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Evaluation of Alternatives to Provide Wet-Nighttime Delineation

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Research Report
KTC-16-07/SPR490-14-1F

EVALUATION OF ALTERNATIVES TO PROVIDE WET-NIGHTTIME DELINEATION

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16. Abstract

The objective of this study was to compare the performance of various types of materials, devices, and procedures that can potentially delineate roadways during wet, nighttime conditions. Snowplowable markers provide the most effective wet-nighttime delineation. Durability issues associated with the steel casting marker make the recessed marker preferable over the life of the pavement. Wet reflective tape placed in a groove provided both dry and wet-nighttime delineation and remained durable. The performance of thermoplastic material installed on the pavement surface supports its future use but will not provide wet-nighttime delineation. Inconsistent performance of inlaid tape argues against its expanded use. Poor performance shows that future use of wet-reflective tape should not be considered.

The research indicates an effective lane delineation procedure for four lane roads would include: recessed markers on lane lines (at 80-foot centers), grooved wet-reflective tape for lane lines, and spray thermoplastic for the edge lines. A cost analysis, considering durability of the materials, show that the cost of using more durable materials over the life of the pavement is not dramatically more than the cost of traffic paint. Edge line rumble stripes and centerline rumble strips enhance wet-nighttime delineation and should be incorporated into resurfacing projects on two-lane roads where pavement width permits.

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EXECUTIVE SUMMARY

The objective of the study was to compare the performance of various types of materials, devices, and procedures that can potentially delineate roadways during wet, nighttime conditions. Literature and information from other states have not shown a consensus for what method offers the most effective and durable wet-nighttime delineation. The results of this research can be used to evaluate the most cost-effective methods to establish wet-nighttime delineation for different types of roadways.

Based on KTC's evaluation of the various materials and procedures, the following conclusions are provided. These can serve as guidance for providing pavement markings in future road projects.

- Snowplowable markers provide the most effective wet-nighttime delineation (both recessed and steel casting (Type V) markers). While both markers have advantages and disadvantages when compared against one another, durability issues associated with the Type V marker (related to the pavement condition for older pavements) make the recessed marker preferable over the life of the pavement.
- Although the recessed marker is the preferred snowplowable marker, use of the steel casting (Type V) marker may continue, but only if: 1) it is properly installed on new pavements, and 2) there is a commitment to maintain the pavement in good condition. If used, the lenses in the steel casting marker should be replaced approximately every three to five years (depending on traffic volume). The stability of the casting should be inspected when the lenses are replaced.
- To ensure that snowplowable markers are installed at the proper location relative to the pavement joint, installation must be coordinated with paving operations.
- Snowplowable markers should be installed the proper distance from the joint, even if they are not in complete alignment with the lane lines.
- Based on its expense and poor ability to maintain reflectivity, KYTC should not consider future use of wet-reflective paint.
- Installation of the wet-nighttime materials and devices should, in general, be limited to new pavements. However, they may be installed on existing pavements that are in very good condition.

- Wet reflective tape placed in a groove provided both dry- and wet-nighttime delineation and remained durable. This material maintained high dry and wet reflectivity levels. On multi-lane roadways, wet reflective tape (placed in a groove) is the only alternative to snowplowable markers that can provide wet-nighttime delineation.
- Inlaid wet reflective tape provided high reflectivity for dry pavement, but results varied under wet conditions. Based on the damage snowplows caused to the tape at a test location, questions remain about its durability.
- The durability of inlaid wet reflective tape is contingent on it being placed when the asphalt is at the correct temperature. Placement at the correct temperature ensures tape will be properly inlaid.
- Inconsistent performance of inlaid tape argues against its expanded use.
- The performance of thermoplastic material installed on the pavement surface supports its future use (for example, on high-volume, four-lane roads). However, since surface-applied thermoplastics will not provide effective wet-nighttime delineation, it should be supplemented with snowplowable markers.
- Although grooved thermoplastic is less expensive than grooved tape, the wet reflective tape maintained much higher reflectivity levels (especially under wet conditions). Grooved tape provides the best option to establish wet-nighttime delineation in the absence of or as a supplement to snowplowable markers.
- The most effective durable marking system for interstates, parkways, and rural multi-lane roads would include a combination of snowplowable markers and either thermoplastic material or recessed wet reflective tape.
- Cost analysis demonstrates that the total cost of a durable marking system spread over the life of pavement is not dramatically more expensive than the cost of typical traffic paint (which must be replaced annually on high-volume roads). Durable materials will improve wet-nighttime delineation.
- Edge line rumble stripes (i.e., painting the white edge line over a milled shoulder rumble strip) enhance wet-nighttime delineation. As such, it should be incorporated into resurfacing projects on two-lane rural roads. Where pavement width permits, centerline rumble stripes should also be integrated into these projects. However, rumble stripes should not be used to retrofit older pavements.
- Centerline rumble strips can be combined with snowplowable markers (either recessed or steel casting) to provide maximum wet-nighttime delineation on resurfacing projects on rural, two lane roadways.

1. BACKGROUND

Typical traffic paint does not effectively delineate lanes at night when pavement conditions are wet. Past research studies in Kentucky have evaluated alternative materials, devices, and procedures that could potentially provide durable and effective roadway delineation during wet-nighttime conditions. Materials and methods evaluated in the past include snowplowable raised pavement markers, thermoplastic markings, rumble stripes, and various types of paints and tapes (1).

Information obtained from other states (from various sources) has indicated no consistent or universal standards to delineate wet roads at night. For example, some states continue to use steel casting markers, but several have discontinued or limited their use because of problems with their durability. Some states have opted to place a marker, tape or paint in recessed grooves. Other methods adopted include using wet reflective tape or paint or installing a rumble stripe. There has been no agreement over which method could result in consistent and effective wet-nighttime delineation. Various studies have illustrated the inability of various materials to provide wet-nighttime delineation with a grooved wet reflective tape resulting in the most effective results (2, 3).

A review of state responses to a survey about their policy for pavement marking also showed there are no consistent guidelines. Waterborne paint is used for various applications in all states. However, the type of marking applied to higher volume roads varies. Additionally, there is no standardized definition for what constitutes a higher volume road. Alternative materials noted in the state responses include: high-build waterborne paint, thermoplastics, tape, multi-polymer, epoxy, polyurea, methylmethacrylate (MMA), and modified urethane. However, there was no agreement on a material which could be used to provide wet-nighttime delineation.

The objective of this study was to compare and evaluate the performance of various types of materials, devices, and procedures intended to delineate roadways during wet-nighttime conditions. This study's findings can be used to evaluate the most cost-effective methods of providing wet, nighttime delineation on different types of roadways.

2. DATA COLLECTION

This study monitored the installation and durability of several materials and methods that could potentially provide wet-nighttime delineation. Observations were conducted during daytime and evening hours (and during dry and wet pavement conditions) to evaluate the durability and effectiveness of each material and procedure included in the evaluation.

Reflectivity data were collected using the Delta Optics LTL-X Pavement Marking Retro-Reflectometer, which measures reflectivity in millicandelas per square meter per lux (mcd/m2/lux). In this report, the units for retroreflectivity — whether referred to as levels or readings — are mcd/m2/lux. The procedure described in ASTM E2177 was used to obtain data for wet conditions. The wet-recovery procedure was used where water was spread over the line, with measurements taken after 45 seconds.

