# MnDOT Pavement Marking Field Guide


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# Section A: Introduction

This Pavement Marking Field Guide has been created to assist Field Inspectors and Striping Equipment Operators in the field. It is intended to be used as a quick reference guide.

The information in this guide does not cover all situations encountered. Because all situations differ, engineering judgment is required. Refer to the Minnesota Manual on Uniform Traffic Control Devices (MN MUTCD) and the MnDOT Traffic Engineering Manual (TEM), for additional guidance.

This guide does not address the use of typical layouts for temporary traffic control zones necessary to safeguard the work zone while applying pavement markings. The user should refer to the Temporary Traffic Control Zone Layouts Field Manual (MN MUTCD Part 6K) for the appropriate layouts.

To assist the user of this Field Guide on state highways, addresses and phone numbers for the Minnesota Department of Transportation offices are included in the back of this manual. You may wish to note the number of other road authorities on the NOTES page in the back of this book.

## Permission to Work within the Right-of-Way

Prior to starting work, permission must be obtained from the governing road authority. All road work must be coordinated to protect the public interest.

The governing road authority may limit the hours of work. Peak traffic periods vary by hour or day of week and all work should be scheduled during non-peak hours.

When working in or near an intersection with a traffic control signal system, the road authority with jurisdiction over the signal should be contacted to ensure proper operation of the signal while the work is in progress. When traffic signals are set to flash red for all approaches, or turned off and temporary STOP signs are installed, the intersection may be treated as a unsignalized intersection. In the state of Minnesota only a licensed uniformed law enforcement officer has the authority to override a fully operating traffic control signal system.

The use of any regulatory temporary traffic control device or sign shall be approved by the governing road authority prior to installation.

## MnDOT Pavement Marking Guidance

Currently, guidance for MnDOT pavement marking operations is contained in the technical memorandum "MnDOT Provisions for Pavement Marking Operations." The purpose of the technical memorandum is to provide a consistent statewide approach for pavement marking operations on state trunk highways. This includes guidance on material usage for final pavement markings including both longitudinal lines and special markings (i.e. crosswalks, messages, etc.).

MnDOT continues to emphasize efforts to increase the performance of pavement markings throughout the State. These efforts have focused on improving equipment, streamlining maintenance operations, evaluating new materials, recessing markings, and investigating performance based specifications to better deliver MnDOT's goal to:

**Provide an appropriate pavement marking on all highways, 365 days per year.**

# Section B: Glossary

**Ambient Pavement Temperature**
Temperature of the pavement. (May or may not be the same as ambient air temperature.)

**Appropriate Pavement Marking**
One that meets or exceeds the standards defined in the MN MUTCD including any minimum levels of retroreflectivity, when weather permits. During winter operations, pavement markings should provide presence after pavement is clear of snow and ice.

**Barrel or Drum**
A container typically holding 55 gallons.

**Binder**
A material which holds glass beads to the road surface and provides the color of the pavement marking.

**Broken Line**
A pavement marking consisting of a cycle of marking segments and gaps. Broken lines are permissive; drivers are being informed that they are permitted to cross a broken line. Also referred to as a skip line. MnDOT typically uses a 50' cycle (10' line with 40' gaps between).

**Centerline**
A line indicating the division of the roadway between traffic traveling in opposite directions.

**Channelizing Line**
A line which directs traffic and indicates that traffic should not cross the line.

**Continental Block**
White longitudinal lines placed at crosswalks that are parallel to the flow of traffic.

**Contrast**
The ratio of luminance from a target to the luminance from the target's surroundings.

**Contrast Marking**
A marking with a black border used to enhance contrast with the pavement.

**Conventional Products**
Products such as latex paint with a shorter lifespan than durable products.

**Crosswalk** Marking
Markings that serve primarily to guide pedestrians along the proper paths through an intersection or across a roadway.

**Delineator**
A light-reflecting device mounted at the side of the roadway, in a series with others, to indicate the alignment of the roadway.

**Dotted Line**

A pavement marking consisting of a cycle of marking segments and gaps. Dotted lines provide guidance or warning of a downstream change in lane function. MnDOT typically uses a 15' cycle (3' line with 12' gaps between). For line extensions through intersections an 8' cycle is used (2' line with a 6' gap). In roundabouts the edge line extension is a 6' cycle (3' line with a 3' gap).

**Double Drop**

Dropping standard beads and wet reflective optics.

**Double Solid Line**

A pavement marking used on two-way undivided roadways to inform the driver of a no-passing zone in both directions of travel.

**Dry Film Thickness**

Thickness of line when dry and without glass beads.

**Durability**

Durability refers to a product's ability to withstand damage. The life cycle of a product is taken into consideration when evaluating durability.

**Durable Markings**

Marking materials designed to provide year round presence and retroreflectivity for at least two years.

**Durable Products**

Durable products include epoxy, thermoplastics, polyurea and poly preformed tapes. These products generally have a longer life span than conventional products.

**Edge Line**

A line which indicates the edge of the roadway.

- White solid lines delineate the right-most driving lane from the shoulder or ditch of the road.
- Yellow solid lines delineate the left-most lane of traffic from the shoulder or ditch of the roadway on divided highways, or the left edge of a one-way roadway.

**Epoxy**

Epoxy is a durable pavement marking material that is made up of two components. One component is the pigment and the second component is the hardener. Each component is heated separately and then thoroughly mixed and applied at a temperature of approximately 120 degrees F.

**Gap-to-Segment Ratio**

The ratio of the length of the gap in a broken line to the length of the marking segment.

**Glass Beads**

Glass beads are tiny spherical glass balls that are used to make pavement marking materials retroreflective. Glass beads are dropped on top of freshly applied conventional paints and durable materials such as epoxies. Glass beads can also be untreated or treated. Treated glass beads have a coating on their surface that enables the bead to sink into the paint, while the untreated beads float on the surface. Having a portion of the beads on the surface and in the paint allow

continued retroreflectivity as the paint wears. The proper application of beads is key in creating the marking's retroreflectivity.

**Gradation**
A measure of the sizing of an application of glass beads. The two variables are the overall range of sizes and the percentage by weight of each size.

**Gravity Extrusion**
A method of applying a pavement marking material that uses gravity to force the material out of a specifically sized die.

**Grooving**
The process of placing the pavement marking materials below the pavement surface by creating a long narrow channel or depression in the road.

**Guideline**
A pre-marking applied to the pavement to guide the operator of a striper in applying the final pavement markings. Can also be referred to as a drip line.

**Hazardous Waste**
With respect to removal of pavement markings, waste debris created may be toxic (see Toxicity in Specified Products) and/or flammable and require handling and disposal procedures prescribed by waste management laws, rules, and regulations.

**Hiding**
Hiding is the ability of a paint to cover or block out the surface (substrate) beneath it.

**High-Build Latex Paint**
A high-solids, water-borne paint that is thicker, more durable, and takes longer to cure than regular latex paint.

**Index of Refraction**
For a given material, the index of refraction is equal to the ratio of the speed of light in a vacuum to the speed of light as it travels through the material. It describes the "light bending" property of a glass as the light wave passes from the air to glass or vice versa. It is a measure of the brilliance of retroreflectivity for glass spheres.

**Inlaid**
The process of using a compaction roller to embed Preformed Tape into new bituminous surfaces. Manufacturer's specifications should be consulted for the proper surface temperature range for the material being used

**Lane Line**
A line separating two lanes of traffic traveling in the same direction.

**Latex Paints**
A pavement marking that is water-based. It is typically considered a conventional material. Latex is a quick dry material. It is also referred to as waterborne paint.

**Linear Foot**
A measurement of length.

**Longitudinal**
Running lengthwise; placed lengthwise; parallel to direction of traffic.

**LTL-X and LTL-2000**
The brand name of a held-held retroreflectometer currently being used by the State of Minnesota.

**Lux**
The metric unit of illuminance, one lux is equal to the illuminance corresponding to a luminous flux density of one lumen per square meter.

**MCD**
The abbreviation for millicandela.

**MCD/m$^2$/lux**
It is the unit of retroreflectance.

**Mil**
Unit of length equivalent to 0.001 inches.

**Non-Hazardous** Waste
With respect to the removal of pavement markings, this waste debris may be disposed of using less stringent criteria. This would make it acceptable at some in-state waste facilities as designated by the Office of Environmental Services.

**No-Track Time**
The time required for the applied marking to resist being picked up by vehicle tires and transferred to the adjacent pavement.

**Object Markers**
Markings intended for use on obstructions within or adjacent to the roadway.

**Overspray**
Spray pattern exceeding the desired pattern; e.g., spraying of product in a fine mist beyond the proposed edges of the line being marked.

**Paint**
A conventional water based pavement marking material. Also referred to as latex.

**Pavement Markings**
All lines, symbols, words, colors, or other devices set into the surface of, applied upon, or attached to the roadway at specific locations to guide, warn, regulate, or inform drivers.

**Pavement Message**
All non-longitudinal pavement markings. Some examples are words, symbols, and arrow markings.

**Performance Specification**
A specification written to describe pavement marking materials based on their performance.

**Pigment**
Material in a pavement marking that provides the marking with its color and also provides the necessary diffuse reflection at the back of the glass beads in a pavement marking to create retroreflectivity.

**Plural Component Material**

Any two-part pavement marking system consisting of part A (resin) and part B (catalyst). The resin is the colored part and the catalyst is the clear part. Also referred to as a "binder". Epoxy, polyacrylate, and modified urethane are some examples of plural component materials.

**Preformed Polymer Pavement Marking Material**

Often referred to as "tape," this is a durable material. Tape can be inlaid into freshly placed bituminous surfaces or grooved into bituminous or concrete. Temporary tape can be glued into place on older bituminous or concrete surfaces.

**Polyurethane, Polyurea**

A modified epoxy that is more UV stable.

**Preformed Thermoplastic Pavement Marking Material**

Thermoplastic is a durable pavement marking material composed of glass beads, pigments, binders (plastics and resins) and fillers. This material comes in precut plastic pieces that are heated into the pavement surface. MnDOT uses preformed thermoplastic for pavement messages and crosswalks.

**Pretreatment**

Preparation of a pavement surface for installation of delineation devices, usually consists of cleaning and/or priming.

**Qualified Products List (QPL)**

This is a list of products, such as pavement markings, that are predicted to meet all applicable standards and specifications. Random sample testing is required to verify that specific product lots meet specifications prior to usage. This is also known as the Approved Products List (APL) and can be found at: http://www.dot.state.mn.us/products/index.html.

**Recessed**

The process of placing the pavement marking materials below the pavement surface. This can significantly increase the life expectancy of the marking. Examples of recessing techniques would be grooving, inlaying, installing in a sinusoidal rumble strip, slightly raising the traveled lanes (while leaving the marking area recessed).

**Reflective**

Bending or turning light.

**Resin**

Substance made by chemical synthesis, especially those used in the making of plastics.

**Retroreflectivity**

Retroreflectivity refers to reflection in which originating light is turned in directions close to the direction from which it came. The retroreflectivity of the pavement marking material makes it visible to drivers at night when their vehicle's headlights reflect off the material. It is usually measured in candelas/lux/square meter, which is equivalent to candelas/foot-candle/square foot.

**Retroreflectance**

This is a term used to describe the amount of light reflected from a retroreflective material. This light is measured in candlepower (reflected) per foot candle (incident light) per square foot (of reflected material).

**Roadway**

That portion of a highway used for vehicular travel, exclusive of the berm or shoulder. A divided highway includes two or more separate roadways.

**Rumble Stripes**

Rumble stripes are defined as a rumble strip that contains a pavement marking stripe. These will be referred to as either edge line rumble stripes or centerline rumble stripes.

**Rural Trunk Highway**

State owned roadway segments that have minimal residential or commercial development and where little or no further development is anticipated in the near future.

**Service Life**

The time required for a pavement marking to become ineffective due to loss of retroreflectivity or presence.

**Sharks Teeth**

Triangular shaped markings placed as a yield line.

**Shoulder Rumble Strips**

Rumble strips outside of the edge line.

**Silica**

Silicon dioxide is one of the major oxide constituents of glass used for manufacturing glass beads.

**Skinning**

A condition commonly occurring with paints in the container and when applied as a line or strip where the immediate surface dries first or “skins” and the under surface remains wet (as opposed to through set of a film).

**Slow-Dry Materials**

Products that take longer than ten minutes to dry are called slow-dry. They are usually epoxies or thermoplastics. Traffic control such as coning and/or flagging is required when applying these materials.

**Solid Line**

A continuous pavement marking. Solid lines are restrictive; drivers are being informed that they are not to cross a solid line.

**Spotting**

A technique for pre-marking pavement at predetermined intervals to guide the operator of the striping machine when applying permanent pavement markings.

**Spraying**

A procedure for applying marking material to a surface:

Air Atomizing Spray - Spraying atomization of the liquid paint through air pressure only.

Airless Spray - Where spraying atomization of the liquid paint is accomplished through hydraulic fluid pressure only. No atomization air is used.

**Stop Line**
A line which indicates where vehicles should stop when directed to stop. Also referred to as a Stop Bar.

**Striper**
A self-contained marking system mounted on a truck chassis and used on the road to apply pavement markings.

**Tapes**
Tapes are also referred to as “preforms.” This is a durable marking product that is inlaid on freshly laid bituminous surfaces or is grooved into concrete and older bituminous surfaces.

**Temporary Tape**
Temporary tape is a pavement marking material that is used in work zones for a short period of time. Temporary tape can be utilized to minimize pavement scarring.

**Temporary Raised Pavement Markers (TRPMs)**
TRPMs are a plastic marking device that may be used to simulate solid lines without the use of any other pavement marking material and may be used to supplement other types of pavement markings.

**Totes**
The largest bulk size deliverable for paint and glass beads. Paint totes contain 250 gallons. Glass bead totes contain 2000 pounds.

**Transverse**
Lying, situated, placed across from side-to-side; crosswise. Also, perpendicular to the center line.

**Viscosity**
A measure of a fluid’s tendency to resist flow. Also, the constant ratio of the shearing stress to the rate of shear in the liquid.

**Waste Debris**
With respect to pavement marking materials, white or yellow-colored paint/ bituminous or concrete mixtures generated by the removal of pavement markings.

**Waterborne Paints**
See latex paint definition.

**Wet Recoverable Materials and Processes**
Materials or installation processes that enhance performance of pavement markings during wet weather conditions but still lose retroreflective properties when covered with water. Examples of these include larger glass beads, profiled markings, and rumble stripes. All wet recoverable materials shall be recessed to ensure continued wet weather performance after snow plowing operations. To ensure performance, these materials and processes should be installed as recommended by the manufacturer.

**Wet Reflective Materials**

Materials that enhance performance of pavement markings during wet weather conditions and retain their retroreflective properties when covered by water. Examples of these materials are those that contain specialized retroreflective elements that retain retroreflectivity when covered by water. All wet reflective materials shall be recessed to ensure continued wet weather performance after snow plowing operations. To ensure performance, these materials and process should be installed as recommended by the manufacturer.

**Wide Line**

A line wider than twice the width of a standard line, 4-inch width.

# Section C: Standard Practices

## Functions and Limitations

Pavement markings provide traffic control and positive guidance. In some instances, they supplement the regulations or warnings of other devices such as traffic signs or signals. In other instances, they are used alone, producing results that cannot be obtained by any other device. Accordingly, markings effectively convey certain regulations and warnings that may not otherwise be clearly understandable.

