The delineator fixture pressed nicely into the hole, forcing the grout to push up around the edges. The minimal material that spilled over the edge was easily wiped away for a clean surface. Cleanup of this method was by far the easiest of all methods.

Recommendations

Pittsburg State University School of Construction would like to recommend inserting the solar delineator lights using a trial combination of three methods.

1. Complete epoxy encasement of the solar delineator light.
2. Complete encasement in non-shrink grout of the solar delineator light.
3. Epoxy fill bottom with an upper level of silicon.

PSU SOC recommends that 200 delineator units be installed using each of the three recommended methods. This would provide 200 units installed using each of the three recommended methods for future study. For complete epoxy encasement of 200 units, we estimate a materials cost of approximately $5,000 for epoxy (two hundred 22 oz tubes of epoxy). For complete non-shrink grout encasement of 200 units, we estimate a material cost of approximately $600 (thirty-four 20 lb buckets of non-shrink grout). For the combination of epoxy and silicone, we estimate a cost of $3,300 (two hundred 10 oz tubes of silicone and one hundred 22 oz tubes of epoxy). The total estimated material cost needed to complete the 600 unit sample project would be approximately $8,900.

For coring the holes in concrete, we recommend the use of a 6-inch diamond-tipped core bit, a 30 lb or smaller jack hammer, and an electric hammer drill with a chipping bit. For the holes located within asphalt, we recommend the use of a 6-inch carbide core bit, a 30 lb or smaller jack hammer, and an electric hammer drill with a chipping bit. We estimate the cost of equipment to drill each hole at $11.50 (total = $6,900).

After discussions with the epoxy manufacturer representative regarding our concern that the epoxy sets up too rapidly when the epoxy is placed by hand, they recommended several methods that would allow for quicker placement of epoxy. The representative recommended using either a pneumatic gun or a battery-powered gun to place the epoxy. Our recommendation would be to use the battery-powered gun for placing an epoxy bed or for placing full depth epoxy.

The battery-powered gun has an option to dispense enough material to fill the hole to the desired depth of each hole each time the trigger is pulled. This would allow for quicker placement of epoxy and would reduce the labor hour cost of each hole. However, this would result in the need for an additional epoxy gun to top dress each hole.

Long-term analysis of installation methods is needed to determine which of the three recommended methods will perform the most effectively when considering environmental conditions. These include the freeze-thaw cycles, traffic load, chemical application, and blading to determine how well the adhesion application will work.

Appendix B: Methods Procedures for 6-Inch Holes

Installation Test Methods Procedures for 6-Inch Holes

Method 1: Infinity Inc. Method (Modified to Allow Full Depth Placement)

1. Select the location of YH-DD1.
2. Drill hole into the surface material with a diameter of 6 inches (155 mm = 6.1 inches) and a depth range of 2.25 to 2.5 inches (25 mm = 0.98 inches).
3. Prep hole so that it is free of debris, dust, and moisture. (Follow adhesive manufacturer's recommendations for procedures.)
4. Plaster proper amount of silicon in the bottom of the hole and allow solidification to place YH-DD1 at desired depth.
5. Place the YH-DD1 with lights aligned parallel to the direction of traffic in the hole using mounting brackets and fill the remaining space with additional silicon or epoxy.
6. Wipe away excess materials using adhesive manufacturer's recommendations.
7. Epoxy will harden in 5-7 minutes in 40°F at which time the mounting brackets can be removed.

Materials needed:
Silicon volume = 14.14 cubic inches = $4.03
Epoxy volume = 19.08 cubic inches = $13.93
YH-DD1 = 37.47 cubic inches

Estimated Cost of materials: $17.96

Method 2: Epoxy Fill Bottom with an Upper Level of Silicon

1. Select the location of YH-DD1.
2. Drill hole into the surface material with a diameter of 6 inches and a depth range of 2.25 to 2.5 inches.
3. Prep hole so that it is free of debris, dust, and moisture. (Follow adhesive manufacturer's recommendations for procedures.)
4. Place epoxy in the entire bottom of the hole to a depth of ½ inch.
5. Place the YH-DD1 with lights aligned parallel to the direction of traffic within 5 minutes in the hole using mounting brackets and fill the remaining space with silicon.
6. Wipe away excess materials using adhesive manufacturer's recommendations.
7. Epoxy will harden in 5-7 minutes in 40°F at which time the mounting brackets can be removed.