The following materials/devices were included in the evaluation.

- Steel casting markers (Type V in Kentucky's specifications)
- Recessed pavement markers
- Wet-reflective tape (recessed and inlaid)
- Wet-reflective paint (recessed and surface applied)
- Thermoplastic material (recessed and surface applied)
- Rumble stripes (edge line and centerline rumble strips)

Wet-reflective tape was installed both in a groove and inlaid during resurfacing. The wet-reflective paint and thermoplastics were installed both in a groove and on the surface. The recessed marker involved placing two lenses in a shallow groove. The Appendix contains images of the various materials/devices (during installation and day and night observations).

In addition to these materials and devices, the application of typical traffic paint over a milled rumble strip was evaluated. This procedure results in what is termed a rumble stripe. Rumble stripes were installed on both the edge line and centerline.

A survey of representatives from each of the Kentucky Transportation Cabinet's 12 district offices was conducted to determine what durable pavement marking materials they currently use. The survey also asked respondents for their opinion concerning future use of durable materials and devices.

3. RESULTS

3.1 Highway District Survey

A representative from each of Kentucky's 12 highway districts was contacted to learn about current practices and the future use of durable pavement markings. The following bullet points summarize critical information gleaned from the survey.

- The frequency of restriping using standard traffic paint depends on the type of road and traffic volume. Restriping frequency typically varies from one to three years.
- High build (HP21) traffic paint has been used on some interstates, parkways, and high-volume roadways.
- There has been very limited use of thermoplastic materials in recent years. There have been recent installations of ribbon thermoplastic along with the first installation of a spray thermoplastic (on rural interstates). The most recent installation of spray thermoplastic was on a rural parkway.
- The steel casting (Type V) snowplowable marker is used on the designated highway system (which has changed in recent years). The change in the system has reduced the number of miles on which this marker is installed. Specifically, this marker is no longer typically installed on two-lane roads. Comments concerning this marker were generally positive. However, there were concerns expressed, specifically that the lenses have not been maintained and that durability problems with the casting have emerged when the adjacent pavement begins to deteriorate.
- There has been limited experience with recessed markers. There were positive comments from respondents who had observed installation of recessed markers, with a favorable comparison made to the steel casting markers.
- All respondents had experience with rumble stripes. The response to rumble stripes has been favorable, with respondents observing that rumble stripes improve wet-nighttime delineation.
- To date, the use of durable materials has been very limited; however, respondents expressed an interest in using durable materials in the future.

3.2 Snowplowable Pavement Markers

A steel casting snowplowable marker (Type V in Kentucky specifications) has been used in Kentucky since the 1980s. Maintenance problems associated with this type of maker have increased in recent years, which have been related, principally, to the condition of the

pavement adjacent to the marker. Past evaluations have found that continued use of steel casting markers is warranted if: a) they are installed properly on new pavements, and b) there is commitment to maintain the adjacent pavement and the marker lenses (4). Other states have reported similar maintenance issues. In response, some states have limited or discontinued use of the steel casting marker while others have continued use of this marker while increasing inspections of the marker and the surrounding pavement.

Several recent installations of the Type V marker were monitored. Consistent with previous evaluations, the steel casting proved durable when the adjacent pavement was maintained in good condition. Observations were made at several locations over a few years following the installation of the Type V markers on new pavement. No durability issues with the steel castings arose when there was no problem with the condition of the adjacent pavement. However, the lenses showed evidence of damage, which supported previous recommendations that the lenses should be replaced on an approximately three-year cycle (4).

A recent study identified one alternative to the steel casting (Type V) marker — recessed markers (5). Installing the recessed marker evaluated in this study (Marker One) entails cutting a shallow groove and placing two lenses (of the type used in the Type V marker) in the groove. This recessed marker is a variant of a previous type of recessed marker that was installed in Kentucky in the 1980s. This groove, however, is longer and shallower than the groove used with the previous recessed marker (which used a typical flush mounted marker).

Various groove lengths and marker spacings were evaluated in the initial installations. The evaluation of alternative designs resulted in the use of a nine-foot groove with the two lenses placed 3.5 feet from each end of the groove. This leaves two feet between the two markers. The maximum depth of the groove is 0.4 inch, except at the locations of the two lenses, which have a depth of one inch. The lenses are placed in a bracket with an adhesive that fastens the marker to the bracket. Tabs located on each side of the bracket ensure that the lenses are placed at the proper depth in the groove.

The first test installation (in 2011) involved placing a few recessed markers on a rural interstate. The first contracts for installation of this marker were awarded in 2012, with approximately 925 grooves (1,850 lenses) placed on two rural, four-lane roadways. Additional markers were installed on interstates, parkways, and other four-lane roadways in 2013, 2014 and 2015. New contracts have been awarded which will result in additional installations in 2016.

The 2012 installations were performed with equipment pushed by hand. However, beginning with larger installations in 2013, markers have been placed using a truck with the cutting device, which lets a computer control the depth and profile of the cut.

The installation cost of the recessed markers has decreased, with a lower price associated with larger installations. The data indicate that the future cost should be approximately $40 per groove or slightly less. This breaks down to $30 for cutting the groove, $4 for the housings, $4 for the markers, and $2 for the adhesive. Conversely, a steel casting (Type V) marker costs approximately $25. Using upfront costs to compare total cost over the life of the pavement is slightly misleading because recessed markers demand fewer lens replacements than steel casting markers over their life cycles. Assuming one lens replacement for the recessed marker and three for the steel casting between resurfacings, the total cost over the life of the pavement would be approximately $50 for the recessed marker and $40 for the steel casting marker.

All but one installation of the recessed markers was on asphalt. The amount of time needed to complete a cut has varied for asphalt and concrete. A cut typically requires approximately one minute on asphalt surfaces and two minutes on concrete. The installer has a different set of blades to use for concrete. Observations were made during the installation process at several locations. Installation procedures require that groove cuts are made at least two inches from the pavement joint. Periodic checks using the lenses and bracket ensure the correct groove depth is reached.

Nighttime observations of both the steel casting and recessed marker installations were made during both dry and wet conditions. The observations indicated that snowplowable markers (either the steel casting or recessed marker) provide the most effective lane delineation under wet-nighttime conditions compared to any other type of material or device included in the evaluation. The observations showed that the delineation provided by recessed markers is comparable to what steel casting markers offer. The number of markers visible at any location varies with the roadway geometrics (grade and curvature). Under similar roadway geometric conditions, the number of recessed markers that are visible is comparable to the number of steel casting markers.

Table 1 lists the location of recessed marker installations as well as the number of markers installed and the unit cost per marker installed on new and existing pavements through 2015. The maintenance contracts in Districts 4 and 11 were for existing pavements. Contacts have been let for maintenance contracts in the other districts.

