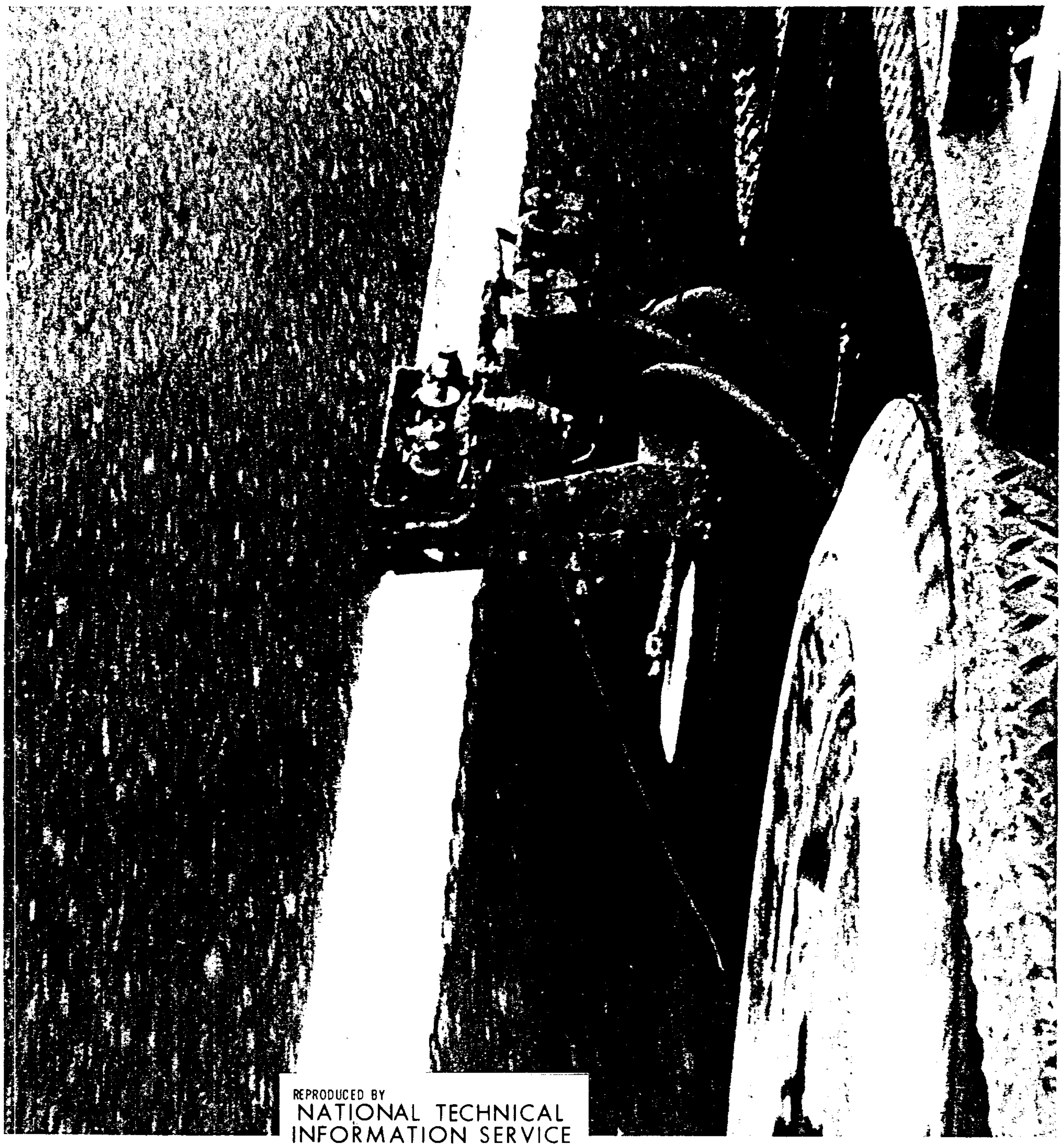
PB82-207101

Roadway Delineation Practices Handbook

Implementation Package
FHWA-IP-81-5

September 1981

U.S. Department of Transportation
Federal Highway Administration



Technical Report Documentation Page

1. Report No. FHWA-IP-81-5	2. Government Accession No. PB82-207101	PB82-207101
4. Title and Subtitle **Roadway Delineation Practices Handbook**		5. Report Date September 1981
		6. Performing Organization Code
7. Author(s) I. J. Fullerton		8. Performing Organization Report No.
9. Performing Organization Name and Address **JHK & Associates** Box 3727 San Francisco, CA 94119		10. Work Unit No. (TRAIS) 31L9013
		11. Contract or Grant No. DOT-FH-11-9491
12. Sponsoring Agency Name and Address Federal Highway Administration Office of Development Implementation Division Washington, D.C. 20590		13. Type of Report and Period Covered HANDBOOK
		14. Sponsoring Agency Code P-0308
15. Supplementary Notes Contract Manager - Mr. Charles Niessner		

16. Abstract

In the context of this Handbook, roadway delineation is defined as a system of devices and or/markings--excluding signs and signals--that regulate, warn, or provide tracking information and guidance to the driver. Intended primarily for use by various levels of design, traffic, and maintenance engineering personnel, the **Roadway Delineation Practices Handbook** provides practical assistance guidelines in the proper application of available delineation systems. Although not intended to be a state-of-the-art report, the handbook does provide an overview of current developments in the area of roadway delineation techniques. Major topics within the handbook include "Painted Markings," "Thermoplastic and Other Durable Markings," "Raised Pavement Markers," "Post Delineators" and "Administrative and Management Considerations." Contained within the discussion of each category of delineation techniques is a discussion of issues relating to uses, materials, application procedures, service life, and maintenance. One of the primary functions of the handbook is to offer guidance for implementing the provisions of the **Manual on Uniform Traffic Control Devices** concerning roadway delineation.

17. Key Words	18. Distribution Statement
	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	156	

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Foreword

This Implementation Package provides fundamental concepts of roadway delineation, current practices, and promising new technologies for the future. The information should be of interest to traffic and maintenance engineers and safety specialists concerned with improved roadway delineation.

Research to develop new delineation materials and to determine motorist's delineation requirements is included in the Federally Coordinated Program of Highway Research and Development in Project 1I, "Traffic Lane Delineation Systems for Adequate Visibility and Durability" and Project IL, "Improved Traffic Operations During Adverse Environmental Conditions". Dr. Edward T. Harrigan and Mr. Richard N. Schwab are the respective Research Project Managers and Mr. Charles W. Niessner is the Implementation Manager.

Additional copies of the Implementation Package can be obtained from the National Technical Information Service, Springfield, Virginia 22161.

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NOTICE

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Chapter 1. Overview of Delineation Handbook

INTRODUCTION

Auto ownership and mobility requirements continue to escalate virtually unchecked in all sectors of the nation. The concomitant increase in accidents, delays, and inconvenience has posed a critical challenge to local, state, and Federal traffic operations and safety engineers. In seeking solutions, the emphasis has shifted from the relatively simple, but costly, expedient of new road construction, to improving the efficiency and safety on existing roadway systems.

The development of roadway delineation techniques has generally kept pace with the development of the national highway and street systems. Such evolving techniques have long been considered essential for the optical guidance of the driver thus enhancing traffic flow, driving comfort, and traffic safety. In today's environment, it has become increasingly important to develop and implement economical measures to optimize roadway performance. This requires a thorough knowledge of what technology has to offer and prudent decisions on the application of the most cost effective techniques.

The Federal Highway Administration (FHWA), National Cooperative Highway Research Program (NCHRP), and other concerned agencies have sponsored a number of research and field studies addressing various facets of the roadway delineation problem. In addition, many states and some large cities have conducted extensive laboratory and field tests of new and different delineation techniques under consideration. Many towns, cities, and counties, however, do not have the manpower, expertise, or budget available to investigate and evaluate the numerous devices, materials, or equipment involved in installing and/or maintaining an effective roadway delineation system. A definitive guide to delineation techniques is needed that is more objective than the pursuasiveness of the local vendor.

Recognizing this need, the FHWA initiated a project to develop this Handbook. The overriding purpose of the project was "... to develop a handbook on roadway delineation systems that will assist the practicing engineer in determining the appropriate system for a particular situation."

HANDBOOK PURVIEW

The Handbook is primarily intended for use by various levels of design, traffic, and maintenance engineering personnel. It may also prove of value to consulting engineers, educators, and students. Essentially, the contents cover current and newly developed devices, materials, and installation equipment in terms of demonstrated or anticipated performance based on actual experience or field/laboratory tests.

While the Handbook is not intended as a state-of-the-art report, it provides fundamental concepts of delineation, current practices, and promising new techniques of the future. The materials used to develop the Handbook reflect the experience of state, county, and city agencies. It also summarizes future directions and developments as reported in recent research and by industry's technical representatives.

In the context of this Handbook, delineation is defined as *"one, or a combination of several types of devices (excluding signs) that regulate, warn, or provide tracking information and guidance to the driver."* This definition is interpreted to include the following categories of delineation techniques:

- Painted Markings
- Thermoplastic and Other Durable Markings
- Raised Pavement Markers
- Post Delineators

The Handbook does not establish FHWA policies or standards. It is meant as a supplement to, and for use in conjunction with, standards and applications set forth in the *Manual on Uniform Traffic Control Devices* (MUTCD), 1978 Edition (Ref. 1). As such, the Handbook offers guidelines for implementing the policies and directives contained in the MUTCD. The Handbook does not attempt to detail the numerous research projects associated with delineation systems technology. However, major research findings used in developing these guidelines are clearly referenced for those interested in pursuing the detail of a particular research aspect. The basic definition of terms as applied in this Handbook is included as Appendix A.

Delineation generally refers to any method of defining and limiting the roadway operating area for the driver. The function of roadway delineation as stated in the MUTCD Part III Markings is to "... supplement the regulations and warnings of other devices such as traffic signs or signals. In other instances, they are used alone and produce results that cannot be obtained by the use of any other device . . . (by) conveying certain regulations and warnings that could not otherwise be made clearly understandable"(Ref. 1).

The standard applications defined in the MUTCD have been established to convey information to the driver in several ways (i.e. color, pattern, width). For example, yellow lines delineate the separation of traffic flowing in opposing directions while white lines denote traffic flowing in the same direction. Broken line patterns are permissive in character while solid lines are restrictive. Width of line indicates the degree of emphasis. Detailed standards related to color, pattern and width are presented in Sections 3A-2 through 3A-6 of the MUTCD. It is stressed that "each standard marking shall be used only to convey the meaning prescribed for it in this Manual (MUTCD)." It is assumed that agency personnel involved with planning or designing roadway delineation projects is familiar with the MUTCD or its state-mandated equivalent.

HANDBOOK ORGANIZATION

The Delineation Practices Handbook has been structured to provide the practicing engineer a convenient guide for determining the most effective delineation techniques for a given set of circumstances. Basically, the sequence of subject matter falls into four parts:

- Introductory and background material (Chapters 1 and 2)
- Technical description of current delineation practices (Chapters 3 through 6)
- Summary of Administrative and Management Issues and Practices (Chapter 7)
- Technical Supplement (Appendices)

To the extent possible, the Chapters presenting technical descriptions of delineation techniques are organized around a common format. (That is–Uses, Materials, Application, Service Life, and Maintenance.) To avoid redundancy, a particular discussion applicable to more than one delineation technique is detailed in Chapter 2 and referenced in subsequent chapters.

The appendices provide detailed technical information to support, supplement or expand the basic practices described in the body of the text. Of special interest are the Model Specifications for the various delineation devices and products. It should be recognized that while these specifications represent the most current versions available, certain of these are still in the review and acceptance stage and should therefore be considered tentative. The originating organization, date, and the current status of each performance or composition specification is clearly stated on the cover sheet. The use and adaptation of model specifications by local agencies is discussed in Chapter 7, Administration and Management.

Chapter 2. Driver's Needs and Delineation Characteristics

Today, roadway delineation is a common and expected component of the highway system. The question is no longer one of whether delineation is effective but rather one of how to provide the best system of delineation for the least cost.

Previous to discussing the various delineation techniques and devices, the visibility needs of drivers and the roadway and traffic characteristics which affect the development of delineation systems are reviewed. The properties and characteristics of reflective materials and the pavement surface impact on many of the pavement marking materials and devices; consequently, a short discussion of these factors is also included to provide the background for subsequent chapters.

DRIVER'S NEEDS

The ideal form of delineation and the best materials to be used would be that which provides the most guidance and warning to the driver. A great deal of complex research has been directed toward defining the behavioral and perceptual characteristics of drivers and relating these "human factors" to the safety and operational efficiency of the Nation's roadway system. This research has been well documented and has played a significant role in the development of new materials, specifications, and standards. The field of human factors research related to the driving task is much too complex to be included as part of this Handbook. Accordingly, this discussion is limited to a summary of those driver characteristics which may exert an influence on the design and installation of delineation systems.

Functions of Delineation Markings

The primary purpose of a roadway delineation system is to provide the visual information needed by the driver to steer a vehicle safely in a variety of situations. The delineation technique used must define the field of safe travel, must be visible in daylight and darkness, and in periods of adverse weather such as rain and fog.

Markings have definite functions in a proper traffic control system, As defined in the MUTCD, they are applied for the purpose of regulating and guiding the movement of traffic, and of promoting safety on the highway. In some cases, they are used to supplement the regulations or warnings of other traffic control devices. In other cases, they are the sole means of effectively conveying certain regulations, warnings, and information in clearly understandable terms, without diverting the driver's attention from the roadway. In addition, the capacity of a highway is often increased by the orderly and proper regulation of traffic flow which results from correct application of pavement markings.

The application of markings is more than a matter of painting lines. It is, in effect, the installation of a traffic-regulating system on a highway. As with all other traffic control devices, markings must be readily recognized and understood, and this goal can only be achieved by using a uniform system of markings, when they are desirable or warranted. A motorist should be confronted with the same type of markings whenever he may travel, and these markings should convey exactly the same meaning wherever they are encountered.

Driver's Performance Factors

Generally, the ability of the driver to safely and accurately operate his vehicle is based on driver's perception of a situation, his level of alertness, the information available, and his ability to assimilate the available information. The driver's tasks include:

- *Control:* The physical manipulation of the vehicle. In this overt action, the driver exercises lateral and longitudinal control by means of the steering wheel.
- *Guidance:* The selection of safe speed and path. In this decision-process, the driver must evaluate the situation to determine the speed and path appropriate to existing conditions and then translate decisions into control actions (e.g. lane positioning, headway, passing, etc.).
- *Navigation:* The planning and execution of the trip, origin to destination.

Of these three tasks, failure in control has the most severe consequences in terms of accident potential. Visual perception is critical to the driving task. Consequently, to be effective roadway markings must yield the appropriate visual clues. The ability to see and perceive as a basis for vehicle control is a function of contrast between background and the roadway, particularly at night. The need for contrast decreases with greater background luminance; therefore there is better detection in daylight. During clear daylight hours, visibility presents little problem. Visual information is indirectly available from features of the roadway and surrounding terrain; hence, delineation devices are less important to the driving task. At night, these indirect "delineators" become ineffective and the motorist must rely on the more direct roadway markings to perceive his safe route of travel. Down-the-road visibility is restricted when contrast and luminance is reduced. Rain and other adverse weather conditions further degrade driver's visibility.

Effect of Adverse Visibility

The effect of adverse visibility on driver performance was the subject of a recent major research effort including simulation experiments and field tests (Ref. 2). The simulation experiments provided the following insights into driver performance under adverse visibility:

- As visibility range is reduced, delineation configuration or pattern becomes increasingly important. Solid edgelines, longer dashes, and shorter cycle length tend to counteract some of the effect of reduced visibility.
- The car hood restricts minimum forward view to approximately 20 feet ahead of the driver's position; when one dash disappears below the hoodline before a succeeding dash is visible, steering performance becomes very erratic. Thus, delineation gap length is a key variable.
- Longer dashes can give some indication of road curvature even though only one dash is visible. raised retro-reflective pavement markers (RPM's) are limited in providing any curvature information unless more than one marker is visible. Thus RPM's should be spaced more closely on curving sections.
- Preferred speed decreases with reduced visibility, or at constant speed, steering performance degrades.

In summary, the simulation experiments indicated that steering performance is affected by the combined efforts of reduced visibility and delineation configuration. In other words, steering performance degrades with decreased visual range and with a reduction in the total amount of information available to the driver. This suggests that visual range and delineation configurations are important variables in the design of delineation systems.

Normally, under clear visibility conditions, drivers tend to position their vehicles somewhat to the left of the center of the lane. This is based on the fact that the driver is sitting on the left and therefore has a better view of the left side of the vehicle. This also permits the driver to maintain a relatively constant lateral position in relation to the left lane or center line.

The analyses of the field test data revealed several important effects of delineation visibility on vehicular control. When delineation visibility was degraded, either by reduced contrast or by a covering film of water, driver reactions generally were as follows:

- The drivers shifted their vehicle's mean lateral lane position away from the left lane line to approximately the center of their traffic lane.
- Lateral control performance deteriorated as indicated by a substantial increase in the vehicle's lateral position variability.
- Mean speed was not appreciably affected except in rain experiments. Even there, the average speed reduction was only on the order of 2 mph under the worst visibility condition.
- Speed control seemed to be generally unaffected although the vehicle's speed variability was uniformly higher in the rain.

These experiments demonstrated a systematic relationship between pavement striping contrast and the ability of the driver to constantly maintain the position of the vehicle on the travel path. The significance of this is that the expression for this relationship may be used in predicting the probability of inadvertent vehicular excursions from a traffic lane as a function of striping contrast. Thus, a relationship between contrast and accident potential can be established.

The rain experiment indicated the effectiveness of retro-reflective raised pavement markers and the inadequacy of painted pavement striping for guiding drivers in the rain. With only painted striping for guidance, wet weather drivers demonstrated a potentially dangerous combination of increasing lateral placement variability and decreasing mean distance from the lane line. At the same time, they were showing signs of heightened agitation, indicating they were exerting greater effort. When they returned to a roadway section where RPM's supplemented the painted markings, their performance recovered and their psychophysiological status returned to its normal level. Even in dry weather, the drivers controlled their vehicle with less lateral position variability when raised markers were used along with striping. It should not be concluded that the addition of RPM's improves driver performance under *all* circumstances, although it appears highly likely.

This work (Ref. 2) represents well-designed and carefully developed research which should contribute to a better understanding of the application and use of delineation systems. The application of these findings will assist in the design and maintenance of delineation systems, particularly under poor visibility conditions.

KEY VARIABLES

There are several key variables that should be considered in determining the most appropriate delineation treatment and technique. These include the geometry of the roadway, the climatic characteristics, traffic volumes and composition, and the type of substrate. A brief review of the significant effects of these variables is given below. More detailed descriptions of the research and demonstration projects supporting this summary review are available in the referenced reports.

Roadway Geometry

Roadway geometry has more effect on the delineation "treatment" than on the various delineation techniques. In this context, *treatment* refers to such issues as the installation of center lines, edge lines, post delineators, etc. as well as width, spacing, gap-to-segment ratio, colors, etc. *Techniques* involves the various delineation devices, materials, and application procedures.

In a definitive study of "Roadway Delineation Systems" conducted by the National Cooperative Highway Research Program (NCHRP Report 130, Ref. 3), the research centered around the following set of geometric situations:

- Tangent sections
- Horizontal curves
- No passing zones
- Pavement width transitions
- Merging-diverging areas
- Turns
- Turns with deceleration and/or storage lanes
- Stop approaches
- Railroad crossings, cross-walks, etc.

Each of these situations have a unique set of driver information needs and associated delineation requirements. These "classic" situations were used to model and evaluate the safety aspects of various delineation treatments and their impact on driver behavior and traffic performance.

The study showed that the application of standard delineation treatments where no previous delineation existed significantly reduced accident rates. Major changes in delineation treatments can produce measurable changes in traffic performance; however, minor variations of delineation treatments (such as spacing, gap-to-stripe ratio, colors) have not affected accident rates or shown significant differences in traffic performance measures. Thus, it was concluded that minor variants of delineation treatments must be judged on factors other than accident reduction.

In addition to this NCHRP research, there have been a series of before and after studies dealing with the effect of pavement markings and, in particular, edge striping on traffic performance and accident rates. In general, these studies are not comparable even though most of them concentrated on rural two-lane roads. The inability to make direct comparison was a result of the vastly different conditions that were present, such as lane widths, the absence or presence of shoulders, and other environmental factors.

Nonetheless, the studies indicated that edge lines on tangent sections tend to decrease variability in lateral placement and to shift the vehicle away from the roadway edge. Because of the accident potential (head-on collision) inherent in shifting vehicles toward the center line, hence towards vehicles traveling in the opposite direction, many states prohibit edge lining pavements narrower than 18 feet (5.5 m). Other studies have shown that edge lines reduced speed through horizontal curves and minimized center lane straddling (Ref. 4).

Another study evaluated the safety and cost effectiveness of six delineation treatments for various geometric situations (Ref. 5). The treatments included:

- No delineation
- Center line
- Center line plus edge line
- Center line plus post delineators
- Center line plus edge line plus post delineators
- Center line plus guardrails

Total accident rates were computed for each of the various treatments and geometric situation combinations. The study showed that the mean accident rate for various treatment combinations decreases with increases in sophistication of delineation.

It should be noted that some recent experience on winding and or mountainous roadways has demonstrated a tendency of drivers to increase speed beyond safe levels where edge lines were provided. The decrease in head-on type collisions were offset by an increase in run off the road accidents. It has been suggested that the better definition of the roadway provided by edge lining gives the driver a false sense of security in his ability to control his vehicle and maintain a safe position in the roadway.

Climatic Characteristics

The prevailing climate and weather conditions greatly influence the effectiveness of delineation techniques from the standpoint of driver visibility. Durability of materials and installation activities are also influenced by weather.

Rain, at any time, reduces the ability of the driver to visualize his surroundings. At night, glare from the headlights from on-coming vehicles, windshield wiper action, and the slippery pavement surface coupled with degraded reflectivity of painted markings make the driving task on rainy nights particularly hazardous and difficult. Reflectorized raised pavement markers and post delineators are much more effective than painted markings which lose their reflectivity due to surface water film. During daytime rainy periods, the raised markers do little to improve visibility, but the audible effect of passing over the markers serves to alert the driver of a potential inadvertent encroachment into an adjacent lane.

Rain does not adversely affect the durability of pavement markings. It has been reported, however, that the tire action on wet thermoplastic markings produces a cleansing effect. Maintenance personnel cite numerous incidents of improved daytime visibility (i.e. contrast) of thermoplastic lane lines after several hours of rain. Conversely, post delineators are subject to splashing from wet highways which degrades the reflectivity and may require cleaning.

Snow, even more than rain, affects the driver's visibility since even moderate snowfall will completely obliterate most all pavement markings. The problem of delineation in high snowfall areas is compounded by potential damage to pavement markings from snowplow activity, studded tires, and the use of chemicals and de-icing salts. Post delineators (with extension posts where drifts are abnormally high) will provide effective edge line and road alignment-type delineation but are vulnerable to knockdowns by the snowplows.

Fog creates an extremely hazardous situation by seriously reducing driver's visibility. There are no really cost-effective delineation techniques that will provide adequate roadway delineation although experiments with various forms of surface highway lighting have been undertaken (Refs. 6, 7). Near delineation of the roadway has been improved somewhat by closer spacing of high intensity reflective raised markers combined with non-reflective RPM's to create a rumble effect when passing over the line. Similarly, where near visibility is a recurring problem, the gap between stripes has been decreased in the problem location so that at least one or two stripes will be visible.