Pavement markings have definite limitations. They may be obscured by snow, may not be clearly visible when wet, and may not be very durable when subjected to heavy traffic. Despite these limitations, under favorable conditions, pavement markings can convey warnings or information to the driver without diverting his/her attention from the roadway.

## Standard Applications

Each standard marking shall only be used to convey the prescribed meaning in the Minnesota Manual on Uniform Traffic Control Devices (MN MUTCD). Before any new highway, roadway detour, or temporary route is opened to traffic, all necessary markings shall be in place.

Markings no longer applicable, including preparatory markings, which may confuse the driver, shall be removed or obliterated as soon as possible. Road conditions and restrictions may require other markings. However, these markings should be removed or obliterated after the conditions improve or the restrictions are withdrawn. Also, all pavement markings shall be reflectorized.

## Colors

Pavement markings shall conform to standard highway colors as defined in the MN MUTCD, Section 3A.5.

## Longitudinal Pavement Markings

Longitudinal pavement markings conform to the following basic concepts:

- Yellow lines delineate the separation of opposing traffic flows or mark the left edge of the pavement on divided highways and one-way roads.
- White lines delineate the separation of traffic flows in the same direction or mark the right edge of the pavement.
- Broken and dotted lines are permissive.
- Solid lines are restrictive.
- The width of a line indicates the degree of emphasis.
- Double lines indicate maximum restrictions.
- Raised pavement markers serve as position guides and may supplement other types of markings.

## Widths and Patterns of Longitudinal Lines

The widths and patterns of longitudinal lines are as shown in Figure C-1 (see also MN MUTCD, Section 3A.6):

- A normal width line is 4 or 6 inches.
- A wide line is at least twice the width of a normal line. The typical width of a wide line is 8 inches.
- A double line consists of two normal width lines separated by a 4 inch space.
- A broken (standard skip) line consists of 10-foot segments and 40-foot gaps.
- A dotted line for intersections and interchanges typically consists of 2-foot segments and 2 to 6-foot gaps.
- Dotted lines for lane drop markings consists of 3-foot segments and 12-foot gaps.

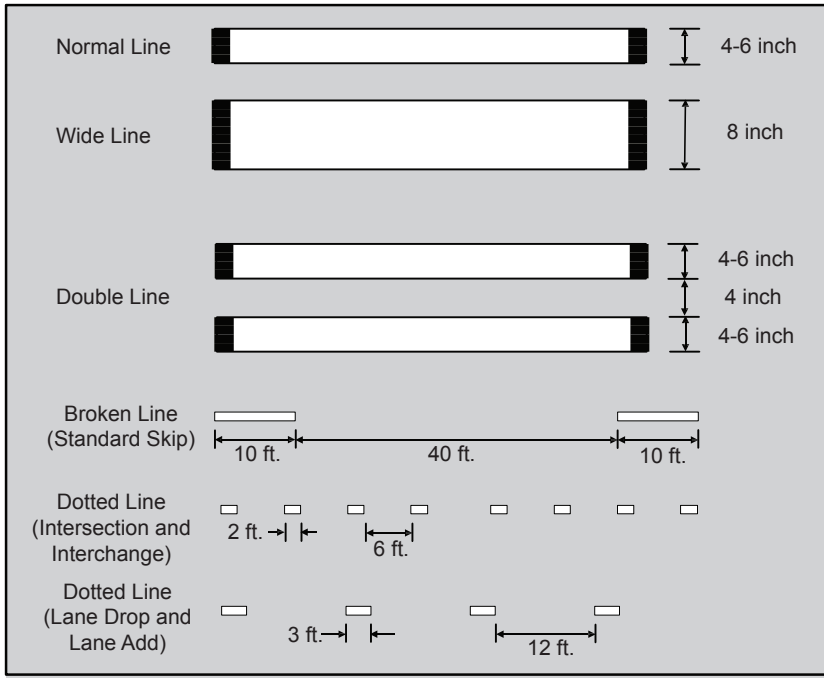



**Figure C-1: Widths and Patterns of Longitudinal Lines**

## Longitudinal Lines

The following examples illustrate the application of the principles and standards set forth in the previous sections.

- A normal, broken, white line is used to delineate lanes where travel is permitted in the same direction on both sides of the line. The most frequent application is as a lane line for a multi-lane roadway.
- A normal, dotted, white line provides guidance or warning of a downstream change in lane function. A wide dotted white line may be used for greater emphasis.
- A normal, broken, yellow line is used to delineate the left edge of a travel path where travel on the other side of the line is in the opposite direction. A frequent application is as a centerline of a two-lane, two-way roadway where overtaking and passing is permitted.
- A normal, solid, white line is used to delineate the edge of a path where travel in the same direction is permitted on both sides of the line. Crossing the line is discouraged but not prohibited. It is also used to mark the right edge of the pavement. Frequently this is used as a lane delineation line when approaching an intersection. A wide solid white line is used for greater emphasis.
- A double, solid, white line is used to delineate a travel path where travel in the same direction is permitted on both sides of the line but crossing the line is prohibited. It is frequently used before obstructions guiding the driver to pass on either side of the obstruction.
- A double line consisting of a normal, broken, yellow line and a normal, solid, yellow line delineates a separation between travel paths in opposite directions permitting traffic that is adjacent to the broken line to pass “with care” and prohibiting traffic adjacent to the solid line from passing. This is a one-direction, no-passing marking. It is used on two-way, two- and three-lane roadways to regulate passing. It is also used to delineate the edges of a lane where travel in either direction is permitted as part of a left-turn maneuver. To permit a left turn maneuver, the marking shall be placed with the solid lines on the outside and the dashed lines to the inside of the lane. Traffic adjacent to the solid line may only cross this marking during a left-turn maneuver.
- A double line consisting of two normal, solid, yellow lines delineates travel in opposite directions prohibiting passing in both directions. This is a two-direction, no-passing marking. Crossing this marking “with care” is permitted only when making a left turn. It is frequently used before an obstruction that must be passed on the right or to form a channelizing island separating traffic in opposite directions.
- A double, normal, broken, yellow line delineates the edge of a lane where direction of travel periodically changes and the line serves as a centerline at some point. It is used for a reversible lane.
- A normal, dotted line is used to delineate a line through an intersection or interchange area. It shall be the same color as the preceding line.
- A solid, yellow line delineates the left edge of a travel path to restrict passing on the left or to delineate the left edge of each roadway of divided streets or highways, one-way roadways, and ramps in the same direction of travel.

## Transverse Markings

Transverse markings, which include shoulder markings, word and symbol markings, stop lines, crosswalk lines, speed measurement markings, and parking space markings shall be white. However, transverse median markings shall be yellow. Blue and red are permitted under certain circumstances.

Because pavement markings are viewed from a low angle, transverse lines are proportioned to give visibility equal to that of longitudinal lines. Pavement marking letters, numerals, and symbols shall adhere to the MN MUTCD and to the markings section of the Minnesota Standard Signs Manual.

# Section D: Retroreflectivity

Using beaded lines for nighttime reflectivity is now accepted worldwide. The advantages of using reflective beads are apparent when driving on a rural road at night. Added benefits of reflective beads are to protect marking material from tracking and to improve durability.

Unbeaded paint lines will reflect light randomly in all directions. When round reflective beads are added, light is reflected directly to the source of the light. In the industry, this is called retroreflectivity. The following illustrations demonstrate this.

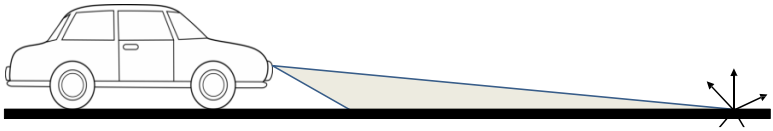


**Figure D-1: Roadway with Unbeaded Markings**

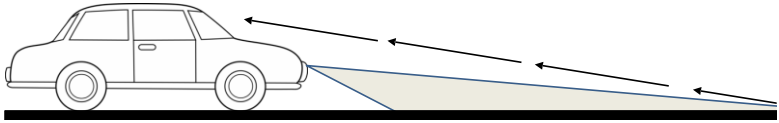


**Figure D-2: Roadway with Beaded Markings**

In Figure D-1 the light rays from an automobile's headlights illuminate a surface that does not retro-reflect. The light shining on the road, or an unbeaded line, is reflected in all directions. Only a very small amount is reflected directly back to the driver.

The beaded line illustrated in Figure D-2 produces a much greater quantity of light reflecting directly back into the driver's eyes. Therefore, the driver sees the line better.

MnDOT Standard Specification 2582.3.C.3 requires that markings shall meet a minimum level of retroreflectivity. Pavement markings that meet these minimum initial levels of retroreflectivity will generally meet service life expectations.

Research has shown that the threshold between an acceptable and an unacceptable pavement marking based on nighttime driver visibility needs is between 80 and 120 MCD/$m^2$/lux. MnDOT has adopted the minimum performance of 100 MCD/$m^2$/lux for a white line and 80 MCD/$m^2$/lux for a yellow line. These minimum performance values are used to schedule maintenance or replacement of all pavement marking installations and used to determine when pavement marking materials can be left beyond expected service life.

# Section E: Retroreflective Glass Beads

Glass beads are tiny spherical glass balls that are used to make pavement marking materials retroreflective. Glass beads are dropped on top of freshly applied conventional paints and durable materials such as epoxies.

## Components

Most beads used in pavement markings are made from recycled glass. Beads with higher refractive indices (RI) are made from virgin glass and have a different chemical makeup. Glass beads can also be untreated or treated. Treated glass beads have a coating on their surface that enables the bead to sink into the paint, while the untreated beads float on the surface.

Beads are generally shipped in 50-pound bags with 40 bags shrink-wrapped on a pallet. They may also be shipped in 2000-pound totes or bags.

## Characteristics of Glass Beads

### *Refraction Index*

When light strikes a bead it is refracted and reflected. Refraction is the bending of the light. Refraction is observed when a pencil is dropped into a half filled glass of water; the pencil appears bent. The amount of refraction of light is characteristic of the glass itself and is known as the refractive index (RI) of the glass or bead. The refractive index of the glass is dependent upon the chemical and physical make-up of the glass material. Various types of beads have different indices of refraction and cause different amounts of light to be retroreflected. Glass beads used in the pavement marking industry are available in RIs of 1.50, 1.65, and 1.90. The glass bead material with a RI of 1.90 is very expensive to produce and not as durable as the soda glass type. Ceramic beads are typically used in pavement marking tape and other wet retroreflective products. They have a RI of 2.4-2.6.

The retroreflectivity of glass beads is better explained by examining the path of light as it enters a single bead in the paint as shown in Figure E-1. There are actually millions of tiny beads in each mile of beaded line that must perform this principle

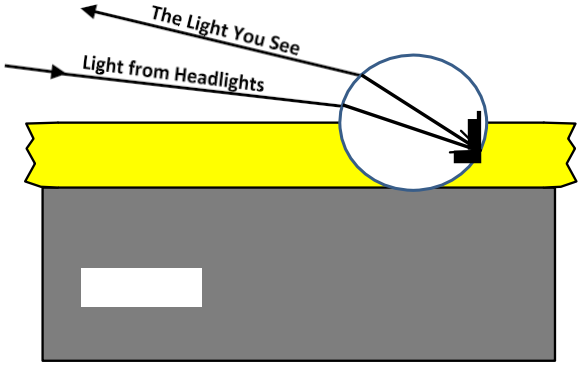



**Figure E-1: How Beads Reflect Light Back to Source**

As the headlight beam enters the bead, it is bent or refracted downward. This beam then shines on the back surface of the bead, which is embedded in the binder. It works a lot like a mirror. If the binder were not present, the light would continue through the bead and bounce in several directions. This is one reason for proper bead embedment depth. The light is bent (refracted) downward by the curved surface of the bead to a point below where the bead is embedded in the paint. Thus, when light is reflected off the paint at the back of the bead, a large portion of that light is reflected through the bead and refracted back toward your eyes.

## Application Considerations

Reflective beads for painted markings are typically applied under pressure. A separate gun adds reflective beads to the wet paint at the time of application. This is necessary for the beads to achieve the proper embedment in the paint before its fast drying nature causes it to form a surface skin. The bead supply tank is pressurized to force the beads through the system to the bead gun. Since the system is under pressure and is not loaded in a vacuum, moisture can condense inside the tank and cause clogging problems. For this reason, the manufacturer usually adds a moisture-proofing agent. Bead application rates are dependent on material type.

The proper placement of beads and pavement marking material on a road surface is the most important step in obtaining a durable reflective line. During this process, all variables must be controlled. The following must be considered.

### *Pavement Surface*

Most highway marking material is applied on Hot Mix Asphalt (HMA) or Portland Cement Concrete (PCC). The major problem with these surfaces is obtaining a lasting bond between the binder and the substrate. This bond may be affected by dirt, substrate texture, the chemical or mechanical properties of the surface, concrete latency, curing compounds, and road surface oils in new HMA pavement. The presence of residue, expansion joints, cracks, and sealants can adversely affect the performance of the line. Surfaces should be clean and dry when the marking is applied.

### *Binders*

The resin in the marking material (paint, thermoplastic, etc.) is the “glue” adhering the beads to the road surface. The pigment/binder thickness is an important variable closely related to bead retention and the quantity of beads used. The type and quantity of pigmentation and filler play an important role in the retroreflectivity of the beads as well as the daylight appearance of the line. After the best striping materials are selected, the three most important variables involved in the application of lines are the equipment, operator skill, and ambient conditions.

### *Bead Embedment*

Retroreflectivity and line durability is dependent upon the embedment depth of the bead in the binder. For optimum retroreflectivity and durability, a bead should be embedded at 50-60% of its diameter. Embedment of less than 50% may affect the longevity of the beads. Increasing embedment beyond 60% significantly decreases the amount of light that can be directed back to the driver. A bead totally embedded in the binder is non-retroreflective because no light enters the bead. Not all beads will be embedded 50-60%. Some beads will be completely buried and others will be embedded less than 50%.

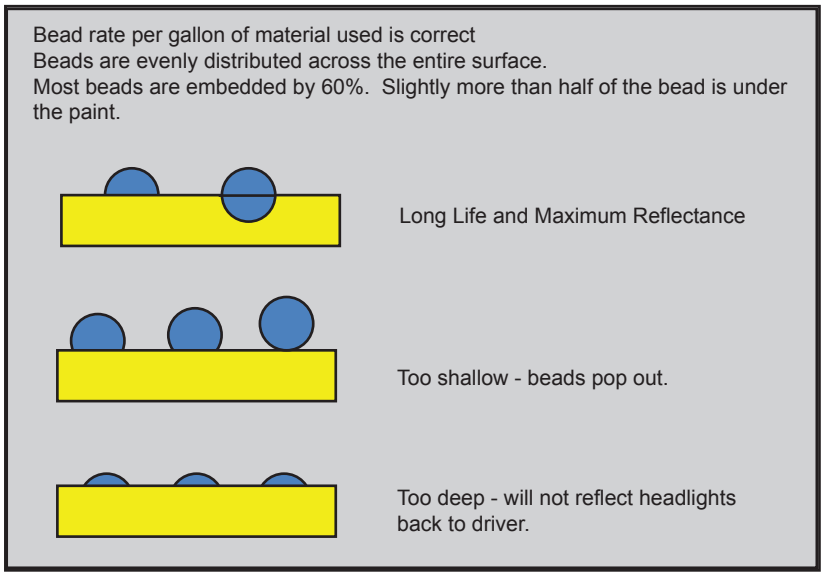



**Figure E-2: Bead Embedment**

A new line will generally have 70% of all the beads completely buried in the paint or other marking material. The remaining 30% will be embedded in the surface and exposed to the headlights. Figure E-3 illustrates the embedment of various sizes of beads in a 15 mil wet line. Figure E-4 illustrates proper bead embedment. Figure E-5 shows beads that were sprayed too late behind the paint operation. The beads in this picture are insufficiently embedded. Figure E-6 and Figure E-7 show beads embedded in a paint line that is too thin.