Materials needed:
Epoxy volume = 14.14 cubic inches = $10.33
Silicon volume = 19.08 cubic inches = $5.44
YH-DD1 = 37.47 cubic inches

Estimated Cost of materials: $15.77

Method 3: Complete Epoxy Encasement Placement Technique 1

1. Select the location of YH-DD1.
2. Drill hole into the surface material with a diameter of 6 inches and a depth range of 2.25 to 2.5 inches.
3. Prep hole so that it is free of debris, dust, and moisture. (Follow adhesive manufacturer's recommendations for procedures.)
4. Place epoxy in the entire bottom of the hole to a depth of $1^1/_8$ inches.
5. Place the YH-DD1 with lights aligned parallel to the direction of traffic within 5 minutes in the hole using mounting brackets and firmly insert into the epoxy substrate causing epoxy to rise around YH-DD1.
6. Fill remaining hole with epoxy to top of aluminum level of YH-DD1.
7. Wipe away excess materials using adhesive manufacturer's recommendations.
8. Epoxy will harden in 5-7 minutes in 40°F at which time the mounting brackets can be removed.

Materials needed:
Epoxy volume = 33.22 cubic inches
YH-DD1 = 37.47 cubic inches

Estimated Cost of materials: $24.25

Method 4: Complete Epoxy Encasement Placement Technique 2

1. Select the location of YH-DD1.
2. Drill hole into the surface material with a diameter of 6 inches and a depth range of 2.25 to 2.5 inches.
3. Prep hole so that it is free of debris, dust, and moisture. (Follow adhesive manufacturer's recommendations for procedures.)
4. Place epoxy in the entire bottom of the hole to a depth of ½ inch.
5. Place the YH-DD1 with lights aligned parallel to the direction of traffic within 5 minutes in the hole using mounting brackets to hold at desired depth and fill the remaining voids with epoxy.
6. Wipe away excess materials using adhesive manufacturer's recommendations.
7. Epoxy will harden in 5-7 minutes in 40°F at which time the mounting brackets can be removed.

Materials needed:
Epoxy volume = 33.22 cubic inches
YH-DD1= 37.47 cubic inches

Estimated Cost of materials: $24.25

Method 5: Epoxy Spot Placement at Bottom with an Upper Level of Silicon

1. Select the location of YH-DD1.
2. Drill hole into the surface material with a diameter of 6 inches and a depth range of 2.25 to 2.5 inches.
3. Spot place epoxy in the bottom of the hole to a depth of ½ inch at approximate location where 4 corners of bottom section of the YH-DD1 will set in the hole.
4. Place the YH-DD1 with lights aligned parallel to the direction of traffic in the hole and fill the remaining space with additional silicon.
5. Wipe away excess materials using adhesive manufacturer's recommendations.
6. Epoxy will harden in 5-7 minutes in 40°F at which time the mounting brackets can be removed.

Materials needed:
Epoxy volume = 4.14 cubic inches = $3.03
Silicon volume = 29.08 cubic inches = $8.29
YH-DD1 = 37.47 cubic inches

Estimated Cost of materials: $11.32

Method 6: Non-Shrink Grout Full Depth

1. Select the location of YH-DD1.
2. Drill hole into the surface material with a diameter of 6 inches and a depth range of 2.25 to 2.5 inches.
3. Place non-shrink grout in the entire bottom of the hole to a depth of $1^1/_8$ inches.
4. Place the YH-DD1 with lights aligned parallel to the direction of traffic in the hole and fill the remaining space with additional non-shrink grout if needed.
5. Wipe away excess materials using adhesive manufacturer's recommendations.
6. Grout will harden in approximately 20-45 minutes at which time the mounting brackets can be removed.

