# Washington Demonstration Project: LED Lane Delineation and High Visibility Barrier Delineation for I-90 through Snoqualmie Pass in King and Kittitas Counties, WA

**Final Technical Brief**
**July 2015**

HIGHWAYS FOR LIFE
*Accelerating Innovation for the American Driving Experience.*


U.S.Department of Transportation
**Federal Highway Administration**

# FOREWORD

The purpose of the Highways for LIFE (HfL) pilot program is to accelerate the use of innovations that improve highway safety and quality while reducing congestion caused by construction. **LIFE** is an acronym for **L**onger-lasting highway infrastructure using **I**nnovations to accomplish the **F**ast construction of **E**fficient and safe highways and bridges.

Specifically, HfL focuses on speeding up the widespread adoption of proven innovations in the highway community. Such "innovations" encompass technologies, materials, tools, equipment, procedures, specifications, methodologies, processes, and practices used to finance, design, or construct highways. HfL is based on the recognition that innovations are available that, if widely and rapidly implemented, would result in significant benefits to road users and highway agencies.

Although innovations themselves are important, HfL is as much about changing the highway community's culture from one that considers innovation something that only adds to the workload, delays projects, raises costs, or increases risk to one that sees it as an opportunity to provide better highway transportation service. HfL is also an effort to change the way highway community decision makers and participants perceive their jobs and the service they provide.

The HfL pilot program, described in Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) Section 1502, includes funding for demonstration construction projects. By providing incentives for projects, HfL promotes improvements in safety, construction-related congestion, and quality that can be achieved through the use of performance goals and innovations. This report documents one such HfL demonstration project.

Additional information on the HfL program is at www.fhwa.dot.gov/hfl

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16. Abstract

As a part of the HfL initiative, FHWA provided an approximately $180,000 grant to the Washington State Department of Transportation (WSDOT) to improve pavement visibility along I-90 through Snoqualmie Pass in King and Kittitas Counties.

The key innovations on this project included the installation of light-emitting diode (LED) lane delineators and high-visibility barrier delineators. Although these delineators have been used in other States (e.g., Oregon, New York, California, and Colorado) as well as for small projects in the State of Washington, this is WSDOT's first pilot project that utilizes them on a large scale. WSDOT plans to monitor this pilot program for the next 3 years to determine if the LED lights are effective. Maintaining delineation for I-90 in the Snoqualmie Pass vicinity has been a challenge for WSDOT, and it is anticipated that the new LED lights installed for this project will provide more durable and reliable delineation, giving drivers a more positive delineation especially at night and during severe weather conditions.

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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<br>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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# ABBREVIATIONS AND SYMBOLS

| | |
|---|---|
| FHWA | Federal Highway Administration |
| HfL | Highways for LIFE |
| IRI | International Roughness Index |
| LED | light-emitting diode |
| OBSI | onboard sound intensity |
| OSHA | Occupational Safety & Health Administration |
| RPM | raised pavement marker |
| SAFETEA-LU | Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users |
| WSDOT | Washington State Department of Transportation |

# INTRODUCTION

## HIGHWAYS FOR LIFE DEMONSTRATION PROJECTS

Highways for LIFE (HfL) is the Federal Highway Administration's (FHWA) initiative to advance longer-lasting and promote efficient and safe construction of highways and bridges using innovative technologies and practices. The HfL program provides incentive funding to highway agencies to try proven but little-used innovations on eligible Federal-aid construction projects. The HfL team prioritizes projects that use innovative technologies, manufacturing processes, financing, contracting practices, and performance measures that demonstrate substantial improvements in safety, congestion, quality, and cost-effectiveness. An innovation must be one the applicant State has never or rarely used, even if it is standard practice in other States. Recognizing the challenges associated with deployment of innovations, the HfL program provides incentive funding for up to 15 demonstration construction projects a year. The funding amount typically totals up to 20 percent of the project cost, but not more than $5 million.

The HfL program promotes project performance goals that focus on the expressed needs and wants of highway users. They are set at a level that represents the best of what the highway community can do, not just the average of what has been done. The goals are categorized into the following categories:

- **Safety**
    - Work zone safety during construction—Work zone crash rate equal to or less than the preconstruction rate at the project location.
    - Worker safety during construction—Incident rate for worker injuries of less than 4.0, based on incidents reported on Occupational Safety and Health Administration (OSHA) Form 300.
    - Facility safety after construction—Twenty percent reduction in fatalities and injuries in 3-year average crash rates, using preconstruction rates as the baseline.
- **Construction Congestion**
    - Faster construction —Fifty percent reduction in the time highway users are impacted, compared to traditional methods.
    - Trip time during construction — Less than 10 percent increase in trip time compared to the average preconstruction speed, using 100 percent sampling.
    - Queue length during construction—A moving queue length of less than 0.5 miles in a rural area or less than 1.5 miles in an urban area (in both cases at a travel speed 20 percent less than the posted speed).

- **Quality**
    - Smoothness—International Roughness Index (IRI) measurement of less than 48 inches/mile.
    - Noise—Tire-pavement noise measurement of less than 96.0 A-weighted decibels (dB(A)), using the onboard sound intensity (OBSI) test method.
- **User Satisfaction**
    - An assessment of how satisfied users are with the new facility compared to its previous condition and with the approach used to minimize disruption during construction. The goal is a measurement of 4 or more on a 7-point Likert scale.