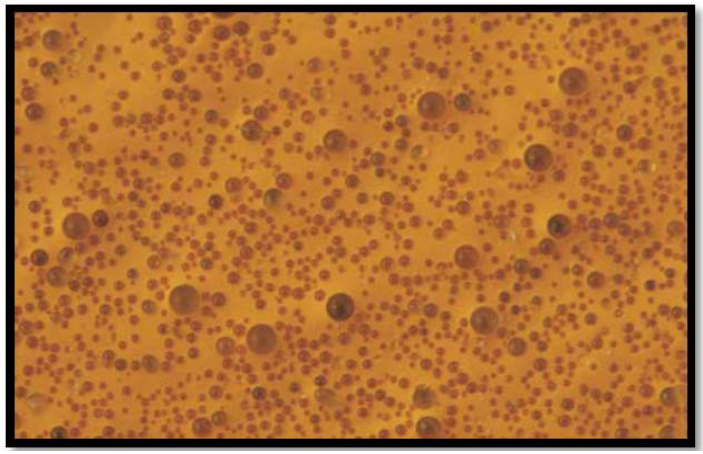


**Figure E-3: Beads in a 15 mil Wet Line**

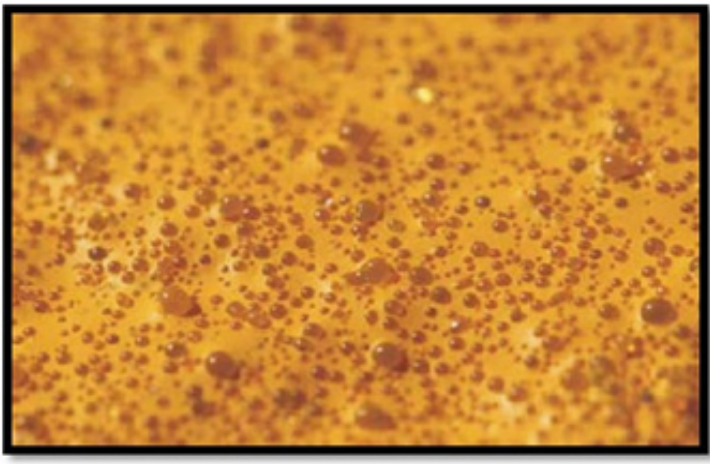


**Figure E-4: Reflective Bead at Proper Embedment Depth**

**Figure E-5: Improper Bead Embedment**

**Figure E-6: Top View - Reflective Beads Applied that are Too Thin**

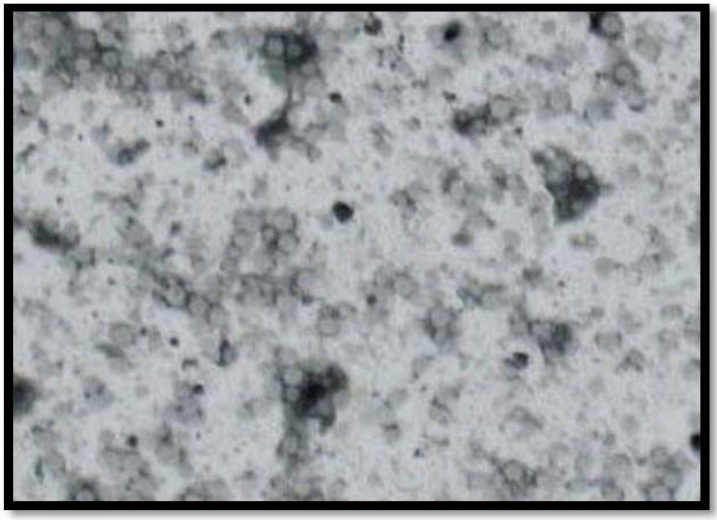


**Figure E-7: Magnified View - Reflective Beads that are Too Thin**

### *Equipment*

The application equipment must be in good condition and properly designed for the type of product it is to apply. The development and use of computer-aided delivery systems have helped provide adequate means to accurately control film thickness and bead application rates.

**Figure E-8: Typical Bead Application**

### *Operator Skill*

Operator skill is essential to achieve reasonable control over “liquid markings” and bead application. This applies to both the driver of the vehicle and the operator of the application controls.

### *Ambient Conditions*

Pavement markings shall only be applied when the ambient conditions will give the best results. When striping must be done under more adverse conditions, the results may be affected.

Chart E-1 on the following page is a troubleshooting guide for bead application problems.

## Chart E-1 Retroreflective Bead Trouble Shooting Guide

| PROBLEM | CAUSE | EFFECT | REMEDY |
|---|---|---|---|
| Beads on one side | ▪ Bead gun out of alignment.<br>▪ Clogged bead gun. | Poor night visibility. | Adjust alignment of gun cap. |
| Excessive Bead Use | ▪ Worn gun needle, seat and orifice.<br>▪ Excessive glass bead pressure. | Supply problems. | ▪ Rebuild gun.<br>▪ Decrease pressure. |
| Beads in Middle of Line | ▪ Bead tank pressure too low.<br>▪ Bead gun “off” and “on” control screw not adjusted.<br>▪ Bead gun cap out of alignment.<br>▪ Too big of a bead gun tip. | Poor night visibility. | ▪ Increase pressure.<br>▪ Adjust control screw.<br>▪ Align cap deflector.<br>▪ Change to a smaller tip. |
| All beads buried | ▪ Bead gun too close to paint.<br>▪ Bead gun angle too shallow.<br>▪ Excessive paint millage. | Poor night visibility. | ▪ Re-align bead gun.<br>▪ Adjust angle of bead gun.<br>▪ Check wet millage thickness. |
| All beads on top of line | ▪ Bead gun too far from paint gun. | ▪ Loss of durability.<br>▪ Initial very bright line. | Re-align bead gun. |
| Pulsed bead application | ▪ Bead tank pressure inadequate. | ▪ Violates standard.<br>▪ Loss of effectiveness. | ▪ Raise tank pressure.<br>▪ Rebuild applicator to increase pressure. |
| Excessive amount of beads on road beside line | ▪ Too much overlap of bead pattern on line pattern. | Loss of retroreflectivity. | Move bead gun closer to roadway. |

# Section F: Latex Paint

## Latex Paint

Traffic paint is a thin layer of blended material. This chapter will describe latex (waterborne) traffic paint. Reflective beads are added to the surface of the paint during application to produce nighttime retroreflectivity.

## Components

Paint is mainly composed of finely ground pigments that are mixed into a resin or binder system. Various ingredients and additives are incorporated for certain desired properties. A liquid (water) is added to the mixture to produce a material that is pliable by application equipment. All of the ingredients/components in traffic paint are added specifically for one or more of the following functions: aiding the manufacturing process, increasing storage time in containers, easing application, and increasing durability once the paint has been applied.

## Pigments

Prime pigments are used to impart chemical properties such as UV stability or physical properties such as color and hiding. Hiding is the ability of a paint to cover or block out the surface (substrate) beneath it.

Once the necessary amount of prime pigment is added for hiding, less expensive extender pigments or fillers are used to bring the pigment level up to the required point. Extender pigments not only reduce cost, they give paint consistency, durability, permeability, and scrub-ability. These properties are very important when considering the harsh environment and abuses that traffic paint must withstand.

## Resins or Binders

The resin is the component that bonds the pigment and beads together. It also provides the adhesion to the road surface. The resin is the binder or glue in paint.

Latex paints typically use three types of resins. They are polyvinyl acetate latex, methyl methacrylate, or a one hundred percent acrylic resin. These materials are pre-reacted and put into solution using emulsifiers. These emulsions are materials that normally do not mix. Once the paint has been applied, it must allow the water to evaporate in order for the paint to “break” and adhere to the roadway. This settling is generally called coalescence. One hundred percent acrylics are used predominantly due to faster “no track” times and less heat needed during application.

Because of high humidity, latex paint will take longer to dry. Therefore, on low humidity days, latex paint will dry much faster. When there is less water in the air, the water can leave the film or evaporate much faster.

## Characteristics of Latex Paint

There are many disadvantages and advantages to using latex paints for pavement markings. One major disadvantage of latex paint is its sensitivity to temperature. Precautions must be taken to protect stored material from freezing and extreme heat. During application, latex paint is very sensitive to high humidity, which can drastically increase drying time. Conversely, low humidity creates a quicker drying time. Paint is

also the least durable of all the markings and is not recommended for roadways with high traffic volumes.

One advantage of latex paint is cost. It is the least expensive of all pavement markings. It can also be applied at a faster rate than most other markings and under ideal conditions can have a very fast dry time. Also, no solvents are needed for cleanup. Fast dry latex paint will achieve its best drying times under perfect ambient conditions: daytime, sunny, 70°F, low humidity, and a breeze.

Some characteristics of latex paint are:

- Heat sensitivity
- Freezes easily
- Strong ammonia odor
- Humidity may affect drying times
- Can be flushed out with water and/or ammonia
- Generally not a hazardous waste for disposal - placarding not required (dependent on formulation)
- Reacts adversely to metals other than stainless steel
- Requires specially lined drums to prevent chemical reaction
- Can settle in the drum
- Unused paint is hazardous waste for disposal purposes
- Can be very flammable
- Can easily settle in drum

Latex paint is a one-component material that is generally shipped in 55 gallon drums with full open top lids or in 250 gallon totes. Latex paint generally has a shelf life of one year. This information should appear on the shipping documents. Quality assurance tests may be performed to confirm that the original formulation is approved by the government agency and to verify the manufacturer's certification.

## Application Considerations

Traffic paint is applied by conventional or airless spraying.

### *Conventional*

Conventional spraying uses air jets in the tip of the paint gun to break up, or atomize the paint. The tip then defines the shape of the spray to produce a properly applied line. The quantity of atomizing air needed to sufficiently break up the paint will depend, to a large extent, on the paints rheology or flow characteristics.

The pressure needed to force the paint through the application system and out of the gun can vary from 60 to 140 psi, depending on the size of the plumbing and the type of spray gun used. This can be achieved using one of the following methods:

- In a pressure-pot system, the holding tank is pressurized to push the paint through the heat exchangers and lines to the gun for application.
- In a pumper system, the holding tank is not pressurized. A diaphragm pump is used to draw the paint from the tank and force it through the system and out to the gun.

### *Airless*

In an airless system, the paint is forced out through a tiny hole in the tip of the gun at a high pressure, typically 2500 to 3000 psi. The size of the hole determines how much paint is applied and the angle of the inner surfaces of the tip determines the width. Unlike the conventional system, there is no air mixed with the paint in the gun. The pressure created by the pump mechanism explosively forces the paint through the gun tip breaking the paint up into very small particles. The primary method for altering the width and thickness of the applied line is to change the tip.

Additional factors must also be considered when applying traffic paint and are described in the following sections.

### *Material Temperature*

The manufacturer's Product Data Sheets specify the material application temperature ranges. Fast-dry (ammoniated), latex paint only needs enough heat to allow a good flow of material through the application system (generally in the range of 90°F to 120°F at the gun tip).

Overheating fast dry, latex paint can also "drive off" the methanol and ammonia creating longer dry times. These two additives act as driers to keep the paint film open, helping the water escape.

### *Ambient Conditions*

Latex paint requires liquids to evaporate. This evaporation is dependent on the humidity (moisture in the air). Humid days will cause drying problems. Lower humidity and good air movement greatly improves latex materials drying. To achieve the optimal results, neither solvent nor latex traffic paint shall be applied below 50°F (air temperature).

### *Pavement Surface Considerations*

The pavement shall be free of dirt, oil, grease, laitance, curing compounds, and moisture. On new Hot Mixed Asphalt (HMA) pavements, paint may dissolve road oils and cause a discoloration of the line. This line should be repainted as soon as it has dried in order to achieve the proper color.

### *Quality Assurance Field Testing*

Quality assurance field-testing shall be conducted in accordance with agency specifications.

Chart F-1 on the following pages is a troubleshooting guide for paint application problems.

## Chart F-1 Paint Application Trouble Shooting

| PROBLEM | CAUSE | EFFECT | REMEDY |
|---|---|---|---|
| Excessive Thickness (overall) | ▪ Paint tank pressure too high.<br>▪ Paint gun volume control (if present) open too wide.<br>▪ Pump pressure too high.<br>▪ Applicator speed too low. | ▪ Buried beads-poor initial nighttime retroreflectivity.<br>▪ Slow drying time-paint tracked by motorists.<br>▪ Paint won't cure properly-shortened life. | ▪ Reduce tank pressure.<br>▪ Adjust paint gun volume control.<br>▪ Reduce pump pressure.<br>▪ Increase speed. |
| Excessive Thickness (middle of line) | ▪ Paint tank pressure too high.<br>▪ Paint gun volume control (if present) open too wide.<br>▪ Pump pressure too high.<br>▪ Atomizing air pressure off or too low.<br>▪ Material buildup in paint gun tip and/or shroud. | ▪ Buried beads-poor initial nighttime retroreflectivity.<br>▪ Slow drying time-paint tracked by motorists.<br>▪ Paint won't cure properly-shortened life. | ▪ Reduce tank pressure.<br>▪ Adjust paint gun volume control.<br>▪ Reduce pump pressure.<br>▪ Increase atomizing air pressure.<br>▪ Clean tip and/or shroud. |
| Excessive Thickness (along one side) | ▪ Material buildup in paint gun and/or shroud.<br>▪ Clogged hole(s) in paint gun atomizing tip. | ▪ Buried beads-poor initial nighttime retroreflectivity.<br>▪ Slow drying time-paint tracked by motorists. | ▪ Clean tip and/or shroud.<br>▪ Clear clogged hole(s) in paint gun atomizing tip. |
| Insufficient Thickness | ▪ Paint tank pressure too low.<br>▪ Paint gun volume control (if present) not open enough.<br>▪ Pump pressure too low.<br>▪ Vehicle speed too high.<br>▪ Atomizing pressure too low.<br>▪ Material buildup in paint gun and/or shroud.<br>▪ Material buildup in paint filter(s) and/or plumbing. | ▪ Poor line quality and/or shortened life.<br>▪ Beads won't adhere and/ or poor or no nighttime retroreflectivity. | ▪ Increase tank pressure.<br>▪ Adjust paint gun volume control.<br>▪ Increase pump pressure.<br>▪ Increase applicator speed.<br>▪ Increase atomizing air pressure.<br>▪ Clean paint tip and/or shroud.<br>▪ Clean paint filter(s) and/or plumbing. |

**Chart F-1 Paint Application Trouble Shooting, cont.**

| PROBLEM | CAUSE | EFFECT | REMEDY |
|---|---|---|---|
| Wide Paint Line | ▪ Paint gun set too high.<br>▪ Worn or damaged paint gun tip and/or shroud. | ▪ Line does not meet standards.<br>▪ Line has fuzzy edges. | ▪ Lower gun.<br>▪ Repair or replace tip and/or shroud. |
| Narrow Paint Line | ▪ Paint gun too low.<br>▪ Paint gun tip slot not at 90 degree angle to paint line.<br>▪ Clogged paint gun tip and/or shroud.<br>▪ Low air pressure in paint machine tire. | ▪ Line does not meet standards.<br>▪ Not as visible as a full-width line (day or night). | ▪ Raise paint gun.<br>▪ Reposition paint gun tip.<br>▪ Clean paint gun tip and/or shroud.<br>▪ Inflate tire. |
| Uneven Paint Line | ▪ Atomizing air pressure too low.<br>▪ Paint tank pressure too low.<br>▪ Old paint (viscosity too high).<br>▪ Loose paint gun tip and/or shroud.<br>▪ No shroud. | ▪ Poor appearance.<br>▪ Line has fuzzy edges.<br>▪ Slow drying time.<br>▪ Paint won't flow smoothly. | ▪ Increase atomizing air pressure.<br>▪ Increase material tank pressure.<br>▪ Rotate material stock.<br>▪ Secure paint gun tip and/or shroud<br>▪ Increase heat (enough to get paint to flow evenly)<br>▪ Install shroud. |

# Section G: Epoxy

## Epoxy

Epoxy is a durable, plural-component, pavement marking material consisting of a pigmented resin base (Part A) and a catalyst (Part B). Before installation, both components (Part A and Part B) are mixed at a ratio of 2 parts resin to 1 part catalyst, and applied by a specialized epoxy application truck. This material is sprayed and combined with drop-on reflective beads to provide nighttime retroreflectivity.