Blowing sand, like fog, can seriously reduce driver's visibility. It can also collect on the roadway and obscure pavement markerings. It may damage paint and thermoplastic by the abrasive sandpaper effect of tire action on the sand over the marking. Because of the hazards inherent in blind driving through fog or blowing sands, some agencies close the highway or provide platoon escorts through the affected areas.

In addition to the physical presence of rain, snow, fog or blowing sands, weather in terms of extremely hot or cold climates can influence delineation. For example, some materials such as thermoplastics or paint are specially formulated to withstand extreme temperatures. That is, a thermoplastic product formulated for the Northeast would not be applicable to the Southwest. The effects of the freeze-thaw cycle on the pavement surface as well as on the delineation materials can induce early failure by weakening the the bond with the pavement surface.

Summer heat can also be deleterious to pavement markings. In sections of Arizona, California, Nevada, Texas, and other hot climates, where surface temperatures frequently exceed 120° F (49° C), thermoplastic on asphalt pavement will "crawl" and distort. It will also become badly marked with tire tracks which will result in reduced daytime visibility (i.e. contrast) but will not significantly effect nighttime reflectivity. In addition, the ultra violet rays of strong sunlight can affect the color and life of conventional delineation materials.

In summary, the climate and weather conditions must be considered to determine not only the most appropriate delineation treatment (spacing, etc.) but to assure that the delineation techniques and materials are compatible to the site-specific conditions. The reduced visibility associated with the effects of weather such as rain, snow, fog, etc. make driving extremely hazardous. Consequently, the safety aspects of providing the best possible guidance to the driver in such situations transcends the traditional cost effectiveness concerns.

Traffic Characteristics

Traffic conditions can effect the choice of delineation treatments and techniques from two standpoints: traffic volumes and traffic composition. Traffic volumes are important in that average annual daily traffic (AADT) is often the major criteria used to select specific types of delineation techniques. For example, high density roadways may be better served by the installation of high durability devices such as raised markers, hot laid thermoplastic, or epoxy. This will not only provide long-term delineation, but will avoid the necessity of frequent restriping. Hence the exposure of maintenance crews and traffic disruption can be significantly reduced. Higher initial cost can be balanced against the safety and long-term economic benefits of the more durable techniques.

Low AADT may indicate that painted markings alone or in combination with RPM's or post delineators are adequate and may last one or more years without restriping. It may be found that markings for very low density roadways can be served by reduced thickness or line width depending on the site characteristics.

Traffic composition can affect the effective life of various delineation materials. Trucks, buses, and other heavy equipment constituting the majority of traffic can damage or wear out roadway markings much faster than traffic composed of passenger vehicles. Rural farm-to-market low density roads or industrial access roadways, for example, may therefore require heavier or more durable applications than would be indicated strictly on the basis of AADT.

As a general rule, however, AADT is most often correlated with service life as shown in the example in Figure 1. Some agencies have developed more complex correlations. For example, the District of Columbia uses the number of wheels crossing as an indicator rather than simple AADT. The reasoning is that traffic abrasion occurs only when the wheels of a vehicle passes over a marking. Edge lines or heavily traveled freeway lane lines may not experience the same wear as lower AADT areas in which criss-crossing or encroachment is more pronounced (Ref. 8).

The technique used by D.C. for calculating the life expectancy as a function of traffic flow is based on the following assumptions and definitions:

- Wear of pavement marking materials is a function of the second power of the number of vehicles per lane passing over the materials laid normal to the directions of traffic flow.
- *Life Expectancy* is defined as measured by the total number of vehicles per lane that have passed over the marking when it is worn completely from the wheel paths.
- *Service Life* is a measure of the number of vehicles per lane that have passed over the material when the marking is no longer serviceable on account of having lost its luster or its reflectivity (night visibility) of having been worn completely from the surface in the wheel paths.
- Pavement markings of conventional traffic paint and instant setting materials lost their luster and beads lose reflectivity to the extent to which they should be renewed when material in the wheel paths has been worn away to half its original area.
- Thermoplastic markings retain brightness and beads are still reflective until all of the material in the wheel paths has been worn away from the pavement.
- *Cost Effectiveness* is the ratio of the cost per linear foot of marking to the service life expressed in millions of vehicles per lane of traffic.

This technique appears to work well for high density facilities. Whether general or sophisticated correlations are developed depends on the types and functions of the specific site. The point of emphasis is that the traffic characteristics of a given site can become an important consideration especially in evaluating cost effectiveness of the more durable delineation techniques.

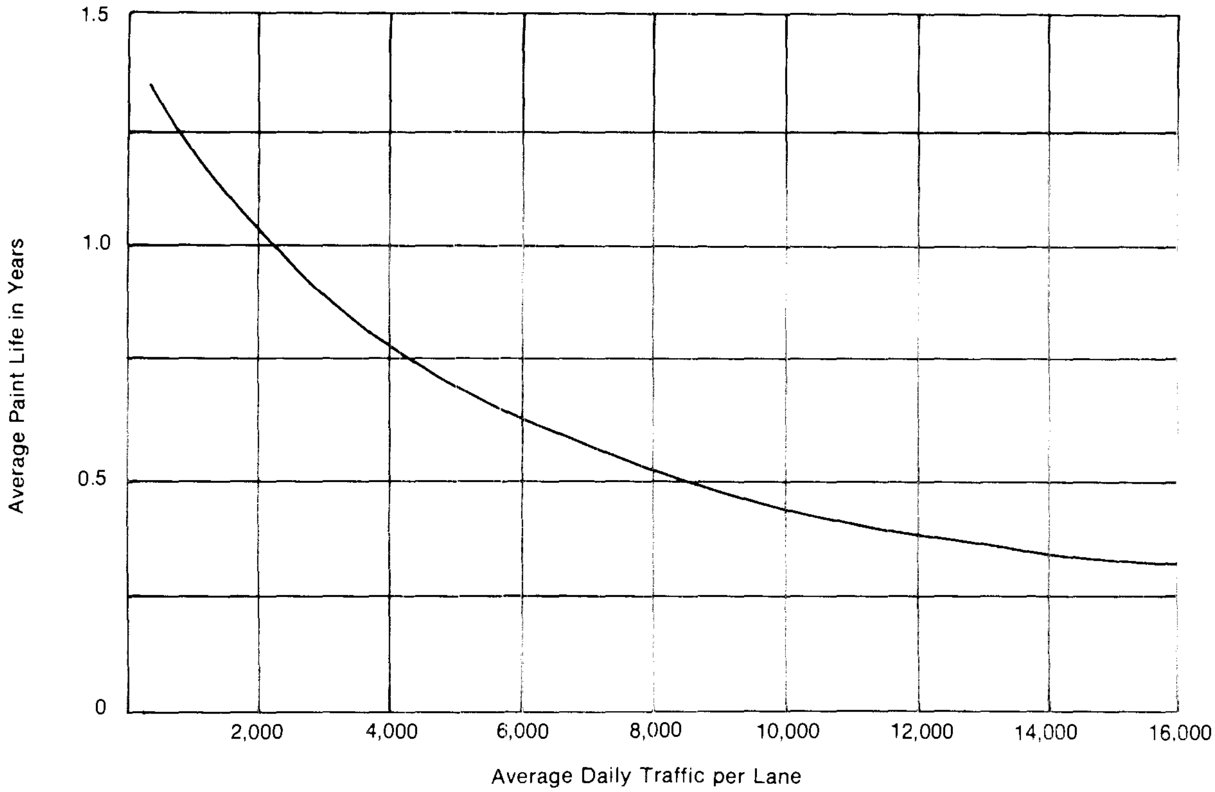
Effect of Substrate

Variations in type and condition of the pavement (substrate) determines to a large extent, the durability and visibility of the materials used in pavement markings. It is therefore appropriate to review the basic characteristics of the two most widely used pavement surfaces.

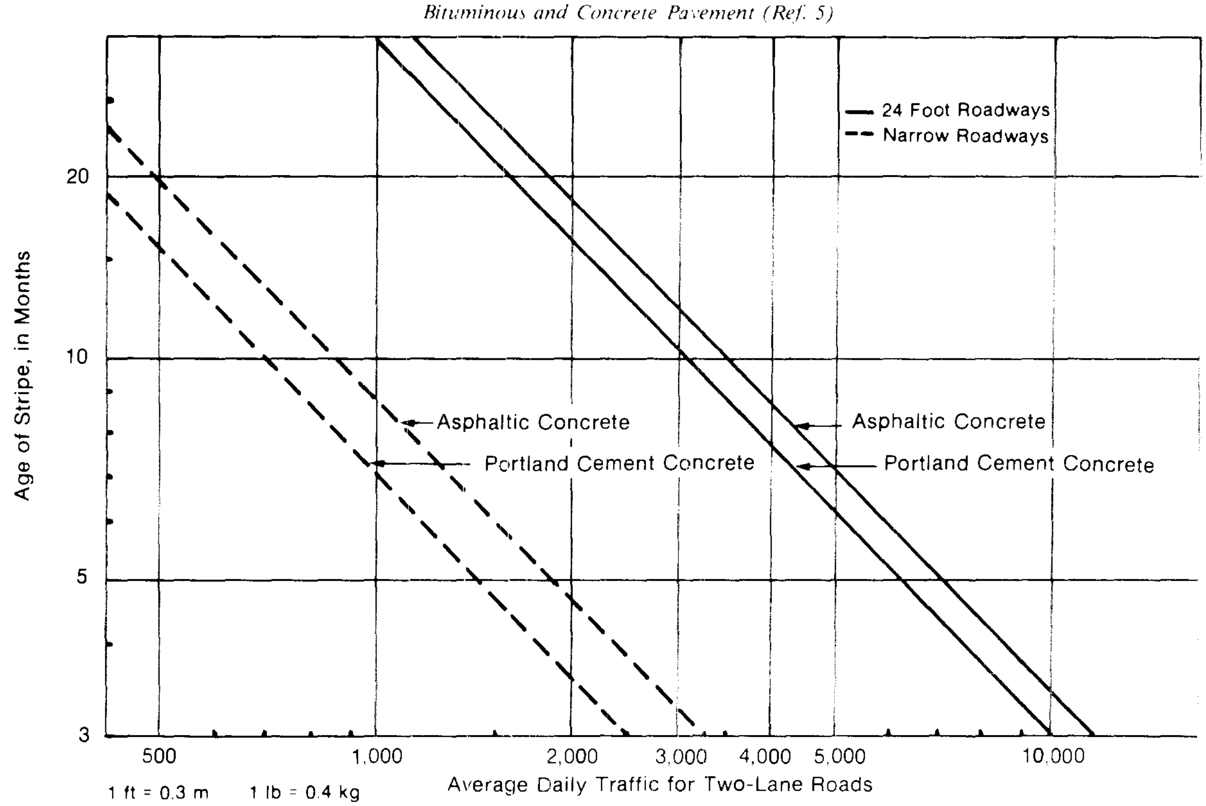
Basically, the roadway surfaces upon which traffic markings are applied fall in two general catagories: asphaltic concrete (AC) or Portland cement concrete (PCC). The term "asphaltic concrete" denotes a dense-graded road surface made of hot mineral aggregates plant-mixed with hot asphalt. "Bituminous concrete" is a more general term which includes both asphalt concrete and similar mixtures made with refined tar. The coarse aggregate is generally crushed stone, crushed slag, or crushed gravel, to which is added sand or sand and filler. Bituminous concrete has the important advantage that traffic may use it immediately after construction (Ref. 9).

Another form of asphaltic concrete is referred to as "open-graded". In this form, only coarse aggregate is used. When applied as a surface course, it has a high porosity and permeability as well as a rough surface texture. The porous characteristics minimizes the potential for hydroplaning by allowing numerous escape channels for water beneath a moving tire. Of importance to delineation, water ponding on the pavement surface and striping is reduced, thereby minimizing the time in which pavement markings are ineffective as a reflective device (Ref. 10).

Portland cement concrete consists of a relative rich mixture of Portland cement, sand, coarse aggregate and water laid as a single course. When properly designed and constructed, it has a long life and relatively low maintenance requirements. A minimum of five to seven days curing time is required before the pavement is ready for use.



a) Paint Striping as Affected by Traffic Density for Both Bituminous and Concrete Pavement (Ref. 5)



b) Conditions for Noticeable Traffic Stripe Wear (White Traffic Paint Placed at 15 mils, Wet with 6 lb. of beads/gal) (Ref. 5)

Figure 1. Representative Plots of Service Life vs. AADT

As the service life of asphalt pavement is dependent on so many variables (type of aggregate, type of base, traffic density, climate conditions, etc.), an "average" life expectancy is of little value. It is, however, a general "rule of thumb" that PCC pavement outlasts asphalt by about 2:1. Another major difference is that PCC is much smoother than AC and is often scored or treated to increase its skid resistance.

The life of the pavement is particularly significant when considering the application of highly desirable delineation treatments. For example, raised pavement markers or thermoplastic markings under certain circumstances could outlive an aging asphalt pavement surface. The relative high initial cost of these treatments is justifiable on the basis of durability and longevity. Since imminent resurfacing or reconditioning of AC would cancel out one of the major advantages of such long term delineation techniques, alternate methods should be considered for the interim period.

Greater quantities of paint or hot-applied thermoplastic materials are required with the open-graded pavement surface because of its porous nature. It does, however, provide better wet-night visibility. With raised markers, the problems in obtaining a secure bond with the rough surface results in a higher percentage of dislodged markers.

These properties and characteristics have a profound effect on the performance of various delineation materials and devices. Accordingly, the type and condition of the pavement surface should be carefully considered in the selection of the most appropriate delineation system.

Implications of Variables

The ideal form of delineation is that which provides the best overall return as measured by informed driver behavior, safety, free movement of traffic, and cost. There are various marking and delineation techniques that may be used individually or collectively as appropriate.

The particular advantages or drawbacks of each of these techniques and their general characteristics are described in the following chapters. In order that best use be made of the funds available for marking devices, it is necessary to choose delineation techniques that meet the requirements of a specific site economically and adequately.

The selection of delineation techniques and materials for purchase is a recurring activity for highway and traffic engineering agencies. There is no universal delineation configuration that serves all needs equally well. To achieve the best balance among driver requirements, safety aspects, and economic considerations, each of the variables discussed above must be assessed to determine their impact on effectiveness. The following chapters seek to place in perspective current practices and the rationale used in the decision process.

REFLECTIVITY FOR NIGHT VISIBILITY

According to the MUTCD "... *markings which must be visible at night shall be reflectorized unless ambient illumination assures adequate visibility.*" There are so few roadways within an agency's jurisdiction that are typically well illuminated that the trend among state and local agencies is to reflectorize all roadway markings. The exception is generally painted curbs and perhaps parking lines.

Glass beads are mixed or dropped on paint, thermoplastic, polyester, and epoxy pavement markings to provide the necessary reflectivity. The characteristics, typical usage, and the major factors influencing the application of glass beads are discussed below. The corner cube reflectivity technique used in raised pavement markers is discussed in Chapter 5.

Reflective Properties of Glass Beads

The amount of light reflected by glass beads is a function of three factors: index of refraction, bead shape, size, and surface characteristics; and the number of beads present and exposed to light rays. The scientific principle involved in the use of glass beads to reflectorized roadway markings is based on retro-reflection. That is, the light is reflected back to the light source. Typically, the major source of light available during night driving is provided by vehicle headlights. As shown in Figure 2, the light rays from headlight beams shining on an unbeaded (non-reflectorized) pavement strip is reflected in all directions; thus, only a very small portion of the light is reflected directly back to the light source. In the case of a beaded stripe, much more light is reflected backward (retroreflection) to the vehicle light source and is therefore much more visible to the driver.

For the beads to refract and redirect light two properties are necessary; transparency and roundness. Glass beads meet both of these criteria. Early experiments in the use of crushed glass and aluminum or brass beads proved unacceptable because these materials failed to meet these criteria.

The need for transparency and roundness can be explained by examining the path of light as it enters a single bead in painted line. First, the glass bead must be transparent so that light can pass into the sphere. The light beam, as it enters the bead, is bent (refracted) downward by the rounded surface of the bead to a point below where the bead is imbedded in the paint. Light striking the back of the paint-coated bead surface is refracted back toward the path of entry much like a mirror (Figure 3). If the paint were not present, the light would continue through the bead and bounce in many directions.

Refractive Index

When a headlight beam strikes thousands of these small spherical beads, the visibility of the line is greatly enhanced in terms of brightness. The degree of brightness depends on the Refractive Index (RI) which in turn, is a function of the chemical make up of the beads. Commonly, beads used in traffic paint have an RI of 1.50. There are some 1.65 beads used in thermoplastic and 1.90 beads used for airport markings.

Each glass sphere works like a light-focusing lens and has a definite focal point outside the back of the bead. The closer the focal point is to the back surface of the sphere, the brighter the light return. For example, as shown in Figure 4, the 1.50 RI bead has a focal point further behind the back of the bead than as the 1.65 bead. With the 1.90 RI bead, the focal point is very close to the bead's back surface. Consequently, a painted line reflectorized with 1.90 RI beads will be brighter than those using 1.65 or 1.50 RI beads.

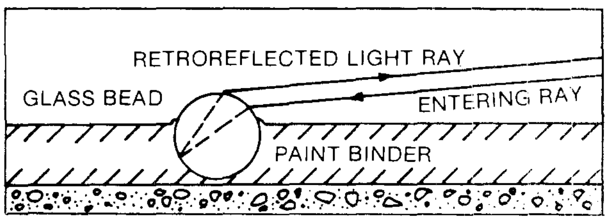


Figure 3. Glass Bead Reflection

The chemical composition of glass beads differs for each reflective index. The 1.50 RI bead is a hard soda lime glass made from crushed scrap window pane glass, called cullet. This glass has a high silica content, which results in a chemically stable glass. Beads made from this glass will remain optically clear when exposed to strong acids, alkalies, moisture and salts for long periods.

Both 1.65 RI and 1.90 beads are produced from basic raw materials in a glass manufacturing tank. The 1.65 RI has 50 percent by weight less silica and an increase in weight percent of calcium oxide; consequently, is less acid stable than 1.50 beads.

The 1.90 RI glass beads has no silica or calcium as part of its formulation. The formulation is proprietary, but its major components, barium and titanium, are very stable; therefore 1.90 RI beads are more acid resistant than the 1.65 RI.

The difference in acid resistance may not seem significant since reflectorized lines would not come into contact with concentrated acids. However, in the normal atmospheric environment, carbon dioxide and water vapor are present, forming a mild carbonic acid.

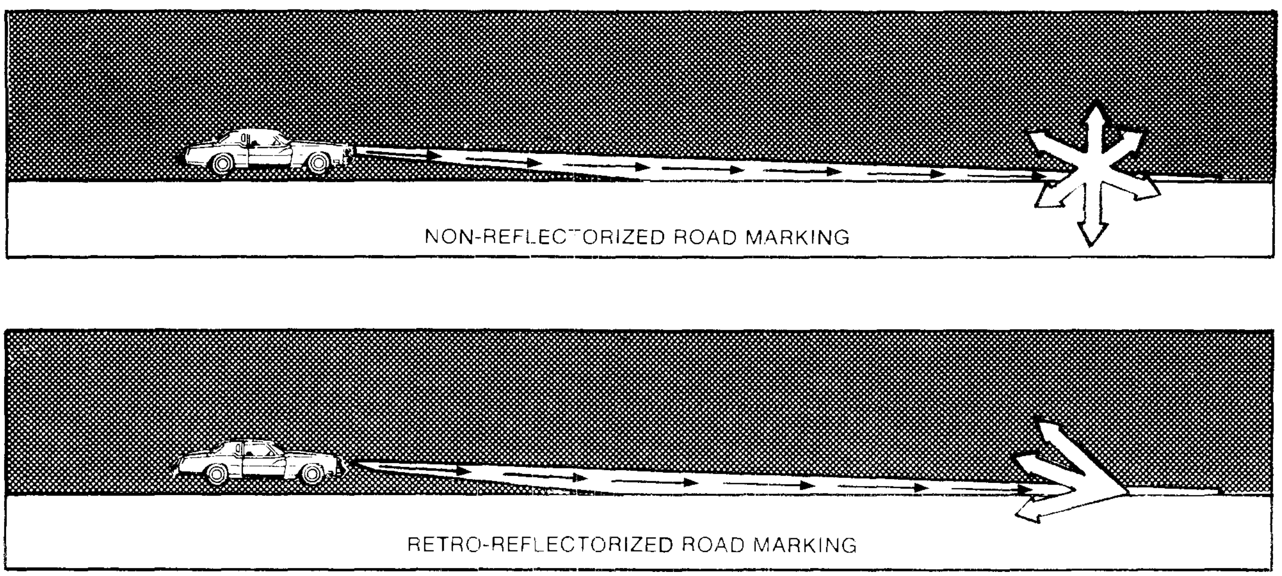


Figure 2. Light Reflection Characteristics

In industrialized areas, sulphur dioxide and moisture in the air can combine to form a mild sulphuric acid, which is even more corrosive. Thus, the 1.65 RI glass beads are potentially less durable than the 1.50 RI or 1.90 RI beads.

Because glass beads are purchased and used by weight, density becomes an important factor. Each RI bead has a different density; the higher the RI the higher the density. For example, to obtain the same bead population, the relationship of beads per gallon for the three RI beads would be:

RI	lbs/gal
1.50	6.0
1.65	7.3
1.90	11.0

Despite the increased brightness gained with the higher refractive index, most state and local highway agencies use 1.50 RI beads. Because beads are made from cullet, a recycled product, they are less expensive than those manufactured from basic raw materials. They also exhibit more chemical stability and require fewer pounds per gallon because of less density. Some agencies use a mixture of 1.50 and 1.65 beads on highways, and a few supplement the 1.50 beads with 1.90. For the most part, 1.90 RI beads are used to reflectorize airport markings.

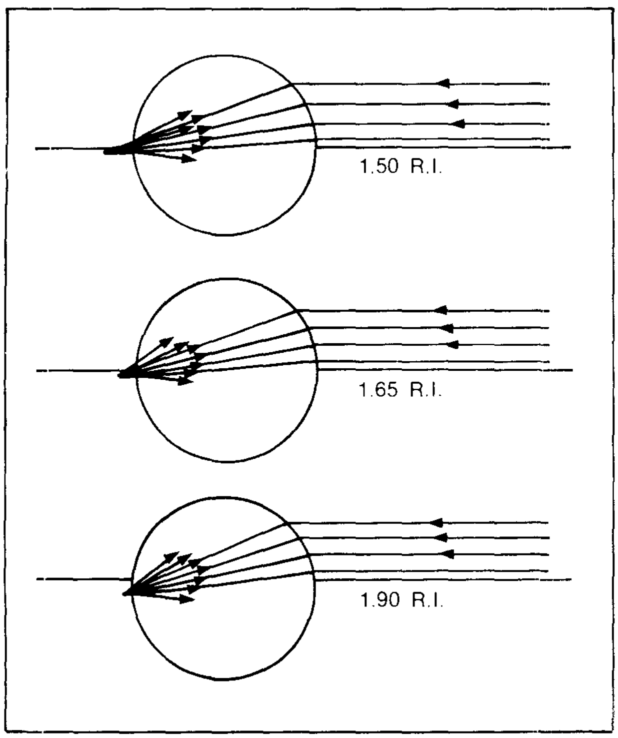


Figure 4. Focal Point for Commonly Used Glass Beads

Bead Size or Gradation

Glass beads are supplied in a range of sizes from the very small size of about 60 microns (0.0024 in) to larger sizes of 850 microns (0.034 in). The size of beads are usually expressed in terms of U.S. Sieve Number; that is, the size of the mesh screen that a bead will pass through. For example, a U.S. Sieve #20 will permit all beads with a diameter of 840 microns (0.033 in) or less to pass through the mesh; a #200 mesh will allow only those beads of 74 microns (0.0029 in) or less to pass.