### PROJECT OVERVIEW

As a part of the HfL initiative, FHWA provided an approximately $180,000 grant to the Washington State Department of Transportation (WSDOT) to improve pavement visibility along I-90 through Snoqualmie Pass in King and Kittitas Counties. The key innovations on this project included the installation of light-emitting diode (LED) lane delineators and high-visibility barrier delineators. Although these delineators have been used in other States (e.g., Oregon, New York, California, and Colorado) as well as for small projects in the State of Washington, this is WSDOT's first pilot project that utilizes them on a large scale. WSDOT plans to monitor this pilot program for the next 3 years to determine if the LED lights are effective.

## PROJECT DETAILS

### PROJECT LOCATION AND BACKGROUND

This WSDOT project is located on Interstate Route 90 over Snoqualmie Pass, from milepost 47.00 to milepost 55.15. Figure 1 shows the location of the project.

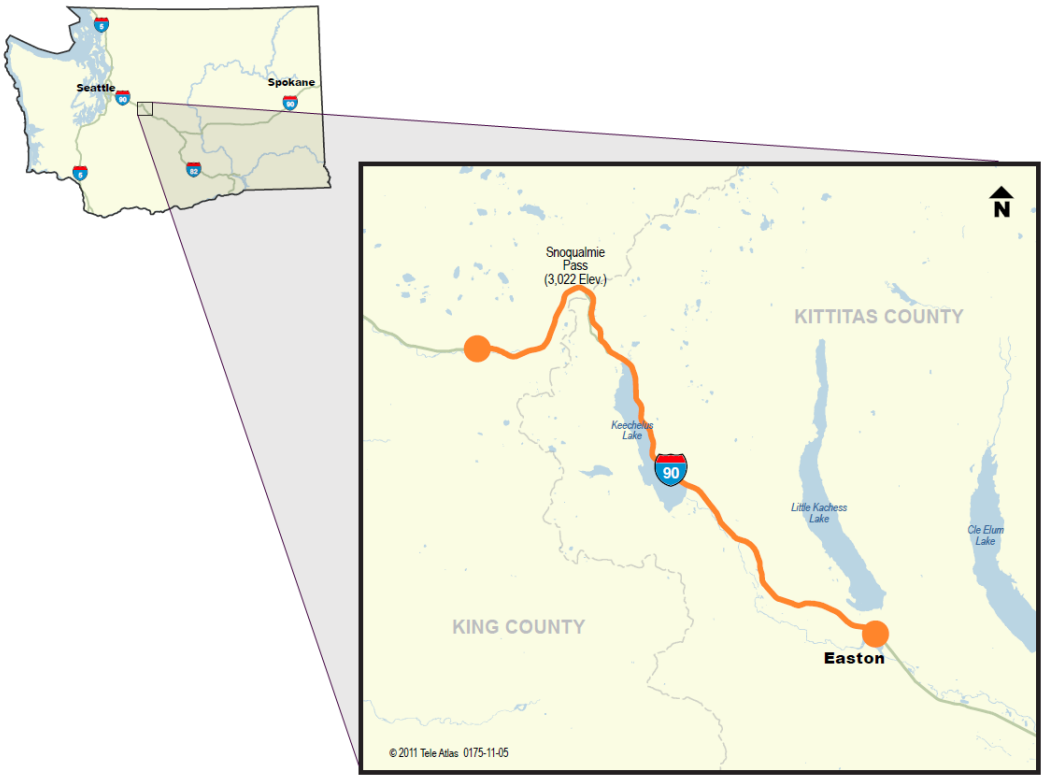


Figure 1. Map. Project location in King and Kittitas Counties.

On an average day, 29,000 vehicles travel over this roadway, and the traffic volume can exceed 50,000 vehicles per day on weekends and holidays. Traffic volumes are expected to increase 2.1 percent every year, reaching an average of over 41,000 vehicles per day by 2030. In addition, I-90 across Snoqualmie Pass is a strategic freight corridor carrying international, domestic, and intrastate trade. Thirty-five million tons of freight cargo, or over $160 billion worth of goods, crosses I-90 Snoqualmie Pass every year.

Located at an approximate elevation of 3,022 feet above sea level, this corridor receives an average of 435 inches of snow each year. Using a snow-water equivalent precipitation, the year-round average precipitation is 120 inches. As such, WSDOT crews are ready 24 hours a day, 7 days a week to treat the roadway and remove snow and ice during the winter. Operations include avalanche control, which closes the roadway for motorist safety. Low- light times of the day account for over 40 percent of the total collisions in this area, and over 75 percent of these low-light collisions occur during the months that contain the most inclement weather, from late fall to early spring, when lane delineation is critical, yet most difficult to maintain.

Maintenance of roadway markings (i.e., delineation) in this mountainous location has always been a challenge to WSDOT. In addition to rain and snow obscuring roadway visibility, the roadway markings undergo heavy wear and tear due to various factors related to winter driving and maintenance. Snow removal operations, studded tires, and vehicles using tire chains are believed to severely shorten the life of pavement markings. However, reapplication of roadway delineation (both striping and barrier markings) requires specific roadway conditions, including a dry, clean surface without de-icing chemicals and temperatures well above freezing. This leaves

WSDOT a limited work window, generally spring and summer. As a result, the roadway has generally had poor visibility and, especially under adverse conditions, the roadway looked to have almost no delineation in some areas.