## Components

### *Pigments*

Epoxy resin pavement markings use pigments, similar to all other pavement marking materials. Pigments are ground and dispersed into the resin side of the system.

### *Mixture*

The epoxy resin is mixed with the catalyst creating a binder system that is sprayed to form a durable pavement marking. To realize all the advantages of an epoxy system, it is critical that the components are properly mixed. Each component is stored in separate tanks on the epoxy application truck and heated to temperatures in accordance with manufacturer recommendations. Proportioning pumps draw the material at a 2:1 ratio. The material is then mixed by either a static mixing tube and sprayed onto the road surface at approximately 1200 psi or mixed inside of an impingement gun operating at 2500 - 3000 psi.

### *Reflective Beads*

Beads are uniformly applied across the entire width of the marking by a bead gun located immediately behind the epoxy spray gun. Dual bead guns are typically used for the application of the beads. Large and small beads are typically applied at a rate of 11 to 13 lbs/gal for each bead size for a total of 25 lbs/gal. This varies by individual contract.

## Characteristics of Epoxy

Epoxy striping material is classified as 100 percent solids, meaning the evaporation of solvents or water is not used to cure the material. Without this evaporation process, a typical application rate of 20 mil wet yields 20 mil of dry material. Epoxy striping material is cured via a thermoset chemical reaction.

### *Advantages*

- Can be applied at lower temperature
- Makes a mechanical bond with the road surface
- Good bead retention
- Low profile resists snowplow damage
- Good life cycle costs
- Epoxy does not contribute volatile organic compounds

### *Disadvantages*

- Slow cure (no-track time)
- Mix proportions are critical

## Method of Application

The mixed epoxy material is heated and sprayed onto the road surface. The equipment performing this operation is a specially designed epoxy truck that cannot be used to apply any other liquid binder material. Because of the composition of the material, environmental temperatures will increase or decrease the no-track times.

### *Shelf Life*

Epoxy material has a shelf life of one year. The manufacture date should be stated in the shipping documents.

### *How to Mix the Material*

The mix ratio for epoxy resin material is typically 2:1 (2 parts resin to 1 part hardener). It is very important that components are mixed thoroughly and at the correct ratio prior to being sprayed on the road surface. The mixing operation is a function of the epoxy installation truck. It shall be performed in accordance with manufacturer's recommendations.

### *Temperature*

Slow dry epoxy should not be applied unless the surface and ambient air temperatures are a minimum of 50°F and rising. Remember that no-track times increase as the temperature decreases and vice versa. Always check temperature minimums (surface and ambient air) for each agent when applying epoxy. Be sure to consult the manufacture's recommendations.

### *Pavement Surface Considerations*

The road surface shall be free of curing compounds, laitance, oil, grease, salt, dust, or other debris. Epoxy materials shall not be applied if moisture is present on the road surface. Epoxy materials can be applied over other epoxy materials. Removing the old material before applying the new material is preferable.

Chart G-1 on the following page is an epoxy application troubleshooting guide.

## Chart G-1 Epoxy Application Troubleshooting Guide

| PROBLEM | CAUSE | EFFECT | REMEDY |
|---|---|---|---|
| Heavy Centers | Inadequate fluid delivery. | ▪ Tracking.<br>▪ Erratic wear patterns.<br>▪ "Railroad Tracks" initially. | ▪ Increase fluid pressure.<br>▪ Decrease tip size. |
| Light Centers | Inadequate fluid delivery. | ▪ "Railroad Tracks" with time.<br>▪ Tracking from the edges.<br>▪ Erratic wear patterns. | ▪ Increase tip size.<br>▪ Replace tip. |
| Surging Pattern | ▪ Pulsating fluid delivery.<br>▪ Hour glass pattern. | ▪ Does not conform to standards.<br>▪ Erratic wear patterns. | ▪ Reduce demand.<br>▪ Remove restrictions in supply system by checking low and high pressure filters.<br>▪ Check individual pump pressures in both directions of travel for unequal pressure.<br>▪ Check any supply or pressure side plumbing for leaks. |
| "Lop-sided" Millage | ▪ Worn tip sides.<br>▪ Clogged tip. | Erratic wear patterns. | ▪ Replace tips.<br>▪ Clean tips. |
| Line Too Wide | ▪ Gun too high.<br>▪ Too wide a fan angle on tip. | Does not meet standard. | ▪ Lower gun.<br>▪ Adjust tip size if necessary. |
| Smearing and Discoloration | Opened to traffic before marking has cooled down. | Reduced visibility. | Wait until cool before opening road to traffic. |

# Section H: Preformed Thermoplastic

## Preformed Thermoplastic

Preformed thermoplastic is a durable pavement marking system where thermoplastic symbols and legends are supplied in their final form and shape. Typically, the marking is supplied in large pieces, which are put together as a giant puzzle. Preformed thermoplastic pavement marking material combines the convenience of preformed markings with the performance qualities of hot applied thermoplastic. This heavy-duty intersection grade pavement marking material is ideal for high traffic areas where maximum wear and tear is present. Various brands are applied differently, so it is important to be familiar with the installation instructions for the type you are using. Always follow manufacturer instructions.

### *Type of Materials*

There are two basic types of preformed thermoplastic markings:

1. Those that don't require preheating the road surface to a given temperature - MnDOT uses this type.
2. Those requiring that the road surface be preheated to a certain temperature

## Components

Preformed thermoplastic markings are composed of pigments, reflective glass beads, fillers, binders, and additives.

### *Pigments*

Pigments are primarily used to impart color and to provide some chemical property such as UV stability. Titanium dioxide is typically added to provide a white color. Organic pigment is typically added to provide a yellow color.

### *Fillers*

Fillers are typically a pigment and also provide bulk. Once the necessary color has been obtained, fillers such as a mixture of calcium carbonate, sand, and other inert materials are used to provide the volume of filler to give the necessary durability.

### *Binders (Resins)*

Binders are thermoplastic; they melt when heat is applied. The binder holds the pigments, reflective beads, and fillers together. Heat is used to form the initial shape. The material does not change chemically on heating and application.

### *Reflective Glass Beads*

Preformed thermoplastic is produced at the factory with a certain percentage of beads intermixed within the melted material. Additional beads are also added to the surface of the material when it is applied.

### *Additives*

Additives such as plasticizers are added to control flow characteristics. Because

the plasticizer can burn away, overheating and excessive reheating of preformed thermoplastic can affect the durability and overall quality of the marking.

### *Solvents*

Preformed thermoplastic pavement markings contain no solvents. It is the heating process that transforms the thermoplastic material from a solid into a liquid.

## Material Characteristics

Other factors that should be considered when using preformed thermoplastics are packaging, shelf life, and primers/sealers.

### *Packaging*

Linear preformed thermoplastic is packaged in 3 to 4 foot long strips in sturdy cardboard boxes. Symbols are manufactured in pieces so they may be packaged and shipped easily.

For pavement messages and crosswalk blocks, utilize precut messages, symbols, and blocks meeting the requirements of the Minnesota Manual on Uniform Traffic Control Devices and the MnDOT Standard Signs Manual. Kits provided by the manufacturer are acceptable. Use of line material to piece together individual letters, symbols or crosswalk blocks is not allowed.

### *Shelf Life*

Preformed thermoplastic has a shelf life of one year when stored inside at a temperature between 35°F and 95°F. Due to the heavy weight of the thermoplastic, no more than 25 packs shall be stacked on top of one another.

### *Primers/Sealers*

Primers/Sealers are used as a “bridge” between preformed thermoplastic and the surface where preformed thermoplastic will not readily adhere such as worn old HMA. Essentially, the primer bonds to the surface, and the thermoplastic bonds to the primer. In order to prevent moisture from entering under the marking on Portland Cement Concrete (PCC), it is important to seal the surface with a primer/sealer before the marking is installed. This will help prevent failures during freeze/thaw periods. Follow manufacturer recommended installation instructions to ensure that the correct type of primer/sealer is used.

## Application Methods

Preformed thermoplastic can be applied with a propane fueled heat torch. When you arrive at the work location, review the temperature conditions, weather conditions, and pavement conditions to make sure that the preformed thermoplastic can be successfully applied based on manufacturer recommendations. If the situation does not comply with the manufacturer’s recommendations, it is recommended that you wait until conditions improve before installing the preformed thermoplastic.

### *Heat Torch*

This method of application ensures that proper heat is applied to the preformed thermoplastic for a good bond to the road surface.

The flame of the propane fueled heat torch should be moved in a fan shaped pattern

to ensure even heating of the material. To obtain the best results, the torch should be moved in a slow even motion approximately 4 to 12 inches over the material. It is helpful to keep the wind at your back so the heat will be carried across the marking.

***Application on HMA***

1. Thoroughly clean the application area. All loose particles (sand, dust, and other debris) must be removed. Utilize a power blower or compressed air if possible as shown in Figure H-1. Otherwise, sweep the entire area completely.

**Figure H-1: Cleaning Pavement Prior to Application**

2. Ensure that no moisture is present prior to positioning the preformed thermoplastic material on the pavement surface. A heat torch may be used to remove moisture
3. If required, preheat the surface to the temperature recommended by the manufacturer. Not all types of preformed thermoplastic require preheating.
4. Position the preformed thermoplastic on the pavement surface. Position all connecting parts of the marking on the road with the exposed beaded side up. Make sure the marking is properly placed and that there are no gaps between the segments of legends and symbols as shown in Figure H-2.

**Figure H-2: Placement of Material**

5. Begin heating the material by moving the torch slowly and steadily over the material. Move the heat torch in a sweeping motion, approximately 2 feet wide over the marking at a height of 4 to 12 inches so that heat is evenly distributed across the marking, slowly melting the material. The preformed thermoplastic material must be heated throughout the process to achieve a bond with the pavement as shown in Figure H-3.

**Figure H-3: Arrow Symbol Being Applied by Heat Torch**

6. As you heat the preformed thermoplastic, monitor the visual signs or temperature requirements. It is important not to "overheat" the material otherwise the top coating of beads will sink into the preformed thermoplastic and be less retroreflective initially.
7. Heat the external edges of the marking to taper them, helping minimize the risk of plow damage.
8. Inspect the freshly applied preformed thermoplastic marking to ensure that complete bonding has occurred over the entire area. After the preformed thermoplastic has cooled to near ambient temperature, try to lift an edge or cut an area in the interior of the material with a chisel where it appears to have been heated the least. Try to lift a portion of the material; if the material can be lifted without evidence of asphalt on the underside, insufficient heat has been applied. Simply reapply heat until adequate bonding has occurred. This is called an "adhesion test. (Figure H-4).
9. When performing the adhesion test on material applied on PCC roads, you should see a thin layer of the material adhering to the road surface. After performing the adhesion test, remember to reheat the tested area as illustrated in Figure H-3.
10. Preformed thermoplastic will cool and set rapidly within a few minutes of application. If desired, setting time can be accelerated with a spray of cool water or hand casting of additional reflective glass beads on top of the marking.

**Figure H-4: Adhesion Test Being Performed**

***Application on PCC or Old HMA***

1. Follow steps 1, 2, and 3 as stated above for application on HMA. Worn, polished concrete should be ground or milled so the surface becomes rough.
2. Lay out the marking pattern using chalk or crayon as required for guidance.
3. Apply primer/sealer to areas outlined in chalk or crayon. Allow the primer/sealer to dry until it will not transfer to the finger when touched. The more porous the surface, the more sealer is required. Caution: do not accelerate the drying process by using an open flame. The sealer may be flammable at this stage.
4. It is important to apply primer/sealer to the entire area where the preformed thermoplastic will be applied.
5. Continue with steps 4 through 9 as stated above for application on HMA.

## Application Considerations

The pavement surface must be dry before applying preformed thermoplastic or primer/sealer. The pavement surface must also be free of dirt, dust, chemicals, and oily substances. Do not apply on top of any existing marking materials other than thermoplastic. However, first remove any loose thermoplastic and ensure that no moisture is present. If the old thermoplastic is oxidized (powdery surface), grind or heat it and scrape the top surface so fresh material is exposed. A primer/sealer may be required on PCC or old HMA. Make sure to follow manufacturer instructions.

Most preformed thermoplastic materials may be applied at air temperatures down to 35°F. However, surface temperature is critical and must conform to manufacturer recommendations.

Protective clothing should be worn during the installation of preformed thermoplastic pavement marking materials. The protective clothing should consist of leather boots or work shoes, and long pants (note: synthetic fabrics should be avoided). General safety rules should be followed when using propane.

## Inspection and Quality Control

A vital component of quality assurance is inspection and quality control before, during, and after application. Regardless of the method of installation, there are some absolutes that must be followed.

The following factors must be addressed in order to achieve good application:

- Sufficient heating of the material during application
- Ambient and surface conditions
- Reflective bead embedment

Never leave job sites without performing the adhesion test (referred to under Application on HMA, Step 8) to test the bond between the HMA and the material. Any deviation from manufacturer recommendations may result in application failures and shall be properly documented if unavoidable. Chart H-1 on the following page is a troubleshooting guide for preformed thermoplastic application problems.