Two markers were installed in each groove. Because the unit cost for the first contracts was per marker, it had to be doubled to obtain a cost per groove. The unit cost was then converted to a cost per groove (including both markers). The data in Table 1 list the number of grooves and the unit cost per groove (including both markers). Almost all installations were on rural interstates, parkways, and other rural, four-lane roadways. The initial installations were on new pavements. Later contracts added installations on existing pavements (starting in 2015). Since 2012, the number of road miles on which marker installation has taken place has grown steadily — from the initial five miles in 2012 to approximately 30 miles in 2013, 45 miles in 2014, and about 240 miles in 2015. Several additional contracts let in 2015 were not installed, so the number of miles installed will increase in 2016.

Table 1. Recessed Marker Installations

Install Date	Location (County; Route)	Mile-point	Grooves*	Unit Cost**
2012	Mercer; US 127	14.5-17.2	350	63
	Mercer; US 127	1.0-2.6	200	76
	Jessamine; US 27	0.1-0.8	750	68.3
2013	Bath; I-64	117.8-123.6	761	71
	Rowan; I-64	134.75-138.3	459	75
	Woodford; US 60	0-7.4	1,497	32
	Fayette; I-75	105.4-107.4	552	52
	Scott; I-75	125.5-134.4	2,352	36
2014	Fayette; I-75	97.9-105.4	992	37
	Montgomery/Bath; I-64	112.3-117.8	756	56
	Bath; I-64	123.6-129.1	710	40.5
	Rowan; KY 32	6.3-7.8	325	53
	Fayette; KY 418	0.1-2.9	100	60
	Fayette; US 25	8.1-9.5	504	37
	Fayette; US 60	9.8-11.8	662	37
	Woodford/Scott/Fayette; I-64	65.8-73.9	1,430	34
	Scott; I-75	121.1-125.5	1,408	40
	Grayson; WK Parkway	114.8-116.9 (WB)	142	56
	Anderson; BG Parkway	47.2-52.0	765	41.1

Table 1. Recessed Marker Installations (continued)

Install Date	Location (County; Route)	Mile-point	Grooves*	Unit Cost**
2015	Perry; Hall Rogers Pkwy.	57.3-59.1	413	50.8
	Perry; KY 80	11.0-14.6	45	79
	Knott; KY 80	0-5.1	897	40.8
	Anderson; BG Parkway	58.3-61.8	387	36
	Jefferson; I-64	13.1-19.4	3,767	52
	Grant; I-75	152.4-166.3	3,205	42
	Madison; I-75	86.3-97.5	4,400	36
	Mason; US 62	14.4-15.6	500	46
	Fleming; KY 11	10.4-12.9	521	39.7
	McCracken; I-24	1.1-3.0	261	70
	Rowan; KY 32	0-2.2	280	49
	Barren; Cumberland Pkwy.	0.9-9.0	1,075	48
	Marshall; I-24	22.1-26.6	322	60
	Bath; KY 11	0-7.5	270	40
	Pulaski; Cumberland Pkwy.	72.1-84.3	3,236	36
	Fayette; Man-O-War	NA	811	40
	Gallatin; I-71	56.7-59.7	1,213	48
	Franklin/Shelby; I-64	43.9-53.1	1,403	62
	Lawrence; KY 644	0-1.5	100	48
	Lewis; KY 9	8.0-11.2	2,040	46
	Fayette; US 60	8.1-9.8	812	39.2
	Pike; US 460	14.4-18.9	700	46.5
	Scott; US 62	10.6-13.3	508	45
	Greenup; KY 67	0-13	2,367	40
	Jefferson; KY 22	0.1-3.5	94	51
	Campbell; US 27	13.0-13.2	42	44
	Campbell; US 27	14.9-16.7	360	55
	District 4 Maintenance	several roads	10,936	38
	District 10 and 11 Maintenance	several roads	3,000	45

* Two markers per groove

** Unit cost (includes groove and two markers)

There has been concern over whether water would accumulate in grooves and obscure the view of the recessed lenses. Observations show that the amount of water that accumulates in a groove during a heavy rain depends on the grade. Grooves on level surfaces will accumulate more water than grooves situated on more inclined surfaces. However, with the design used (3.5 feet between each lenses and the ends of the groove), observations during varying amounts of rain have demonstrated that, although one lens may be covered for a short period of time, it is rare for both lenses to be covered, which is the advantage of installing two lenses in each groove.

Researchers have studied the visibility of the lenses during various rainfall intensities. For example, Kentucky Transportation (KTC) researchers monitored grooves during one very heavy rain on US 60 in Woodford County. This is a large installation that extends approximately eight miles over rolling terrain. During rainfall, water accumulation in the groove resulted in only one lens being visible in about nine percent of the grooves, with neither lens visible in about four percent. Water accumulation was most prevalent on long, flat segments and at the bottom of sag vertical curves. The water accumulation did not prevent the recessed markers from providing effective lane delineation, and it cleared out of the groove shortly after the heavy rain subsided. About nine percent of the lenses were not visible during the heavy rain, with observations during dry conditions showing approximately four percent missing (revealing about five percent were covered by water).

During a snow event, snow accumulates in the groove. Observations have also indicated that salt and other debris accumulate in the groove during winter weather. However, rain and traffic rapidly clean the lenses and groove.

There has also been a question about whether the pavement cut contributes to pavement failure. However, this study found no evidence that the grooves cut for recessed markers undermine pavement durability. In a few instances where the bracket was absent, some pavement was missing beneath the missing marker.

The durability of the recessed markers was assessed for some installed markers in place for up to four winter seasons. Observations have shown a very low percentage of missing lenses. An inspection in 2016 of the largest installation in 2012 found about 10 percent of the lenses missing after four winter seasons. For several installations with thousands of lenses, only an extremely small number were missing.

KTC surveyed — in July 2015 — the condition of all installations placed in 2012, 2013, and 2014. Of the 1,708 lenses installed in 2012, only 3.2 percent were missing after three

winters. Of the 14,040 lenses installed in 2013, only 1.7 percent was missing after two winters. Of the 17,172 lenses installed in 2014 only 0.8 percent was missing after one winter. The most significant losses occurred at one 2012 installation site, where approximately seven percent of the lenses were missing. The highest loss rate for the 2013 installations was 3.6 percent. The most significant loss for the 2014 installations was 3.4 percent. Most of the installations — irrespective of their age — had less than one percent missing. Overall, in this inspection, 1.3 percent of the lenses were missing. Of those missing, in slightly over one-half (55 percent) only the lenses were missing, with the lenses and bracket missing in the remainder. In some cases some asphalt was also missing along with the marker and bracket.

To compare the durability of lenses in steel casting markers and recessed markers, installations on adjacent roadway sections were compared. The same lenses are used on both steel casting and recessed markers. Comparisons focused on the lane lines. The first installation compared was on US 27 in Jessamine and Garrard Counties. In 2012, recessed markers were installed in Jessamine County, while steel casting markers were installed in Garrard County. Each installation was approximately one mile in length. A nighttime inspection conducted in 2016 found that approximately 16 percent of the steel casting lenses and one percent of the recessed marker lenses were either missing or significantly damaged. Another comparison examined installations on US 60 in Fayette and Woodford Counties. Several miles of each marker type (steel casting in Fayette County and recessed in Woodford County) were installed in 2013. After three years in service, a nighttime inspection performed in 2016 found that approximately 16 percent of the steel casting lenses and seven percent of the recessed marker lenses were either missing or significantly damaged. This recessed marker installation had one of the highest loss rate for any installation. It should be noted that none of the steel castings were missing at either location (with no problems with the pavement).