## PROJECT DESCRIPTION

To augment roadway striping and general roadway delineation, and to enhance visibility for drivers to provide positive guidance and reduce the risk of collisions, WSDOT installed new LED lane delineators and high-visibility barrier delineators along the 15-mile Snoqualmie Summit vicinity. This project, STPF-DEMO-0902(398), was awarded to Acme Concrete Paving, Inc., and the work was conducted from May 5 through October 17, 2014.

## PROJECT INNOVATIONS

Three different types of LED delineators were used for this project to improve visibility of the I-90 corridor through Snoqualmie Pass: puck style, raised pavement marker (RPM) style, and barrier delineators. Table 1 shows the locations, colors, and milepost limits of the delineators. All delineators were installed at a spacing of 80 feet for tangent and curves of radius 5,000 feet or larger. For sharp curves with radius less than 5,000 feet, the delineators were installed at a spacing of 40 feet. Additional details regarding the delineators are provided below.

Table 1. Location and color of LED delineators.

| Type of Delineators | Direction | Location of Delineators | Color of LED | Milepost Limits |
|---|---|---|---|---|
| Puck Style Delineator | Westbound | Edge Line | Yellow (Median Shoulder), White (Outside Shoulder) | 47.00 to 55.15 |
| RPM Style Delineator | Westbound | Skip Line | White | 47.00 to 55.15 |
| | Eastbound | Edge Line | Yellow (Median Shoulder), White (Outside Shoulder) | 47.00 to 55.15 |
| | Eastbound | Skip Line | White | 52.61 to 55.15 |
| Barrier Delineator | Eastbound | N/A | Yellow (Median Shoulder), White (Outside Shoulder) | 52.61 to 55.15 |

## Puck Style LED Delineator

Unlike the traditional above-ground delineators that are more prone to damage due to snow removing operation, these puck style delineators are designed to be inserted into the ground so that the surface of the delineator is leveled with the ground. SolarCap-YH-DD1 delineators with a diameter of 5.7 inches and a thickness of 2.0 inches were used for this project. Figure 2 shows a detailed diagram for the puck style delineators, and Figures 3 through 8 show the installation procedure in a step-by-step manner.

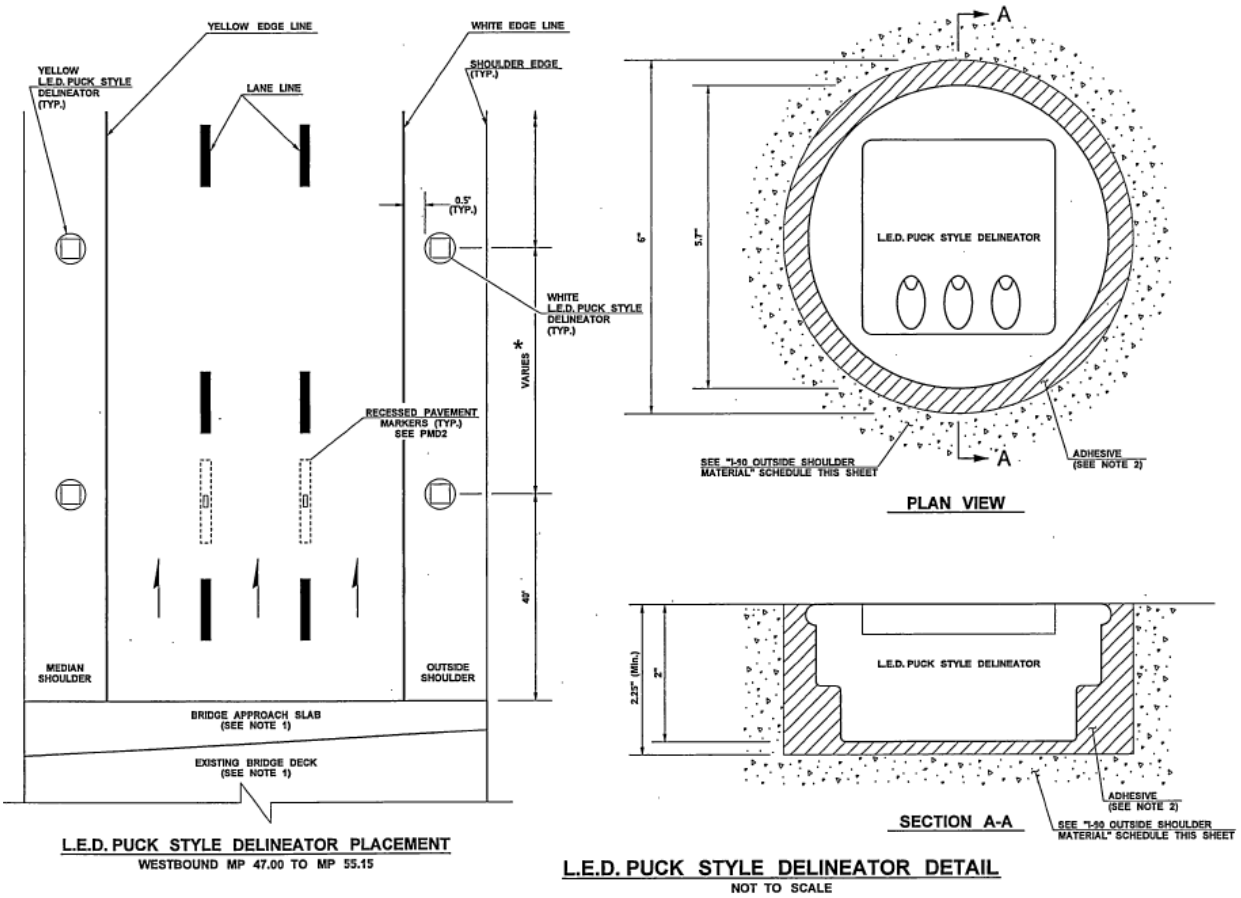


Figure 2. Diagram. Detailed diagram for LED puck style delineator.