The size range or gradation is a variable that has a direct influence on both immediate and long term reflectivity. Maximum reflectivity occurs when approximately 50 percent of the bead diameter is embedded in the paint binder. Accordingly, larger beads with a diameter of twice the dry paint thickness will provide excellent reflectivity as soon as they are dropped in the striping material. Since these beads are only partially anchored in the binder, they will be dislodged by traffic action within a relatively short period. As these larger beads disappear, the smaller spheres become effective as the paint film wears away (Ref. 11). Figure 5 illustrates this principle.

In general practice, a typical application of drop-on beads will range from #20 mesh to #100 mesh. The specified gradation and percent of weight for each size bead is a subject of some controversy. Primarily, it is a local policy decision based on a number of factors discussed below.

The theoretical considerations of striping materials and bead size must be adapted to the reality of stripe

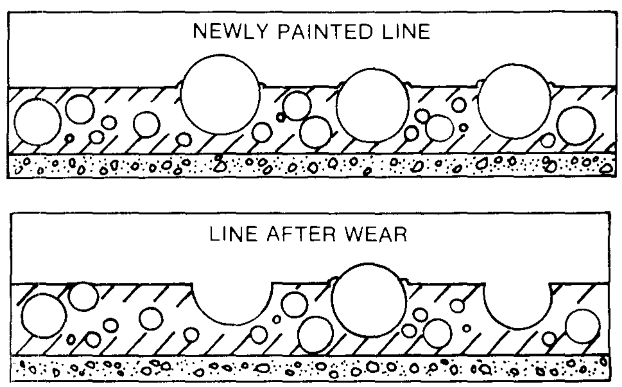


Figure 5. Effect of Wear on Beaded Paint Stripe

application operations and to the uncertainties of weather and control of materials. In addition, the drying time of the striping material affects the settlement of the beads into the binder.

The application rate (e.g. paint thickness), service life of the material, and the amount of beads applied must also be considered. For example, a paint-bead system based on a wet paint thickness of 15 mils with a relatively long service life and a bead application rate of 6 lbs/gal would probably call for a wide range of bead gradation. Conversely, for a system based on a 11 mil wet thickness and a bead application of 4 lbs/gal that is restriped frequently, a narrower range of sizes would be indicated.

Some research studies have shown that larger beads, 40 mesh or greater in size, are lost very early because they are poorly anchored. The extremely small sizes (80 to 100 mesh) are so light that they may be blown away by the force of the spray gun action and never reach the binder. Thus, without considering the cost factors involved, the optimum gradation should be somewhere between a top size of 40 mesh and a bottom size of about 80 mesh. This conclusion was predicated upon a wet film thickness of 15 or 16 mils. (Ref. 3).

Flotation Beads

In seeking to improve the performance of conventional glass beads, manufacturers have developed a "flotation" bead. Flotation beads are standard glass beads treated with a special chemical substance that causes all beads, large and small, to float to their diameter in wet paint rather than sinking completely into the paint film (Figure 6). Since all beads are exposed, a brighter stripe is obtained.

The two major advantages associated with flotation beads involves application and performance. Flotation beads will provide a more consistent level of brightness regardless of large variations in film thickness because all beads will float so that half of the bead is exposed. With standard beads, a heavy application of paint will submerge a large portion of beads, thereby reducing initial brightness.

With regard to performance, if all other variables are held constant, a flotation beaded line will be noticeably brighter than a standard beaded line. Tests have shown a stripe containing a broad gradation range of flotation beads will wear as long as one containing a broad gradation of standard beads and will remain brighter.

Flotation beads are more expensive than standard beads by several cents per pound, which could be significant to agencies purchasing millions of pounds of beads annually. However, this additional cost is offset since fewer pounds of the smaller beads would be required to provide the same level of reflectivity. For example, 4 lbs. (1.8 kg) of the smaller beads produce more reflective bodies than 6 lbs. (2.6 kg) of the mixed gradation.

Another disadvantage of flotation beads is that they are of limited use in systems requiring the application of beads by pressure spray. For example, in some systems using hot applied fast dry paints, the paint skims over so rapidly that the beads must be applied partly into the paint spray under pressure. As a consequence some of the beads are covered by the paint and will not "float".

Application Techniques

Pavement markings can be reflectorized in three basic ways: the beads can be dropped on, they can be premixed in paint or other striping materials before application, or a portion of beads can be dropped on premixed materials.

The most commonly used technique is spraying (under pressure) or dropping (by gravity) a quantity of beads on to the wet material. The bead nozzle is located immediately behind the paint nozzle or extrusion shoe so that the beads are dropped almost simultaneously with the paint application (See Figure 7).

One often cited problem in the application of drop-on glass beads is that in areas of high humidity, the beads tend to adsorb moisture and lose their free flowing characteristics. This is due to the enormous surface area of the beads. When the beads agglomerate, they fall as a mass rather than as individual beads; thus clumping in the film. It is not uncommon for beads to clog the dispensing equipment which must be cleared before striping can continue. To avoid this problem, beads can be moisture-proofed by adding small amounts of absorbent powders such as china clay or by coating with a proprietary silicone-based material which effectively resists moisture.

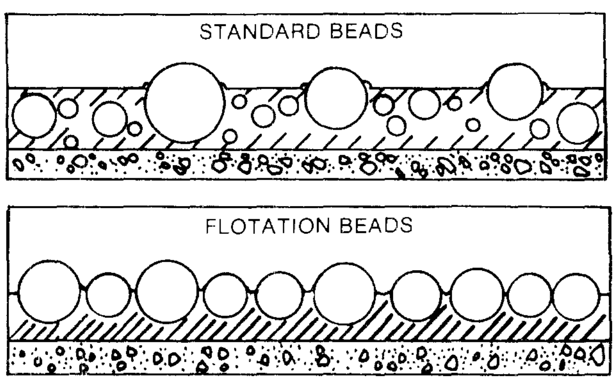


Figure 6. Flotation-Type Beads

Premixed Striping Materials

To obtain greater durability and better distribution of beads, fine gradation beads (60 to 200 mesh) can be added to the paint formulation to produce a "reflectorized paint". The initial reflectivity of premix paint is poor since very few beads are exposed. As the stripe is subjected to traffic, the thin coating covering the beads is worn away and the reflectivity improves markedly and retains its brightness for a significantly long period of time. Initial reflectivity can be achieved by dropping coarser gradation beads on the premixed material.

During the 1960's and early 1970's, about 20 percent of the state highway departments used premix paint supplemented by drop-on beads. While the performance of the stripes in terms of durability and brightness was judged superior, a number of problems were reported. The settlement of beads in the paint during storage was an acute problem at first. This was solved in part by using smaller beads and a suitable suspension agent in the formulation. Drum rolling equipment and stirring devices were also developed.

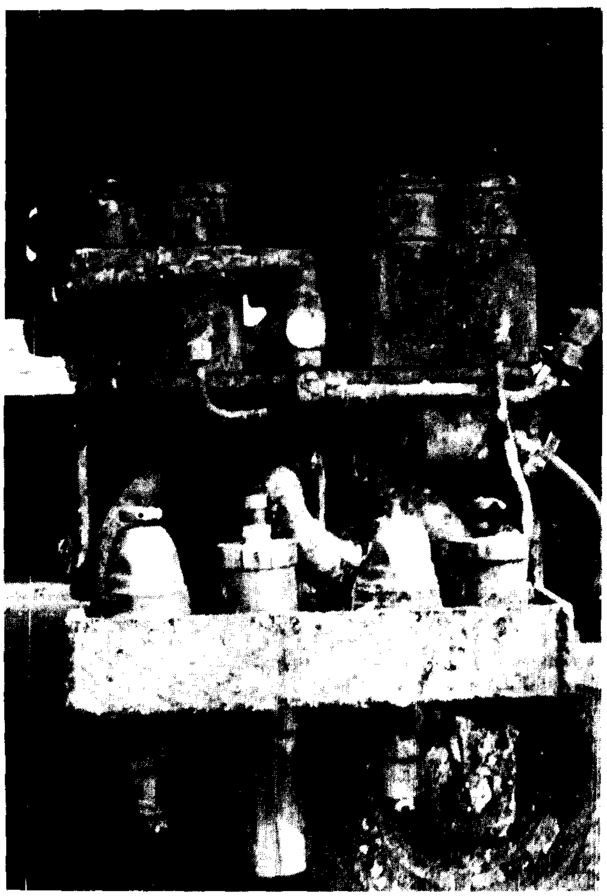


Figure 7. Paint and Glass Bead Spray Applicator

A number of premix users reported excessive wear of paint spray nozzles. Paint crews generally exhibit little enthusiasm for this technique as they perceive it to be "more trouble than its worth". As a result, there remains only a few major premix users despite its superior performance.

Cold applied, preformed thermoplastic material is manufactured by premixing beads when the material is in a molten state. To obtain more reflectivity, a top dressing of beads can be applied as the material is hardening.

Volume of Beads Applied

As with the gradation of beads, the rate of beads applied for a given quantity of striping material is a matter of some controversy. It is generally agreed, however, that such factors as the size of beads, the thickness of the binder, the type of bead (flotation or non-flotation), and the service life expectancy of the reflectorized stripe all exert an undeniable influence on optimum rate of application. Numerous research studies involving both field and laboratory tests have addressed the effect of each of these factors in terms of durability and cost-effectiveness (Ref. 12, 13).

Traditionally, the paint-bead combination most often utilized was on the order of 15 to 17 mil (.38 to .43 mm) wet paint thickness with 5 to 7 lbs/gal (0.6 to .08 kg/l) of beads within the 20 to 100 mesh range.

In seeking to provide an equally efficient reflectorized painted stripe at a reduced cost, it has been demonstrated that 10 to 11 mil (.25 to .28 mm) wet paint thickness with 4 lb/gal (0.5 kg/l) of 40 to 80 mesh beads performs quite adequately (Ref. 14, 15, 16). A number of states (California, Pennsylvania, Colorado, Kansas, for example) have adopted this paint/bead combination and have reported significant savings with no appreciable loss of effectiveness.

Summary of Glass Bead Usage

The use of glass beads to provide night visibility of pavement markings is intimately related to the characteristics of the striping material (binder) used. The painted markings should be considered as an entity rather than as a combination of independent materials. For example, bead durability is tied in with the life expectancy of the binder, which, in the case of paint is relatively short, but is relatively long for thermoplastic and other durable materials.

Current research findings, practices, and policies related to selecting the glass bead component of the pavement marking for typical delineation situations are summarized below.

Optical Characteristics

- Although higher index of refraction beads (RI 1.65, 1.90) initially retroreflect more light, the difference is hardly visible to the human eye although it can be measured with a photometer. (Ref. 17) They are also chemically and mechanically more unstable than 1.50 RI beads.
- The 1.65 and 1.90 RI beads have a higher density than the 1.50 bead; consequently, they must be applied at a higher weight rate to obtain the same bead population.
- For most situations, soda-lime based glass beads with an RI of 1.50 provide adequate reflective properities, are extremely durable, and are more economical than the higher RI beads.
- Beads with an RI of 1.65 or higher may be justified in situations requiring increased brightness especially at long distances. (Ref. 18). One must consider, however, their inherent chemical and mechanical instabilities compared to 1.50 RI beads.

Bead Gradation

- The standard gradation range used by 85 percent of the state highway agencies is 20 to 80 mesh (Ref. 11).
- Some evidence suggests that uniform smaller sized beads (40 to 80 mesh) produce a brighter, more durable marking. (Ref. 19) This is not true in wet road conditions, however.
- Typical Specifications for glass beads are provided in Appendix B.

Flotation Beads

- Floating beads are preferred by a number of agencies because of the superior embedment.
- Flotation beads are especially effective with a smaller, more uniform bead gradation and paint wet thickness of 11 mils. This may require, however, more frequent restriping and a lower wet night visibility.
- In the smaller gradations, flotation beads provide more reflective surfaces per pound than standard beads; consequently, fewer pounds are required, thus offsetting the additional cost of these specially treated beads at the expense of reduced wet night visibility.

Application Techniques

- The drop-on application of glass beads is the most widely used technique for combining the beads with the paint film.
- Beads premixed in the paint provide poor initial reflectivity but good long-term brightness, where no drop-on beads are applied.
- Smaller size beads are generally used in premix paint to avoid the bead-settling problem in paint storage and the wear and tear on the paint spray nozzle.
- Agencies using premix paint apply drop-on beads (1 or 2 lbs./gal.) to provide immediate reflectivity.
- Moisture-proof beads for drop-on applications are frequently specified for areas of high humidity and where beads are stored for long periods of time. The moisture-proofing protects the free-flowing properties and provides for a more even dispersion when spray applied.

Volume of Beads Used

- Optimum amount of beads to be applied depends on paint thickness, size of beads, expected service life of marking and the type of application and equipment.
- Normal application is 6 lbs./gal (0.7 kg./l.) but 4 lbs./gal. (0.5 kg./l) has been reported to be effective.

Chapter 3. Painted Markings

The use of painted stripes on the roadway surface to divide the traffic stream and provide guidance to the driver has existed since the dirt roadway gave way to paved surfaces. Today, painted markings used alone or in combination with other devices comprise the most commonly used delineation technique. This chapter covers the various uses, materials, equipment, and installation procedures associated with painted roadway markings.

USES

Basically, painted markings can be classified as either longitudinal lines or transverse markings which serve to provide "positive" guidance by defining the limits of a driver's field of safe travel (such as lane lines, center lines, edge lines or crosswalks, stop bars etc.). They are also used for "negative" guidance; that is, for informing the driver where it is not safe (or permitted) to travel (e.g. gore areas, islands, painted medians, etc.).

The specific applications of painted markings are defined in the MUTCD in terms of standard colors, widths, patterns, and placement. The basic delineation concepts are provided here for convenience. However, the MUTCD should be consulted for more precise installation information. (The same application standards also govern the installation of other forms of pavement markings such as thermoplastic and raised pavement markers.)

Longitudinal lines generally include center lines, lane lines, and edge lines and must conform to standard highway colors. Standard highway colors include yellow, white, and red. The use of black paint is allowed in combination with the three standard colors where the pavement itself is too light-colored to provide sufficient contrast. The fundamental use of color and pattern as summarized from the MUTCD is given below.

- Yellow lines delineate the separation of traffic flows in opposing directions or mark the left edge of the pavement of 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.
- Red markings delineate roadways that shall not be entered or used by the viewer of those markings.
- Broken lines are permissive in character.
- Solid lines are restrictive in character.
- Width of line indicates the degree of emphasis.
- Double lines indicate maximum restrictions.
- Markings which must be visible at night shall be reflectorized unless ambient illumination assures adequate visibility.

Table 1 defines the basic types of pavement stripes. Figure 8 illustrates typical applications of longitudinal markings.

MATERIALS

Any discussion of the materials used in painted markings must consider the three interactive elements of the paint system: the paint itself (pigment and binder), beads (reflective glass spheres), and pavement surface (substrate). For example, different paints react differently on asphaltic and concrete pavements. Glass beads reflect differently depending on the binder and its thickness.

Conventional traffic paint continues to provide the nucleus of the Nation's roadway delineation system. Continual improvements have been made in paint composition and application techniques to provide increased cost effectiveness. There are a number of interacting factors that affect the performance of the various types of traffic paint.

The following discussion provides a background for the subsequent discussion of the major factors influencing the selection of the most appropriate paint for a given situation. It includes a review of the categories of paint, essential properties, and performance criteria. The use of glass beads to reflectorized paint is discussed in Chapter 2.

Classification of Paint

There are several ways of classifying paint. The first basic description involves the reflectance; that is, whether or not glass beads have been added for night time visibility. "Reflectorized paint" contains glass beads of specified size and volume either intermixed, dropped on, or in combination. Paint without beads is generally used for markings not requiring night visibility such as parking spaces, curbs, etc.

Paint can also be classified by whether it is cold-applied or hot-applied. The temperature at which

Table 1. Types of Pavement Stripes

DESCRIPTION	COLOR	WIDTH	APPLICATION
Single Broken	White	4" (100 mm)	Separation of lanes on which travel is in the same direction, with crossing from one to the other permitted; i.e.: lane lines on multilane roadways.
	Yellow	4" (100 mm)	Separation of lanes on which travel is in opposite directions, and where overtaking with care is permitted; i.e.: centerline on 2-lane, 2-way roadways.
Single Solid	White	4" (100 mm)	Separation of lanes, or of a lane and shoulder, where lane changing is discouraged; i.e.: lane lines at intersection approaches, right edge stripes.
		6" (150 mm)	Lane lines separating a motor vehicle lane from a bike lane.
		8" (200 mm)	Delineation of locations where crossing is strongly discouraged; e.g.: separation of special turn lanes from through lanes, gore areas at ramp terminals, paved turnouts.
Double Solid	White	4-3-4"*	Separation of lanes on which travel is in the same direction, with crossing from one side to the other prohibited; e.g.: channelization in advance of obstructions which may be passed on either side.
	Yellow	4-3-4"*	Separation of lanes on which travel is in opposite directions, where overtaking is prohibited in both directions. Left turn maneuvers across this marking are permitted. Also used in advance of obstructions which may be passed only on the right side.
Solid plus Broken	Yellow	4-3-4"*	Separation of lanes on which travel is in opposite directions, where overtaking is permitted with care for traffic adjacent to the broken line, but prohibited for traffic adjacent to solid line. Used on 2-way roadways with 2 or 3 lanes. Also used to delineate edges of a continuous left turn lane — solid lines on the outside, broken lines on the inside.
Double Broken	Yellow	4-3-4"*	Delineates the edges of reversible lanes. (Until the end of 1979 this marking can be used in California to designate continuous left turn lanes.
Single Dotted	Either	4" (100 mm)	Extension of lane lines through intersections. Color same as that of line being extended. Also used to extend right edge line of freeway shoulder lanes through off-ramp diverging areas in problem locations.
	White	8" (200 mm)	Separation of freeway through lane and auxiliary lane or exit lane.
Transverse	White	12" (305 mm)	Limit lines or STOP bars; also crosswalk edge lines (minimum 6 ft - 1.8 m apart) when not in the vicinity of school grounds.
	Yellow	12" (305 mm)	Crosswalk edge lines contiguous to school buildings and grounds; also optional for crosswalk edge lines located within 600 ft (185 m) of school buildings or grounds and, under special circumstances, within 2, 800 ft (855 m).
Diagonal	White	12" (305 mm)	Crosshatch markings, placed at an angle of 45°, 200 ft (60 m) apart, on shoulders or channelization islands to add emphasis to these roadway features.

*4-3-4" indicate width of stripes and gap between them. Metric equivalent is 100-75-100 mm.

Source: Based on Ref. 20

Passing Zone
Both Directions

Passing Zone
One Direction

No Passing Zone
Both Directions

a) Two-Lane, Two-Way Roadways

Normal
Treatment

Reversible Center Lane

Two-Way
Left-Turn Lane

b) Multilane Roadways

Figure 8. Typical Applications for Longitudinal Roadway Delineation

paint is applied has a direct relationship to the third area of classification, drying time. Drying time is influenced by the chemical composition, the temperature of the paint and pavement during application, wind velocity, and paint thickness. The categories of paint based on drying time are generally defined as follows (Ref. 15):

- *Conventional:* Cold applied paint of normal viscosity requiring over 7 minutes to dry, can require several hours depending on thickness of coat, atmosphere and road condition.
- *Fast Dry:* Hot applied paint which will dry to no-track condition within 2 to 7 minutes.
- *Quick dry:* Hot applied paint drying to no-track condition within 30 to 120 seconds.
- *Instant Dry:* Hot applied, heavily bodied paints which dry within 30 seconds.

Finally, paint can be classified according to the type or family of base material used in paint composition. Some of the commonly used bases include:

- Oil base (alkyd resin)
- Rubber base (chlorinated rubber)
- Oleoresinous (drying oil (dispersion) varnish, modified alkyd)
- Water base

Essential Properties

In general, there are two basic criteria by which paint performance is judged: durability and visibility. Durability involves service life of the painted stripe as a function of the material remaining on the pavement surface over time. Visibility concerns the brightness of the material particularly at night. These properties are described by ASTM D-7B-66T (Ref. 21).

Drying time is also a major performance consideration since the faster drying paints: 1) do not require coning off the area for an extended drying period, 2) decrease the exposure of the paint crew to traffic, and 3) lessen the disruption to traffic. Other properties that are typically included in specifying traffic paint can be defined in terms of:

- *Requirements before Application.* Paint should be chemically stable with an adequate storage life. It should maintain a constant viscosity, resist caking, settling, gelling, skinning or color changes.
- *Requirements during Application.* The paint should be adaptable to application by commercial striping equipment and should permit uniform and easy spray application with economical and easy clean-up requirements. It should have a strong wetting action to permit penetration of the contaminated substrate (dirt, oil, sand, etc.) and thereby provide good adhesion.
- *Requirements after Application.* Paint should not bleed nor discolor on bituminous surfaces and should resist the chemical action of alkalies characteristic of concrete road surfaces (i.e. Portland Cement Concrete (PCC). Paint must also withstand the action of chemicals used in snow and ice control as well as abrasives such as sand and gravel. Traffic paint must also be flexible enough to expand and contract with day and night temperature changes. It should be tough enough to resist the effects of traffic abrasion. It should be sunlight and water resistant, but sufficiently permeable to allow moisture to escape from the substrate.

The importance of these requirements and the form of their inclusion in the paint composition specification may vary among agencies. Some of the site-specific considerations that may influence the essential properties built into a particular paint formulation include:

- *Substrate type:* Certain formulations perform differently on asphalt concrete and Portland Cement Concrete.
- *Climate and Weather:* The range of temperatures to be expected during application and during service life of the paint as well as climatic conditions (rainfall, snow, blowing sand, extensive sun) create different requirements.
- *Travel Characteristics:* The traffic abrasion that a painted stripe must withstand is a function of AADT, the mix of vehicle (passenger cars, trucks, etc.), and the type of marking (that is, longitudinal lines last longer than transverse lines; edge lines last longer than lane lines because of fewer crossovers).

Paint Formulation

The major constituents of paint are: the base vehicle (binder), pigment, and solvent. The vehicle is the film former made up of drying oils, resins, or plasticizers in a formula which provides **adhesion** to the substrate and **cohesion** to hold the paint together. It also provides most of the resistance properties. The pigments give opacity, color, hardness, and special weathering properties. Optimum pigment volume concentration for good durability lies in the 42 to 59 percent range (Ref. 22). Solvents dissolve the film former, regulate the rate of film setting (drying) by controlling the rate of evaporation. It is also associated with adjusting the film solids and with the ease of application.

The use of volatile organic solvents in oil-based paint formulations is the subject of increasing concern to environmentalists. In fact, according to the California Air Resources Board, petroleum-based solvents used in paint and for clean-up purposes are the third largest source of air pollution in Los Angeles, San Diego, San Francisco, and Sacramento (Ref. 23).

The need to reduce pollution resulting from the use of solvents such as toluene in paint has led to the development of a Model Rule for the control of hydrocarbon emissions. Approved by the California Air Resource Board in July 1977, the Rule prohibits selling or applying any coating containing more than 250 grams (0.5 lb) of volatile organic material per liter (0.26 gal) of coating. This ruling becomes effective for traffic paint five years after local adoption. By 1978, three local Air Control Boards had adopted the Model Rule for their local jurisdictions.