In 2011, steel casting markers were installed on an approximately three-mile section of I-75 in Fayette County at the same time as the initial recessed marker installation. Follow-up inspections in 2016 (after five years in service) revealed that none of the castings were missing but approximately 80 percent of the lenses were either damaged or missing. Inspections of steel casting markers that were installed along a three-mile segment of the Bluegrass Parkway in 2011 indicated that, after five years, only three castings were missing but approximately 65 percent of the lenses were damaged or missing.

KTC researchers contacted installers to identify road segments where aged steel casting installations were available for inspection. Installations up to nine years old were identified. Another installation over 10 years old was also inspected. Day and night inspections were

conducted to determine the percentage of castings missing as well as the percentage of lenses damaged or missing. The following bullet points summarize the results of those inspections.

- Nine years after installation on a 2.9 mile section of KY 4 in Lexington, 22 percent of the castings were missing, and 73 percent of the lenses were either damaged or missing.
- Eight years after installation on a 4.8-mile section of the US 27 bypass at Nicholasville, 12 percent of the castings were missing with about 93 percent of the lenses damaged or missing.
- Seven years after installation on a 1.4-mile section of the KY 956 Berea bypass, there were no missing castings, although 24 percent of the lenses were damaged or missing.
- Six years after installation on a 1.4-mile section of a high-volume, multi-lane urban section of US 27 in Lexington, less than one percent of the castings were missing with about 50 percent of the lenses damaged or missing. There were a higher percentage of damaged lenses in an interchange area where numerous lane changes occur.
- Four years after installation on a 5.0-mile section of the Bluegrass Parkway, no castings were missing, but 33 percent of the lenses were damaged or missing.
- Four years after installation on a 6.4-mile section of US 27 in Garrard County, there were no castings missing, and 33 percent of the lenses were damaged or missing.
- Between 12 and 14 years after installation, inspections of a 2.0-mile section of US 150 in Boyle County found that 26 percent of the castings were missing , while 93 percent of the lenses was either damaged or missing.

KYTC awarded a contract to replace lenses on Type V markers in 2015. This was the first time lenses had been replaced in several years. KTC researchers inspected several locations where the lenses were replaced. In 2016, an inspection of a segment of US 150 in Lincoln County, which had last been resurfaced in 2010 with the lenses replaced in 2015, found there were no castings missing, and a nighttime inspection found no damage to any of the replaced lenses. No problems with the pavement were observed in this location. The inspections confirmed that Type V markers can remain effective as long as pavement remains in good conditions and lenses are replaced at least every five years. Nighttime observations of the adjacent section on US 150, where the lenses had not been replaced, revealed that over 90 percent of the lenses were missing.

Observations of the installation process indicated that a critical part of the installation for both types of markers is to obtain a clean and dry cut. If a marker is installed the same day as the cut, it facilitates providing a clean cut to install the markers.

An issue with the durability of the steel casting markers has been the requirement to install the markers at least two inches from the pavement joint. The joint is a potential area of pavement failure, which can dislodge the casting from the pavement. Grooves for recessed markers must also be installed at least two inches from the pavement joint. The lateral position of the steel casting and recessed groove were observed at numerous locations. At each site, the steel casting marker had been installed both at a proper location as well as on the joint. Coordination with the paving operation is needed to ensure that the snowplowable marker is installed at the proper distance from the pavement joint.

Another problem related to placing the cut (with the marker) away from the joint arises when the lane lines are painted at the joint. However, the distance from the joint should be maintained even if there is not complete alignment with the lane lines.

Tests were made of alternative adhesives used in the recessed marker installation. The same epoxy used for the steel casting (Type V) marker has been used on recessed marker installations. The alternative adhesives in the test included two polyurethane materials (Q-Seal 295 summer and winter grade), a crack sealer material, and an adhesive used for airport applications. In each groove one marker was installed with epoxy and one with a test adhesive. Markers applied with the test adhesives were installed in December 2015. All of the markers remained in the grooves in the spring of 2016 (after one winter season).

The following list summarizes factors which should be considered when deciding between recessed or steel casting markers:

- Cost
    - Steel casting markers are less expensive to install, however, the cost difference between marker types is minimal when the cost of installation and replacement lenses used for the life of the pavement are taken into account.
- Lenses Durability
    - The lenses on recessed markers have a longer useful life than lenses on steel casting markers.
- Nighttime delineation
    - Both provide effective delineation. Both perform similarly under dry conditions. However, steel casting markers provide slightly better performance during heavy rain due to water collecting in the groove at locations with no grade.

- Installation
    - There are well-established procedures for effectively installing both types of markers. The markers must be installed at a proper distance from the pavement joint, which has been an issue for both types of markers during previous installations. The consequences of improperly installing the steel casting marker are more severe if it results in the casting becoming dislodged from the pavement.
- Housing Durability
    - Lenses for the recessed marker are placed in a small plastic holder while the lenses for the Type V marker are placed in a steel casting. When the pavement becomes unstable in the area of the housing, the Type V marker will loosen and a snowplow can dislodge the housing (typically along with some attached pavement). Because of the Type V marker's weight, the potential for an injury event to result once it has become dislodged is higher than for the recessed marker's plastic holders. This places the recessed marker at a significant advantage over the Type V marker.

Among all products evaluated, KTC's research concluded that steel casting and recessed markers provide the most effective wet-nighttime delineation. However, given that the durability of steel casting markers (related to pavement condition) can be problematic and the fact that dislodged steel casting markers can potentially cause serious injuries, the recessed marker is the preferred type of snowplowable marker. The use of steel casting (Type V) marker may continue, but only if: 1) it is properly installed on new pavements and 2) there is a commitment to maintaining the pavement in good condition. If they are used, the lenses in the steel casting marker should be replaced approximately every three to five years. The exact replacement interval will depend on a road's traffic volume. The casting's stability must be inspected when lenses are replaced.

3.3 Wet Reflective Tape

One alternative material included in the test was a wet reflective tape. The tape used was 3M Stamark High Performance wet reflective tape (Series 380 WR ES). There has been very limited use of this type of tape on state-maintained highways in the past, with the tape placed on the pavement surface. Observations show that the tape is not durable if placed on the surface when it is exposed to the method of snowplowing typically in use, where a steel blade exerts its full weight on the pavement.

Two methods of tape installation were evaluated — placing the tape in a groove and inlaying the tape during the resurfacing process. The groove depth was 80 mils.

One test section, located on US 127 in Franklin County, had the tape placed in a groove. This is a four-lane road with concrete pavement. Both white (edge line and lane line) and yellow (centerline) tape were installed. The length of the test section was approximately 0.7 mile, with approximately 9,150 feet of white tape and 10,350 feet of yellow tape installed. The equipment used to cut the groove for the recessed markers was also used to cut the groove for the tape. The grooved tape was installed in August 2013. The contract cost for this small installation was $3.45 per linear foot.

The grooved tape installation was monitored from late-2013 through mid-2016, a period that encompassed three winters. The grooved tape remained durable, and its dry and wet reflectivity remained high. The most recent inspection in 2016 found isolated evidence of snowplow contact. There was only a very minor tape loss (a few inches) in a handful of these locations.