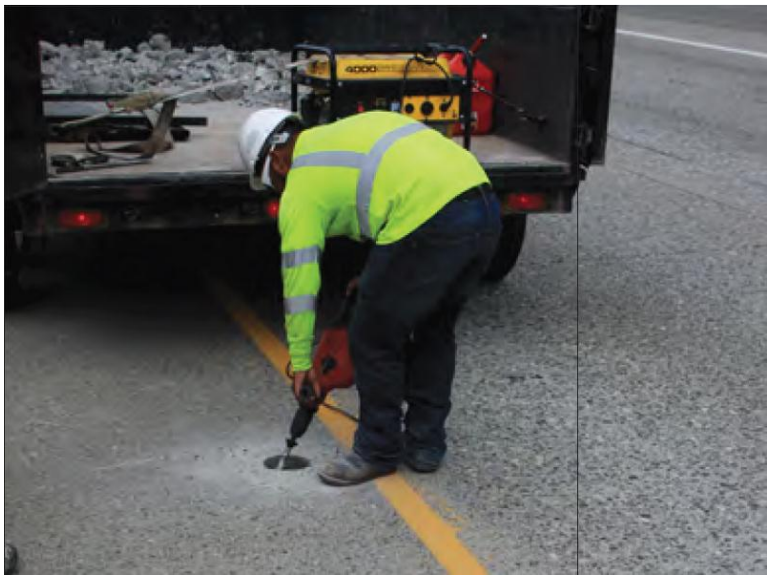

Figure 3. Photo. Drilling a hole into the pavement for the LED delineator.

Figure 4. Photo. Filling the bottom of the hole with epoxy.

Figure 5. Photo. Aligning the base of marker into the hole.

Figure 6. Photo. Application of epoxy to the perimeter of the marker base.

Figure 7. Photo. Grinding relief in front of the base of lane marker.

Figure 8. Photo. Inserting and securing the LED into the base.

**RPM Style LED Delineator**

The RPM style delineator used for this project was the Solar Road Stud MS-100C having a square dimension of 4 inch by 4inch, with a shaft at the bottom 1 inch in diameter and 1.8 inches in length. Figure 9 shows a picture of the delineator, and Figure 10 shows a detailed diagram.

Figure 9. Photo. RPM style LED delineator with shaft.