## Chart H-1 Preformed Thermoplastic Troubleshooting Guide

| PROBLEM | CAUSE | EFFECT | REMEDY |
|---|---|---|---|
| Bonding/ Adhesion | Surface is not clean. | Poor surface bond - low durability. | Clean with blower to remove surface debris. |
| | Moisture in road surface. | Poor surface bond - low durability. | Heat road to remove moisture. |
| | Non-conforming existing marking (i.e. tape, paint, etc.) | Poor surface bond - low durability. | Remove or install before or behind old marking. |
| | Deteriorating road surface. | Poor surface bond - low durability. | Resurface. |
| | Too little heating. | Poor surface bond - low durability. | Visual signs/ temperature should be observed. |
| | Deicing chemicals on road surface. | Poor surface bond - low durability. | Power wash area or wait until after rain to install. |
| | Dated material. | Poor surface bond - low durability. | Rotate stock - 1-year shelf life. |
| | Curing agents on Portland Concrete Cement. | Poor surface bond - low durability. | Blast or power wash. |
| | Worn polished aggregates on road surface. | Poor surface bond - low durability. | Grind and blow clean. |
| | Lack of sealer. | Poor surface bond - low durability. | Use sealer. |
| Low or no Retroreflectivity | Too little or too much heat. | Glass beads not embedded enough or sunken into material. | Look for visual signs when heating. |
| Gaps between individual pieces not melted together. | ▪ Too little heat.<br>▪ Shelf life exceeded.<br>▪ Individual pieces not touching before heating. | ▪ Poor adhesion.<br>▪ Poor appearance. | ▪ Make sure pieces are touching before heating.<br>▪ Heat more.<br>▪ Rotate Stock. |

# Section I: Preformed Polymer Tape

## Preformed Polymer Tapes

Preformed Polymer tapes come in rolls. The tape consists of pigments, resins, and reflective materials (glass beads or reflective elements) and comes ready to use with or without adhesives. Additional adhesive (primer) can be applied to the pavement to enhance the bond. This material can be used for lane lines, legends, symbols, and transverse markings.

## Components

Tapes are similar to other markings: pigments are used to produce color, and suitable resins are used to provide the necessary wear characteristics.

### *Resins*

Pre-reacted resins hold the beads and pigments in place. For this reason, the tape is ready for installation upon delivery. Additionally, there may be an adhesive backing on the bottom side of the resin for adhesion to the roadway surface.

### *Reflective Materials*

The manufacturer has already added reflective materials to the resin. Additional reflective materials are not added in the field.

### *Primers/Glues*

Tapes, depending upon the type, may use primer and/or adhesives in addition to those already applied by the manufacturer. These various compounds are used to promote adhesion to the roadway surface.

Generally, tape that has been properly stored (sheltered at room temperature) will be usable for a period of one year. In addition to the normal requirements for accepting materials on the project, the manufacturer's expiration date must also be clearly shown. Certification letters for the tape and for all related sealers and primers must be provided.

## Types of Preformed Tapes

Tapes fall into one of two categories: permanent and temporary (removable).

### *Permanent Tapes*

Permanent pavement marking tapes are either flat or patterned. These tapes may require the use of a primer/sealer (unless otherwise recommended by the manufacturer). The cost of the sealer is usually included in the price of the tape. When applied properly, this material resists movement under traffic. Prior to the application of this material, a primer/sealer may be required depending on the temperature and condition of the roadway. Permanent tapes are generally used for longitudinal edge lines, skip lines, stop lines, crosswalks, legends, and symbols. Tape should be cut at joints and cracks.

Patterned tape is textured and is sometimes referred to as "profile tape." Patterned tape used for longitudinal edge lines or skip lines on HMA is usually inlaid or is sometimes applied in a groove.

Standard preformed pavement marking tape is composed of rows of diamond shaped, raised elements as shown in Figure I-1.

**Figure I-1: Preformed Tape**

### *Removable Tapes*

Removable tapes can be removed (pulled from the pavement surface) without using heat, solvents, or mechanical eradication. Generally, these tapes should be removed within 6 months of installation and should not leave any permanent residue on the road surface. The use of primers or additional glue may or may not be required. Although these tapes are similar in appearance to permanent tape, they may have an additional fiber mesh bonded in the resin. This mesh provides the necessary tensile strength allowing the tape to be pulled up from the roadway without breaking or tearing.

Blackout or black tape is another type of removable tape that is used to temporarily cover existing marking on an HMA road. Black tape, however, does not contain any reflective material. For example, if a permanent lane needs to be temporarily moved during construction and then reestablished at a later time, the black tape could be applied over the existing lines to hide them and new lines applied with another removable tape. When construction is complete, the original lanes can be reestablished by removing the black tape and the other temporary tapes. Black tape shall not be used on PCC roads.

## Methods of Application

Flat and patterned tapes are normally installed by using a roller applicator. This is a walk-behind push cart that holds and applies one or two rolls of tape. The applied tape is then pressed onto the road surface using a walk-behind tamper cart. Weights are stacked on this cart to provide the necessary force to press the tape to the road. Tape manufacturers specify the required weight needed for each type of tape. This roller applicator and tamper procedure helps ensure that the tape is applied straight, especially in long line applications. If the manufacturer requires additional primers or glues, they can either be rolled or sprayed onto the tape and/or road surface.

When patterned tape is inlaid, no primer is used. It is inlaid with the last pass of the paving roller; the temperature of the HMA is critical. It may also be laid into grooves that are cut into the concrete.

Only precut messages and symbols in custom kits meeting the requirements of the MN MUTCD and the pavement markings section of the MnDOT Standard Signs Manual should be used. Use separate pieces or segments to form individual letters or symbols only to the extent supplied by the manufacturer. Do not use standard rolls of line material to piece together individual letters or symbols or crosswalk blocks. Do not use narrower line material to piece together wider lines.

## Pavement Surface Considerations

The minimum application temperature is determined by manufacturer recommendations. Prior to the application of the tape, the surface must be free of contaminants. Contaminants may include dust, dirt, or moisture. If tape is applied to a surface containing dust, dirt, or moisture, poor adhesion will result. Chart I-1 is a preformed tape application troubleshooting guide.

### Chart I-1 Preformed Polymer Tape Troubleshooting Guide

| PROBLEM | CAUSE | EFFECT | REMEDY |
|---|---|---|---|
| Material rolls up or shifts. | ▪ Not bonded prior to traffic.<br>▪ Tape crossing traffic.<br>▪ No primer adhesive. | Loss of effectiveness. | Replace material with proper tamping, adhesive, and primer. |
| Poor material adhesion. | ▪ Moisture in pavement.<br>▪ Dirty surface.<br>▪ No primer.<br>▪ Expired shelf life.<br>▪ Incorrect milling heads. | ▪ Errant delineation.<br>▪ Loss of material.<br>▪ No delineation. | Replace material applying properly. |

*Note: Since the material is preformed, the only actions that are necessary are being sure that the material is the correct material specified, is placed properly, and is applied properly. FOLLOW MANUFACTURER RECOMMENDATIONS.

## Applicator Certification

Contractors applying preformed tapes on MnDOT projects are required to possess documentation that they are certified to install this material.

# Section J: Wet Reflective Markings

Increasing retroreflectivity of markings during rainy, foggy, nighttime conditions is a major challenge. It has been shown that pavement markings reduce crashes at night on dry pavement, but not as well at night on wet pavement.

Increased retroreflectivity performance in wet, nighttime conditions may help to reduce crashes, but ensuring and defining this improved performance includes a particular set of challenges. Pavement marking retroreflectivity under wet pavement conditions averages only 46% of the comparable values under dry pavement conditions. For example, to achieve a wet pavement retroreflectivity of 150 mcd/m$^2$/lux, the marking would need a dry pavement retroreflectivity of 326 mcd/m$^2$/lux.

## Wet Weather Performing Materials and Processes

Pavement marking materials and processes that provide improved performance during wet weather at night are available. These materials and processes may be substituted for the traditional materials.

There are two major categories for materials and processes that improve performance of pavement markings during wet weather:

1. **Wet Recoverable Materials and Processes**
   These are materials or installation processes that enhance performance of pavement markings during wet weather condition but still lose retroreflective properties when covered by water. Examples of these include larger glass beads, profiled markings, and rumble stripes. To ensure performance, these materials and process should be installed as recommended by the manufacturer.

2. **Wet Reflective Materials**
   These are materials that enhance the performance of pavement markings during wet weather conditions and retain their retroreflective properties when covered by water. Examples of these materials are those that contain specialized retroreflective elements that retain retroreflectivity when covered by water.

All wet reflective materials shall be recessed to ensure continued wet weather performance after snow plowing operations. Wet reflective poly-preformed tape should utilize contrast (black outline) markings when used on PCC pavements.

**Figure J-1: Grooving operation prior to placement of the wet reflective material.**

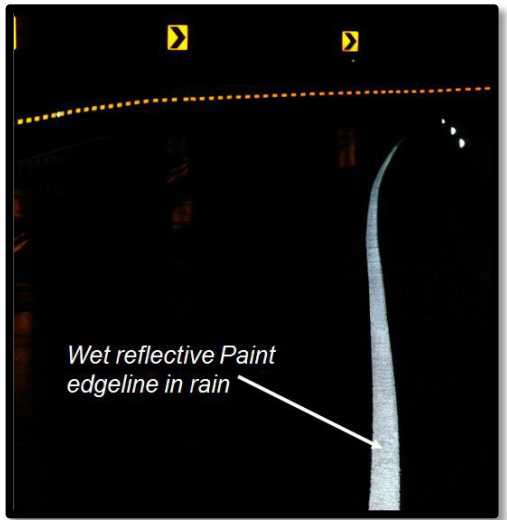



**Figure J-2: Wet roadway at night with a wet reflective edge line.**

# Section K: Rumble Strips and Stripes

Crash analysis has revealed that lane departure crashes, such as run-off-the-road, sideswipe and head-on crashes on rural two-lane, two-way highways in Minnesota result in an over represented number of fatalities and serious injuries. Both traditional pavement markings and rumble strips are used to decrease the number of these lane departure crashes.

Some states have begun aggressive campaigns to combine traditional pavement markings and rumble strips into a rumble stripes, where the pavement marking is installed on the rumble strip. The advantage of this rumble stripe is that while the rumble strip remains effective, the pavement marking performance is enhanced at night during wet weather conditions. This enhanced performance provides improved visual information to the driver during these times as shown in Figure K-1.

**Figure K-1: Rumble Stripes During Daytime and Nighttime**

For current information on Rumble Strips and Stripes, along with dimensions and details, refer to Rumble Strips and Stripes on Rural Trunk Highways Technical Memorandum, the MnDOT Office of Traffic, Safety, and Technology Pavement Markings website, and the Traffic Engineering Manual (TEM).

## Types of Rumple Strips and Stripes

### *Shoulder Rumble Strips*

These are longitudinal rumble strips installed outside of the edge line (the yellow or white line that separates the travel lane from the left or right shoulder.) The intent of shoulder rumble strips is to notify inattentive drivers that they are leaving the traveled lane - with the goal of reducing run-off-the-road crashes. They are also useful during snowy conditions to help the driver keep the vehicle in the traveled lane.

### *Rumble Stripes*

These can be either:

- Edge line Rumble Stripes - installed to separate the travel lane from the shoulder(s).
- Centerline Rumble Stripes - installed to separate opposing traffic on undivided highways. The goal of these is to reduce head-on and opposite direction side-swipe crashes.

### *Transverse Roadway Rumble Strips*

These are placed across the traveled lane to alert drivers approaching a change of roadway condition or a hazard that requires substantial speed reduction or other maneuvering.

## Requirements

### *Shoulder Rumble Strips*

Shoulder rumble strips shall be placed on all rural highway projects where shoulders are constructed, reconstructed, or overlaid and where the posted speed limit is 55 mph or greater, and the paved shoulder width is 4 feet or greater. (This is a change from the previous standard, where shoulder rumble strips were required on highway paved shoulders of at least 6 feet in width.) Shoulder rumble strips may also be placed on rural trunk highways on shoulders less than 4 feet in width. Shoulder rumble strips shall also be placed on the left shoulder of multi-lane divided roads.

### *Centerline Rumble Stripes*

Centerline rumble stripes shall be placed on all rural highway construction and maintenance projects where bituminous pavement is constructed, reconstructed, or overlaid and where the posted speed limit is 55 mph or greater. This applies to both multi-lane undivided and two-lane undivided highways.

**Figure K-2: Centerline Rumble Stripes**

## Exceptions

On rural highways where the paved shoulder width is 2 feet or less, shoulder rumble strips or edge line rumble stripes may be placed on both sides of the road in lieu of a centerline rumble stripe. In all cases, edge line rumble stripes may be substituted for shoulder rumble strips and still meet the standards within Technical Memorandum No. 14-07-T-01.

Shoulder rumble strips are not required in areas where there is a bus shoulder. However, it is assumed that bus shoulders will usually be installed in areas that are NOT defined as rural trunk highways in MnDOT's Access Management Guide.

Shoulder rumble strips are not required in locations with guardrail or cable barrier. Even in cases where shoulder rumble strips are not required due to a narrow paved shoulder width, their installation, or the installation of an edge line rumble stripe, is encouraged for proactive safety reasons.

As a systematic proactive safety measure, Districts shall consider placing centerline rumble stripes and shoulder rumble strips on inplace shoulders at locations where no construction, reconstruction, or overlay projects are scheduled in the near future. The District Materials Engineer should make recommendations regarding the structural adequacy of the inplace roadway and/or shoulder to receive rumble strips.

### *Width of rumble strips*

Rumble strips are usually 12" in width. The width of the rumble strip can be reduced to within the range of 8"-12" when paved roadway width is limited. A 16" rumble is required on freeway segments. Any designs of rumble strips that are smaller than 8" in width or that deviate from the 12" corrugation cycle detailed in Figures 4-8 of Tech Memo 14-07-T-01, shall require approval by the State Traffic Engineer.

The standard width of rumble strips for centerline rumble stripes is 16". Any reduction from this shall require approval by the State Traffic Engineer.

All rumble strips shall meet any and all specifications for Milled Rumble Strips as stated in the MnDOT Standard Specifications for Construction or Special Provisions. This includes a requirement that rumble strips be milled in bituminous pavement, and not rolled.

### *Modifications for concrete pavement*

On concrete paved roadway surfaces, there are two options for how to install shoulder rumble strips:

1. Installing 3' long structural rumble strips on alternating panels and shoulder rumble strips on the adjacent paved bituminous shoulder.
2. Milling in either continuous or intermittent shoulder rumble strips outside the edge line but on the concrete surface.

The recommended practice for placing centerline rumble stripes on concrete pavements is to install two 8" wide rumbles on either side of the centerline joint (each 2" away from the joint).

### *Bicycle travel on shoulders*

Shoulder widths that provide less than 4 feet of clear space with rumble strips are not considered adequate to accommodate bicyclists. Where practical and feasible, Districts are encouraged to provide a minimum of a 6-foot paved shoulder where shoulder rumble strips will be placed on trunk highways with existing or potentially significant bicycle travel. Refer to the Tech Memo for additional details.

# Section L: Interim Pavement Markings

Interim pavement markings are a thinner marking applied in order to maintain traffic until the permanent pavement markings can be placed.