Previous to the development of the Model Rule by the State, Los Angeles had introduced "Rule 66" which specified the *type* of solvent that could be used in white and yellow traffic paint for air pollution control districts. Type I, based on toluene and aliphatic thinner, can be used in all areas of the state except in counties which comprise air pollution control districts. For counties located in air pollution control districts, Type II consisting of methyl ethyl ketone, ethyl amyl ketone, and special aliphatic thinners have been specified.

This trend to restrict the volume or type of commonly used solvent indicates that paint formulations will change dramatically, at least in California. Commercial paint manufacturers as well as State materials laboratories are seeking to reduce organic gas emissions by shifting from the more conventional formulations to those using non-volatile solvents or solvent ratios such as water borne or epoxy coatings.

Presently, chlorinated rubber modified alkyd paint is widely used for a variety of conditions. When heated to 122°F (50° C) it will dry to "no-pick-up" in 1 to 5 minutes due to fast solvent release. It is characterized as a hard and durable resin which will produce a tough, wear-resistant film. It will tolerate extremes in climate as demonstrated by successful use in Saudi Arabia, Finland, and Brazil. It also exhibits excellent adhesion to asphalt, bitumin and concrete surfaces as well as superior recoatability. A tentative Model Performance specification for the Purchase of Pavement Marking Paints is given in Appendix B.

Purchase of Materials

Specifications for purchasing traffic striping paint are usually written in the form of a chemical composition specification or a performance specification. Inasmuch as the cost and availability of some of the chemical components used in the manufacture of paint may vary radically from week to week, detailed composition specifications favored by many agencies in the past are being replaced by performance specifications. In some cases, a combination performance-composition specification is used which indicates the percent by weight of the desired ingredients by generic classification without specifying a brand name or chemical formula.

Each form of specifications has its own unique advantages and disadvantages. One recent study (Ref. 24) surveyed 24 states and 15 national paint manufacturers. While the majority of the states surveyed continued to use composition specifications, the manufacturers appeared to favor the performance specification.

The performance specification enables a user to realize the full advantage of current paint manufacturing technology. The state of the art in paint manufacturing has moved ahead so rapidly that it is extremely difficult for the engineer to understand this advanced technology and keep pace with the paint chemist. Furthermore, the manufacturers indicated that the most effective way to lower the cost is through their own research and development technology. For example, during this 1978-79 study, the average bid price for the chemical composition specification was $3.60 per gal ($0.95 per l) for yellow and $3.36 per gal ($0.89 per l) for white paint. With the performance specification the average bid price was $3.15 per gal ($0.83 per l) for yellow and $2.95 per gal ($0.78 per l) for white.

The major disadvantage in using the performance specification is the difficulty in judging performance. Most states use a point system for evaluating the paint. This assessment is highly subjective and depends on the view of the individual members of the evaluation team. Values assigned to color, durability, contrast, appearance, etc. varied in many states depending on the priorities of the specific agency.

Another disadvantage is the potential difficulty in getting suppliers to replace paint that does not meet the performance specification. This can be a time-consuming process and may necessitate legal action.

The advantage of a composition specification is the assurance that the purchaser is getting a paint based on his own formulation. The development of a composition specification is normally the function of the Materials department of the using agency. In this process, several types of paint with varying formulations are applied on asphalt and concrete road surfaces for evaluation. Based on the final results obtained, a composition specification is then written to assure that the user obtains the same product that gave maximum service life. Quality control testing in the laboratory is included in the specification to assure that the product furnished is within the standards required for successful application and performance.

After carefully weighing the advantages and disadvantages associated with paint specifications, this study concluded that ". . . *Paint purchased using performance specifications appears to result in a lower average price than paint using chemical compound specifications*" (Ref. 24).

It also concluded that when policy directs that the composition specification be used, the chemical components should be reviewed annually to determine the most cost-effective composition. It is frequently possible to substitute one chemical compound for another or reduce the quantity of a high price component without sacrificing performance or color.

Testing

The prediction of the life of paint is a critical factor in evaluating candidate paint types. Field tests of various paint compositions is time-consuming and conventional laboratory tests such as falling sand, the Taber Abrasion test, and the Weather-Ometer frequently do not produce the best results.

A major study has been undertaken to develop an economical and practical accelerated laboratory test to estimate traffic marking material durability which would reflect the same results obtained in field test (Ref. 25). Two broad conclusions emerged from this study. First, field tests can be performed to give an overall durability ranking. Next, it was concluded that relatively simple, highly accelerated laboratory tests can be performed to provide data from which field test results can be predicted with a high degree of reliability. If field tests are performed in parallel with the laboratory tests, statistical methods can be used to select the least number of test required, and provide the coefficients for predictive equations.

If field tests and subsequent regression analyses are not performed, laboratory test data for the predictive equations can be obtained from the study. ("Accelerated Test of Traffic Marking Material Durability" Report No. FHWA-RD-78-93, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., 1978 - Available through the National Technical Information Service, Springfield, VA 22151).

PERFORMANCE

A great deal of emphasis has been placed on the properties of traffic paint and on developing an optimum paint formulation that will produce increased durability, appearance, and visibility. Such emphasis has resulted in a number of paint families that effectively meet agency specifications.

There are three basic reasons for the interest in evaluating the performance of paint. First, it is necessary to assess the cost effectiveness of using painted markings compared to other forms of delineation. Next, if paint is indicated as the appropriate delineation medium, it is necessary to evaluate paint samples to determine the best product to purchase. Ultimately, it is necessary to determine how long a painted stripe can be expected to provide adequate delineation so that restriping operations can be planned and scheduled.

Recent research indicates that the precise composition of paint in use today has a relatively minor impact on the performance of the in-place pavement markings. It has been suggested that ". . . *a poor paint properly applied will out perform a good paint improperly applied* . . ." It is also well documented that 90 percent of all paint failures are due to the type of substrate and the condition of the surface (Ref. 26).

Performance Descriptors

A number of terms are used by various agencies to describe paint performance. Some of these terms such as "service life," "expected life," "lifespan or useful life," "paint failure," etc. often have different meanings and care should be exercised in using these terms interchangeably. It is difficult to define these descriptors in quantitative terms as subjective judgment is frequently the sole determinant.

Any pavement stripe deteriorates gradually with time and exposure to traffic and weather. Some agencies define the life of the stripe based on a subjective estimate of the time from application to the point in which the deterioration is such that the agency decides to restripe. Hence, the life of the stripe is somewhat dependent upon the extent of deterioration that can be tolerated before restriping is necessary.

As mentioned earlier, the determination of service life is used in evaluating painted test lines and in computing the economic aspects of various materials. It is based on appearance, durability, and night visibility of sample materials placed on test sections. Each of these three characteristics are rated numerically from 0 to 10, with 10 indicating a perfect condition and 0 complete failure (i.e. no appreciable amount of paint remaining). A detailed procedure for determining service life is provided in Appendix B "A Model Performance Specification for the Purchase of Pavement Marking Paints" as developed by the Institute of Transportation Engineers. For many agencies, the current practice is to assume that the service life as calculated by this procedure is at an end when the combined weighted ratings fall to 4 or below. This is sometimes referred to as "effective life."

It has been suggested that using a rating scale with 11 grades (0 through 10) is somewhat cumbersome. For example, the difference between 7 and 8 would be so minor that it is difficult to maintain consistency with such marginal judgments. Accordingly, it might be desirable to use a rating scale with fewer grades, say, six grades between "perfect" and "complete failure" (Ref. 27).

Of major significance is the fact that performance is a function of numerous variables, not just the paint itself. That is, the performance of identical materials will vary as a result of: traffic volumes and traffic characteristics; geographic and climatic conditions; type and condition of pavement surface; and method and circumstances of application.

Causes of Failures

The integrity of a traffic stripe can suffer from at least three mechanisms, singly or in combination: loss of substance by abrasive wear on the upper surface; cohesive failure of the paint (that is, failure within the paint layer), or adhesive failure at the interface with the concrete substrate. Another possible cause of failure often overlooked is within the PCC or asphalt region immediately below the paint-concrete interface. The stresses causing such failures arise from the reaction of the road surface to the forward forces of vehicles and the forces of the weight of vehicles (Ref. 25).

Since single stresses apparently do not cause failure, failure may involve fatigue. Factors contributing to loss of strength of the paint, the interface, and the concrete may include temperature and humidity cycling, light radiation damage, chemical attack by salt, acids (from nitrogen and sulfur oxides in the air), and physical attack by solvents (including all those in gasoline and oil), tire studs and chains, and snow plows.

With so many possible failure mechanisms and cause-and-effects relationships, it is not surprising that there is a great variation in the reported performance of various types of materials. It is also the reason that abrasion tests have not been completely successful in predicting the useful life of painted markings.

Range of Service Life

Although the estimated life of painted markings is a function of numerous site-specific variables, AADT is the most commonly used variable in defining service life. Most agencies consider a reasonable target to be 6 to 12 months under "normal" conditions. Three months service may be acceptable for roadways with very high traffic density, while some paints may last well over a year on roads with low AADTs. It should also be noted that paint wear is especially high in cold weather; therefore painted markings applied in the fall will have a shorter life expectancy than those applied in the spring.

In summary, the service life of paint depends primarily on:

- Traffic density and type
- Position of marking (center line, edge line, lane lines, transverse markings)
- Composition of material and substrate
- Thickness of paint film
- Season of year paint is applied

The position of the marking will determine the amount of traffic that actually passes over the marking. For example, longitudinal lines in general have a longer life than transverse markings and edge lines last longer than lane lines.

Some paints are formulated to be more durable, but tend to be more expensive. The type and condition of pavement surface also effects service life. That is, paint normally lasts longer on bituminous asphalt than on PCC. On the average, center line stripes placed on PCC may require repainting each year, whereas stripes placed on AC may require repainting only every two years. It has also been found that paint laid over paint will perform better than on new installations provided that the base layer of paint is in moderately fair condition on a stable substrate.

Thicker paint films on stable pavement surfaces will usually provide increased durability. This is not however a linear relationship. The additional life of a stripe thicker than 15 mils (0.4 mm) is not in direct proportion to the additional thickness used.

Because of the great variations in the parameters associated with service life of paint, each agency should develop its own estimated service life based on local conditions and experience. An "average" service life based on a compilation of nationwide experience has little meaning from an operational standpoint.

APPLICATION

The equipment, procedures, and policies involved in the application of paint have a profound influence on the ultimate performance. This is equally true for all forms of pavement delineation treatments. Among the major concerns is compatibility of materials and equipment, size and capabilities of crew, protection of crew, and traffic control during the application process.

While it may be assumed that the preferred material will dictate the type of equipment, in actual practice, the opposite is usually true. That is, the material used is frequently based on the capabilities of available

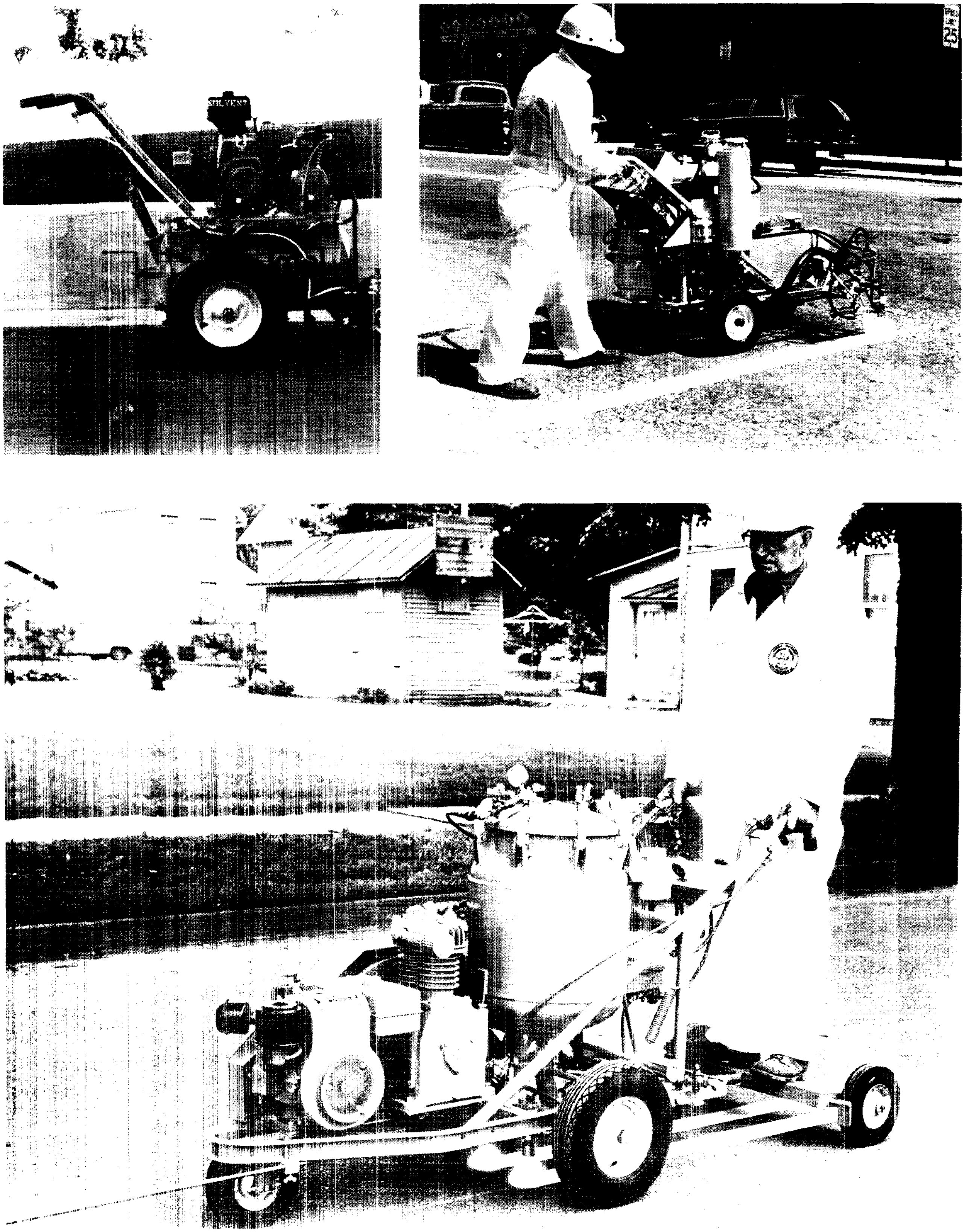


Figure 9. Small Paint Application Units

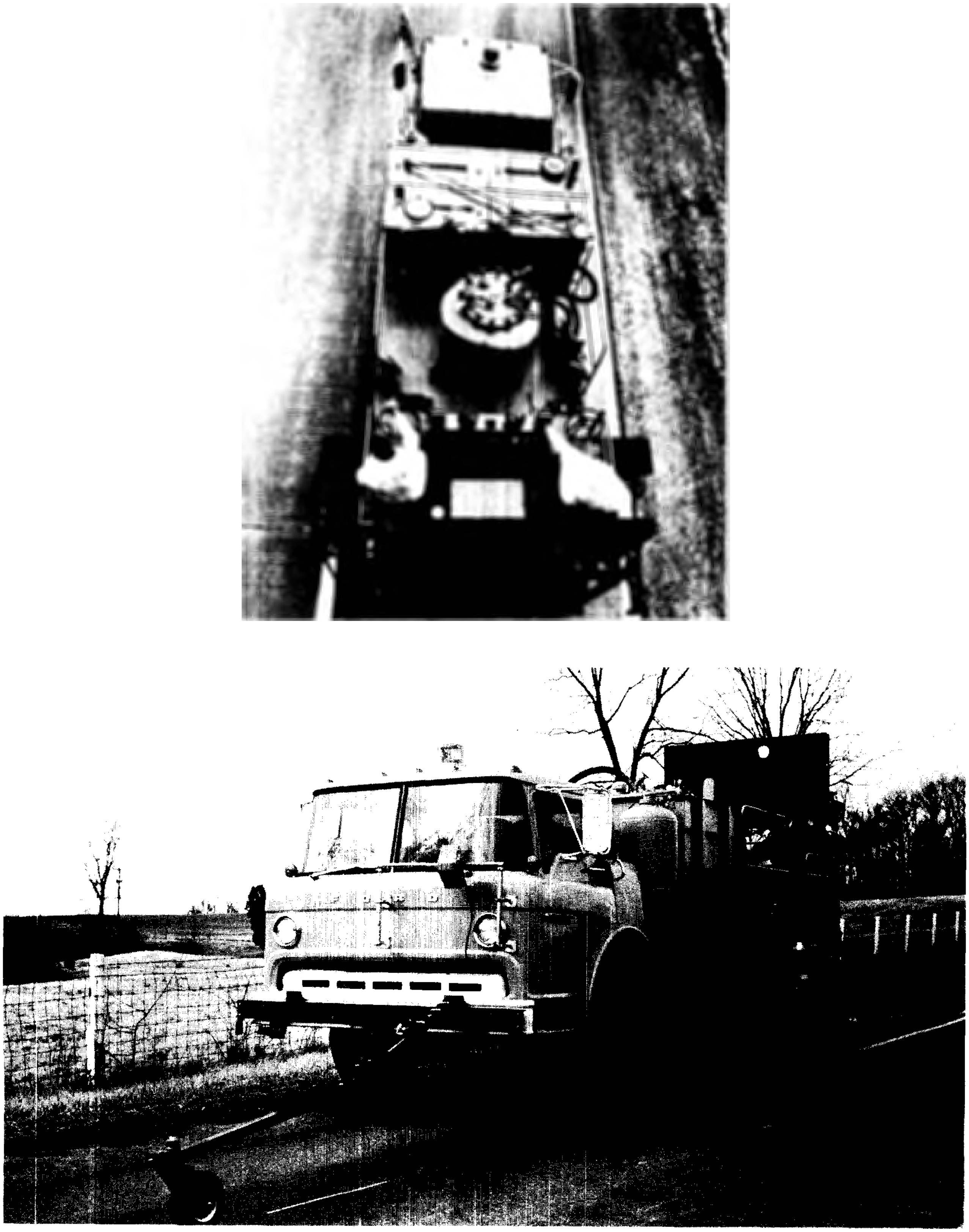


Figure 10. Truck-Mounted Paint Application Units

equipment. For example, it may be determined from lab and field tests and from economic analyses that a rapid dry hot-laid paint will provide the necessary durability and is economic from the standpoint of crew safety and traffic disruption. If the agency equipment is compatible only to cold-laid paint, most agencies will opt to use the cold-laid materials. Capital expenditures for new equipment or the use of a contractor are often beyond the available budget.

This serves to illustrate the point that tradeoffs and compromises must be made among all the elements involved in the selection of the most appropriate delineation treatment. There are few straightforward decisions that can be made independently.

Equipment

Painted markings can be applied with a variety of equipment. Selection of the proper equipment will depend on the size of community, miles of roadway, geographic characteristics, pavement surfaces, and the types of markings.

Equipment basically falls within two broad categories. The first is the small, self-propelled, manually-controlled low capacity paint striper and the other is the heavy duty, multilane, truck-mounted unit. The smaller applicator is generally used for striping crosswalks and other transverse lines and legends. Commercially developed units may have several unique characteristics. One type may be self-contained including a small engine to propel and operate air compressors, paint and bead tanks, spray gun, and bead dispenser. In other types, the compressor may be an auxiliary unit with a connecting hose to the spray unit. Typical small paint units are illustrated in Figure 9.

The larger truck mounted unit is almost always used for longitudinal striping. These units are available commercially or can be customized based on agency specifications. While the specifics may differ, heavy-duty units typically have the following characteristics.

The truck bed must be large enough to carry all of the necessary striping equipment and should have sufficient power to maintain a steady speed up grades so that the spray equipment can produce a uniform stripe. The truck is equipped with special warning lights and, if not preceded and followed by protecting trucks, arrow signs are provided to warn traffic and to direct passing movements. The front of the truck is usually equipped with a device that will enable the driver to follow a target on the pavement ("cat tracks") or to follow a previously placed line. The device must be retractable so that it can be lifted free of the pavement when the striping operation is discontinued or the device is not in use. Current models of stripers are shown in Figure 10. A typical layout is shown in Figure 11.

Two different methods are used to supply the traffic paint to the spray guns. In one, the paint drums are lifted from a supply truck to the striper truck by a hoist and the paint is then pumped directly from the drums to the paint guns. A valved T in the hose may be used to permit pumping from either of two drums.

In the other method, paint tanks are located on the striper. These may be filled from drums or tankers by either mechanical pumps or air pressure. In either method, the paint screens that must be used in the lines must be freely accessible so they may be cleaned frequently. Additional screens should be located close to the paint spray guns. The hoses that connect fixed parts of the paint spray equipment to the movable parts must be resistant to the cleaning solvent being used and to the solvent used in the paint.

The striper truck should be equipped with an accurate speedometer so that the truck speed is known. A volume meter for each paint supply is a valuable addition to monitor the quantity of paint applied.

An air pressure system transports the paint to the spray guns at a pressure determined by the quantity of paint to be delivered. It also supplies air at a lower pressure to an air jet at the paint nozzle to atomize the paint. Air also moves the glass beads from the bead tank to the gravity-type bead dispensers. (When hot paint is used, the glass beads are pneumatically applied.) Air is also used in control valves for the paint guns, etc. Some agencies use an air blast just ahead of the paint gun to blow loose paint chips and other debris from the area being sprayed.

The air supply comes from an air compressor driven by a gasoline or diesel engine, which is mounted on a skid frame bolted to the truck bed. Controls should be provided so that the engine power matches the load on the compressor. Protective devices are desirable to shut down the engine in the event of a malfunction.

The air pressure is also connected to the cleaning system, which consists of a tank of paint solvent that can be connected to the paint lines and nozzles by suitable valves. The lines, nozzles, and screens must be cleaned daily after use. The cleaning solvent is returned to a drum on the striper truck.

The paint spray guns and bead dispensers are mounted on carriages underneath the truck bed just behind the rear axle as shown earlier in Figure 6. The carriages can be moved laterally by the spray gun operator. A positive placement of the carriage is required. If edge lining is done at the same time as center lining, two carriages are needed.

The paint spray guns and bead applicators are synchronized so that the bead applicator starts at the appropriate time after the paint spray gun starts. All spray guns and bead applicators are controlled by an intermittent timer containing a timing mechanism driven by a ground contact wheel (Figure 12).

Heating the paint prior to application has proved effective in terms of achieving more uniform consistency under changing temperature conditions and in reducing drying time. Low heat (up to about 120° F/49° C) can be obtained by using a heat exchanger in the paint supply tank. This uses hot water from the truck radiator or from the compressor radiator. If higher temperatures are required, it is necessary to jacket the paint supply lines and to supply hot water to the jackets.

Temperatures above 180° F (82° C) generally require an external heating system to supply heated liquid (a coolant or special fluid) to the heat exchanger and to heat the paint lines. Some pavement stripers for quick dry heated paint have a compressor located behind the driver and a heat exchanger mounted on the truck bed.

One type of striper is capable of applying material under varying pressures up to 2,000 psi (14,000 kPa) and temperatures up to 350° F (177° C). Another form of striper used by Florida has a million-BTU (293-kW) heater, a 250-cfm (0.12 m^3/sec) compressor, dual steering, and a paint temperature capability of up to 225° F (107° C) while painting three lines.