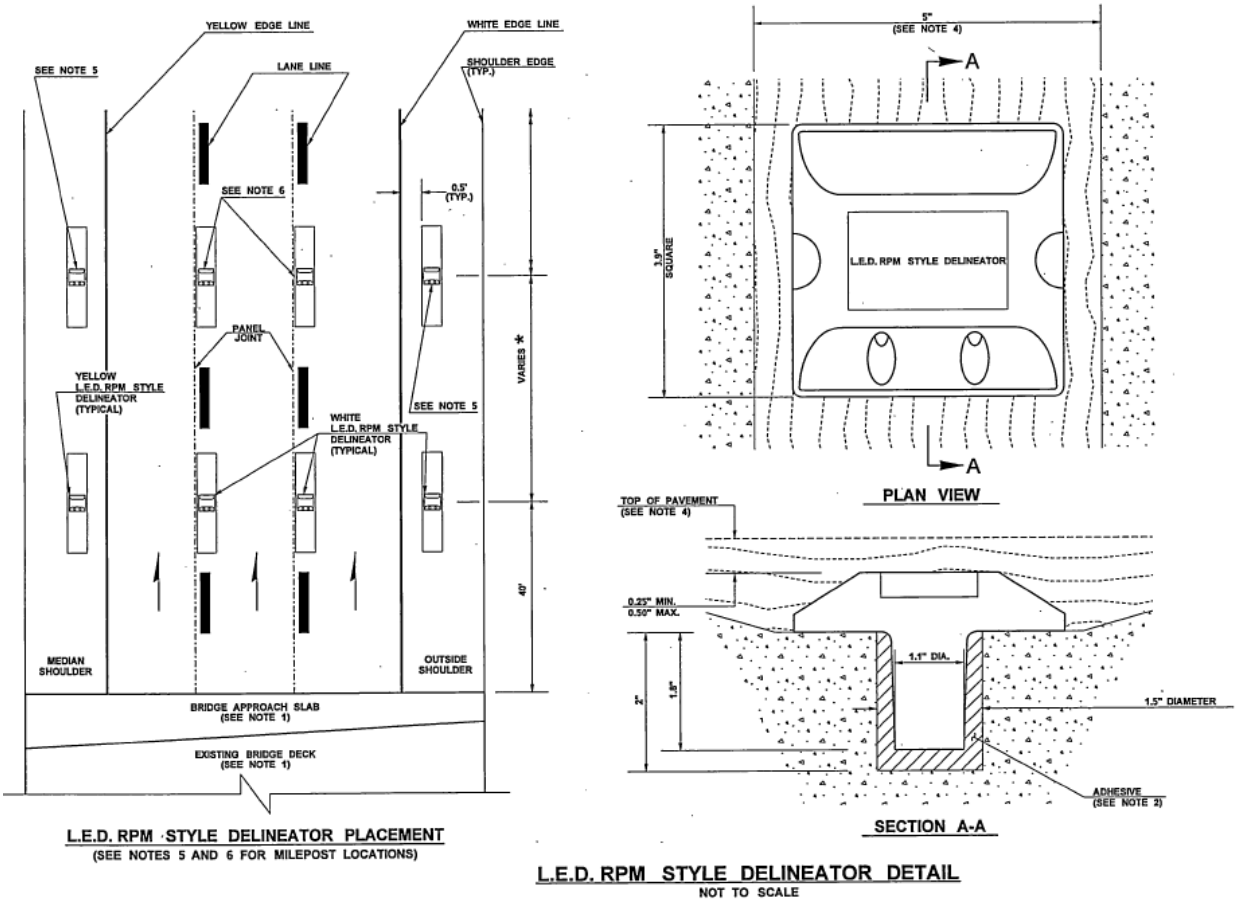


Figure 10. Diagram. Detailed diagram for LED RPM style delineator.

To protect the RPM style delineators from winter driving and maintenance, especially the snow removal operation, these delineators were installed within a longitudinal groove that was 10 feet in length and 4 inches in width, as shown in Figure 11. Figure 12 shows a diagram of the recession of the delineator within the grooves and shows that the top of the RPM style delineator was located at a depth of 0.25 to 0.5 inches below the pavement surface. A picture of the installed RPM style delineator is provided in Figure 13.

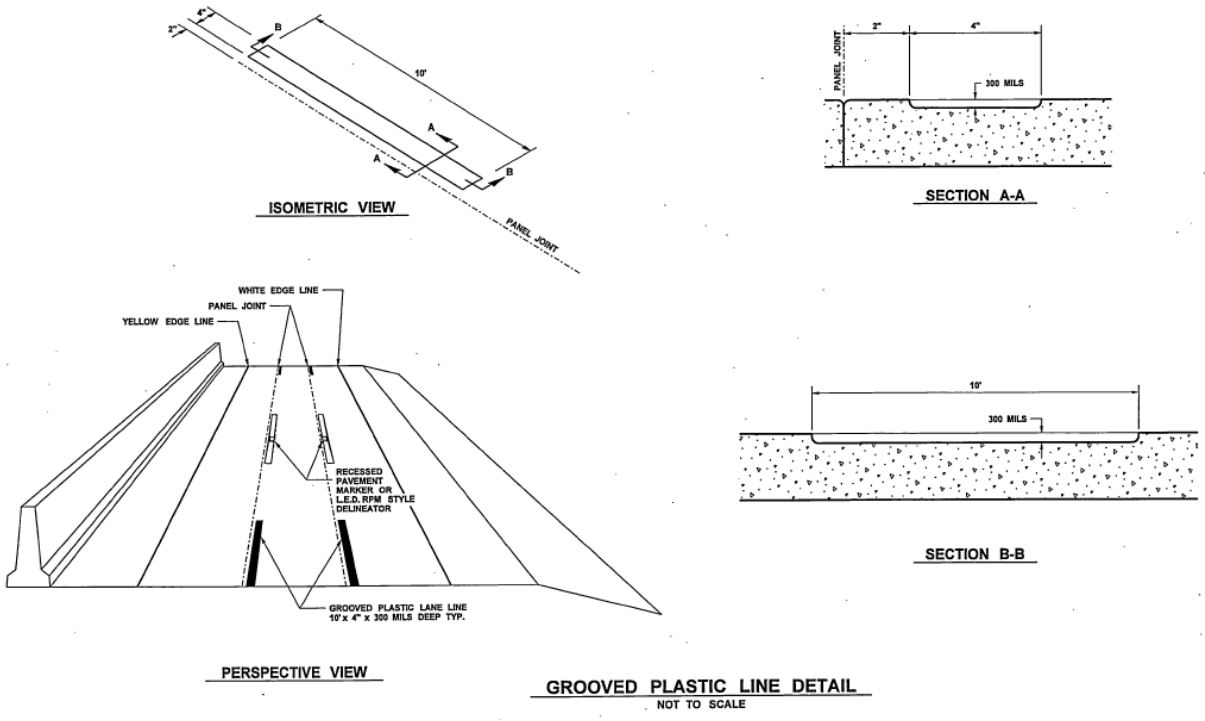


Figure 11. Diagram. Detailed diagram for grooved line.