Reflectivity levels varied significantly by the direction of the tape measured. This difference was more pronounced in dry conditions than wet. The following table summarizes the reflectivity measurements over the evaluation period (with measurements for both directions shown) for the grooved tape installation on US 127.

Date	White/Dry	White/Wet	Yellow/Dry	Yellow/Wet
Nov-13	1,180/500	530/320	880/400	350/240
Apr-14	1,270/640	480/410	840/400	450/230
Jul-14	1,290/650	460/370	940/470	290/210
Nov-14	1,220/700	440/340	850/430	280/230
Jul-15	1,180/720	370/310	860/410	290/200
Dec-15	1,130/720	340/280	780/410	280/210
Apr-16	1,170/770	300/280	820/470	250/240

Observations during wet-nighttime conditions confirmed the high reflectivity measurements and showed the grooved tape installation provided effective delineation under wet, nighttime conditions.

A very small section of wet reflective tape was installed (inlaid) in 2013 on KY 420 in Franklin County during a resurfacing project (approximately 1,150 linear feet of yellow and white). This is a two-lane road. The cost for this small installation was $3.45 per linear foot.

Observations revealed durability problems caused by snowplow operations, with short sections of the tape having been removed. The following table summarizes reflectivity measurements (with measurements for both directions shown) for the inlaid tape installation on KY 420. No data were collected after 2014 because the tape was painted over.

Date	White/Dry	White/Wet	Yellow/Dry	Yellow/Wet
Nov-13	1,200/650	360/320	940/450	360/230
Apr-14	1,050/480	380/340	910/390	480/240
Jul-14	1,310/660	350/320	800/350	360/180
Nov-14	1,000/520	270/210	730/400	330/180

Observations during wet-nighttime conditions indicated some reflectivity had been lost due to snowplow activity. One challenge in the installation process was applying tape to the pavement while it (the pavement) was still at a temperature to ensure the tape would roll into the asphalt correctly. The data and observations indicated that tape which had not been damaged maintained high reflectivity.

There has been a large installation of inlaid wet reflective tape on city streets in Henderson. The tape was installed in the fall of 2012 at a reported unit cost of about $1.00 per linear foot. The low cost was a result of the large quantity installed. Additional installations have not been made due to cost increases. Yellow tape was used for centerlines, with white tape reserved primarily for transverse applications (crosswalk, stop bars, etc.). Inspections through early 2016, which encompassed four winters, found no major durability problems. There was evidence that snowplows have scraped the top of the tape. However, there was no evidence of tape being removed from the pavement. Discussions with the city revealed that the major installation challenge related to durability was that the tape must be placed close to the paver to ensure the tape is properly inlaid.

The following table summarizes the average of the reflectivity measurements for the inlaid tape installations in Henderson. There was a very large range in the readings for dry conditions (especially for the white material, which was typically used for transverse markings). The wet reflectivity levels were very low.

Date	White/Dry	White/Wet	Yellow/Dry	Yellow/Wet
Nov-13	750	no data	480	35
Aug-14	630	60	520	45
Nov-14	860	80	550	40
Aug-15	600	90	520	40
Apr-16	300	50	440	40

The other installations of inlaid wet reflective tape inspected as part of this study are located in Boone County on rural, two-lane county roads. Boone County installed tape as part of resurfacing projects over the course of several years, with some of the installations up to 15 years old. The county has reduced its use of inlaid wet reflective tape in recent years due to its increasing cost. Inspections found that the tape remained on the pavement up to 15 years after its initial placement. However, the reflectivity declined, as shown by the measurements for inlaid tape installations summarized in the table below (all yellow centerline tape).

Location	Years Installed	Yellow/Dry	Yellow/Wet
Oak Brook	1	520	70
Camp Ernst	3	480	40
Bullittsville	12	400	25
Rice Road/Hicks Pike	15	70	0

These inspections demonstrated that inlaid tape can be a durable material if it is installed properly during resurfacing. Construction crews made efforts to ensure that the tape was inlaid when the pavement was hot. While the reflectivity remained acceptably high during dry conditions for several years, the tape did not provide effective wet-nighttime delineation.

3.4 Wet Reflective Paint

Another material tested as part of this study was wet reflective paint, which was installed at three test locations. On US 31E in Nelson County, the paint was surface-applied to an existing pavement. The paint was also placed in a groove (with a depth of 50 mils) on both an existing pavement (KY1501 in Kenton County) and a new pavement (KY 420 in Franklin County). These installations were all on two-lane roads. The cost of the paint with no groove was $0.50 per linear foot compared to $0.65 per linear foot when placed in a groove.

The surface applied paint used on US 31E in Nelson County was installed in August 2013. The contract included 14,435 feet of yellow and 10,850 feet of white paint. The paint remained durable for a couple of years; however, major losses of reflectivity occurred within a year.

Nighttime observations during rain confirmed the loss of this reflectivity. Patched sections within the installation, which were repainted with typical traffic paint, offered better delineation than the wet reflective paint. Close inspection revealed the loss of large elements in the wet reflective paint, which were designed to provide delineation during wet conditions.

The following table summarizes the reflectivity measurements for the surface-applied installation of wet reflective paint on US 31E in Nelson County.

Date	White/Dry	White/Wet	Yellow/Dry	Yellow/Wet
Aug-13	880	no data	390	no data
Dec-13	460	180	280	110
May-14	160	55	160	45
Nov-14	160	50	140	45
May-15	110	40	110	30

In September 2013, wet reflective paint was installed in grooves on KY 1501 in Kenton County. Almost all of this installation took place on fairly old pavement on the two-lane road. Approximately 27,750 linear feet of yellow and white paint was used on the installation. Measurements identified reflectivity problems immediately following installation on some sections of the yellow centerline paint (especially on the oldest pavement). The yellow paint was restriped in 2014 with typical traffic paint. The following table summarizes reflectivity measurements for the yellow paint.

Date	White/Dry	White/Wet	Yellow/Dry	Yellow/Wet
Sep-13	800	no data	90-420	no data
Nov-13	475	300	150-370	40-250
May-14	420	225	130-220	55-100
Nov-14	410	170	no data	no data
May-15	400	180	no data	no data

Reflectivity measurements remained high for the white paint on dry pavement, although these declined under wet conditions. A short section of this test was on a new pavement. Reflectivity measured higher on the new pavement. A limited number of measurements were taken on the end portion of some yellow stripes that were not restriped. The measurements (taken in May 2015 on short portions of yellow paint) were slightly over 200 dry and slightly over 100 wet. Observations in May 2015 indicated that the yellow paint remained durable on the new pavement.

Wet reflective paint was installed (in a groove on new pavement) on KY 420 in Franklin County in May 2014 (21,375 feet of white paint and 18,799 feet of yellow paint was required for the two-lane road). The yellow center line was installed in a groove while the white edge line was placed over a milled rumble strip, resulting in a rumble stripe. Inspections have found

the paint is durable. Nighttime observations indicated the reflectivity is generally consistent, but there is a small section that has lower reflectivity. The following table summarizes the reflectivity measurements over the period before the section was restriped with typical traffic paint.