A new California striper generates heat in a patented device that uses rotational, mechanical energy to heat

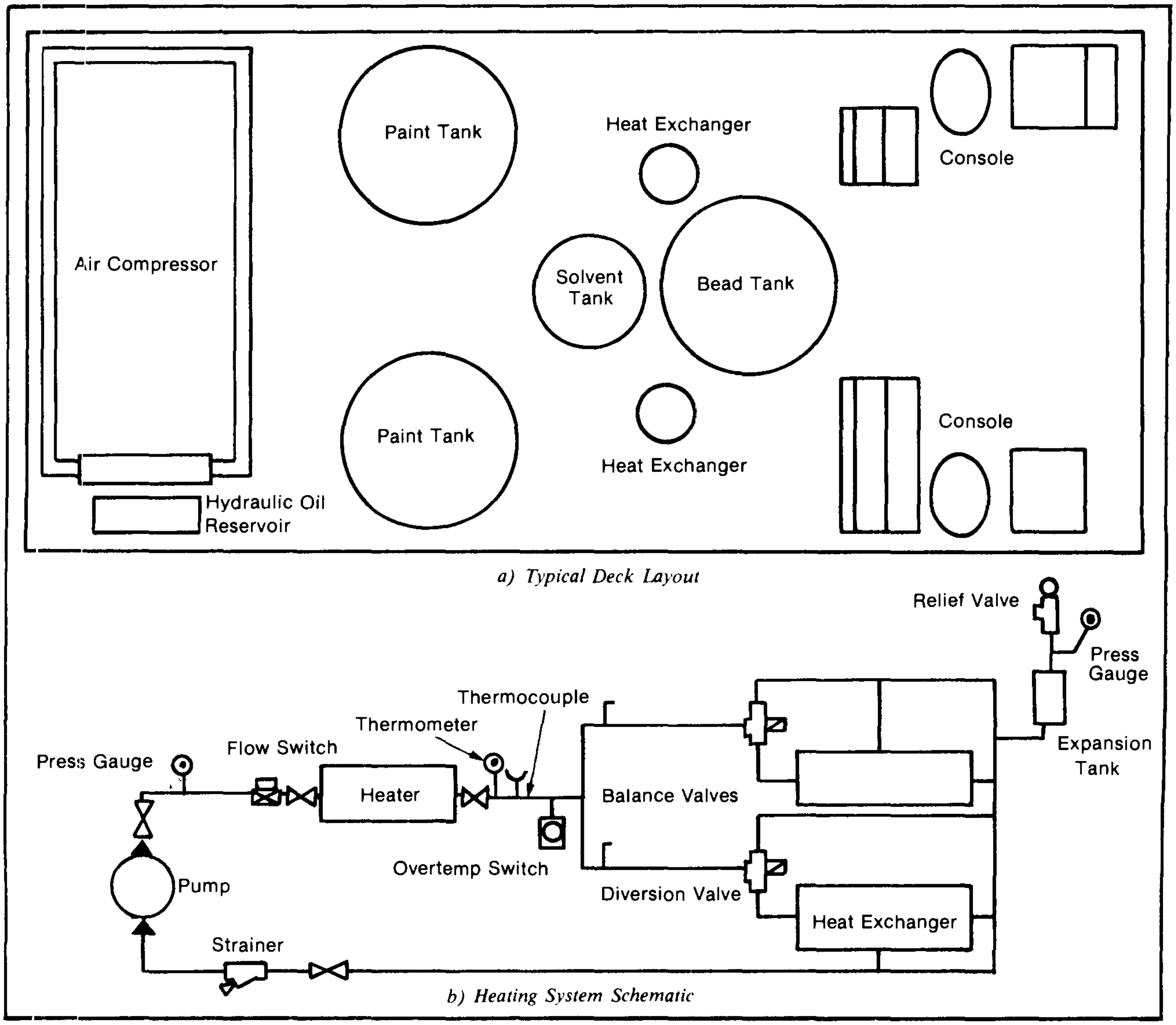


Figure 11. Layout of Large Scale Paint Striper

paint directly without the need for a heat exchanger. Temperature can be controlled to within 1° F (0.6° C) over a range from ambient to 400° F (204° C). The prototype has been tested with various materials and at speeds up to 20 mph (32 km/h). Paint drying time, depending on material, ranges from 6 to 90 sec. Operation is by a two-man crew plus a follow-up truck with warning signs. The machine can stripe from the right or left side (retractable spray guns at center line of tandem axles) or straddling the line (sulky in front of truck). Up to three lines may be applied simultaneously. Another feature of this striper is a multiple-nozzle airless spray gun capable of layer operation; e.g., two thin layers of paint, followed by beads, then another layer of paint and a top course of beads. Because it is not necessary to clear the paint lines and spray guns at the end of a day's work, a full day of striping is possible. This new striper is reported to reduce bead use by 15 percent and paint by 10 percent (Ref. 7).

Missouri, North Carolina, and several other states have stripers that utilize a high fluid pressure (1,400 - 1,800 psi; 9,600 - 12,400 kPa) paint spray system. No air atomization of the paint is required. Wyoming now has three of these units with air motors to drive the high-pressure pumps.

Figure 12. Paint Control Panel

Line Protection and Safety

Although heated paints and a few quick drying cold applied paints do not require protection of the freshly painted line from traffic, there are still a number of slower drying paint materials that require some form of protection. The type of protection required dictates the size of crew.

The most common form of protection is traffic cones. The striper may be equipped with an apparatus that sets the cones or with a platform at the rear or side of the striper to accommodate a crew member who sets the cones manually. In other operations, the cones are placed from a following truck equipped with a lighted arrow board. For small spot maintenance jobs or in placing crosswalk markings, cones can be placed as shown in Figure 13.

For the most part, the cones are placed in the skip portion of a broken line or are offset on the side or alternate side of solid lines. Machines for picking up cones have been developed by some states. Other agencies pick up cones manually.

On well traveled ways, some agencies will use one or more following trucks equipped with arrow boards for directing traffic away from the equipment and crew and to protect the line from traffic. Extreme care and caution in these situations are required to protect the working crew.

Crew Size

The size of the crew depends on the nature of the operation and on agency policy. If edge lines are applied at the same time as center lines and no passing lines, two spray gun operators are needed. Thus, considering that the striper truck has a driver and assistant, a crew of four men is required. A supply truck and operator is generally required for most operations. If cones are needed, another man is required. The crew foreman coordinates the operation and generally follows the striper. The cones must be retrieved by another truck with two or three men. The trucks supporting the paint striper are used for protection of the line if cones are not needed and generally follow at about 500 foot (150 m) intervals.

The simplest striping operation requires about five men and two trucks plus the striper truck. Considerable planning and coordination is needed to attain an efficient and low-cost operation. Because the striping operation is seasonal in many states, it is necessary that the crew should place markings as early in the morning as possible, but not before conditions are suitable. Because of rigid work hours, striping is too often started in the morning before the pavement surface has dried.

Good workmanship is often sacrificed because of the constant push for increased production. Short cuts in application are seldom cost-effective. Materials can be wasted, machinery clogged, and the quality of the stripe jeopardized if proper attention to detail is abandoned in favor of a few additional miles of striping.

MAINTENANCE

In the case of painted markings, maintenance involves repainting when the striping loses its contrast, base film, and reflectivity. The decision to repaint and scheduling the activity is usually based on established policy and is a function of the agency maintenance chief. The availability of materials, equipment, and crews are also important considerations from a maintenance standpoint. Materials must be selected, purchased, and stored. Equipment must be serviced and maintained to assure proper operations and prevent on-the-road breakdowns. Trained crews must be available and appropriately scheduled.

Scheduling Restriping Activities

Some agencies have predetermined schedules which identify sections of roadway to be periodically restriped. Such restriping programs involving a large volume of streets and highways can be computerized to assure a cost-effective allocation of equipment, crew, and materials. When a smaller mileage is involved, a manual scheduling process is commonly used. In either case, past experience and agency policy define which roadways must be restriped once, twice, or three or more times a year.

Other agencies may prefer to schedule restriping based on night inspection of the various facilities. In some cases, residential streets and other low ADT roadways are on a periodic basis and the busier high ADT facilities are scheduled on an "as needed" basis indicated by night inspection.

Determining when to replace painted markings is, at best, an inexact science vulnerable to subjective judgment and budgetary expedience. Several agencies have reported that overtime costs for night inspection cannot be justified, especially since the resulting evaluation is based on an individual's opinion without a precise scientific technique. Local knowledge of traffic and climatic conditions coupled with experience with the various delineation materials is considered an equally effective technique for scheduling these activities.

The weather patterns of the area determines, to a large extent, the time period available for maintenance. In high snowfall areas, for example, painting is usually limited to the late spring, summer, and early

Figure 13. Coning for Spot Maintenance

fall months. The materials selected and application techniques employed reflect the relatively short life expectancy of painted markings under heavy winter conditions.

Another factor that should be considered in scheduling repainting activities is coordination with major improvement programs and with other maintenance activities. Resurfacing, realignment, or changes in traffic patterns which would require new or repainted markings may render previously scheduled restriping unnecessary. If these activities are not adequately coordinated, significant expense of removing a newly restriped line could be incurred. While agencies hesitate to report such lapses, it is a relatively common occurrence.

This is not to suggest that restriping should be indefinitely postponed because of planned changes or improvements, particularly if the markings are significantly degraded in a hazardous location. The type of paint, the thickness laid, or the use of temporary markings should be carefully considered when changes are anticipated. The option to postpone restriping must be balanced against the possible cost of removal and the potential safety and legal ramifications should the lack of adequate delineation create an unsafe condition.

Warehousing and Storing of Materials

Traffic paint is usually furnished in accordance with agency specifications. It is tested at the factory, placed in sealed containers and shipped ready for use. The size of containers is specified by the agency and may vary from 5 gal (19 l) to the larger 30 gal (113 l) or 55 gal (208 l) drums.

While the specifications for traffic paint are written to insure against caking and excessive settling of the pigment, it may be necessary to stir the paint to insure complete remixing prior to use. Paint that has settled and formed a hard cake on the bottom of the pails should be set aside unused, and full data regarding lot number, quantitiy, etc. should be reported and arrangements made for the paint to be returned to the manufacturer.

Traffic paint that will remain in storage for some time and particularly throughout the winter months, should be stored upside down so that any deposit or settling will occur on the lid of the container. When it is opened, the settled pigment may easily be scraped off of the cover and incorporated with the balance of the mix.

Occasionally a pail of traffic paint will show a green film on the top and along the edges of the pail. This discoloration disappears immediately upon mixing, and is of no significance in the performance of the paint. However, sometimes traffic paint will contain "skins." Specifications usually provide that the lining of traffic paint containers shall be of such character as to resist the solvent and prevent skins being loosened into the body of the paint. For example, the manufacturer of paint containers may have used the wrong materials as a liner. This lining will loosen and form skins. Paint containing skins of this character should be set aside and arrangements made to return it to the vendor.

In almost all cases, paint should be mixed thoroughly before being placed in the paint tank of the application equipment. Thinner should not be necessary. (The wash thinner usually furnished is intended solely for cleaning equipment and not for thinning the paint.)

A 1979 study of the cost effectiveness of various storage and warehousing practices (Ref. 24) specifically addressed the economic feasibility of:

- Recycling drums for shipment and storage of paint
- The use of 55 gal (208 l) drums verses 30 gal (113 l) drums
- Bulk paint storage versus drum storage

Several states tried using recycled drums but experienced a significant leakage problem since the lids did not fit properly. Considering the loss of paint through leakage and the relatively small savings realized by using recycled drums, it was concluded that this did not represent an economically feasible alternative.

The study showed that the use of 55 gal (208 l) drums in lieu of 30 gal (113 l) drums resulted in a 40 percent reduction in the number of drums. Based on a comparison of drum costs and their resale values for both sizes it was determined that considerable savings in purchasing costs alone could be realized from the use of 55 gal (208 l) drums.

The problems in converting to the larger drums lies in handling the heavier loaded drums at the various storage areas. The full 30 gal (113 l) drums can be loaded by hand into supply trucks. To handle the much heavier 55 gal (208 l) drums, fork lifts or other equipment would be needed. Therefore, the cost for additional equipment may offset some of the initial savings. However, an additional savings would accrue since the amount of waste (paint remaining in drums) would be reduced because fewer drums would be utilized.

A real potential for savings appears to exist in the bulk paint storage concept. Possible cost savings, plus the ability to store large quantities of paint in a small area, make the bulk storage method an attractive alternative.

In addition to the obvious savings of about $0.35 per gallon (.09 per l) afforded by eliminating the cost of the drums, it has been estimated that about 3 gal.(11.4 l) of paint remain in each discarded barrel. Thus, there would be an additional savings due to reduction in waste. The installation of storage facilities, maintenance, and energy costs will offset some of these potential savings.

The State of Illinois recently installed bulk storage facilities in two of its nine districts. Evaluation of these installations is presently underway to determine its real cost effectiveness.

Spotting

It is generally necessary to spot or cat track the pavement surface before applying a new traffic stripe. The customary method of spotting is to use a rope and make spots approximately every five feet (Figure 14). When working in traffic, the workmen applying cat tracks must be protected with signing, flagmen and lane closure as required. Another procedure is to mark the pavement with a dribble line using a striping machine. It permits the rapid placing of a guide line with a minimum number of control points.

Another method frequently used for resurfacing jobs is to place a temporary offset line on the shoulder beyond the paved area before the overlay is placed. After the new surface has been placed, the striping machine then paints the stripe using the offset line as a guide on the new surface directly over the old line. This method has proved very satisfactory.

Where a traffic line has been obliterated by resurfacing, FHWA policy requires that striping be in place before the roadway is open to traffic. The practice of placing heavy cat tracks or dribble lines to serve traffic until the surface is cured and the standard stripe can be painted is followed in some states, but is discouraged by FHWA. However, when cat track marks are used they should not be applied more than three inches in width, so that they can be completely covered when the line is painted.

Pretreatment of the Surface

Earlier experience with traffic paints suggested that better adhesion with the pavement might be achieved by some form of pretreatment. It was fairly well documented that repainted stripes performed better than the initial application on bare pavement. It was therefore hypothesized that pretreatment, particularly on PCC would lengthen the life of paint.

Several forms of pretreatments have been used without significantly increasing durability. Some states, however have followed the practice of applying a light coating of paint without beads as a sealer on new pavement surfaces.

The first or primer coating laid at 4 to 5 gals.per mile (9.4 to 11.8 l/km) dries rapidly and seals the pavement. This eliminates the decoloration which sometimes occurs from the solvent action of the traffic paint on asphalt pavements, and provides better adhesion on PCC (Ref. 28).

Figure 14. Spotting Technique

One of the major concerns has been that paint is most frequently applied to dirty pavement surfaces. Laboratory tests have indicated that cleaning the surface prior to application substantially improves adhesion. Consequently, a field study was undertaken to assess the effectiveness and economic feasibility of various types of surface preparation techniques. The techniques that could be used for this purpose included airblasting, sandblasting, grinding, burning, washing (hydroblasting), acid etching, and wire brushing.

Of the different methods, wire brushing appeared best suited to the subject application. It was easy to use, worked well over irregular surfaces, did not damage the surface, had no logistics or time lapse problems, and removed road film. In this method, a wire brush assembly is mounted forward of the centerline spray gun and is controlled by the same circuit that operates the gun thus activating and deactivating simultaneously.

Brushing pressure on the road is controlled by a regulator on the air supply. It appeared that optimum brushing efficiency was obtained when operation of the brush was at its highest rate of speed (600 rpm) with a broom pressure that causes a 0.25 in. (6.35 mm) deflection of the side bristles. Excessive broom pressure results in excessive fiber deflection and early failure, poor cleaning action, and unnecessary strain on the drive parts.

The cost for the wire brushing operation totalled about $0.26 per mile (0.16/km). It was concluded that the service life of paint was not noticeably improved by brushing under the conditions of the field tests (hot, dry weather, relatively clean roads). It may still be a useful tool for other road conditions and may be more important in the application of spray or extruded thermoplastic markings which do not have the wetting capabilities of solvent-based paint (Ref. 29).

Removal of Painted Markings

Every highway maintenance facility needs to provide a capability for removing existing markings that no longer define the safe path of travel. The difficulties involved in the removal of markings have been compounded by the increasingly successful effort to improve paint durability and adhesion.

Traditional Methods

Traditionally, methods of removal include grinding, burning, chipping, appropriate chemical treatment, and sandblasting. Overpainting no longer appropriate markings with black paint and bituminous solutions is specifically disallowed by the MUTCD. This treatment has proved unsatisfactory as the original line eventually reappears as the overlying material wears away under traffic. In addition, lines which were covered in this way are still visible under certain conditions (low angles of illumination) due to preferential reflection from the two contrasting surfaces - the painted line and the adjacent road.

A prime requisite in determining the best method for stripe removal is that the treatment should have a minimum effect on the roadway surface; that is, it will not materially damage the pavement surface or texture. Chemical treatment may cause damage to the pavement surface, drainage channels or pipes, and consequently is seldom considered satisfactory. Removal of markings by grinding is not considered totally successful as some remnants of the marking usually remain. Generally, sandblasting has been the preferred method of treatment.

Sandblasting is particularly effective when the surface is rough and porous. This technique will do little damage to asphalt and the resulting scar will be barely noticeable. Sand deposited on the pavement should be removed as the work progresses to prevent accumulations which might interfere with drainage or constitute a traffic hazard. High pressure water or hydroblasting has also been used successfully under some conditions.

New Removal Techniques

There are a number of disadvantages associated with all of the traditional removal methods. Consequently, the problem of removing traffic markings without damaging the pavement or leaving discernible traces of the marking has received considerable attention during the last several years. Three contractors, working independently, developed removal methods of considerable promise. Two methods involve the burning off of the material. The third method utilized a mechanical approach rather than thermal.

The Excess Oxygen System appears to be the most promising of the thermal techniques. In this system, two wide, flat burner heads are mounted in tandem on a simple hand-propelled cart (Figure 15). The front nozzle (fuel head) burns propane and oxygen while the second nozzle directs pure oxygen at the burning surface. This combination produces an extremely hot flame (5000° F/2760° C) which rapidly combusts the paint stripe. This rapid flash burning allows fast lineal travel down the roadway. Faster lineal travel permits less heat to be transferred to the pavement. Consequently, the possibility of pavement surface damage is substantially reduced. After the passage of the burner, optimal removal conditions are indicated by the presence of an ash on the surface of the pavement marking. This ash consists largely of glass beads,

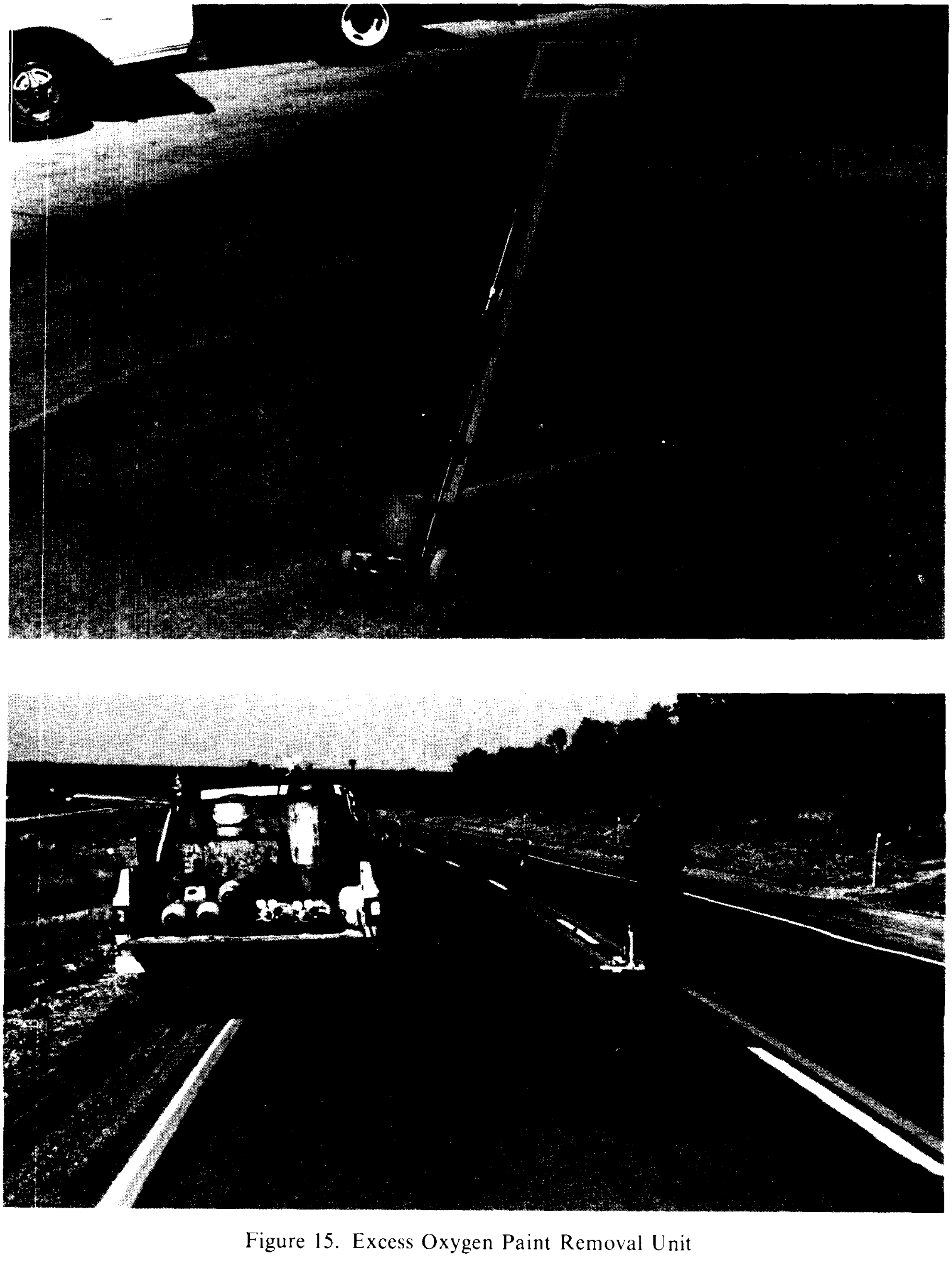


Figure 15. Excess Oxygen Paint Removal Unit

pigments, extenders, and fillers. The resinous binder material will have been burned away. The ash should appear uniformly across the marking to indicate sufficient burning.

The rate of removal varies with the thickness of the marking. Up to 20 mils (.5 mm) of a typical alkyd-chlorinated rubber paint marking can be removed per pass at a rate of 7 to 15 feet (2-5 m) per minute. For heavier build-up of paint, more than one pass may be necessary because of the ashing residue. That is, as the ash residue accumulates, it provides a shielding that prohibits further penetration of the flame into the marking.

The equipment and its operation is simple and inexpensive. Much of the required equipment already exists in most highway division maintenance facilities. The only equipment unique to this method is the fuel and excess oxygen heads which are commercially available as an off-the-shelf item. Plans, specifications, and operations manuals are available from FHWA (Ref. 30,31). A number of states are building their own version of this unit at a cost ranging from $200 to $400. The operating cost including fuel, labor, and vehicle costs is approximately $0.05 to $0.10 per linear foot (.3 m) of four-inch (10.16 cm) marking removed.

The second thermal method of stripe removal uses a specially-designed burner to combust propane and oxygen in a wide flame composed of a larger number of separate tips. After combustion, the paint stripe is treated with a mild scarifier. The field tests to date indicate that use of the cooler flame results in scarification, thus, more damage to the pavement than the method above (Ref. 32).

In the mechanical paint removal system, hardened steel cutter wheels applied to the stripe weaken the paint-pavement bond. Application of high-pressure water jets complete the paint removal. This method has shown significant promise in very small-scale tests; it is the only concept amenable to scale-up to self-propelled equipment for rapid, large-scale removal jobs. Further equipment development is continuing (Ref. 33).