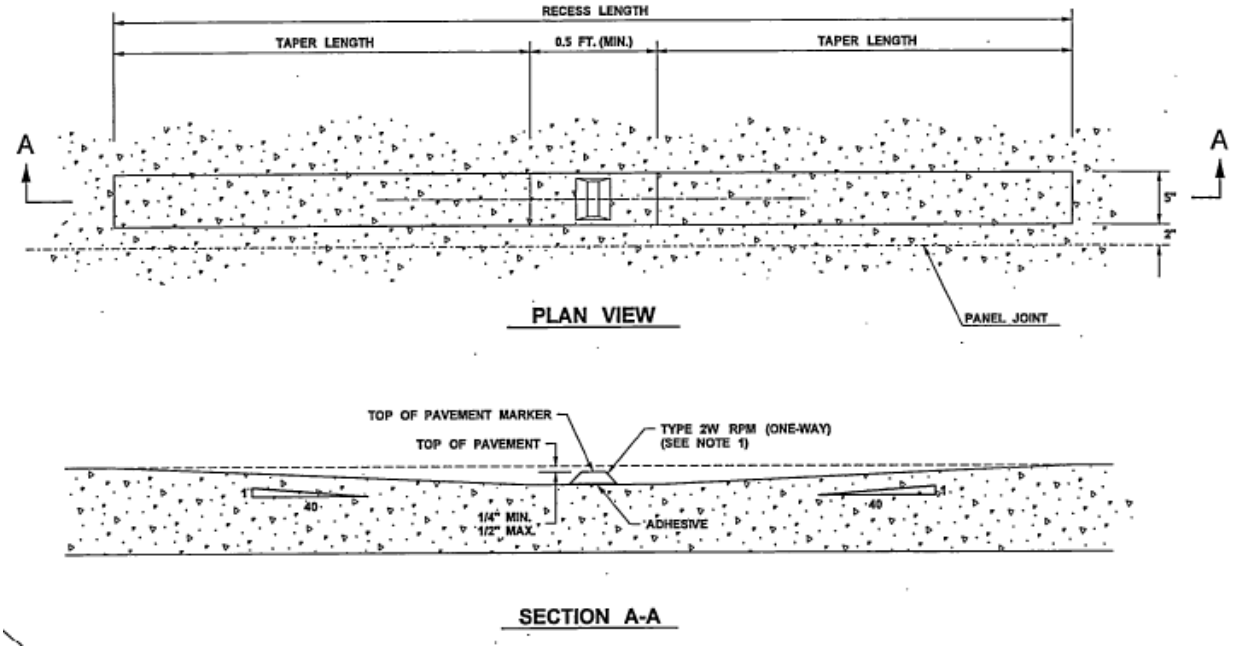


Figure 12. Diagram. Detail for recession of LED puck style delineator.

Figure 13. Photo. RPM style LED delineator installed on I-90.

**LED Barrier Delineator**

The LED delineator used for the barriers on this project was the YH-YS Solar Stud. This delineator has a dimension of 4.3 inches by 3.5 inches and a thickness of 1.3 inches. These barrier delineators can be installed on existing barriers or precast barriers prior to placement on the roadway. Figures 14 and 15 show a diagram of the barrier LED and a picture of an installed delineator, respectively.

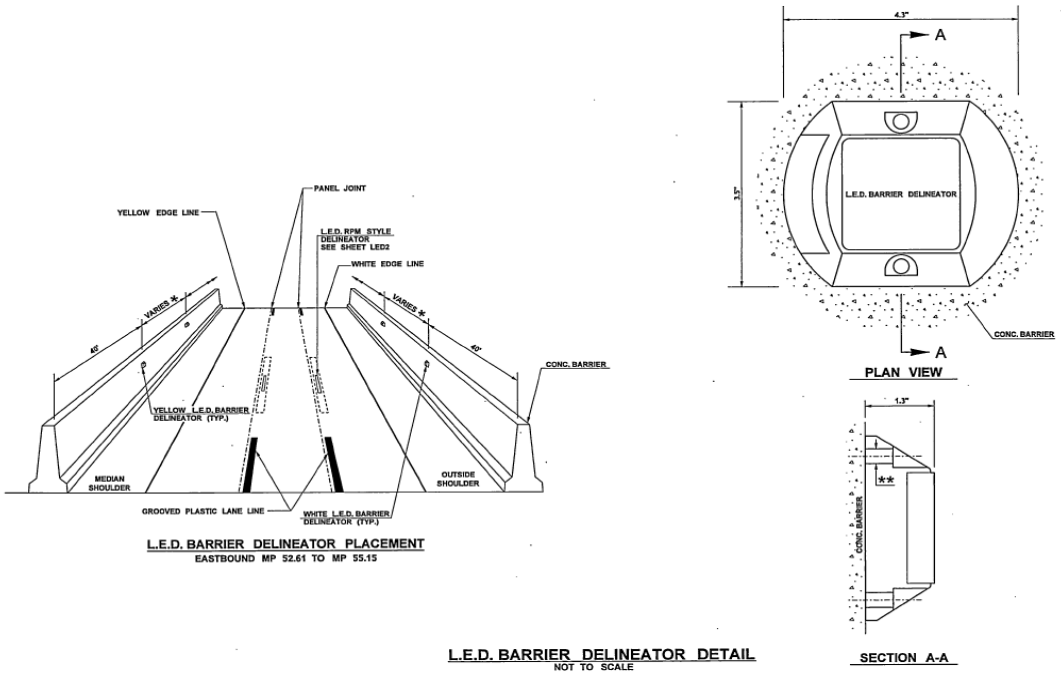


Figure 14. Diagram. Detail for LED barrier delineator.

Figure 15. Photo. LED barrier delineator used for the I-90 project.

Figure 16 shows a picture of the I-90 roadway at night after the LEDs have been installed. WSDOT anticipates that the new lane and barrier delineation with LED lights will be more durable and require less frequent repair or replacement, thus reducing impact to the public for construction traffic control. WSDOT also expects that these LED markings will provide positive lane and barrier delineation that is twice as durable as existing delineation methods, cutting repair or replacement frequency by 50 percent.


Figure 16. Photo. Nighttime view of I-90 through Snoqualmie Pass with new LED delineators.

## SAFETY ASPECTS OF WSDOT'S I-90 PROJECT

Figure 17 shows the number of nighttime crashes observed within the limits of the project before, during, and after the installation of the new LED delineators. Although the figure does not indicate a significant reduction in nighttime collisions, it is deemed too early to draw a solid

conclusion. WSDOT is planning to monitor the number of crashes over the next 3 years to evaluate the effectiveness and performance of the LED delineators.