Materials needed:
Grout volume = 33.22 cubic inches = $3.00
YH-DD1 = 37.47 cubic inches

Estimated Cost of materials: $3.00

Coring Methods Procedures for 6-Inch Holes

Method 1: Drill Hole to 2.50 Inches Using Jack Hammer to Break Away Concrete

1. Select the location of YH-DD1.
2. Mark 6-inch core bit to a depth of 2.50 inches. This can be done by a black magic marker or with duct tape with a fan to gauge depth.
3. Drill hole using a 6-inch diameter diamond-tipped core bit to a depth of 2.50 inches.
4. Use jack hammer to break loose concrete inside the core to approximate depth being sure not to go past depth.
5. Using a bushing tool bit or chipping bit to smooth and level bottom surface to desired depth.
6. Clean hole and measure for correct depth uniformity.

Tools and Labor needed for 30 minutes estimated per hole:

2 man crew	=	$20.00	
6-inch diamond wet coring bit	=	$6.26	
Core drill	=	$3.13	
Electric jack hammer	=	$0.50	
Electric hammer drill	=	$0.55	$325 for operation
Bushing bit	=	$0.40	4 at $60 each for operation
Air compressor with nozzle	=	$0.66	
Water is needed			

Estimated Cost of operation per hole: $30.84

1. Assuming production rate of 30 minutes per hole that will include daily set up, travel, and completion of the task.
2. Calculations are based on 8-hour days.
3. Calculations on equipment cost per hole are assuming the completion of 600 holes.
4. 6-inch Diameter Supreme wet concrete cutting core diamond core bits rental is $100 per day or $250 each. Average bit life is 100 holes.
5. Electric jack hammer rental cost is $30 per day or $0.50 per hole.
6. Core drill rental is $50 per day or $3.13 each hole.
7. Cost does not include storm water prevention plan.

Appendix C: Infinity Inc. Installation Manual

Installation Manual for Solar Road Marker (YH-DD1&2)

Infinity Inc.

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Installation Manual for Solar Road Marker (YH-DD1&2)

For Proper Operation

The Solar Road Marker is the self-contained lighting devices for decoration using solar energy which is converted into electricity through solar cells and stored in ultracapacitor as the energy storage device in the daytime and soft glow light using LED is turned on in the nighttime automatically.

Full charge takes minimum 3 hours under direct sunlight and the light is "on" more than 14 hours with fully charged ultracapacitor. In order to operate Solar road marker properly, charge of ultracapacitor by sunlight is necessary. So we recommend that solar light emitting tiles are installed where sunlight is illuminated on solar road marker for minimum 3 hours in a sunny day. Therefore, outdoor places will be suitable for the operation of solar light emitting tiles. In addition, solar road marker can be charged by even indirect sunlight. In case of charge by indirect sunlight, it is required to check the operation status of solar road marker before installation in the following check procedure.

Check procedure

1. Put solar road marker on the intended site for the intended direction to be installed in the morning.
2. Check the operation status of solar road marker whether it is turned on or not in the night time.
3. If turned on, it will be all right to install them on the intended site. Otherwise, please find more suitable sites.

And we recommend that solar road marker should not be installed in the following places

◈ Shadow areas

Basically, we recommend that solar road marker should not be installed in the shade in a daytime. But, if sunlight is illuminated on the solar road marker for minimum 5 hours in a daytime, it is possible to operate. If you doubt about the operation of solar road marker, please check the operation status of solar road marker before installation according to the above-mentioned check procedure. Please remind, for proper operation of solar road marker, sunlight is necessary for the solar road marker for minimum 3 hours in a sunny day, but some obstacles like the eaves, trees can block off sunlight for a while in accordance with the direction of sunlight. If you doubt about the operation of solar road marker, please check the operation status of solar road marker before installation according to the abovementioned check procedure. Also solar road marker is made of aluminum and polycarbonate so that some chemicals like solvents, toxic gas have a bad effect on it. Please do not install solar road marker around those chemicals.

Installation

Installation procedure(refer to below pictures) of solar road marker is same as those of standard paving bricks in both mortar-less and mortared installation Below pictures show you the whole procedure of installation for solar road marker.