Chapter 4. Thermoplastics and Other Durable Markings

The use of thermoplastic and other highly durable marking materials as an alternative to conventional traffic paint has been under study for over 15 years. The growing popularity of thermoplastic, epoxy, or polyester installations has been attributed to readiness for immediate use, superior durability, and the potential for long-term economy and traffic safety. While the initial cost of these highly durable markings can range as high as 5 to 15 times the cost of conventional painted markings, their long service life and improved visibility makes an attractive alternative in many situations.

This chapter summarizes the current uses and suggested procedures for application of thermoplastic materials including hot-laid (extruded and sprayed) and the cold-laid preformed plastics. It also covers the relatively recent use of epoxy and polyester pavement marking materials.

USES

Thermoplastic and other durable markings have the same basic uses as traffic paint (Chapter 2). The MUTCD (Ref. 1) application guidelines related to standard colors, widths, patterns, and placement of painted markings also apply to these types of durable markings. Specifically, thermoplastics can be used as center lines, lane lines, edge lines, crosswalks, stop bars, gore markings, barrier lines, parking lines, and on-the-street regulatory, warning, and directional legends or symbols.

Field tests and operating experience have shown that the characteristics of various types of highly durable markings serve some uses better than others. Moreover, as with most delineation techniques, the most effective usage in terms of cost and safety is a function of a particular combination of site-dependent variables. Consequently, the decision to use plastic-based markings in a given installation must be weighed against the advantages and disadvantages associated with the site characteristics as well as the materials, per se.

MATERIALS

Hot extruded and cold laid thermoplastic materials have been in use for many years and are considered a cost-effective alternative to conventional paint markings when durability is a prime criteria. Because of the wide operational experience, the emphasis in this chapter focuses on the traditional thermoplastics. There are, however, several generic materials (epoxies and polymerics) that have been developed and tested that warrant consideration. These materials are discussed at the end of this chapter.

Evolution of Hot Applied Thermoplastics

In its early uses, thermoplastics heated to above 375° F (191° C) were extruded on to the pavement surface at approximately 90 to 125 mils (2.3 to 3.1 mm) thickness. Reflective glass spheres were premixed in the base material and a top dressing of beads was applied as the molten plastic was extruded. The material solidified, ready for use, within minutes. This provided a brilliant white (or yellow), highly reflective marking that was at least six times the thickness of conventional traffic paint. In addition to the inherent durability of the plastic itself, these markings provided a limited level of wet night visibility since these thick stripes extended above the surface water film formed by the light rain that normally causes reflective painted stripes to lose their reflective properties.

There were a number of problems associated with early hot extruded installations. Generally, more failures were experienced on the smoother PCC surfaces than on asphalt pavements. The lack of bond and the formation of blisters within the thermoplastic stripe were particularly troublesome in high snowfall areas. Snowplow blades would snag the leading edge of the stripe or the blister and rip the material from the surface. Plowing damage would occur on asphalt pavement installations, but not to the extent experienced on PCC because of the better bond achieved (Ref. 34).

In these early uses, there were no standard installation procedures. Pavement surfaces were preconditioned by airblasting, sandblasting, hydroblasting, grinding or not cleaned at all beyond a surface sweeping. Where primer coatings were used, the primer formulations varied considerably. In addition, the condition of the pavement (age, temperature, dampness) during application differed significantly. Given these circumstances, the performance of the early thermoplastics was so diverse that little commonality could be established. Even where the major factors were held constant, there remained unexplainable variations in performance.

Despite these problems, hot melt thermoplastics exhibited such potentially desirable traits that research continued to identify and resolve the inconsistencies experienced. As a result, thermoplastic materials, installation equipment, and application techniques have been in a continual state of flux during the last ten years. In addition to improvements by the industry in the formulation of the base thermoplastic materials and primer, hot spray application promises to resolve several of the problems characteristic of the extrusion process. Morever, as more operational experience is obtained, performance and cost-effectiveness can be more accurately predicted.

The development of the hot-spray application is considered by many to represent a significant breakthrough (Ref. 35). Among the major advantages cited for hot spray thermoplastic over hot extruded applications include the ability to apply thinner coatings, better bond with pavement surface, and better distrubution and retention of glass beads. It has also been pointed out that the difficulties of maintaining the required high temperatures of the material as it travels down the chute to the applicator and during the extrusion process is largely eliminated in the spray process. Moreover, the hot spray material hardens instantly upon application.

Properties of Thermoplastics

Hot-laid thermoplastics are generally defined as synthetic resins which soften when heated and harden when cooled without changing the inherent properties of the material. The formulation of thermoplastic pavement markings includes three basic components: plastic and plasticizers (binder); pigment and fillers; and glass spheres. The exact chemical composition varies considerably. Formulas of commercially available materials are proprietary and continually change as the price of chemical components fluctuate. For this reason, composition is usually specified in terms of minimum percent weight of each basic component. A tentative model specification is provided in Appendix C.

Although the percent by weight of the components vary among specifications, a typical range may be as follows:

Binder	15 to 35%
Glass Beads	14 to 33%
Titanium Dioxide (TiO_2)	8 to 12%
Calcium Carbonate or or other inert filler	48 to 50%

Formulations differ for materials to be applied by the extrusion or hot spray process. They also differ for use in hot or cold climates. For example, one manufacturer supplies an alkyd base (synthetic resin) material for use in Northern areas and applied by extrusion. A hydrocarbon base (organic compound) material is recommended for spray application in more temperate climates. Most material suppliers will formulate the thermoplastic compound in response to agency specification, although they may recommend some minor variations.

Use and Properties of Cold-Applied Thermoplastics

The discussion to this point has centered around hot melt thermoplastic materials. The high temperature necessary to achieve a molten state for application requires expensive installation equipment and experienced operators. Cold plastic striping material eliminates this requirement, requires no hardening time, and under certain circumstances exhibits a high level of durability.

These materials are most frequently used for crosswalks, stop-bars, words and symbols, and other specialized treatments. Some local agencies have also indicated a preference for the cold-applied tape as center lines and lane lines in areas of low traffic density. As with the hot-applied thermoplastics, these plastics are reported to perform better on bituminous asphalt surfaces than on Portland Cement Concrete.

There are two basic forms of cold-applied plastic materials as described in the Model Performance Specification (Appendix C). The first type is an extruded cold flow plastic tape with imbedded glass beads, with or without a top surface dressing of beads. It is generally used in thickness of 90 mils (2.3 mm) or 60 mils (1.5 mm) and is either precoated with pressure sensitive adhesive for self-bonding or an adhesive for application on the roadway can be supplied.

The second type of materials include preformed plastics that are somewhat more pliant than the cold extruded type. A top dressing of beads is recommended for areas where immediate reflectivity is required. Standard thickness of these films are 30 mils (0.76 mm) and 60 mils (1.5 mm) and can be precoated for self-bonding or can be applied with a contact cement. The composition by weight of the components of both types of cold applied plastic markings are specified in Appendix C.

A special type of the preformed plastics has been recently introduced for use as temporary markings in construction work zones. The major advantage of this material is its easy removability. It can be removed intact (or in large pieces) from either asphalt or PCC pavement surfaces manually or with a roll-up device without the use of heat, solvents, grinding, or sandblasting.

APPLICATION

The various categories of thermoplastic installations require very different application techniques. In selecting the most appropriate thermoplastic materials, the application procedure for each category should be carefully considered from the standpoint of the physical requirements to achieve a proper bond, as well as the equipment and manpower requirements.

The type of installation (transverse or longitudinal markings), type of facility (urban/rural etc.), type of pavement, magnitude of the installation, and other project characteristics will influence the method of application. For example, a small intersection project to install crosswalks or stop bars will differ from a major improvement project in which delineation markings are a line item in the construction contract.

In almost all cases, thermoplastics, hot or cold laid can be applied with small, manually-operated equipment or can be applied mechanically with large, fully automated equipment. The exception is applying cold, preformed legends or symbols. These must be applied by hand, but is a relatively simple operation. The major characteristics of the basic application procedures are reviewed below.

Application Thickness

The matter of application thickness is the subject of some controversy. If durability is a function of thickness, the thicker markings would naturally have a longer life but would require more material, thus more cost. It can be argued that this extended life may outlast the reflective properties, and, in some cases, the roadway surface itself. Therefore, the value of an expected life of six to ten years could be meaningless if the pavement is subject to resurfacing or if the bead loss (reflectivity) renders the stripe ineffective at night.

The thicker markings in the range of 90 to 125 mils (2.3 to 3.1 mm) provide better wet night visibility when the beads are still in place, but are more vulnerable to snowplow activity. In practice, the thicker application continues to be specified so that either the extrusion or spray process can be used. (Appendix C). The extrusion process is more compatible to thick applications, especially if 125 mils (3.1 mm) is desired. The spray process is best suited to application of 90 mils (2.3 mm) or less. These lighter coatings have generally performed well and are more cost effective.

Proponents of the thinner applications (40 to 60 mils - 1.0 to 1.8 mm) report acceptable durability and reflectivity over a 3 to 4 year life span, lower material costs, faster application, and less damage by snowplow activity. The average wear of thermoplastic material (including studded tire wear, traffic abrasion, and snowplow shaving) has been estimated at 10 mils (.25 mm) loss per year. Thus, a stripe of 40 mils (1 mm) could be expected to survive three to four years (Ref. 35). Even these thinner applications provided limited wet night visibility since moderate surface water film does not cover the marking and therefore does not completely inhibit reflectivity.

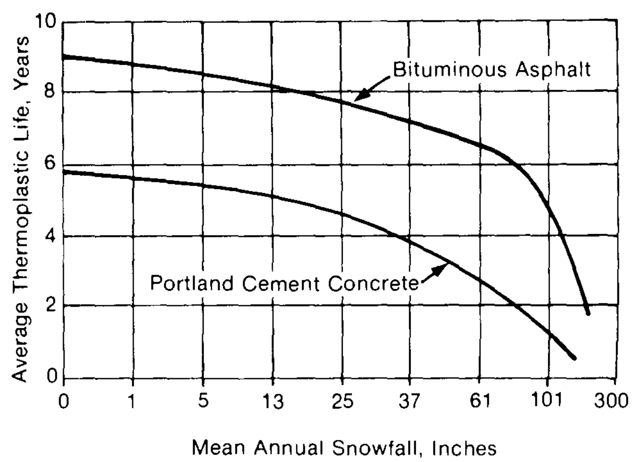
Effects of Snowplow Activity

Under some situations, hot extruded thermoplastic traffic markings may be severely damaged by snowplow operations. Early research developed a correlation between the intensity of snowplow activity as measured by mean annual snowfall and thermoplastic durability (Ref. 34). This relationship is shown in Figure 16. No other correlation was found between other variable such as traffic density, pavement pretreating, primer type, and pavement age in this early (1969) survey.

Recent laboratory tests (Ref. 35) suggest that where an adequate bond is established, the action of the snowplow is only a minor contributor to thermoplastic marking loss. The failure is most probably caused by the freeze-thaw cycle characteristic of many snowfall areas. In any case, winter failures are more frequent on Portland Cement Concrete than on bituminous asphalt pavements because of the better bond achievable on asphalt surfaces. (It should be noted that plastic is considered impervious to de-icing chemicals and sands.)

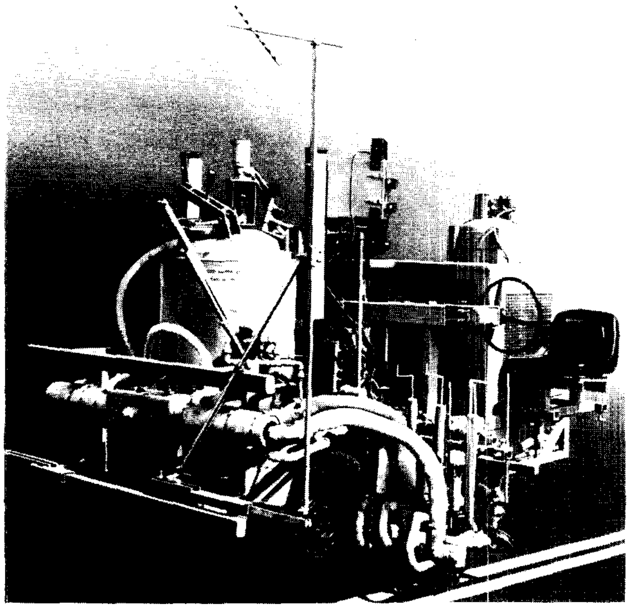
Installation of Hot Applied Thermoplastics

Molten thermoplastic can be extruded or sprayed on to the pavement surface by means of a manually

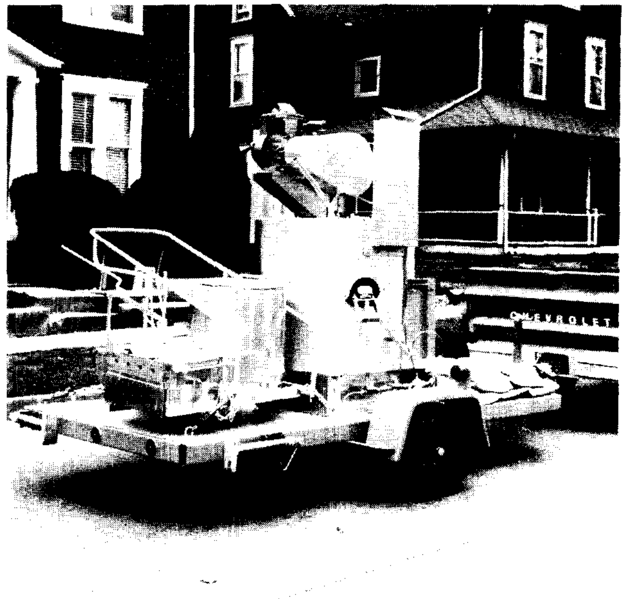


Source: Ref. 34

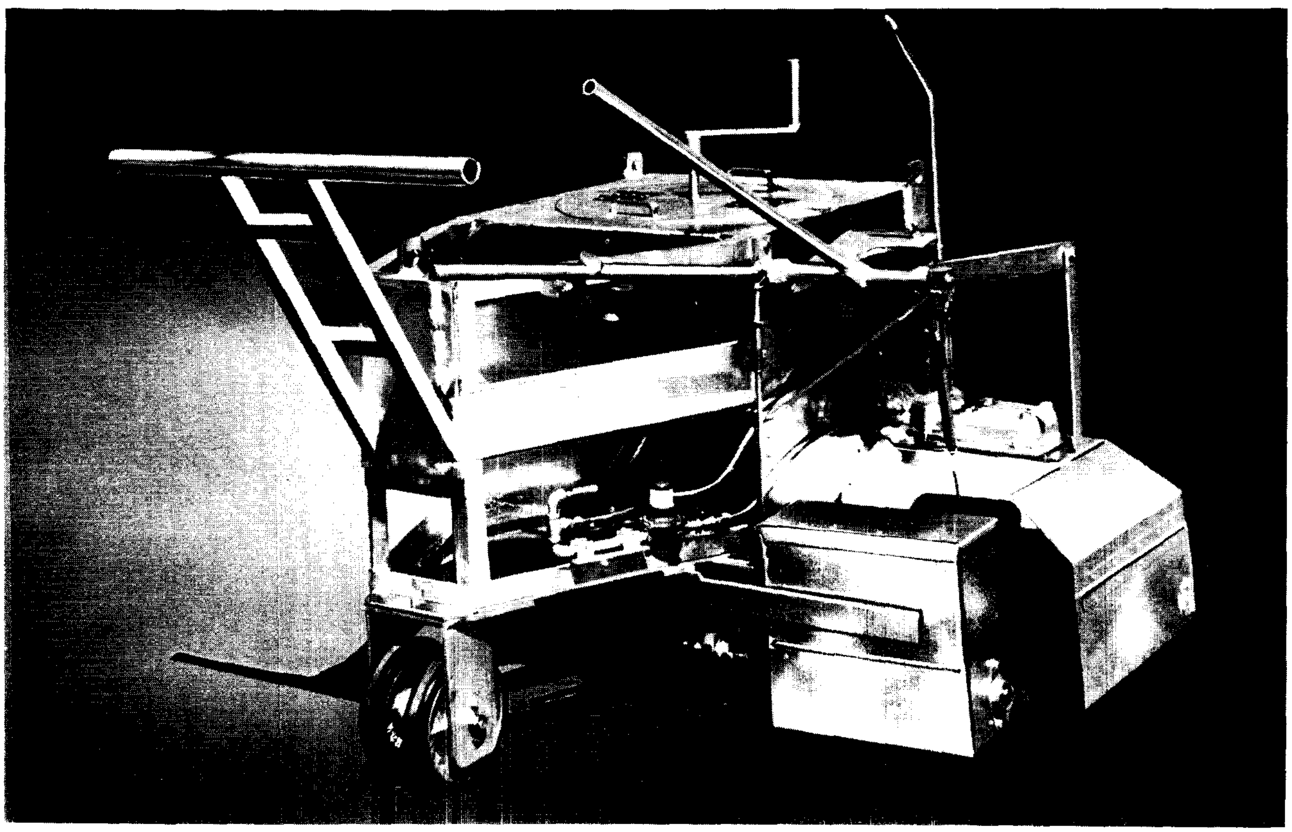
Figure 16. Average Thermoplastic Life vs. Annual Snowfall



a) Self-Propelled

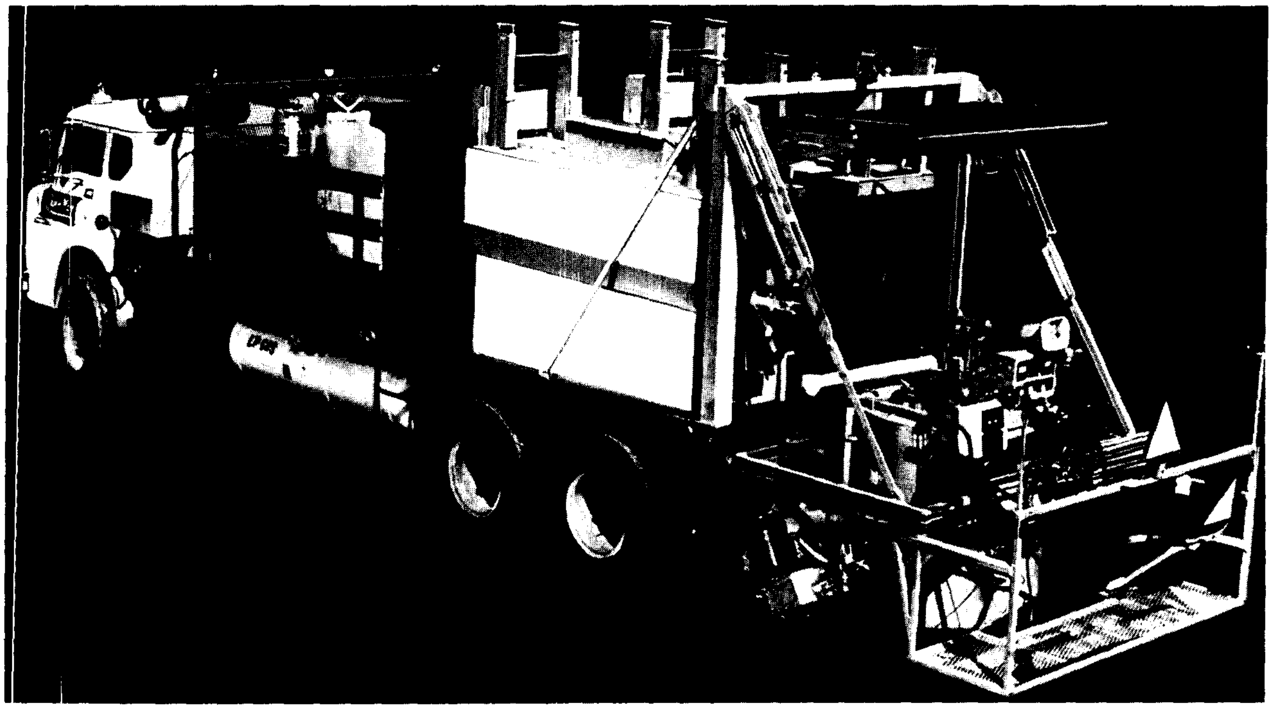


b) Small Truck-Trailer

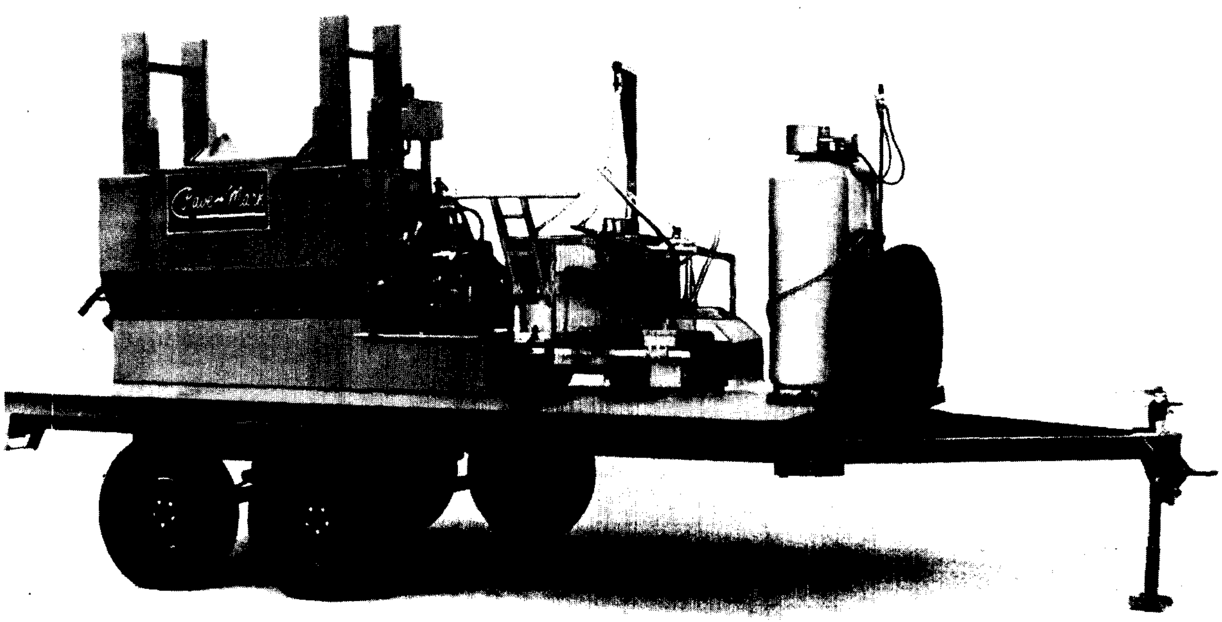


c) Manual Applicator

Figure 17. Small Thermoplastic Application Equipment

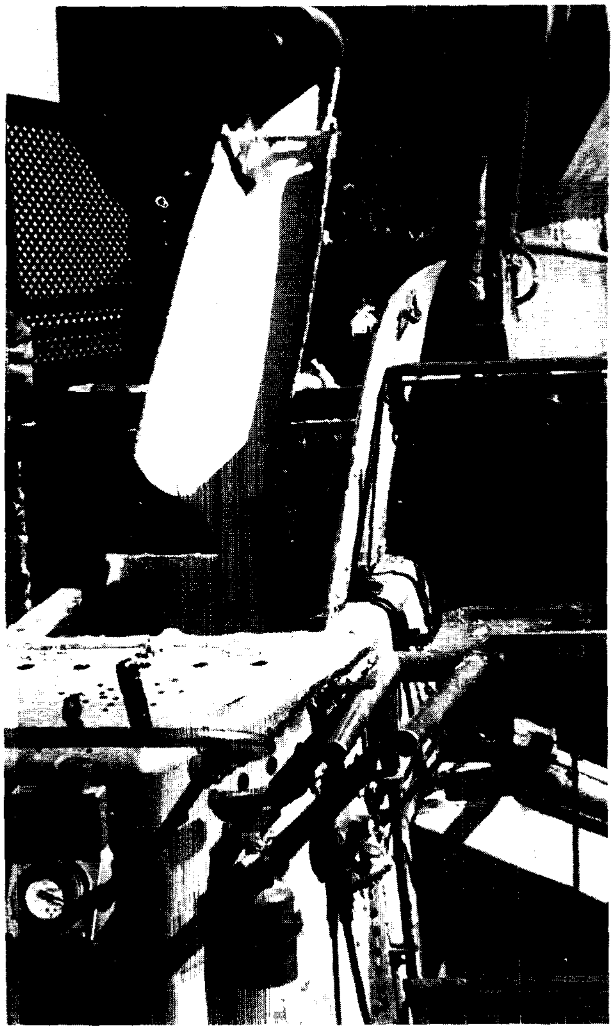


a) Truck-Mounted Equipment



b) Trailer-Mounted Equipment

Figure 18. Large Scale Thermoplastic Application Equipment



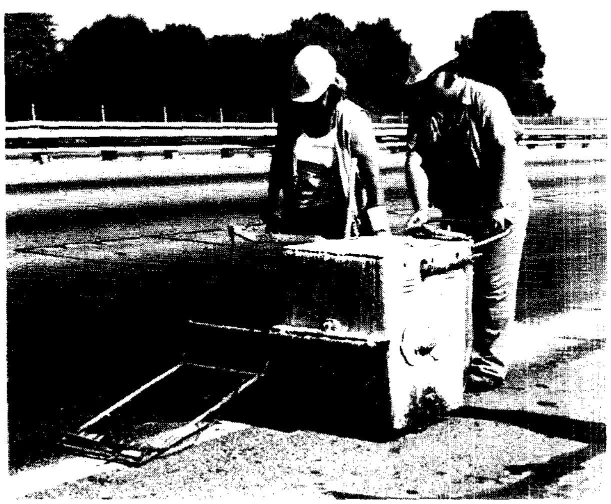


Figure 19. Loading and Extruding Thermoplastic

operated device for small runs (Figure 17) or by large automated equipment for major construction projects (Figure 18). Typically, 2000 lbs. (907 kg) of thermoplastic materials supplied in granular or block form will yield approximately 6600 feet (2.11 km) of 4-inch (10 cm) striping with a 90 mil (2.3 mm) thickness.