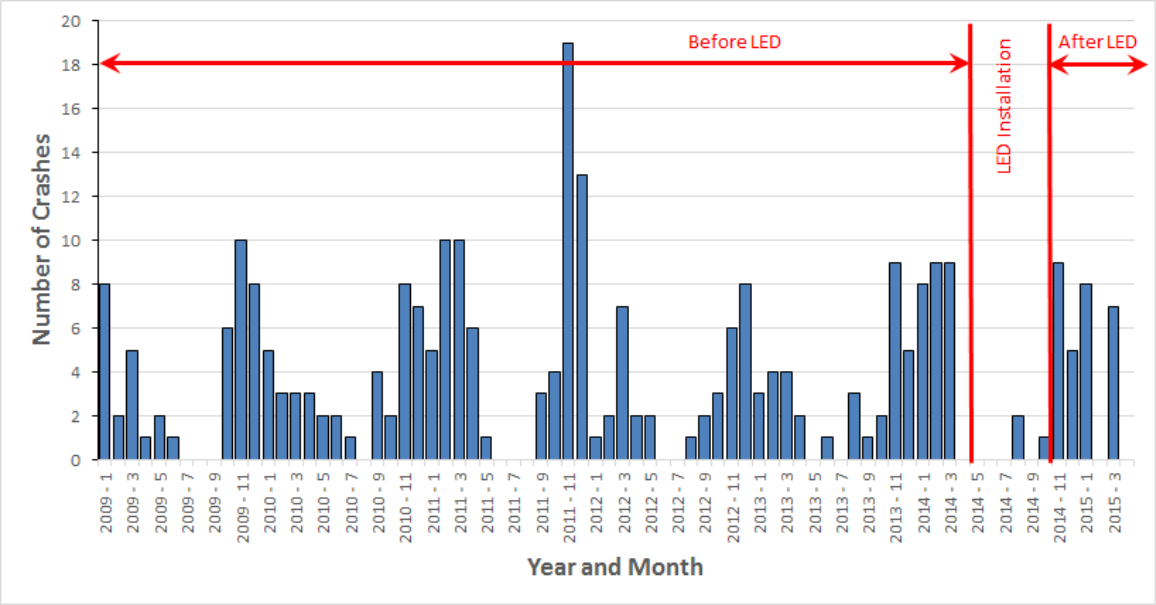


Figure 17. Graph. Number of nighttime crashes within the limits of I-90 project.

## USER SURVEY

Prior to installation of the LED delineators, WSDOT had conducted an online survey regarding the visibility of the existing lane markings. The survey questions included the following:

- Typical time of year (spring, summer, fall, and winter) and time of day (day/night) the respondents drive over the Snoqualmie Pass on I-90.
- Visibility of the pre-LED pavement lane markings at various conditions (daytime/raining, daytime/snowing, nighttime/raining, nighttime/snowing). The respondents were asked to rate these conditions based on a 5-point adjectival scale ranging from “very good” to “very poor.”

A total of 1,979 responses were received for this survey. The questionnaire and the results, as well as some of the comments received from this survey, are provided in appendix A. It was found that the distribution of the survey responders were well spread out for the various seasons and lighting conditions of the roadway. The survey results in terms of percent responses regarding the visibility of the lane markings at various conditions are shown in Figure 18. It is clear that the respondents thought the visibility of the lane markings was not good, especially during the night and under snowing conditions. Converting these results into a 5-point numeric Likert scale with 5.0 representing “very good” and 1.0 representing “very poor,” the following overall scores are obtained for the various conditions. These overall scores once again indicate that the respondents were of the opinion that the visibility became worse at night and under snowing conditions:

- Daytime and raining: 2.8 points.
- Daytime and snowing: 2.3 points.
- Nighttime and raining: 1.6 points.
- Nighttime and snowing: 1.4 points.

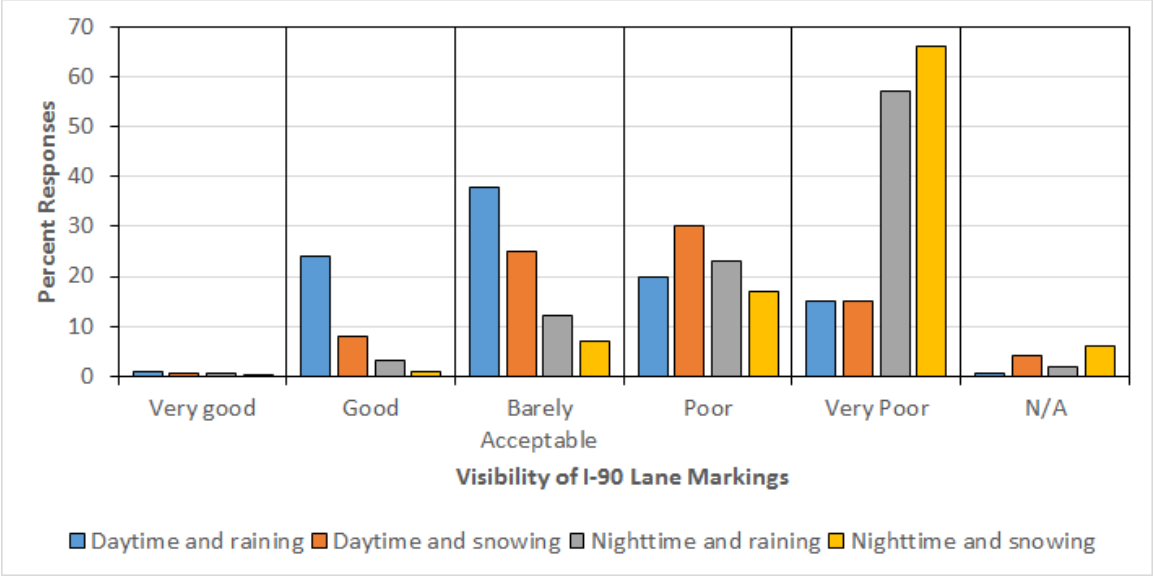


Figure 18. Graph. Pre-LED survey results on visibility of I-90 lane markings.