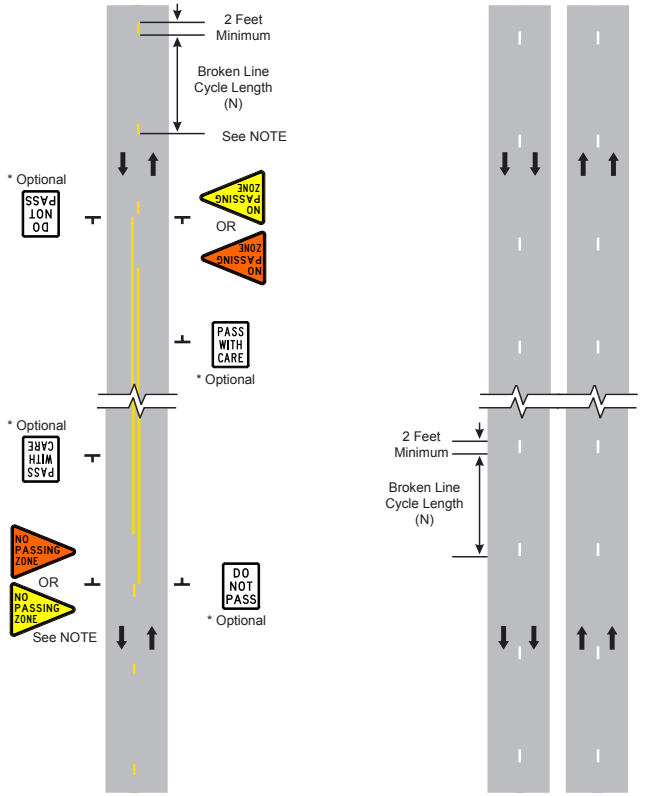
Paint, temporary tape, and temporary raised pavement markings (TRPM's) are used for interim pavement markings. Temporary tape is more expensive than liquid markings, but can be cost effective when used to minimize scarring, especially on projects with many stages. Temporary tape does not require application of a primer under normal conditions, but manufacturer's application recommendations should be followed. Interim pavement markings in transitions and shifts need to be wet reflective or supplemented with TRPM's.

All centerlines, no passing zones, and lane markings shall be in place prior to opening roadways to traffic. Edge lines shall be placed within 14 calendar days of opening a roadway. All interim broken or dotted-line pavement markings shall match the inplace striping location, use the same cycle length as permanent markings, and have line segments that are at least 2 feet long. Interim pavement markings placed on the final pavement surface shall be in the exact location of the final pavement markings and within tolerances listed in the plan and specifications.

Interim pavement markings are maintained by the contractor. All pavement markings and devices used to delineate road user paths should be reviewed during daytime and nighttime periods

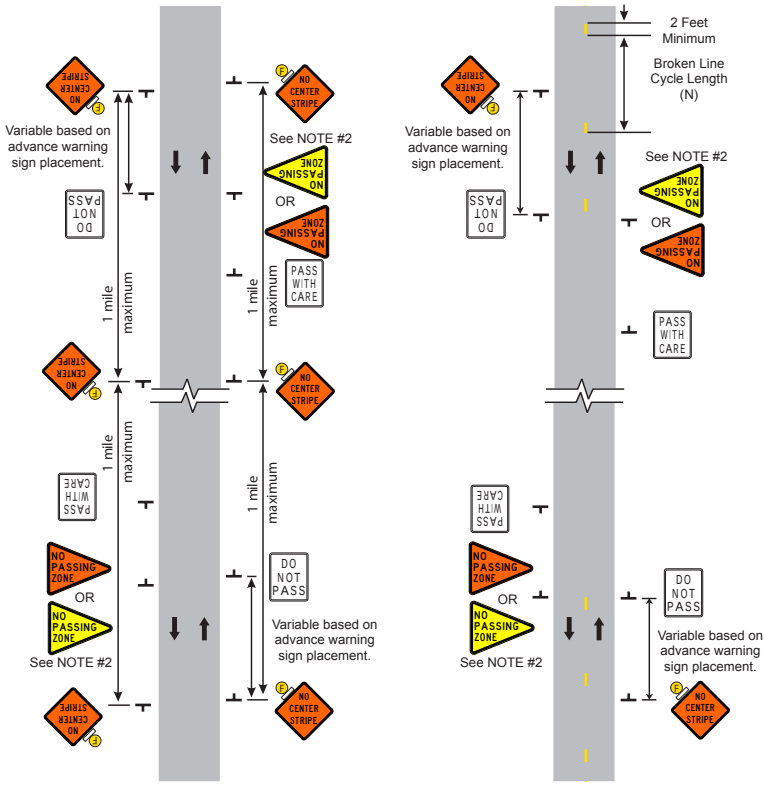
**Figure L-1: Interim Broken Line Pavement Marking**

# Figure L-2: Interim Pavement Marking 14 days or less.




NOTE:
Any NO PASSING ZONE sign (W14-3) used in a temporary traffic control zone that is applicable in its current location or will remain in place after completion of the construction project may have a black legend and border on a yellow retroreflective background.

# Figure L-3: Interim Pavement Marking 3 days or less.




NOTE:
1. Either layout may be used for up to 14 days when the average daily traffic is less than 400.
2. Any NO PASSING ZONE sign (W14-3) used in a temporary traffic control zone that is applicable in its current location or will remain inplace after completion of the project may have a black legend and border on a yellow retroreflective background.

# Section M: Temporary Raised Pavement Markers

## Pavement Markers

Pavement markers are pre-manufactured, reflectorized devices that provide positive in roadway delineation at night, especially during inclement weather and in areas where roadway alignment variations dictate guidance that cannot be achieved by pavement markings and roadside delineation alone. The color of raised pavement markers under both daylight and nighttime conditions shall conform to the color of the marking for which they supplement or substitute.

## Types of Pavement Markers

Pavement markers are composed of a base material that is designed to resist impacts from traffic and to provide an adherent surface securing the marker to the roadway. Some agencies use a series of hard, non-reflectorized raised markers to form a line where overhead lighting is available. Other agencies require that all pavement markers be reflectorized. The retroreflective surface can either be reflective sheeting or a prismatic reflector. The outer cover of the prismatic area can be either plastic or glass.

The most common type of pavement markers are the temporary raised pavement markers (TRPMs). Permanent ceramic raised pavement markings (RPMs) are discouraged in Minnesota and not used by MnDOT because of snowplow concerns.

## Temporary Raised Pavement Markers (TRPMs)

Raised temporary pavement markers are normally used with construction zone markings. They are commonly referred to as “temporary markers” or “TRPMs”. Specifications often require the use of temporary pavement markers in transition areas of work zones that will encroach upon the traveled roadway for a period of more than two days, and in other areas as required by the engineer.

TRPMs are glued to the roadway with a bitumen or epoxy adhesive. Most markers of this type consist of a plastic body with a reflective surface.

On MnDOT projects, TRPMs are to be replaced when they become damaged or have been removed by traffic. These markers will be inspected on a routine basis and replaced as necessary.

TRPMs shall not be used as an interim pavement marking between October 1 and May 1 because of snowplowing operations.

Another general type of temporary raised marker is the “peel and stick” type. These typically have a paper backing that is removed to expose a butyl/adhesive pad. The marker is then applied to the roadway and firmly pressed in place.

**Figure M-1: Temporary Raised Pavement Marker**

Not recommended for use due to snow plow concerns.

**Figure M-2: Raised Pavement Markers**

***Simulating a Solid Line and a Broken Line***

When TRPMs are used to simulate a line, the following guidelines apply unless otherwise indicated in the Plan or directed by the Engineer:

- Broken Line - place three (3) TRPMs per 10-foot skip stripe, 5-foot on center, and 40-foot gap.
- Solid Line - place TRPMs, 10-foot on center for tangent sections; place TRPMs, 5-foot on center for curve sections over six (6) degrees, steep grades, and concrete pavements.
- Double Solid Line - place two (2) TRPMs separated by 4 inches side-by-side using the same spacing required for Solid Lines.
- When substituting for wide lines, raised pavement markers may be placed laterally adjacent to each other to simulate the width of the line.
- When supplementing dotted line markings, place one (1) raised pavement marker 12-foot.

Refer to Figure M-3: Simulating a Solid or Broken Line with TRPMs.

### *Supplementing a Solid Line and a Broken Line*

In the following situations, TRPMs do not provide adequate simulation of solid lines and shall only be used to supplement solid lines:

- Areas where the markers, even 5-foot on center, become visually separated. This occurs frequently on low speed urban highways with sharp curves and short transition areas. This also occurs where there are steep grades and dips.
- Areas with high ambient lighting which may diminish the retroreflective capabilities of the markers.

When TRPMs are used to supplement a line, the following guidelines apply unless otherwise indicated in the Plan or directed by the Engineer:

- Solid Line - place TRPMs, 3 m (10-foot) on center.
- Double Solid Line - place two (2) TRPMs separated by 100 mm (4 inches) side-by-side, using the same spacing required for Solid Lines.
- Broken Line – place two (2) TRPMs to supplement each broken line segment.
- Broken Line – place three (3) TRPMs per 10-foot skip stripe, 5-foot on center, and 40-foot gap.
- Solid Line - place TRPMs, at spacing no greater than 50-foot, except when supplementing left edge line markings, a spacing no greater than 25 foot should be used.
- Double Solid Line - place two (2) TRPMs separated by 4 inches side-by-side, using the same spacing required for Solid Lines.
- When substituting for wide lines, raised pavement markers may be placed laterally adjacent to each other to simulate the width of the line.
- Dotted line - markings and spacing appropriate for the application should be used.

### *Types of TRPMs*

The TRPMs are classified into four types as follows:

1. TRPM Type 1 - These markers are acceptable for use on all roadways for short or long term projects. They may be used to supplement or simulate solid or broken lines.
2. TRPM Type 2 - These markers are acceptable for use on projects with Average Daily Traffic (ADT) of less than 3000. They may be used to supplement or simulate solid or broken lines.
3. TRPM Type 3 - These markers are acceptable for use on all roadways for short or long term projects. They may be used to supplement solid or broken lines. These markers are NOT acceptable to simulate solid or broken lines. If these markers do not conform to the color requirements herein they shall not be placed directly on the pavement marking line.
4. TRPM Type 4 - These markers are acceptable for use on chip or sand sealing operations. These markers are designed to be placed prior to the sealing operation with a protective cover that is removed after the seal coat is applied.

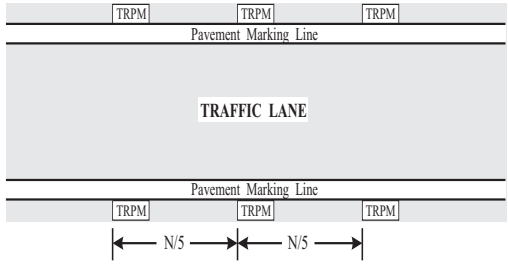
A list of approved raised pavement markers of each type is available on the Qualified Products List (QPL) for Work Zones, posted on the Office of Traffic, Safety, and Technology (OTST) website at http://www.dot.state.mn.us/products/pavementmarkings/reflectiveelementsforpavementmarkings.html.

### *Installation, Maintenance, and Removal*

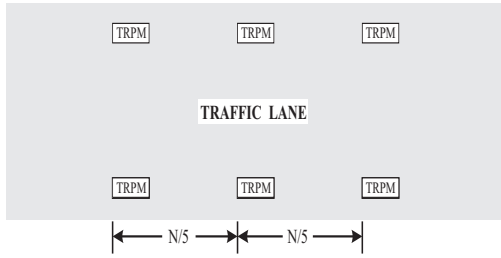
Installation, maintenance, and removal of the TRPMs shall be done on a continuous basis as directed by the Engineer. The Contractor shall remove all containers, wrappers, and used or damaged markers, etc. from the job site at the time of installation, during the project, and at the time of removals. All TRPMs shall be new and unused when placed.

Damaged or missing TRPMs shall be replaced by the Contractor within twenty-four (24) hours after notification by the Engineer, at no cost to the Department.

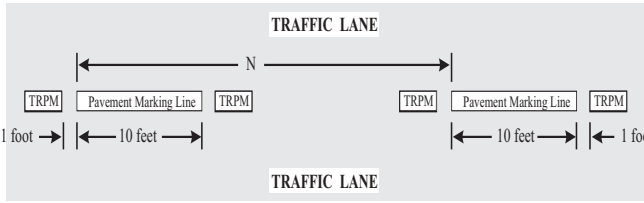
Prior to installing TRPMs, the pavement surface shall be air blown or brushed to remove surface dust and dirt. The TRPMs shall then be fixed to the pavement surface as per the manufacturer's recommendation.




SUPPLEMENTING A SOLID LINE




SIMULATING A SOLID LINE




SUPPLEMENTING A BROKEN LINE

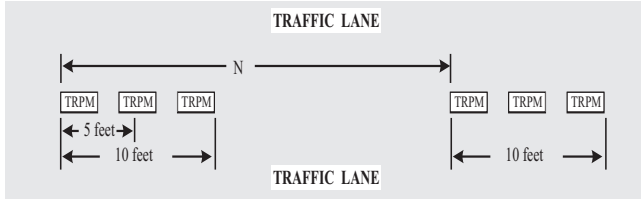



**Figure M-3: Simulating a Solid or Broken Line with TRPMs**

# Section N: Removal

## Definition / Purpose

Pavement markings are removed to change or modify the existing travel lanes or messages and to prepare the road surface for new markings.

## Undesirable Effects

If pavement markings are not eradicated properly, several different markings may exist at the same time, as shown in Figure N-1. Often, the scars left by some removal methods may appear like additional pavement markings as shown in Figure N-2. This may create a hazardous condition for motorists.


**Figure N-1: Roadway with Multiple Messages**

**Figure N-2: Pavement Marking Removal Scarring**

It was once common practice to cover the existing marking with either black paint or asphalt as shown in Figure N-1. Heavy traffic would often wear away this paint or asphalt and the unwanted marking would become visible again. From a safety perspective, this is not a practical solution and is excluded by the MN MUTCD.

**Figure N-3: Black Paint Wearing Off of Previous Marking**

## Methods of Removal

There is no method of pavement marking removal that is free from drawbacks. Whatever the method, it must effectively remove the marking to the specified degree, while at the same time doing the least damage to the pavement.

Methods that have typically been used are:

- Blasting (hydro, sand or shot)
- Grinding

The effectiveness of the method is dependent on three primary things:

1. The type and thickness of the marking being removed
2. The type of pavement
3. The skill of the operator

For example, thermoplastic markings cannot withstand abrasive blasting because the heat generated when the abrasive strikes the marking melts the thermoplastic. Grinding is not desirable on grooved or tined PCC because it will remove the texturing of the pavement surface. Most chemical strippers are hazardous materials with disposal problems. Heat can make HMA pavement slick. Depending on the amount of heat, safety problems may result. This is particularly true if yellow markings containing lead are removed. Hydro-jetting or hydro-blasting uses water and can cause slick pavements in the wintertime.

For larger projects, truck-mounted, hydraulically controlled, dual scarifying drums with a built-in vacuum system could be considered. A trailing sweeper/vacuum unit recovers the coarser paint/surface waste mixture.

Markings may also be temporarily masked with tape (not paint) until they can be removed or obliterated. An additional option would be in the use of Temporary Raised Pavement Markings (TRPMs).

Lines and scars from line removal may look different at night. Nighttime inspections are desirable to determine that the pavement markings are visible and understandable under day and night conditions.