Date	White/Dry	White/Wet	Yellow/Dry	Yellow/Wet
May-14	620	480	330	280
Jul-14	500	330	200	160
Dec-14	420	240	160	150
Jul-15	390	140	120	110

3.5 Thermoplastic Material

A test section of ribbon thermoplastic was installed on KY 234 in Bowling Green, a four-lane, urban street. The thermoplastic material was placed in a groove that had a depth of 120 mils. The installation occurred in August 2013, and the contract cost was $1.05 per linear foot. The quantities were approximately 10,850 linear feet of four-inch yellow tape and 2,550 feet of four-inch yellow tape. There have not been significant problems with durability through 2016, which includes three winters. Some of the material showed signs of cracking, however, only a small percentage of material has been lost. The 2016 inspection noted an increase in the loss of material. The following table summarizes the reflectivity measurements (for white lane lines and yellow centerline).

Date	White/Dry	White/Wet	Yellow/Dry	Yellow/Wet
Sep-13	650	no data	440	no data
Dec-13	no data	no data	480	270
May-14	560	210	430	250
Jul-14	540	240	430	190
Nov-14	440	150	410	130
Jul-15	310	100	280	100
Apr-16	240	80	210	110

In 2013, large installations of spray and ribbon thermoplastic were placed for both lane and edge lines on Interstate 65 (I-65). The thickness of the spray was 60 mils, with the ribbon installed at 90 mils. The spray thermoplastic cost approximately $0.60 per linear foot for a six-inch line. After three winters only minor snowplow damage has been observed. The following table summarizes reflectivity data for white edge lines. The data for the spray thermoplastic

was taken from Simpson County, with the ribbon thermoplastic data coming from Barren County.

Date	Spray/Dry	Spray/Wet	Ribbon/Dry	Ribbon/Wet
Dec-13	360	70	530	110
Apr-14	410	90	400	110
Jul-14	420	120	450	110
Nov-14	420	50	360	50
Jul-15	220	30	240	90
Apr-16	200	30	220	70

There was some evidence of snowplow contact in the areas where the reflectivity data were collected, which may have contributed to the lower measurements starting in 2015. Reflectivity was not maintained during wet pavement conditions.

There have been more recent installations of ribbon thermoplastic on I-65 in 2015. Measurements were taken in Hart County a short time after installation. These indicated values of 840 on dry pavement and 280 on wet pavement. In 2016, data were collected at an installation of spray thermoplastic on the Cumberland Parkway in Barren County. The measurements at this location were 460 on dry pavement and 100 on wet pavement.

In August 2010, a short section of ribbon thermoplastic was placed in Washington County on KY 555. The material was installed on the white edge line over a milled rumble strip. The material remains durable after several years. The following table summarizes reflectivity measurements.

Date	Dry	Wet
Sep-10	530	220
Oct-11	770	no data
Oct-12	770	no data
Apr-13	730	no data
Aug-14	420	120
Oct-14	380	90
Jul-15	400	170

Thermoplastics were installed on interstates for a period several years ago. A 12-year-old section of thermoplastics on I-65 was inspected. The material remained in place with only minor losses. At this location the reflectivity of the white edge line was 230 for dry conditions, however this fell to zero for wet surface conditions.

3.6 Cost Analysis

KTC's research indicates that an effective lane delineation procedure for four lane roads would include:

- Recessed markers on lane lines (at 80-foot centers)
- Grooved wet-reflective tape for lane lines
- Spray thermoplastic for the edge lines.

The lane- and edge-line widths should be six inches. Compared to the current practice of using paint, this method would provide improved wet-nighttime delineation. But it is also important to compare the cost of different treatments. On a four-lane divided highway, the estimated material cost per mile over the life of the pavement (for both directions) is as follows:

- $6,600 for the 132 recessed markers
    - $40 for installation and $10 per lens replacement
- $7,920 for the grooved wet-reflective tape
    - $3 per foot, assuming 264 10-foot lane lines
- $25,344 for the spray thermoplastic edge lines
    - $0.60 per foot, assuming 21,120 linear feet with one restriping
- $39,864 total cost per mile for the life of the pavement
    - Assuming one replacement for the recessed markers and one restriping for the spray thermoplastic

In comparison, it would cost approximately $28,512 per mile to use traffic paint on lane lines and edge lines. This estimate assumes a 12-year pavement life and a cost of $0.10 per foot. As such, the cost of using more durable materials, which offer better wet-nighttime delineation, is not dramatically more than the cost of traffic paint.

3.7 Rumble Stripes

Rumble stripes were first installed and evaluated in 2009 (6). The FHWA defines a rumble stripe as a rumble strip that has been painted with a retroreflective stripe to enhance the visibility of the pavement edge at night, during poor weather, or both. The evaluation found that, in addition to the audible warning, rumble stripes provide increased wet-nighttime delineation through the portion of the edge line painted on the sloped portion of the groove. Observations during wet-nighttime conditions verified the improved reflectivity offered by the paint on the slope of the groove (which is not covered by water).

Several hundred miles of edge line and centerline rumble stripes have been installed in recent years in Kentucky as part of resurfacing projects. Crash data were analyzed to evaluate their effectiveness under different crash scenarios. The following table summarizes rates of crash reductions at rumble stripe and control locations, comparing the five-year period before installation to the four-year period after installation.

Percent Reduction (Five Years Before/Four Years After)		
	Rumble Stripe Locations	**Control Locations**
Total Crashes	8	4
Injuries	15	7
Lane Departure Crashes	9	6
Single Vehicle Crashes	4	+1
Wet Nighttime Crashes	20	10

The crash data illustrate the benefits that rumble stripes confer. These data indicate that road segments with rumble stripes have had larger reductions in crashes compared to the control segments which lacked them.

The largest difference between the rumble stripe and control locations was for wet nighttime crashes. This reveals the potential of rumble stripes to improve delineation under wet-nighttime conditions.

The significance of crash reductions at rumble stipe locations was tested using a procedure from the Highway Safety Manual (Computational Procedure for Implementing the Shift of Proportions Safety Effectiveness Evaluation Method). This test indicated that crash reductions were statistically significant ($p < .05$). The difference between the before and after proportions was calculated and used to conduct a Wilcoxon signed rank test.

Rumble stripes have also been installed as a retrofit to existing pavements. Durability problems were noted at some locations where the pavement was not in good condition. Based on field observations, the use of rumble stripes should be limited to new pavements.

4. CONCLUSIONS

The evaluation of the various materials and procedures results in the following conclusions concerning their future use.

- Snowplowable markers provide the most effective wet-nighttime delineation (both recessed and steel casting (Type V) markers). While both markers have advantages and disadvantages when compared against one another, durability issues associated with the Type V marker (related to the pavement condition for older pavements) make the recessed marker preferable over the life of the pavement.

- While the recessed marker is the preferred snowplowable marker, use of the steel casting (Type V) marker may continue, but only if: 1) it is properly installed on new pavements and 2) there is a commitment to maintain the pavement surrounding the casting in good condition. If used, the lenses in the steel casting marker should be replaced approximately every three to five years (depending on traffic volume). The stability of the casting should be inspected when the lenses are replaced.