WSDOT is currently conducting a second online survey to gather the public feedback on the effectiveness of the new LED lane markings. The full questionnaire for this second survey is provided in appendix B. The survey was opened in April 2015, and WSDOT is planning to have the survey open until late August 2015.

## SUMMARY

This I-90 project through Snoqualmie Pass is WSDOT's first pilot project that utilizes LED lane delineators and high-visibility barrier delineators on a large scale. Maintaining delineation for I-90 in the Snoqualmie Pass vicinity has been a challenge for WSDOT, and it is anticipated that the new LED lights installed for this project will provide more durable and reliable delineation, giving drivers a more positive delineation especially at night and during severe weather conditions. WSDOT plans to monitor this pilot program for the next 3 years to determine if the LED lights are effective.

# APPENDIX A: QUESTIONNAIRE AND RESULTS OF THE PRE-LED USER SURVEY

A total of 1,979 people took the survey before installation of the LED delineators. The questions and results from the first survey are as follows:

1) What time of year do you typically travel over Snoqualmie Pass (Check all that apply)?

Winter – 89%

Spring – 85%

Summer – 90%

Fall – 84%

2) What time of day do you typically drive over Snoqualmie Pass (Check all that apply)?

Daytime – 90%

Nighttime – 75%

3) How would you rate visibility of the lane marking son Snoqualmie Pass during the following conditions?

Table A1. Results of Question 3 of pre-LED survey

| Conditions | Percent Responses | | | | | |
|---|---|---|---|---|---|---|
| | Very good | Good | Barely Acceptable | Poor | Very Poor | N/A |
| Daytime and raining | 1 | 24 | 38 | 20 | 15 | 0.65 |
| Daytime and snowing | 0.46 | 8 | 25 | 30 | 15 | 4 |
| Nighttime and raining | 0.46 | 3 | 12 | 23 | 57 | 2 |
| Nighttime and snowing | 0.27 | 1 | 7 | 17 | 66 | 6 |

Representative Comments Received from Survey

“Lane markings, particularly west-bound are virtually useless in dark, winter conditions presenting an extremely hazardous situation.”

“The lane markings fade out so bad and for driving a big rig I sometimes find myself in two lanes all of the sudden.”

“Lane awareness is incredibly difficult in the winter once the stripes are worn / obscured.”

“When it snows, there is heavy rain or it’s nighttime, the lane markers become impossible to locate. It is easier to follow the car in front of you.”

“Visibility is very poor east of the summit all the way through the pass past Keechelus Lake towards Easton.”

“We commute every day to Bellevue from Ellensburg. The lane markings are terrible when it’s raining. The oncoming lights are blinding in the rain.”

“The striping does not last and it’s a very bad safety issue that needs to be resolved. You can't see were the lanes are!”

“There have clearly been some attempts to make the lane markings more visible, but their success has been limited and of limited duration.”

“On the old road the lane markers are very bad. It’s great to hear you are working on something new and hopefully better.”

“I understand it’s hard to see the markings during snow events, and the recessed reflectors have done wonders, but any improvements would be greatly appreciated. Thank you for looking into this.”

# APPENDIX B: QUESTIONNAIRE OF THE POST-LED USER SURVEY

Last fall, the Washington State Department of Transportation completed installing solar-powered LED lane markings and high visibility reflectors between the Snoqualmie Pass Summit (milepost 52) and Hyak (milepost 55).

Please take a moment to answer the questions below regarding visibility of lane markings through this area.

1) How often do you travel over Snoqualmie Pass in a year? More than 10 times a year
- 6 to 10 times a year
- 3 to 5 times a year
- Less than 2 times a year
- I don't travel over Snoqualmie Pass

2) What time of year do you typically travel over Snoqualmie Pass (Check all that apply)?

- Winter
- Spring
- Summer
- Fall

3) What time of day do you typically drive over Snoqualmie Pass (Check all that apply)?

- Daytime
- Nighttime

4) Did you notice the new solar-powered LED lane markings and reflectors between the Snoqualmie Pass Summit and Hyak?

- Yes
- No

5) How would you rate visibility of the new solar-powered LED lane markings and reflectors between the Snoqualmie Pass Summit and Hyak during the following conditions?

a) Daytime and raining
   - Very good
   - Good
   - Barely Acceptable
   - Poor
   - Very Poor
   - N/A
b) Daytime and snowing
   - Very good
   - Good

- Barely Acceptable
- Poor
- Very Poor
- N/A

c) Nighttime and raining
   - Very good
   - Good
   - Barely Acceptable
   - Poor
   - Very Poor
   - N/A

d) Nighttime and snowing
   - Very good
   - Good
   - Barely Acceptable
   - Poor
   - Very Poor
   - N/A

6) Do you feel the new solar-powered LED lane markings improved lane visibility?

- Yes
- No

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