## Specifications

Pavement Marking Removal is covered in MnDOT's Standard Specifications for Construction, Spec #2102 . Project specific language on removal methods will be part of the project's Special Provisions.

# Section O: Inspection

## Introduction

The key to high-quality pavement markings lies in proper installation. Proper inspection procedures are essential to assure high-quality installation. In this section, inspectors are given the necessary guidance for field inspection of pavement markings before, during, and after application. The goal is to achieve quality control and quality assurance of pavement markings so that the desired service lives are achieved.

Field inspection by properly trained personnel is done to ensure that high-quality pavement markings are being placed on the roadway. Field inspection of pavement marking construction can be divided into three parts:

1. Inspection of the roadway and weather conditions prior to application.
2. Inspection of the pavement marking application process.
3. Inspection of the finished work for final acceptance.

MnDOT pavement marking material and construction specifications, and test methods can be found at: www.dot.state.mn.us/products/pavementmarkings/information.html.

MnDOT standard drawings for pavement marking messages can be found in the MnDOT Standard Signs Manual at: http://www.dot.state.mn.us/trafficeng/publ/signsmanual/index.html.

## Field Documentation Items

This section supplements Chapter 7 of the MnDOT Traffic Engineering Manual and Part 3 of the MN MUTCD.

### *Inspector's Diary*

The documentation of pavement marking field inspections is important. Inspectors should maintain a daily field diary of information relevant to a pavement marking operation. The diary is primarily for informal documentation of events as they occur on a job site. This includes, but is not limited to:

- Date
- Striping contractor, contact person, phone number
- Roadways striped
- Start and stop times for striping
- Line or pavement message types striped
- Lineal and/or square footage of striping applied
- Material
- Material manufacturer
- Equipment failures and other problems
- Conversations
- Material temperature (if necessary)

- Air and pavement temperatures
- Line width and thickness
- Line retroreflectivity

### *Contractor Documentation*

MnDOT requires the pavement marking contractor to produce documentation of certain items. The inspector is usually responsible for obtaining documentation for such items, which include:

- Material invoice (all jobs)
- Material certification (only for special materials that are not currently tested by MnDOT)
- Material documentation (only if a warranty is specified in the contract)
- Construction Striper Operations Daily Log. Use for pavement messages, non-liquid materials, and projects less than 1 centerline mile in length.
- Data Logging System (DLS). Use when project includes liquid markings and is at least 1 centerline mile in length

### *Inspector's Toolbox*

- Personal protective equipment
- 25 foot tape measure
- 100 foot cloth tape or measuring wheel
- Magnifying glass 3 inch or larger
- Small hand-held broom or brush
- Digital camera
- Striping Report Form
- Kneeling pad (optional)
- Hand held retroreflectometer for pavement markings (optional)

## Air and Pavement Temperature

Under questionable temperature or weather conditions, the temperature of the pavement surface and ambient air temperature must be checked to ensure that the temperatures are in accordance with manufacturer's specifications. Pavement temperature is often measured with an infrared thermometer. Different materials require different surface and air temperatures to achieve proper bonding or curing. Wind speed also affects the accuracy of the drop-on bead application. Markings using drop-on beads should not be placed on days with excessively high winds.

## Traffic Control

One of the most important safety aspects to a pavement marking operation is the level of traffic control that is provided at the job site. Consult the contract for the level of traffic control required at a given job site. The MN MUTCD, Chapter 6K - Temporary Traffic Control Zone Layouts (The Field Manual) contains layouts that should be used for moving or stationary pavement marking operations. The traffic control equipment, devices, and operation should be inspected before and during application to ensure functionality and safety.

## Glass Bead Application Properties

During field striping applications, beads are applied by spraying (pressure drop) onto the wet marking material. Retroreflectivity can be controlled to some degree by drop-on bead application procedures.

Some important field-controlled properties that require on-site inspection are:

1. Mil thickness.
2. The amount and dispersion of exposed beads across the line.
3. The depth of embedment of the beads.
4. Proper location of striping.
5. Tolerances.

Chart I-1 *Retroreflective Bead Trouble Shooting* on page I-7 summarizes some problems that have been encountered during glass bead application and potential remedies of those problems.

### *Amount and Dispersion of Beads*

Inspection of bead coverage across the marking is necessary to assure uniform retroreflectivity across the surface of the marking. In general, the more beads on a surface, the greater the retroreflectivity, although too many beads may cause retroreflectivity to decrease.

Glass bead dispersion may be visually checked by close-up visual examination or by the sun-over-shoulder method. Beads should be uniformly applied over the surface of the markings. If they appear otherwise, notify the operator that his bead gun or pump is likely not functioning properly.

## Checking for Proper Glass Bead Coverage

### *Sun-over-Shoulder Test*

A simple test can be done any time after the line or message has been installed. This method should be performed when the sun is 20 to 80 degrees above the horizon.

The procedure is as follows:

- Select an area of roadway that contains the test line or message. It can be made of any material.
- When the sun is 20 to 80 degrees above the horizon, stand so that the sun is behind you.
- Adjust your distance from the stripe to where the shadow of your head touches the stripe area being observed.
- From this position, evaluate the retroreflective qualities of the stripe. You will be able to see whether the glass beads are evenly distributed over the line or message as shown in Figure O-1 and Figure O-2.

If the coverage is not uniform and the crew applying the material has not left the work site, they should be informed that the applied material is unsatisfactory. If the coverage is not uniform and the crew that applied the material has left the work site, contact the appropriate district traffic office or the OTST pavement marking engineer. These numbers are found in the Appendix of this field guide.

**Figure O-1: Standing Parallel to the Line**

**Figure O-2: Standing Perpendicular to the Line**

### *Bead Embedment Depth*

Bead depth can be estimated by close-up visual examination. Beads should be embedded into the pavement marking material at 60 percent of the bead diameter for maximum retroreflective performance. Because the material that is "behind" the bead is the actual image that is reflected back to the driver, it is important that proper embedment depth is achieved.

Beads not embedded deeply enough will cause the light to be reflected in many directions instead of back to the driver, greatly reducing the retroreflectivity. In addition, beads that are under embedded will be easily worn away after very little traffic wear. Beads that are embedded too deep will still reflect light, but not as much. Therefore, if errors in embedment are made, it is better for the beads to be too deep than too shallow.

### *Checking for Proper Bead Embedment*

There is a simple test can be done to check for proper bead embedment in the field. Any time after the line or message has been installed, select an area of roadway that contains the test line or message. This line or message can be made of any material.

The area needs to be swept clean of any loose material. If the area to be observed has been freshly installed, wait until it has been fully cured before sweeping away loose material. Figure O-3 and Figure O-4 show how to squat down or get on your knees and look at the test area through a magnifying glass. It is important to use a magnifying glass large enough to see the glass beads. One at least 3 inches in diameter is recommended.

For more information on beads and bead embedment refer to Section I: Retroreflective Glass Beads.

**Figure O-3: Checking for Proper Bead Imbedment**

**Figure O-4: Looking Through a Magnifying Glass**

When looking through the magnifying glass, you should see something similar to what is shown in Figures O-5 and Figure O-6.

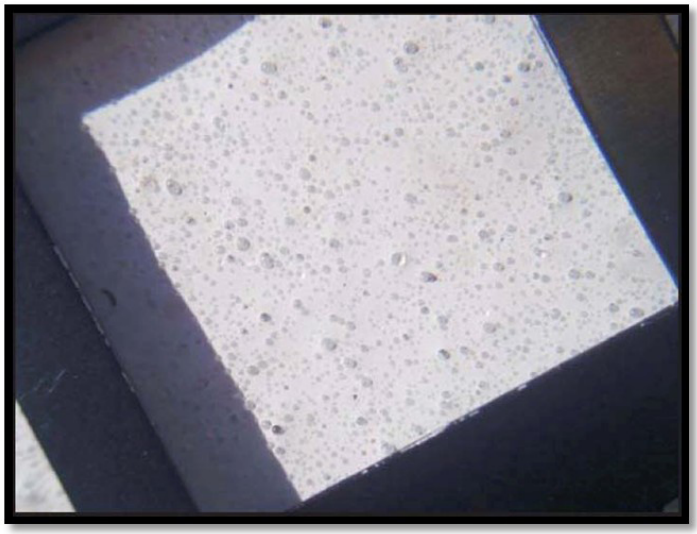


**Figure O-5: White Marking Through a Magnifying Glass**

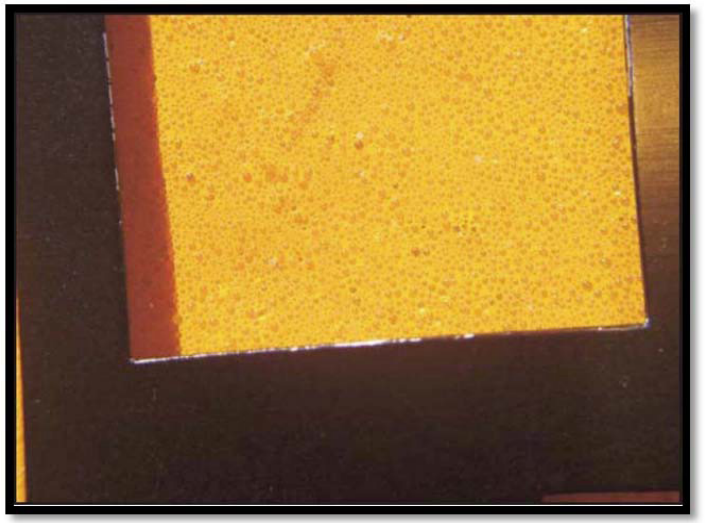


**Figure O-6: Yellow Marking Through a Magnifying Glass**

### *Solutions to Common Problems Associated with Various Striping Applications*

Occasionally during the application of a pavement marking material, problems may be encountered that will cause the marking to have an abnormal appearance and reduce the service life. See the following charts to describe problems that may be observed during the application of various marking materials and corresponding remedies to these problems:

**Chart O-1 Summary of Troubleshooting**

| For Tips on: | See: |
|---|---|
| Bead Application | Chart E-1 |
| Paint Application | Chart F-1 |
| Thermoplastic Application | Chart H-1 |
| Epoxy | Chart G-1 |
| Preformed Tape | Chart I-1 |

### *Final Acceptance*

Final acceptance is a quality assurance measure that involves inspecting the markings a certain amount of time after all markings have been placed. It is recommended that a striping quantity be measured and accepted on a daily basis. MnDOT Standard Specification 2582.3.C requires that markings shall retain a satisfactory level of retroreflectivity, demonstrate good adhesion, resist chipping, and exhibit consistency of color in all lighting conditions.

Final acceptance generally includes two inspection tasks:

1. Measurement of quantities for contract pay items.
2. Measurement of marking retroreflectivity (if specified in contract).

Pay quantities should be measured and documented on a daily basis for each contract. These quantities should also be periodically confirmed with the pavement marking contractor to help avoid future quantity disputes.

Many MnDOT pavement marking contracts now require markings to comply with minimum levels of retroreflectivity a specified number of days after placement for the markings to be accepted. Compliance is often determined by comparing a series of retroreflectivity measurements taken with a handheld or mobile retroreflectometer to minimum levels specified in the contract.

The purpose of final acceptance is to provide a reasonable amount of assurance that newly applied markings will meet or exceed service life expectations for retroreflectivity. Because loosely adhered glass beads are often removed from the marking soon after the markings are open to traffic, retroreflectivity may change rapidly during the first few days after placement. Therefore, retroreflectivity should be measured after markings are applied and retroreflectivity has stabilized, which usually occurs a number of days after striping.

Retroreflectivity measurement for final acceptance should be performed in accordance with MnDOT Standard Specification 2582.3. The sun-over-shoulder method described on page O-3 should only be used as a guide to determine the nighttime appearance of the markings, not for final acceptance purposes.

### *Evaluation of Retroreflectivity*

While other aspects of appearance and durability are important to determine the useful life of pavement markings, those markings are only useful if they can be seen in all conditions, especially at night. Retroreflectivity testing has improved the performance of pavement markings.

Retroreflectivity can be assessed either visually at night or by the use of retroreflectance meters. Currently, MnDOT uses 30-meter geometry instruments. Chart O-2 shows the minimum retroreflective readings using the 30-meter geometry. Each district has its own handheld retroreflectometer. Instruction on the use of and method of collection for the retroflectometer can be found at: http://www.dot.state.mn.us/trafficeng/pavement/manual.html.

**Chart O-2 Minimum Retroreflective Readings for Pavement Marking Material**

| Minimum Retroreflective Readings for Pavement Marking Material (MCD/M²/lux) | | |
|---|---|---|
| **MATERIAL** | **WHITE** | **YELLOW** |
| Preformed Tape | 600 | 500 |
| Thermoplastic | 400 | 250 |
| Thermoplastic (ESR) | 250 | 150 |
| Epoxy | 300 | 200 |
| Latex | 275 | 180 |

Source: MnDOT Standard Spec 2582: Permanent Pavement Markings.

The color of the pavement marking may affect the results of the retroreflective instruments. For example, if a non-leaded yellow paint line begins to deteriorate from UV radiation (i.e. gets lighter in color) but has no bead loss from the initial application, the reflectometer values may increase.

In summary, retroreflectivity and durability are a function of the following parameters:

- The refractive index of the glass bead material
- The gradation or size of the glass beads
- The roundness of the beads
- The coating on the beads
- The embedment of the beads in the material
- The distribution of glass beads in the pavement material
- The number of exposed beads on the marking surface
- The relationship between the diameter of the beads and the striping material thickness

The first four items are controllable manufacturing items. These can be specified and tested for minimum requirements. The last four items are related to the application of materials. Even if the first four items are strictly adhered to, either a bad application of binder material or a bad application of beads will negate the quality of the ingredients and result in a non-durable and/or non-retroreflective pavement marking.

# Section P: Equipment

## Basic Components

Pavement marking equipment comes in many shapes and sizes. All equipment manufacturers have their own configuration of basic components for a given application. A truck manufactured by one company may look considerably different from the truck of a different manufacturer. MnDOT is one of only a few states that owns and operates its own epoxy stripers.

Pavement marking trucks are designed to produce long distance pavement markings. They are self-propelled and are equipped to carry relatively large quantities of material. MnDOT operates and maintains latex and epoxy pavement marking trucks and crews.

Figure P-1 shows a MnDOT epoxy pavement marking striper truck. Figure P-2 shows a MnDOT latex pavement marking striper truck.

**Figure P-1: Epoxy Striper Truck**

**Figure P-2: Latex Striper Truck**

The epoxy striper truck and the latex striper truck look similar but vary somewhat from the specific systems they incorporate based on the type of pavement marking material they are designed to apply. However, the following components can be found on all striper trucks:

- Air compressor (airless applicators included)
- Material holding tank (with mechanical agitators)
- Reflective bead tank (pressurized)
- Cleaning system (cannot be in-line system)
- Material heating system (if necessary)
- Material applicators (spray guns, etc.)
- Reflective bead guns
- Control system (spray gun control, skip timer, etc.)
- Counter system (for measuring distance and/or material)
- Guidance aid (some means for the operator to line up with the road or with existing markings)

The remaining pages in this section are figures illustrating various items of equipment and materials used for pavement markings. The images are not all inclusive, but a representation of some of the items required/used. Note that the pictures show one side of the truck/operator cab. Generally, the other side of the equipment looks similar for painting the line on the other side of the truck.