YH-DD1 INSTALL MANUAL

1. Select the location
2. Dig a hole in the ground (Width: 155mm, Depth: 25mm) YH-DD1
3. Plaster proper amount of silicon in the hole
4. Put the YH-DD1 in the hole and fill the rest of space with the additional silicon or expoxy.

YH-DD2 INSTALL MANUAL

YH-DD2

1. Select the location
2. Dig a hole in the ground (Width: 125mm, Depth: 53mm)
3. Plaster proper amount of silicon in the hole
4. Put the YH-DD2 in the hole and fill the rest of space with the additional silicon or epoxy.

Silicon

Adhering Solar road marker

There are many adhesion methods. We recommend use of silicon or epoxy. In case of using portland cement, use non-contracting type in order to prevent stress applying to solar road marker by contraction and expansion. In case regular portland cement must be used, make sure leave a narrow gap between solar road marker and cement.

Appendix D: Public Survey Comments

I never traveled that route early in the morning so I don't know how strong the lighting is toward the end of the night but I was impressed with how brightly they shined coming off those ramps even late at night.
3/12/2015 1:01 PM View respondent's answers

Traveling at night it marks the lanes and turn lane very well
3/5/2015 9:27 AM View respondent's answers

These del
3/5/2015 8:50 AM View respondent's answers

awesome lighting for guidiance of the ramps love it! much better than overhead lighing they are too bright and my eyes cannot adjust fast enough.
3/5/2015 8:29 AM View respondent's answers

The solar lights are very effective in the fog when the overhead lights are not of use during the fog. They are not useful in a snow storm because they are covered up with snow. I would rate them as both effective, but if you have an interchange that does not have overhead lights, definitely use the solar lights.
3/4/2015 4:11 PM View respondent's answers

The solar markers are very noticeable, although I haven't driven on the ramps in fog, snow, or rain. I have a couple of friends that also made positive comments about the markers.

I really like the solar lighting but also like the overhead lights. I think in fog the solar lighting is better.
3/3/2015 6:29 PM View respondent's answers

If it were just a matter of what allows you to see the lines and edges better, I would go with the solar delineators. But the reason I marked that I prefer overhead lights, is for the times that people use the ramps to pull over and fix a problem, read a map, or make a call.
3/3/2015 3:02 PM View respondent's answers

Half the time the overhead lights are out at the 169 Hwy and Cherry St. The solar markers are always on at night.
3/3/2015 2:40 PM View respondent's answers

The solar delineators could be spaced further apart requiring fewer lights needed at each exit and still maintain the desired effectiveness.
3/3/2015 2:05 PM View respondent's answers

I find the solar delineators to be highly visible and effective in all conditions in which I have encountered them. I have had several conversations with local patrons as well as out of area visitors and have heard only positive reviews. Those complimentary remarks range from high and effective visibility to more economical and sustainable and remarks about preserving the clarity and beauty of the Kansas landscape by avoiding light pollution.

I THINK THE SOLAR LIGHT SERVE THIER PURPOSE PUT I THINK THE OVERHEAD LIGHTING SERVE AS MORE OF A SAFETY AS FAR AS A MOTORIST NEEDING TO GET OFF TO AND OUT OF THE VEHICLE FEELING MORE SAFE WITH THE OVERHEAD LIGHTING.
3/3/2015 2:00 PM View respondent's answers

No glare with Solar, more effective in fog, and more environmentally friendly. I drive this route every day from Chanute to Humboldt and it seems to be very effective. I can't think of any negatives other than deep snow, but overhead lights aren't very effective in that scenario either.
3/3/2015 1:59 PM View respondent's answers

Think lights should be as far to the edge of pavement as possibly, as they tend to make you drive toward the center of the road.
3/3/2015 1:22 PM View respondent's answers