Application Equipment

The manual applicator usually consists of a melting pot holding a manual mixing paddle to keep the plastics from segregating or scorching, the extrusion spigot and die, and a bead hopper and dispenser. In one design, the machine is equipped with a propane tank and regulator to fuel the burner under the melting pot. Another type of equipment utilizes an auxiliary unit for heating the materials which are then transferred to the dispensing unit as shown in Figure 19. An infrared burner over the extension die can be used to maintain the temperature during application. For hot-spray manual application, the striper unit draws its compressed air supply through a long hose from a small truck-mounted machine. These small units have an average capacity of about 12 gal. (45.4 l) of molten thermoplastic, equalling about 100 lbs. (45 kg).

Truck or skid mounted thermoplastic stripers are self-contained units consisting of large melters with automatic agitators, heaters, electronic controls, intermittent interconnected timers to control the flow or spray to form solid or broken lines, material dispensing unit (extrusion die or spray nozzle), and bead hoppers and bead dispensers. The larger mobile units range in size from 1,000 lb. (454 kg) to 3,000 lb. (1360 kg) capacity melting pot (Figure 20).

Applications utilizing these large machines are frequently contracted. The equipment costs can exceed $150,000 and local staffs are seldom experienced in operating such complex machinery. Some agencies maintain a small mobile unit for maintenance jobs or small installations such as new crosswalks or stop bars. Large installations are either bid separately (for existing pavements) or are included as part of a new construction or resurfacing contract. There are, however, a number of agencies who prefer to purchase medium-sized equipment and conduct their own striping activities often with assistance from the materials supplier. Crew sizes range from two men for manual application to up to five for the largest equipment. (Not including following vehicles or other protection and traffic control personnel.)

Storing and Field-Handling of Materials

Hot melt thermoplastic materials are available in block or granular form which are packaged in cardboard containers or heavy duty bags in weights of

20 to 50 pounds (9 to 23 kg). The containers (or bags) should be stacked flat and stored on pallets in a dry place. Water or dampness will not harm the materials, but may weaken or otherwise damage the cardboard containers. The manufacturers suggest that cardboard containers should be stacked no more than 13 boxes high. In periods of extremely hot weather, it is suggested that stacks be limited to 10 cartons.

Dirt, residue from the cardboard or the polyethylene liner will contaminate the material. Consequently, care should be exercised to protect the material so that none of these pollutants are inadvertantly loaded into the melting kettle.

The daily supply of cartons or bags to be carried on the truck bed should be covered. If the cardboard containers do get wet, all paper or line residue should be removed and the material allowed to dry before use.

Before loading, the bulk material should be broken up while still in the carton. This is accomplished easily by striking the carton with a hammer. The carton should then be opened, placed over the kettle, and tilted so that the material will empty into the melting pot.

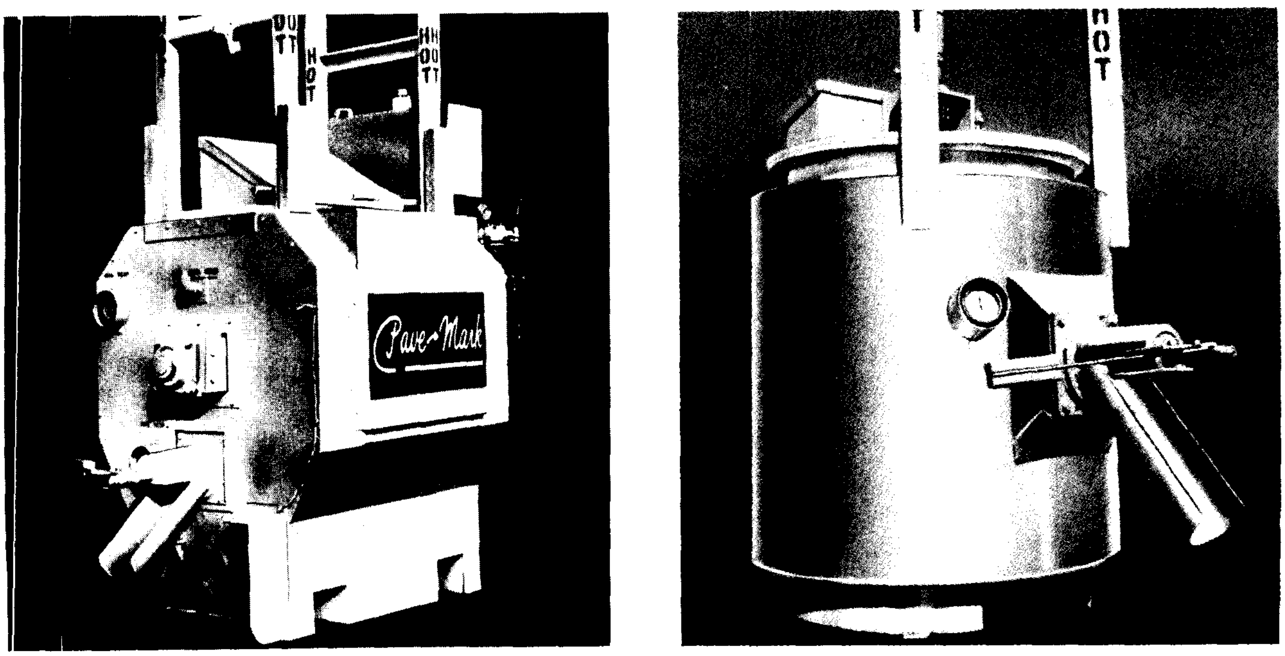
Conditioning the Pavement Surface

The operational procedures for the application of hot melt thermoplastic markings is quite similar to the application of paint. Where no previous markings exist, the roadway must be marked with guidelines (cat tracks) using the same methods described for paint application (See Chapter 3). The roadway should be dry with no surface dampness., dew, or subsurface wetness. The ambient temperature should be above 50° F (10° C) or the temperature recommended by the manufacturer.

The type and condition of the pavement surface during installation is a critical factor in assuring the best possible bond between the thermoplastic film and the roadway. The experience to date shows that better adhesion is generally achieved on bituminous pavement than on PCC. (It has been suggested that the improved bond results from the bituminous surface softening with the heat emitted from the striping equipment and molten material thus fusing more completely with the film.) Preparation of the surface may involve cleaning and/or the application of a primer-sealer to promote adhesion.

Although practices among highway departments differ, most specifications call for application on dry and clean pavement. The appropriate degree of dryness is usually a subjective judgment of the engineer in charge. Early morning dampness is suspected of causing some early failures.

The techniques for removing loose dirt, old paint, oils, etc. to provide the required clean surface include



a) Oil-Jacketed Premelting Kettle

b) Air-Jacketed Premelting Kettle

Figure 20. Typical Melting Kettles Used in Thermoplastic Application

sandblasting, airblasting, hydroblasting, brooming, acid etching or grinding. (Some agencies report no precleaning requirement for bituminous pavements.) The most appropriate technique depends on the condition of the surface and whether any residual paint must be removed. Sandblasting and acid etching are usually restricted to PCC. Better adhesion is reported for installtions in which the concrete was subjected to light grinding before application.

Depending on the type of pavement surface and the recommendation of the supplier, primer may be required prior to application. The New York Department of Transportation and a number of other agencies reported no difference in performance with or without primers when applied to bituminous (AC) pavements (Ref. 34). However, the use of a primer-sealer on PCC surfaces and old bituminous pavements is recommended by most material suppliers.

After conducting extensive test of hot extruded thermoplastic installations, the State of New York has specified the use of epoxy primer on PCC. The large automated hot spray equipment used in California is equipped to lay a two-component epoxy directly ahead of the spray thermoplastic (Ref. 36). The most commonly used primer in recent years has been an epoxy resin. Synthetic rubber-based primers have not proved as effective.

There appears to be no clearcut consensus on the pretreatment — by primer or by cleaning — of the pavement surface prior to application.

There is also little agreement on the optimum application rate of primer. Basically, it depends on age, porosity, and texture of the pavement as well as on the active solid contents of the epoxy solution used. The wet film thickness of primers range from 2 to 5 mils (0.3 to 0.13 mm) and is normally based on manufacturer's recommendation. Recent studies however indicate that 2 mils (0.5 mm) is adequate (Ref. 36).

The proper handling and application of rapid-dry epoxy primer coatings is necessary for good bonding. For example, evidence suggests that the thermoplastic materials should be applied when the primer is still tacky (Ref. 37). Failures have been reported when the primer was either too dry or too wet. One specification (Ref. 35) requires that the spray-applied primer should be of a type that remains tacky for at least 10 minutes at 73° F (23° C). One form of epoxy (with linseed oil) requires 24 hours of curing time.

Similarly, there is little agreement on whether thermoplastic should or should not be applied over paint. There is evidence to suggest that a better bond is achieved on bare pavement. These agencies which maintain their own equipment and use their own forces for day-by-day applications appear to have evolved methods compatible to their unique requirements. In some instances, neither PCC or asphalt surfaces are primed or cleaned despite recommendations from the supplier. Yet the agency will confidently estimate an 8 to 10 year life expectancy based on past experience.

The documented differences in opinions, procedures, and experiences tend to reinforce the assumption that the performance and life expectancy of thermoplastic markings is directly tied in with a multitude of site-dependent variables. It also reinforces the frequently repeated caution that findings, conclusions, and recommendations emerging from research projects be tempered by the judgment and local experience of agency personnel.

Installation of Cold-Laid Plastics

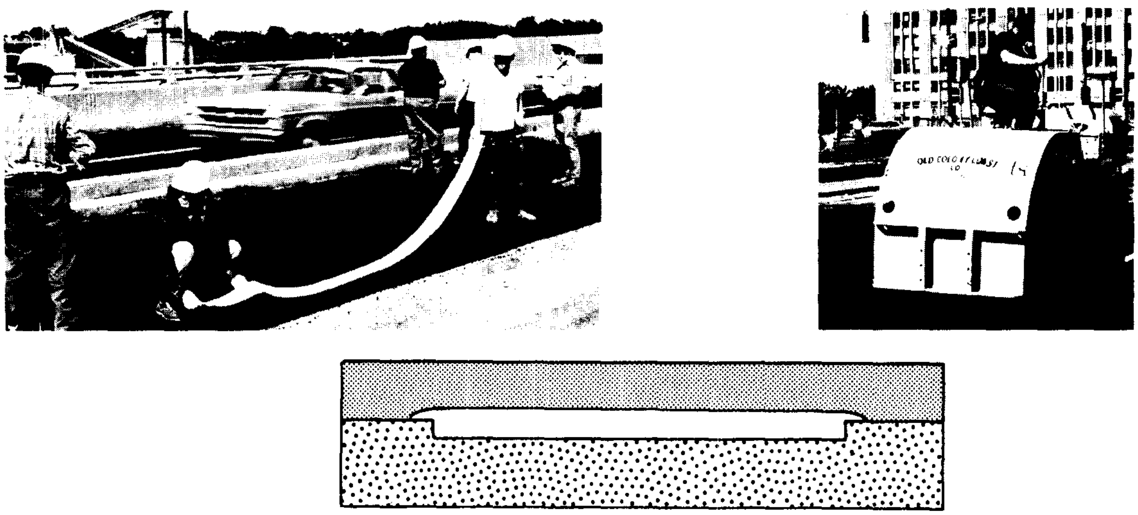
The cold-laid plastic pavement markings are supplied in continuous rolls of various lengths and widths, for yellow or white line markings, and in precut shapes to form standard lengths and symbols. It is also provided in sheets from which special shapes, forms, or letters can be customized.

The line markings can be installed by the inlay method or the overlay method (Figure 21) depending on the type and condition of the pavement. With either of these methods, the markings are ready to receive traffic immediately after installation.

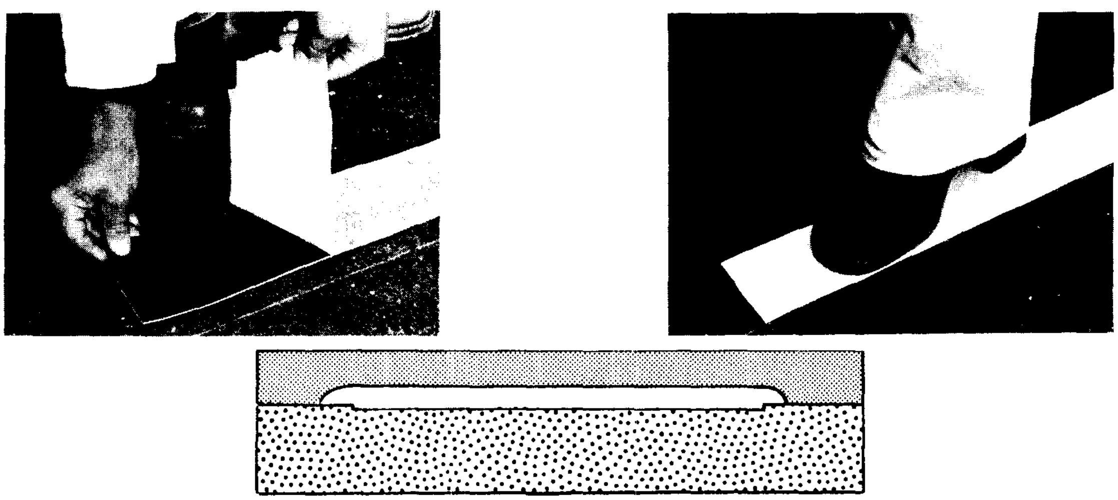
The inlay method is used with new construction or resurfacing of asphalt concrete surfaces. While the asphalt is still warm (at least 130° F/54° C), the pressure sensitive, self-bonding tape is positioned in place and is tamped firmly into the asphalt during the final compaction. For longitudinal markings, a tape applicator device is available which follows the breakdown rollers and lays skip lines, double yellow lines, and solid white edge lines automatically (Figure 22). It is powered by a 12 V battery with a compressed air cut-off mechanism. The tape as positioned is securely bonded to the pavement by the finish roller following behind. Precut shapes and letters must be positioned manually before compaction. The rolling tends to bevel the plastic strip into the pavement thus enhancing the bond and sealing out moisture.

The overlay method is employed on existing pavements. Pressure-sensitive film works well on good AC surfaces. Better bond is achieved on PCC pavement or old AC when contact cement is applied prior to installation. In this case, manufacturers may recommend two coats on the pavement and one on the film, particularly for intersection markings with heavy turning movements. The markings can be tamped by simply stepping on them, but most agencies prefer to use a light hand roller to insure good placement until the continuous tire pressure of traffic can securely bond the film to the pavement.

For construction or maintenance jobs which require the temporary delineation of new or altered travel lanes through the work zone, a thinner, self-adhesive tape can be applied directly on the pavement. Two forms of temporary marking tape is available. One form is intended for use in those types of construction projects where the removal of marking will not be required. The other form is designed for easy removability. Major advantages of the latter material are that it is highly reflective, is quickly installed by a two-man crew, and can be removed easily when the construction project is completed and traffic flow must revert to the original configuration.



a) Inlay Method (For New Asphalt Surfaces)



b) Overlay Method (For Existing Asphalt and PCC Surfaces)

Figure 21. Basic Methods of Installing Cold-Laid Plastic

SERVICE LIFE

Although thermoplastic markings have been in use for a number or years, there is little agreement on its service life. The longevity and durability of the plastic film per se has been fairly well established. The problem arises in attempting to establish an expected service life of a particular material as installed on a given roadway. There are too many factors influencing performance to permit "an average" life to be predicted with any confidence. Figure 23 and 24 represent two forms used to express average life as a function of volume and the durability of material as a function of traffic flow, respectively.

The remaining thickness and/or the percent of longitudinal area retained are the most common measures of service life. For example, it is assumed that the stripe is no longer effective when the thickness falls below 10 to 15 mils (0.25 - 0.38 mm). The longitudinal loss of thermoplastic is most often used in determining service (or "terminal") life as discussed below.

Minimum Retention Requirements

One survey of state highway departments reported in a 1969 study (Ref. 34) showed a wide variation in thermoplastic performance and in agency expectations. A suggested percent of retention for contract warranty as cited in the Tentative Model Performance Specification (Appendix C) is given in Table 2. This requirement is based on a hot extruded application with 90 to 125 mils thickness (2.3 to 3.1 mm).

The Texas Transportation Institute (TTI) developed the following calculation technique for determining percent of thermoplastic retained (Ref. 35). It is based on the nominal area of the stripe, less the area of loss (determined as indicated below), divided by the nominal area and expressed as a percent.

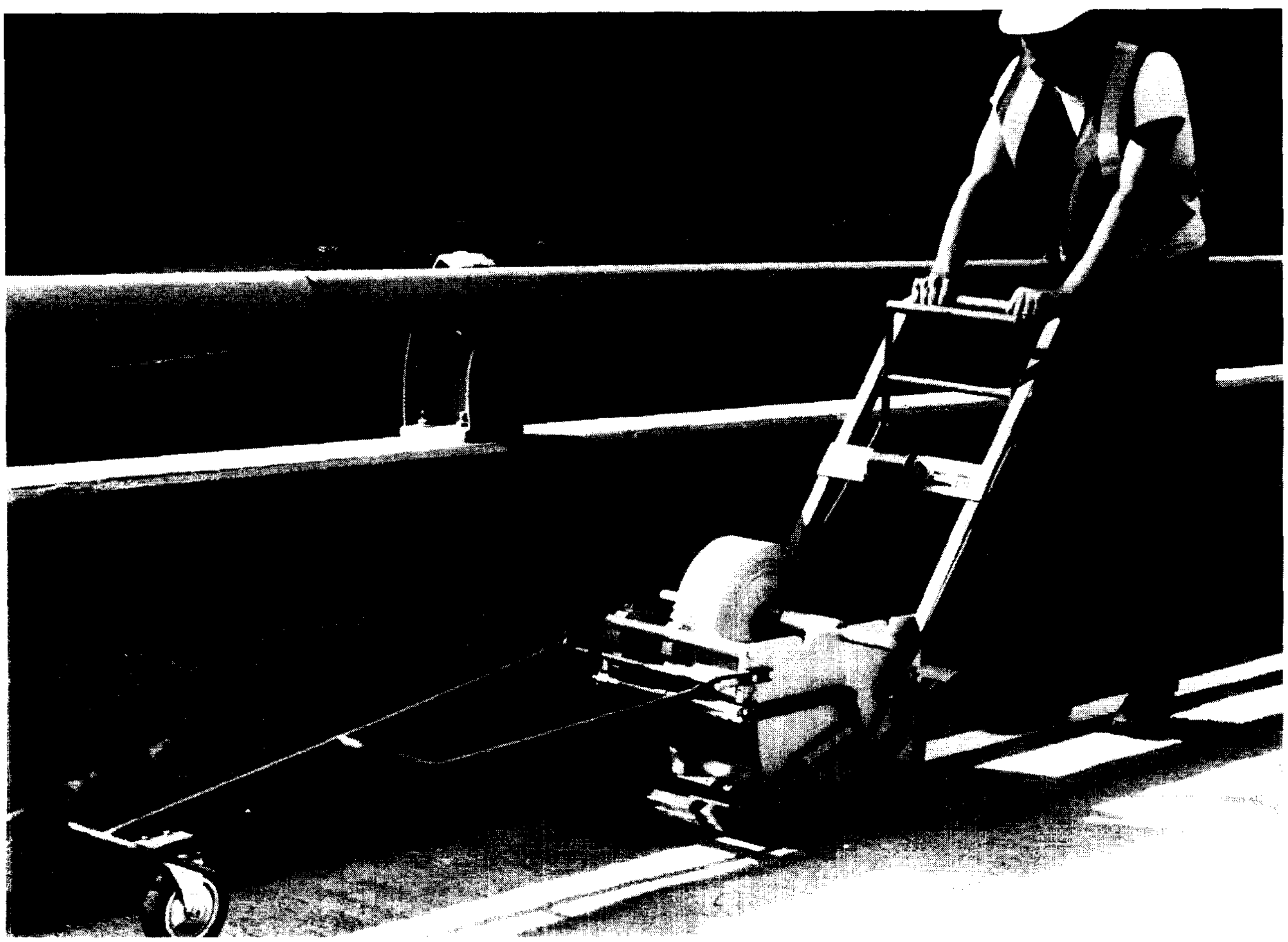
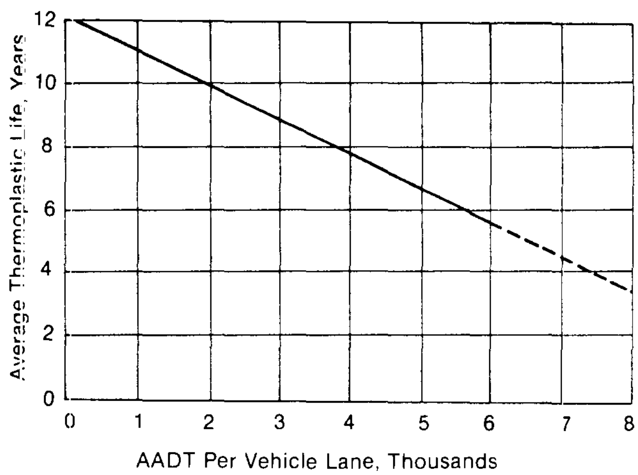


Figure 22. Cold-Applied Tape Applicator

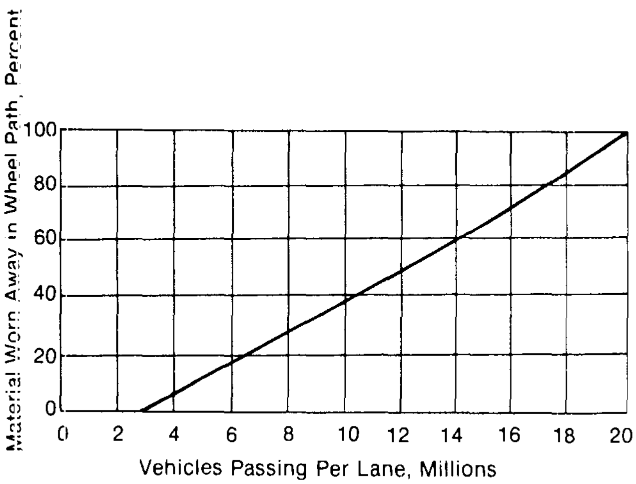
Table 2. Warranty Requirements for Thermoplastics

Duration After Acceptance	Minimum Retention	
	Longitudinal Lines	Transverse Lines
12 Months	90%	90%
24 Months	80%	75%
36 Months	60%	50%



Source: Ref. 16

Figure 23. Life of Thermoplastic Stripes as a Function of Volume



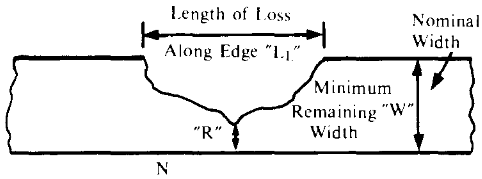
Source: Ref. 16

Figure 24. Performance of Thermoplastic Markings as a Function of Traffic Flow, District of Columbia, 1965 - 1975

Edge Loss

Edge loss is defined as any loss of thermoplastic from one edge which does not continue entirely across the stripe. The area of loss shall be one-half of the nominal width, minus the minimum remaining width in the area of loss, times the length of the loss along the edge.