Figure P-3 is an example of the striper operator cabin. Notice the tanks of materials in front on the cab (to the right), the applicator guns below the cab and the crash attenuator and arrow panel behind the cab.

**Figure P-3: Pavement Markings Truck - Striper Cab**

Figure P-4 shows the pavement marking application carriage. Notice the side-by-side applicators for creating double (side-by-side) lane lines. On the back portion of the carriage are the bead applicators. In front are the material (latex or epoxy) spray guns. The carriage also includes compressed air guns in the front to clean the pavement.

**Figure P-4: Pavement Markings Application Carriage**

Figure P-5 is a stock truck that follows the pavement marking truck. Generally, there are two stock trucks following the pavement marking truck. They carry supplies for the pavement marking truck, provide advance warning to the roadway users, and keep them off of the fresh pavement markings. In addition, the stock truck driver(s) also test the pavement markings to ensure proper curing.

**Figure P-5: Follow-up Stock Truck**

Figure P-6 shows the back of a stock truck with a changeable arrow panel, static warning message, and crash attenuator.


**Figure P-6: Attenuator Truck with Arrow Board**

Figure P-7 shows the striper operator at the markings control panel. In the image, the operator's left hand is on the control switches (on/off, skip, solid, carriage up/down, etc.). His right hand is on the carriage wheel that controls the lateral placement of the markings.

**Figure P-7: Striper Operator Controls**

In Figure P-8 the operator is placing the line by visual inspection looking out the cab window. On some equipment, there is a camera placed on the application carriage with an image that is shown on a screen in the cab. .

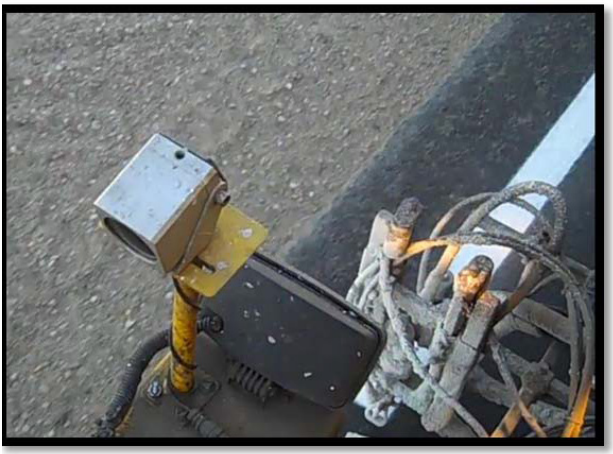


**Figure P-8: Camera on Pavement Markings Application Carriage**

Figure P-9 shows a portion of the center console of the striper operator's cab. This includes many switches and gauges for the materials on the truck (i.e., pump switches, temperature gauges, etc.).

**Figure P-9: Latex Striper Operator Control Panel**

Figure P-10 shows the driver's outrigger wheel used to align the striping truck. In the image, the driver is using the existing pavement markings to align the wheel. On new pavement, the driver may be using sprayed marking points (spotting) or joint lines/edge of the roadway.

**Figure P-10: Striper Truck Driver Outrigger Wheel**

Figure P-11 shows the pavement marking truck (epoxy in this instance) at the truck shop having materials loaded for the day's operation. In this case, the operators are loading beads into the tanks. Figure P-12 shows the supply vacuum tube in the container of beads.


**Figure P-11: Material Tanks (Refilling Beads)**

**Figure P-12: Beads Being Loaded into Supply Tanks**

Figure P-13 shows pavement marking beads (elements) on palettes in shipping containers.

Figure P-14 shows the liquid paint in the containers (totes).

**Figure P-13: Beads in Shipping Containers**


**Figure P-14: Paint Containers**

# Section Q: Retroreflectometers

## Introduction

A critical issue associated with the retroreflectivity of pavement markings is the ability to measure retroreflectivity. Most pavement markings are manufactured on-site, therefore it is hard to measure the retroreflectivity with a high level of accuracy. Instead, agencies and contractors rely on handheld or mobile retroreflectometers to measure the retroreflectivity of pavement markings.

Portable pavement marking retroreflectometers have been available for many years. Pavement markings are currently measured according to 30-meter geometry, which represents retroreflectivity at a distance typical of that which drivers view markings. Retroreflectometer geometry is described in further detail in ASTM E 1710. Contact the OTST Pavement Marking Engineer for a description of the approved retroreflectivity measurement devices.

## Handheld vs. Mobile Units

Portable pavement marking retroreflectometers come in two basic types: handheld and mobile. Examples of both types of retroreflectometers are shown in Figure Q-1 through Figure Q-4.

Handheld retroreflectometers are much less expensive than mobile units and are much easier to use and require less training. However, handheld units are inconvenient when a large number of measurements are required or when measuring on roads with high traffic volumes. There are also safety issues related to the use of handheld units as workers are often exposed to traffic while measuring the retroreflectivity of a marking. Taking handheld measurements often requires lane closures, increasing hazards and delays to motorists.

Mobile units on the other hand are much more expensive than handheld units and require a highly trained operator. However, mobile retroreflectometers produce a very large number of measurements and allow for measurements to be taken at highway speeds without exposing personnel to traffic or requiring lane closures. Some state transportation agencies own mobile retroreflectometers, although most agencies hire qualified contractors to perform mobile retroreflectivity measurements if the measurements are taken to determine contractor compliance with a performance or warranty specification.

**Figure Q-1: LaserLux Van**

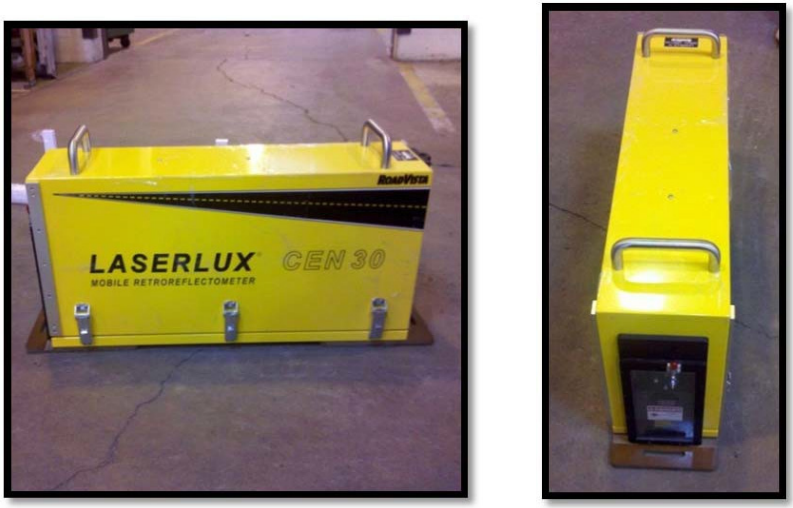



**Figure Q-2: LaserLux Outboard Unit**

**Figure Q-3: LTL-X Handheld Retroreflectometer**


**Figure Q-4: LTL-X Handheld Retroreflectometer**

# Section R: Appendix

### How to check paint coverage METHOD 1:

| Thickness | Gallons per Mile (approximate) | Lineal Feet per Gallon(approximate) |
|---|---|---|
| **Latex Material - 4 Inch Wide Line** | | |
| 12 mil | 13.0 | 400 |
| 15 mil | 16.5 | 320 |
| 20 mil | 22.0 | 240 |
| 25 mil | 26.5 | 240 |
| **Latex Material - 6 Inch Wide Line** | | |
| 12 mil | 20.0 | 270 |
| 15 mil | 25.0 | 210 |
| 20 mil | 33.0 | 160 |
| **Plural Component Material - 4 Inch Wide Line**<br>**This is a mix of generally two to one - two resin (color) to one catalyst (clear).** | | |
| 12 mil | 13.0 | |
| 13.0 gallons divided by 3 parts = 4.3 gallons per mile<br>2 parts = 8.6 gallons per mile of resin (color)<br>1 part = 4.3 gallons per mile of catalyst (clear) | | |

### How to calculate mil thickness of paint lines:

*Need to know:*

1. Gallons of material placed.
2. Total feet striped.

*Formula*:
**Mil Thickness = (4812.5 x Number of Gallons) / Total Feet Striped**

*Example:*
What is the mil thickness of the paint lines where 475 gallons of material was placed and 30 miles of line was striped (not including gaps)?

1. Convert 30 miles to feet:
   30 ft x 5280 ft per mile = 158,400 total feet.
2. Use formula:
   mil thickness = (4812.5 x 475 (gallons))/ 158,400 (feet) = **14.43 mil**

## How to calculate driving speed for different line thicknesses:

Need to know:

1. Mil thickness and driving speed that striper is currently operating.
2. New mil thickness to be placed.

Formula:
**Target Speed = (Current Mil Thickness x Current Driving Speed) / Desired Line Thickness**

Example:
Currently driving 9 mph and placing a 15.4 mil line. What speed should I go to place a 10 mil line?

Target Speed = 15.4 (Current Mil Thickness) x 9 (Current Driving Speed) / 10 (Desired Line Thickness) = **13.9 mph**

**Sample Problem**
An epoxy striper is to place the right edge line on the eastbound section of a four-lane divided roadway through a 5-mile long city and the 10 mile section east of the city. It has been pre-determined that the edge line will be a 15 mil line in urban areas 10 mil in rural areas. The town has been striped using 71 gallons over 4.2 line miles while traveling 9.5 mph.

*What is the actual mil thicknesses placed in the town?*
4812.4 x 71 (gallons) = 641,681 / 22,176 (feet striped (4.2 miles)) = **15.41 actual mil thickness**

*What target speed does the striper need to travel to place the 10 mil line?*
(15.41 (Current Mil Thickness) x 9.5 (current driving speed)) = 146.40 / 10 (desired line thickness) = **15 mph**

## Pavement Marking Character and Message Areas

** Areas are in square feet.*
** Pavement letters are 96" tall.*

| Character | Installed Area | Removal Area |
|---|---|---|
| A | 5.27 | 10.67 |
| B | 7.19 | 10.67 |
| C | 4.79 | 10.67 |
| D | 6.26 | 10.67 |
| E | 5.84 | 10.67 |
| F | 4.61 | 10.67 |
| G | 5.89 | 10.67 |
| H | 5.94 | 10.67 |
| I | 2.56 | 2.67 |
| J | 3.76 | 10.67 |
| K | 5.71 | 10.67 |
| L | 3.79 | 10.67 |
| M | 8.13 | 10.67 |
| N | 7.07 | 10.67 |
| O | 6.04 | 10.67 |
| P | 5.35 | 10.67 |
| Q | 6.30 | 10.67 |
| R | 6.33 | 10.67 |
| S | 5.89 | 10.67 |
| T | 3.79 | 10.67 |
| U | 5.75 | 10.67 |
| V | 4.70 | 10.67 |
| W | 6.18 | 10.67 |
| X | 4.66 | 10.67 |
| Y | 3.86 | 10.67 |
| Z | 5.00 | 10.67 |
| 1 | 2.56 | 10.67 |
| 2 | 5.68 | 10.67 |
| 3 | 5.59 | 10.67 |
| 4 | 5.13 | 10.67 |
| 5 | 6.18 | 10.67 |
| 6 | 6.35 | 10.67 |
| 7 | 3.80 | 10.67 |
| 8 | 6.76 | 10.67 |
| 9 | 6.35 | 10.67 |
| 0 | 6.04 | 10.67 |

| Message | Installed Area | Removal Area |
|---|---|---|
| AHEAD | 28.58 | 64.99 |
| BIKE | 21.30 | 42.00 |
| LANE | 21.97 | 42.00 |
| ONLY | 20.76 | 47.00 |
| PED | 17.45 | 37.00 |
| SCHOOL | 31.86 | 74.00 |
| SIGNAL | 29.84 | 67.20 |
| STOP | 20.44 | 50.00 |
| XING | 20.18 | 42.00 |
| YIELD | 22.31 | 54.27 |
| X | 61.72 | 204.00 |
|  | 15.00 | 48.00 |
|  | 12.01 | 35.00 |
|  | 26.16 | 95.00 |
|  | 25.87 | 88.00 |
|  | 37.04 | 70.00 |
|  | 42.55 | 44.00 |
|  | 18.87 | 67.20 |
|  | 25.10 | 93.39 |
|  | 9.75 | 30.00 |
|  | 0.75 | 1.50 |
| | 3.00 | 6.00 |
|  | 5.79 | 8.00 |
| | 8.69 | 18.00 |
| | 11.58 | 32.00 |
|  | 7.63 | 32.07 |
|  | 3.53 | 14.12 |

**NOTES**

## MnDOT Phone Numbers and Addresses

District 1A - Duluth
Minnesota Dept. of Transportation
1123 Mesaba Avenue
Duluth, MN 55811
218-725-2700

District 1B - Virginia
Minnesota Dept. of Transportation
101 Hoover Road
Virginia, MN 55792
218-742-1100

District 2 - Bemidji
Minnesota Dept. of Transportation
3920 Highway 2 West
Bemidji, MN 56601
218-755-6500

District 2 - Crookston
Minnesota Dept. of Transportation
1320 Sunflower Street
Crookston, MN 56716
218-277-7950

District 3A - Baxter
Minnesota Dept. of Transportation
7694 Industrial Park Road
Baxter, MN 56425
218-828-5700

District 3B - St. Cloud
Minnesota Dept. of Transportation
3725 12th Street North
St. Cloud, MN 56303
320-223-6500

District 4 - Detroit Lakes
Minnesota Dept. of Transportation
1000 Highway 10 West
Detroit Lakes, MN 56501
218-846-3600

District 4 - Morris
Minnesota Dept. of Transportation
610 Highway 9 South
Morris, MN 56267-9596
320-208-7000

District 6A - Rochester
Minnesota Dept. of Transportation
2900 48th Street NW Rochester,MN
55901-5848
507-286-7500

District 6B - Owatonna
Minnesota Dept. of Transportation
1010 21st Avenue NW
Owatonna, MN 55060-1005
507-446-5500

District 7 - Mankato
Minnesota Dept. of Transportation
2151 Bassett Drive
Mankato, MN 56001
507-304-6100

District 7 - Windom
Minnesota Dept. of Transportation
180 S. County Road 26
Windom, MN 56101-1868
507-831-8000

District 8 Hdqrs. - Willmar
Minnesota Dept. of Transportation
2505 Transportation Road
Willmar, MN 56201
320-231-5195

District 8 – Marshall
Minnesota Dept. of Transportation
Regional Office 1800 East College Drive
Marshall, MN 56258
507-537-6146

District 8 - Hutchinson
Minnesota Dept. of Transportation
Regional Office 1400 Adams Street SE
Hutchinson, MN 55350
320-234-8480

Metropolitan District
Minnesota Dept. of Transportation
1500 West County Road B2
Roseville, MN 55113-3174
651-234-7500

Central Office
Minnesota Dept. of Transportation
Office of Traffic, Safety, Mail Stop 725
1500 West County Road B2
Roseville, MN 55113
651-234-7000

Pavement Marking Engineer
651-234-7373
Fax 651-234-7370

Materials Lab
1400 Gervais Avenue
Maplewood, MN 55109-2044
651-366-5592