Sorry, I don't know the area.
2/26/2015 10:24 AM View respondent's answers

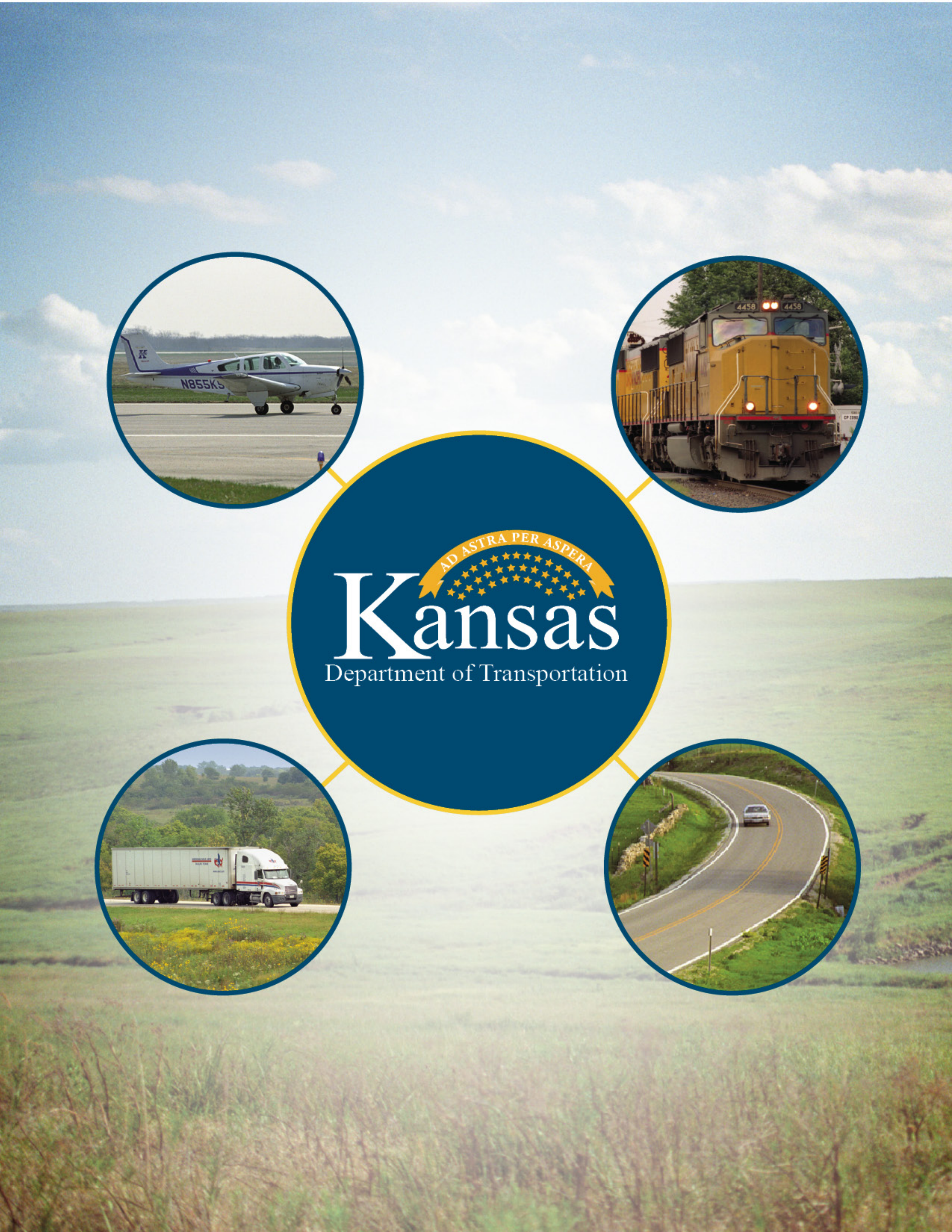
I could not complete the survey because I have not see the markings.
2/25/2015 2:10 PM View respondent's answers

I believe there ate places where both lights are needed. Some places are just so dark and have poorly marked lines and they need both.
2/24/2015 7:40 PM View respondent's answers

I am a truck driver and drive these routes daily beginning at 2am. They have been very effective. I would like to see more of them in Kansas
2/24/2015 4:55 PM View respondent's answers

I normally do not travel on highway 169, so I cannot comment about the effectiveness of the lights.
2/24/2015 2:12 PM View respondent's answers

Was daylight when I passed through that area recently. Will be looking in the future to see, notice the differences.
2/24/2015 1:53 PM View respondent's answers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