- To ensure that snowplowable markers are installed at the proper location relative to the pavement joint, installation must be coordinated with paving operations.

- Snowplowable markers should be installed at the proper distance from the joint even if they are not in complete alignment with the lane lines.

- Based on its expense and poor ability to maintain reflectivity, wet-reflective paint should not be used in the future.

- Installation of the wet-nighttime materials and devices should generally be limited to new pavements. They may be installed on existing pavements that are still in very good condition.

- Wet reflective tape placed in a groove provided both dry- and wet-nighttime delineation and remained durable. This material maintained high dry and wet reflectivity levels and provides the only alternative (on multi-lane roadways) to snowplowable markers as a method to provide wet-nighttime delineation.

- Inlaid wet reflective tape provided high reflectivity for dry pavement, but results varied under wet conditions. Questions remain about its durability, given the damage inflicted by snowplows on the tape at one of the test locations.

- The durability of inlaid wet reflective tape is contingent on the tape being placed when the asphalt is at the appropriate temperature. Placement at the correct temperature ensures tape will be properly inlaid.

- The inconsistent performance of the inlaid tape argues against its expanded use.

- Thermoplastic material can be used as part of the pavement marking system but does not provide effective wet-nighttime delineation.

- The performance of thermoplastic material installed on the pavement surface supports its future use (for example, high volume, four-lane roads). However, since surface-applied thermoplastics will not provide effective wet-nighttime delineation it should be supplemented with snowplowable markers to provide wet-nighttime delineation.

- Although the grooved thermoplastic costs less than grooved tape, the wet reflective tape maintained much higher reflectivity levels (especially under wet conditions). Grooved tape provides the best option to establish wet-nighttime delineation in the absence of or as a supplement to snowplowable markers.

- The most effective durable marking system for interstates, parkways, and other rural multi-lane roads include a combination of snowplowable markers and either thermoplastic material or recessed wet reflective tape.

- When viewed across the life of the pavement, cost analysis indicated that using more durable materials, which improve wet-nighttime delineation, is not dramatically more expensive than typical traffic paint (which requires annual replacement on high volume roads).

- Edge line rumble stripes (i.e., painting the white edge line over a milled shoulder rumble strip) enhance wet-nighttime delineation and should be included in resurfacing projects on two-lane rural roads. Where pavement width permits, centerline rumble stripes should also be included. However, rumble stripes should not be used to retrofit older pavements.

- Centerline rumble strips can be combined with snowplowable markers (either recessed or steel casting) to provide maximum wet-nighttime delineation on resurfacing projects on rural, two lane roadways.

5. RECOMMENDATIONS

Based on the examination of material quality and durability, as well as installation procedures, the following recommendations are made to achieve optimal wet-nighttime delineation.

- Install recessed markers on interstates, parkways, and appropriate multi-lane roads.

- The Cabinet may consider spray thermoplastic on interstates and parkways (in combination with recessed markers).

- Install edge line and/or centerline rumble strips on two lane road resurfacing projects (using established guidelines considering pavement width).

- The Cabinet may consider grooved wet reflective tape for lane lines on high-volume multi-lane roadways in combination with recessed markers along lane lines and spray thermoplastic for edge lines.

6. REFERENCES

1. Agent, K.R.; “Evaluation of Wet-Nighttime Delineation,” Kentucky Transportation Center, University of Kentucky, KTC-13-5, May 2013.

2. “Wet-Reflective Pavement Marking Demonstration Project,” Iowa Highway Research Board, November 2011.

3. “Evaluating All-Weather Pavement Markings in Illinois,” Illinois Center for Transportation, December 2015.

4. Agent, K.R. and Green, E.R.; “Evaluation of the Use of Snowplowable Raised Pavement Markers,” Kentucky Transportation Center, University of Kentucky, KTC-09-09, April 2009.

5. Agent, K.R. and Pigman, J.G.; “Evaluation of Alternative Snowplowing Markers and Snowplowing Procedures,” Kentucky Transportation Center, University of Kentucky, KTC-13-07, June 2013.

6. Agent, K.R.; “Evaluation of Rumble Stripes,” Kentucky Transportation Center, University of Kentucky, KTC-10-1, January 2010.

7. APPENDIX

Photographs of Pavement Marking Materials

Initial Installation Procedure for Groove for Recessed Markers

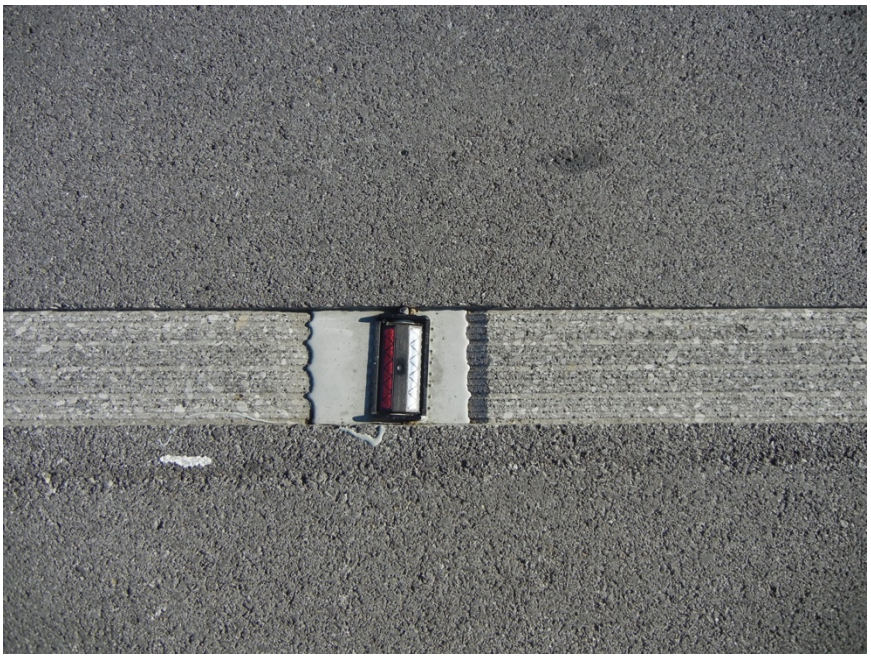
Recessed marker; Original Design

Installation of Recessed Marker

Recessed Marker Installation; Concrete Pavement

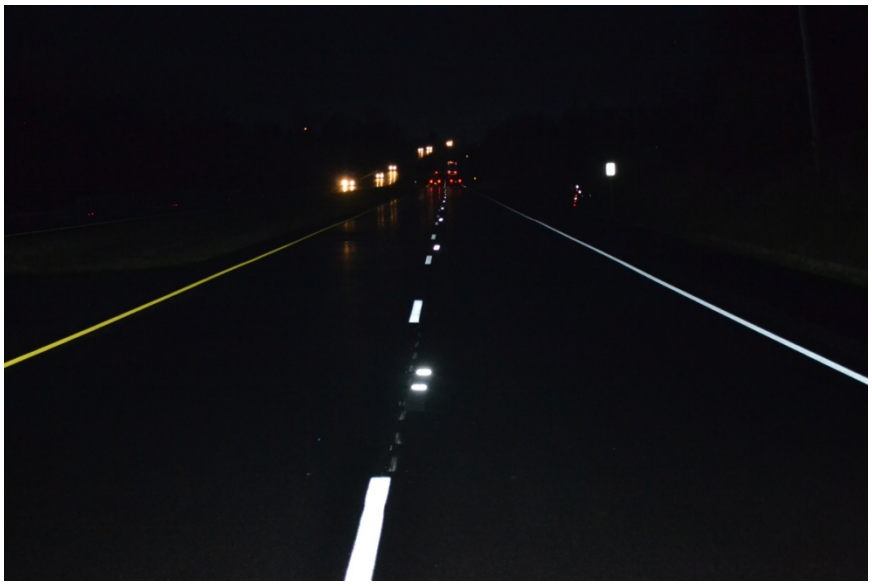
Recessed Marker Installed off Pavement Joint

Recessed Marker Installation



Recessed Marker Lenses

Jessamine County; US 27; Recessed Marker; Pavement Damp



Recessed Markers; Mercer County; US 127

Recessed Markers; US 27; wet-nighttime conditions

Recessed Markers; Woodford County; US 60

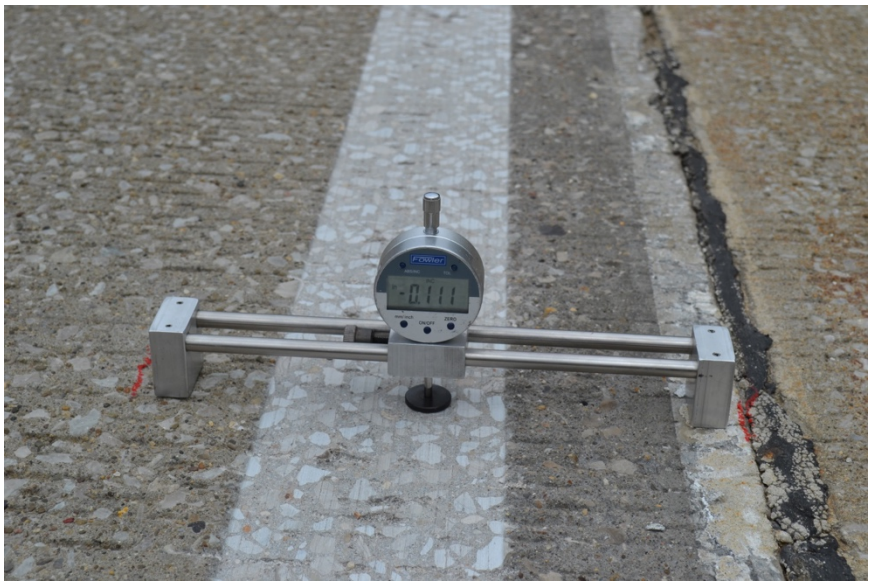
Comparison New and Old Recessed Marker Groove

Mercer County; US 127; Recessed Marker; Lenses Missing

Type V Snowplowable Marker; Installed Few Inches from Pavement Joint

Type V Snowplowable marker; Installed at Pavement Joint

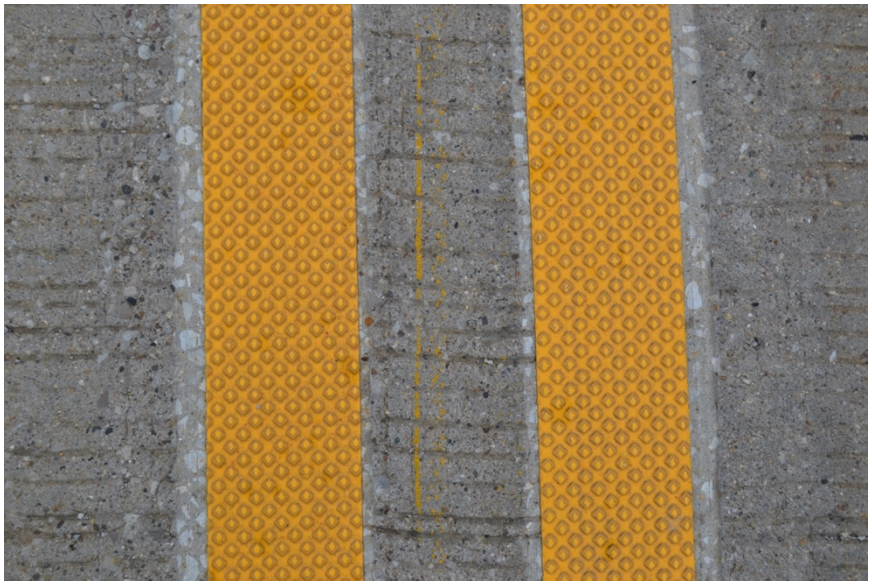
Type V Snowplowable Marker (Durability Issue with Poor Pavement)



Depth of Groove for Recessed Wet-reflective Tape

Installation of Wet-reflective Tape in Groove

Franklin County; US 127; Recessed Wet-Reflective Tape



Franklin County; US 127; Recessed Wet-Reflective Tape

Franklin County; US 127; Recessed Wet-Reflective Tape

Franklin County; US 127; Recessed Wet-Reflective Tape (Wet Conditions)

Franklin County; KY 420; Inlaid Tape; Snowplow Damage

Franklin County; KY 420; Inlaid Tape; Snowplow Damage

Franklin County; KY 420; Inlaid Tape

Franklin County; KY 420; Inlaid Tape (Wet conditions)

Henderson; Inlaid Tape

Henderson; Inlaid Tape

Henderson; Inlaid Tape

Groove Cut for Recessed Wet-Reflective Paint

Install Recessed Wet-Reflective Paint

Nelson County; US 31E; Surface Installation of Wet-Reflective Paint

Nelson County; US 31E; Wet-Reflective Paint (Surface Applied)

Nelson County; US 31E; Wet-reflective Paint; Surface Applied

Kenton County; KY 1501; Recessed Wet-Reflective Paint

Kenton County; KY 1501; Recessed Wet-Reflective Paint

Franklin County; KY 420; Recessed Wet-Reflective Paint

Warren County; KY 234; Recessed Ribbon Thermoplastic

Bowling Green; KY 234; Recessed Ribbon Thermoplastic; Wet Data Collection

Warren County; KY 234; Recessed Thermoplastic

Warren County; KY 234; Cracking of Thermoplastic Material

Washington County; KY 555; Ribbon Thermoplastic

Washington County; KY 555; Ribbon Thermoplastic; Wet Data Collection

Washington County; KY 555; Ribbon Thermoplastic (Wet Pavement)

Simpson County; I-65; Spray Thermoplastic

Simpson County; I-65; Spray Thermoplastic; Wet Data Collection

Simpson County; I-65; Spray Thermoplastic; Snowplow Damage

Barren County; I-65; Extruded Thermoplastic

Edge Line Rumble Stripe

Figure A-14. Rumble Stripe (Wet, Nighttime Condition) (Garrard County).

Retrofit Centerline Rumble Strip; Old Pavement

Barren County; Cumberland Parkway; Recessed Markers and Spray Thermoplastic

Rowan County; KY 32; Centerline Rumble Strip/Recessed Markers

Greenup County; KY 67; Centerline Rumble Strip/Recessed Markers