Example:

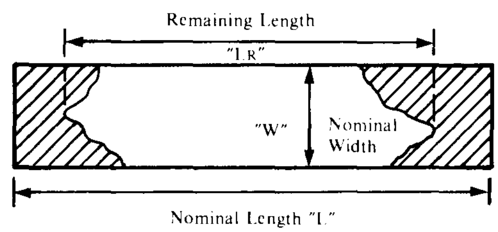


Edge Loss = $L_1 = \frac{1}{2}(W - R)L_1$

End Loss

End loss is defined as the loss at the end of the stripe. The area of loss is the product of the remaining length measured along the centerline multiplied by the nominal width of the line and divided by the nominal area.

Example:

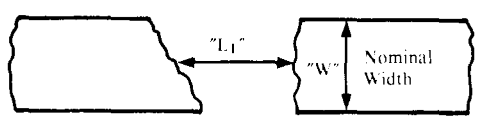


End Loss = $L_2 = (L \times W) - (L_R \times W)$

Center Loss

Center loss is defined as any loss of thermoplastic which extends entirely across the stripe between the two ends of the stripe. The loss shall be determined as the product of the length of loss measured along the centerline multiplied by the nominal width of the line.

Example:

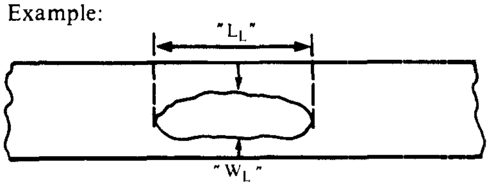


Center Loss = $L_3 = (L_1 \times W)$

Interior Loss

Interior loss is defined as any loss contained entirely within the edges of the stripe. The area of loss shall be calculated as the product of the length of loss in the longitudinal direction multiplied by the width measured in the transverse direction.

Example:



Interior Loss = $L_4 = L_L \times W_L$

Total Percent Retained Calculation

Total Loss = $L_1 + L_2 + L_3 + L_4$

Computation of Percentage Retained

$$\% \text{ Retained} = \left(\frac{\text{Nominal Area - Total Loss}}{\text{Nominal Area}}\right) 100$$

MAINTENANCE

One of the advantages of thermoplastic markings is its durability. Depending on the material used and the roadway characteristics, thermoplastics can provide virtually maintenance-free delineation for a number of years. Some of the maintenance concerns related to thermoplastics are discussed below.

Staining

In very hot climate, thermoplastic markings can become discolored or badly stained by tire tracks particularly on bituminous pavements. This degrades the daytime contrast and visibility. Thermoplastics are, however, somewhat self cleaning during rainy weather. That is, the tire action on wet markings will remove most of the stains. In hot, dry areas, it may be desirable to consider cleaning the markings by washing with a mild detergent.

Patching

The nature of thermoplastic, especially the thicker extruded installations, are such that pieces of the markings can be chipped away if the bond to the pavement is faulty or if the internal cohesion of the pavement itself is unstable. Almost all of the thermoplastic materials, hot and cold applied, can be patched by placing a thin overlay of compatible material over that portion of the old line. This is usually accomplished with a manual applicator.

Replacement

When the thermoplastic markings are no longer effective and must be replaced for safe operations, it is common practice to renew the lines with an overlay of compatible material. This can be treated as a scheduled maintenance activity, a separate project or as part of a larger improvement program. Depending on the size of the installation and agency policy, the work may be performed by agency forces or contracted.

In some cases, thermoplastic markings outlive their reflective properties. One agency experimented with using paint and reflective beads overlaying the old thermoplastic to obtain night visibility. The paint was used as a binder to retain the beads since much of the thermoplastic line was still in place. If the paint adheres to the thermoplastic and if the thermoplastic base is securely bonded to the pavement, this could represent an inexpensive method of upgrading markings with inadequate reflectivity. However, there is no available information on the performance of this combination.

Removal

Thermoplastic markings are intended for long-life installations. As such, they are relatively difficult to

Figure 25. Results of Excellent Job of Sandblasting to Remove Thermoplastic Marking

remove. Those properties that enhance durability (thickness, integral bond with pavement) serve as deterrents to easy removal.

On either bituminous asphalt or PCC, the removal of a thermoplastic marking will leave some degree of scarring on the pavement surface. The extent of the scar will depend on the method of removal employed. Sandblasting is frequently used for large scale removal jobs. One operation features a high-pressure water jet used in conjunction with sandblasting. This minimizes the residual sand left on the pavement and enhances the effects of the sandblasting. Figure 25 presents a close-up of the results of this type of operation.

The excessive oxygen paint removal equipment described in Chapter 3 has also been used to remove hot-spray applied thermoplastic. In this case, the hot flame melts the plastic which is then removed with a straight hoe. Subsequently the residual marking is reburned and the burned residue is brushed away leaving only a slight indication of where the line had been. This will disappear with traffic wear.

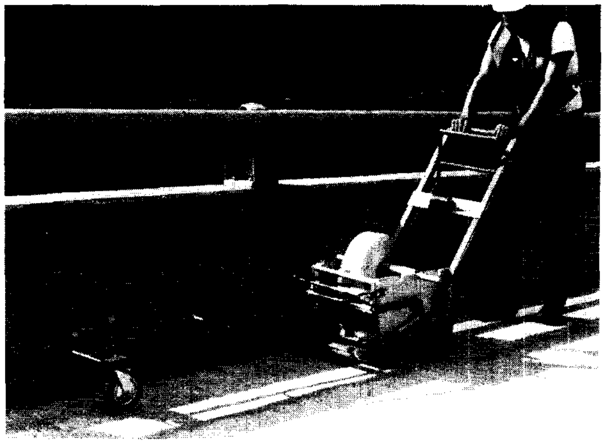
For smaller jobs, an air hammer and chipping blade may be used, although on asphalt surfaces this requires extreme care to prevent inordinate damage to the pavement. Figure 26 shows the results on AC of removal with a special grinding tool. To remove an occasional arrow or legend, a hand hammer and a chisel can do a satisfactory job.

The permanent installations will, of course, be completely covered during any type of roadway resurfacing or rehabilitation project. No vestige of the marking will remain.

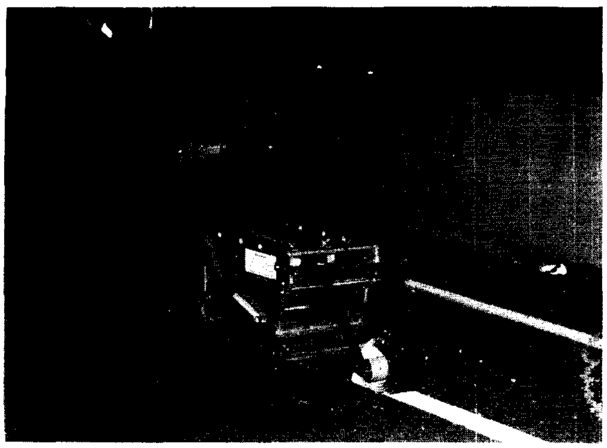
The self-adhesive cold-laid tape specified for short term temporary markings in construction zones can be removed with relative ease. The material can simply be dislodged and removed by hand or rolled up on the applicator as shown in Figure 27. This type of operation will leave no lasting scar. A dim indication of where the material was formerly installed may remain, but this will be eradicated by traffic film in a short time. The aluminum-based material is more difficult to remove if primer was used and/or if the marking has been in place for a long period. In these cases, the aluminum base can be heated to break the adhesive bond. The markings must then be scraped from the roadway surface.

Because of the long life and inherent difficulties in removing permanent thermoplastic markings, care should be exercised in their application to insure that changes in marking patterns are kept to a minimum. Road maintenance programs, future permit work and utility repair programs should also be considered to avoid installing thermoplastics on a roadway that will be resurfaced during the early life of these markings.

Figure 26. Close-up of Thermoplastic Removal by Special Grinding Tool



a) Application of Temporary Marking



b) Mechanical Removal of Temporary Marking

c) Manually Removed Marking

Figure 27. Removal of Cold-Applied Markings

SUMMARY OF USER EXPERIENCE

Under certain circumstances, there are several clear cut advantages of thermoplastic markings when compared to paint. Perhaps the most apparent advantage lies in the replacement factor. A single application of thermoplastic may replace 6 to 20 or more applications of paint. (This, of course, will depend on site characteristics and application policy and procedures.) It is this ratio of application frequency that renders the more expensive thermoplastic installations cost effective.

Various agencies have reported that thermoplastic markings typically outlast paint in a ratio of 3:1 to 15:1 depending on their paint replacement program previously followed, and the specifications for the thermoplastic installation. The "breakeven" point may range from 3 to 6 years. That is, in order to be cost effective, the thermoplastic markings must remain reflective and in place for a minimum of 3 to 6 years. By carefully selecting the materials and application technique for a given installation, a balance can be achieved between service life and the higher initial cost.

The general concensus among users reflects that while thermoplastic installations are frequently practical in terms of durability, day and night visibility, and appearance, it should not be assumed that such installations are appropriate for all situations. The following observations represents a summary of experience to date as reported by using agencies.

- Thermoplastic markings perform better on bituminous asphalt than on PCC.
- PCC pavement should be pretreated prior to applying thermoplastic. Sandblasting or light grinding and the application of the manufacturer's recommended primer-sealer will extend the service life on PCC.
- Thermoplastics should not be applied on new PCC facilities. A one-year curing period is recommended prior to installing thermoplastics.
- Freshly applied thermoplastic markings can receive traffic less than one minute after a hot spray application and from 2 to 10 minutes after hot extruded applications (depending on ambient temperature).
- For mechanical operations, hot spray thermoplastic can be laid as fast as 9 to 12 mph (15-20 km/h). Hot extruded applications are on the order of 3 mph (5 km/h).
- Both hot applied and cold laid thermoplastic markings perform exceedingly well as transverse markings (although the cold tape may become deformed somewhat with heavy turning movements).

- The cold-laid plastic is preferred by a number of agencies (particularly local agencies) because of the ease of application and lack of drying time. For temporary markings, the thin based-tape is easy to apply, easy to remove, and provides excellent reflectivity.

DEVELOPMENT OF PROMISING NEW MATERIALS

The Highway Act of 1973 stressed the need for durable delineation systems that would reduce traffic disruption and maintenance cost. Subsequently, the Federal Highway Administration in a continuing effort to develop improved and practical delineation materials, systems, and equipment, has funded several research programs to formulate and test more durable marking materials. The most promising materials include an instant setting epoxy thermoplastic material that would perform well under severe winter conditions; a two-component epoxy; and a polyester-based liquid. A description of these projects and the results to date are included here because of their potential importance to the state-of-the-art in delineation technology.

EPOXY THERMOPLASTIC

The epoxy thermoplastic (ETP) developed under this research program is a generic pavement marking material composed of epoxy resins, pigment, filler and glass beads. This material differs from most epoxies in that no hardener is used.

Two formulations have been extensively field tested. These formulations vary in the ratio of the two epoxy resins — one a liquid, the other a solid — used in the material. A 50:50 ratio of solid resin to liquid resin yields a flexible material designed for localities experiencing moderate to severe winter conditions. A 60:40 solid/liquid ratio designed for regions with hot, dry summer weather gives a harder material which is less susceptible to summer road film pickup.

Actual field testing showed that both formulations perform about equally well under severe winter conditions. Because of its enhanced resistance to dirt pickup, the 60:40 formulation was selected as the material of choice for further development and implementation. The specific formulation for white ETP is given in Table 3.

The specific formulation for white ETP is given in Table 3, (Ref. 38). The total weight shown in Table 3 represents a volume of 12.8 gallon (48.5 l). This will yield a weight per gallon of 13.1 pounds (1.57 kg per liter). The expected cost for ETP materials is estimated to be $10.00 per gallon ($3.79 per liter).

Application

ETP is applied by the hot spray process at a temperature of 425° to 450° F (217 to 232° C). A top dressing of drop-on beads is applied almost simulaneously with the spray gun operation. No-track hardening times of 5 seconds have been measured in the field under certain conditions. Application thickness ranging from 15 to 25 mils (0.4 to 0.6 mm) have provided adequate durability on both asphalt and Portland Cement concrete pavement. Primer is not required for this application.

ETP has also been successfully applied in below freezing weather. For an installation in Denver, the application temperature of the material was elevated to 485° F (251° C), and was applied with the surface temperature at 22° F (-5° C). Air temperature was 31° F (4° C). No problems were experienced in the application and after a year the site shows no discernible wear and excellent bead retention. If this performance is sustained, the range of climatic conditions under which pavement can be marked will be significantly expanded.

Potential for Large-Scale Usage

In addition to its extremely short no-track time and its excellent performance on all pavement types, ETP has several other distinct advantages. It is a 100 percent solids formulation and is virtually smokeless at application temperatures. Both of these properties are sound environmental considerations. Applications to date have been made with a small, self-propelled striping unit employing an airless, low pressure (50 psi) spray system which gives a crisply defined line with minimal overspray.

Table 3. White ETP Composition

Ciba-Geigy 7097 Araldite epoxy resin or equivalent	60 lbs.
Ciba-Geigy 6010 Araldite epoxy resin or equivalent	40 lbs.
Dupont R900 titanium dioxide or equivalent	20 lbs.
Georgia Marble Cal White Pigment Grade Calcium carbonate	20 lbs.
Cataphote Division (Ferro Corp.) Premixed Gradation reflective glass beads or equivalent	28 lbs.
TOTAL	168 lbs.

Source: Ref. 38

The cost figures of $6.50 to $7.50/gal ($1.71 to $1.98/l) for materials are realistic estimates. It is recognized that costs to manufacture the material in a form amenable to use in large scale equipment may raise the per gallon price. Also, retrofitting State stripers for use with this material would involve a capital investment which must be amortized over the life of the ETP stripe. However, the ETP materials costs are so low considering the durability of the material that a favorable cost ratio with conventional traffic paints can be attained since the higher costs for ETP can be balanced against the savings incurred from decreased striping requirements.

For example, at equal wear rates for a 15 mil (0.4 mm) thick, 4 inch (10 cm) wide line, ETP costs .75 to 1.25 times the cost of fast-drying traffic paint per lineal foot on a materials basis. Considering that under severe conditions a minimum of at least twice the service life may be expected from ETP over traffic paint, the manufacturing and retrofitting costs should not adversely influence the use of ETP on a large scale. When compared with the installed cost of conventional thermoplastic and two-part durable systems, the ETP costs may be more than an order of magnitude lower.

The development of the ETP material formulation is now complete. With the continuing successful performance of the field test installations, additional efforts are underway to implement the large scale use of ETP by States and other agencies. These efforts include the development of a model ETP composition specification and retrofit designs for existing striping equipment.

TWO-PART EPOXY MARKINGS

The Minnesota Department of Transportation, in conjunction with the H.B. Fuller Company, has been engaged in the development of a sprayable, two-component epoxy resin striping compound that would adhere to both bituminous asphalt and PCC pavements and would be abrasion resistant with long-term durability. In the early stages of development (1970-1973) the major concern was in formulating a product with an acceptable cure time, bonding characteristics, and color retention. Two formulations resulted from this development effort. These compounds have undergone extensive testing since 1975 under the FHWA Demonstration Program and have generally performed succcessfully. The properties and characteristics of these promising materials are summarized below. A specification for Epoxy Pavement Marking Material prepared by H.B. Fuller is included in Appendix C.

Application Factors

The two epoxy compounds are supplied in both white and yellow and are applied at 15 mils (.4mm) thickness. The major difference in these materials is in the cure time. The faster cure time material is intended for application as center line striping since it generally can be installed without coning depending on the amount of glass beads used. The slower curing, less expensive formula is intended for edge line marking. The actual curing time of either product varies according to the temperature of the road surface. The higher the temperature, the faster the curing. It can, however, be applied at temperatures as low as 35° F (2° C). Most significantly, it can be applied on wet surfaces and in the rain.

To obtain maximum adhesion, the epoxy should be applied to clean surfaces. Since this material is not affected by dampness, the surface may be cleaned by a hot water (150° F/66° C) spray (2000 PSI) gun located in advance of the epoxy spray unit on the application equipment. The water spray unit is followed by an air nozzle to remove free water. The epoxy striping cannot be placed over paint or other striping materials other than itself.

Durability

Tests conducted from 1973 to 1977 in several states have indicated that the two-part epoxy remains serviceable for up to two years on high volume roads which, in some cases, require repainting every three months. The epoxy is more durable because it forms a chemical bond which makes is resistant to wear from sand, salt, snowplows, and traffic.

Since 1977, these materials have been installed in 16 states on various types of roadways. The average service life that emerges from the experience in these installations should more clearly define the durability parameters.

Application Equipment

In the earlier installations, the two-part epoxy could only be applied with Fuller's striping truck. Development of methods of modifying standard equipment to accommodate the epoxy system is continuing and a number of state agencies and contractors are customizing equipment for this usage.

Cost Considerations

A cost comparison of epoxy, paint and thermoplastic is given in Table 4. Although more expensive by the gallon than paint, Fuller officials estimate that over time the cost of epoxy may ultimately cost only half as much as paint. These cost figures assume the use of agency forces using agency equipment.

Minnesota reports that a typical lane mile of skip stripe could be painted 5½ times for the cost of one application of epoxy (Ref. 39). If the epoxy is serviceable for two years on metro roadways that are normally painted three times a year, the higher cost would be justified. Moreover, the striping crew would be exposed to traffic once instead of 5 to 7 times. It would also provide a traffic delineation system throughout the winter season which is not possible with paint.

Future Potential for Use

It appears that the two-part epoxy marking system will become an effective alternative striping technique as soon as the application equipment is generally available. It seems particularly desirable in areas suffering from harsh winter seasons since it is so resistant to abrasion from the usual snow and ice control activities.

POLYESTER MARKING MATERIALS

The evaluation of polyester pavement marking materials was initiated in 1975 by the Ohio Department of Transportation in cooperation with the FHWA. The project was designed to evaluate color, durability, and reflectivity performance of this type of material for a three-year period.

Although two polyester materials were evaluated, the Glidden product "Romark" was superior to the other product which is no longer manufactured. Romark performed well for the three-year period (Ref. 39).

Table 4. Cost Comparison of Striping Materials

	PAINT	THERMO-PLASTIC	EPOXY (Fast Set)**
Material cost	$.012	$.0714	$.14
Labor and overhead	.017	.0446	.027
Traffic delay	.005	.005	——
Lane marking life	3 mos.	12 mos.	24 mos.
2 year cost	.272	.242	.1670
Cost/lineal foot per year	$.136	$.121	$.0885

*cost based on averages of 40 mil applications, 4" wide striping in the states of Minnesota, Wisconsin, and Indiana.
**cost per lineal foot per application based on a 4" wide, 15 mil stripe on PCC in Minnesota, excluding cost of glass beads.

Application Factors

Polyester striping material is applied at a thickness of 15 mils (.4 mm) with a bead application rate (drop on) of 20 lbs (9 kg) per gallon. The two-component polyester system (resin/catalyst) will dry to a no-track condition in less than 30 minutes provided the pavement is dry and the temperature is at least 60° F (13° C). Faster drying times are achieved at higher temperatures. Typical drying times are on the order of 8 to 12 minutes at 75° F (24° C). Because the film-forming mechanism is not an evaporation process, it can be applied at temperatures down to 0° F (-18° C) with proportionately longer drying times.

This product does not adequately bond to PCC and its indicated usage is for asphaltic pavements. It can, however, be applied over existing markings.

When polyester markings are applied to new asphalt surface, the polyester flakes off of surface aggregate particles due to the presence of free oils creating a line which appears full of holes when viewed close up. This "swiss cheese" effort does not effect visibility when viewed from a normal distance. This effect usually occurs within two months of application. After this initial loss, no further deterioration occurs.

A later installation evaluated the use of 7½ mils (.19 mm) thickness on six resurfacing projects in 1978. The markings are performing satisfactorily, but it is too early to assess long term performance.

Safety of work personnel is of prime concern when handling and applying polyester material. While the resin is not much more difficult to handle than paint, the catalyst (methyl ethyl Ketone peroxide) is a noxious chemical requiring careful handling. Gloves and safety goggles should be worn when handling and during the striping operation.

Durability

Field observation of this product indicated that the material is generally performing well and should continue to be serviceable for several years. At some areas of heavy traffic volumes, the polyester markings were worn out after one year of service. In these areas paint generally lasts only three months.

The project demonstrated that polyester markings are more opaque than paint applied under similar conditions and present a better looking line (daytime) than two coats of paint. Night visibility of polyester is also superior to paint due to the increased number of beads used.

Application Equipment

To properly install polyester striping, the application equipment should be in excellent condition. High-volume truck-mounted equipment is recommended. Conventional hot-paint stripers can be modified for approximately $4,500 to $6,000. A speed of 8 to 10 mph can generally be maintained in long line application. Although not adequately tested at this time, a polyester hand gun is being developed for use in the application of auxiliary markings.

Potential for Future Use

Based on its use to date, it is apparent that polyester markings perform better on asphalt pavements than conventional or fast-dry paints and some plastic materials. Although the per gallon cost is higher than paint, and lower than two-part epoxy, cost comparisons are not appropriate until the specific relationship between traffic factors and material performance is more clearly established (Ref. 40). A preliminary specification prepared by the manufacturer is provided in Appendix C.

Chapter 5. Raised Pavement Markings

The use of glass beads embedded in traffic paint was the first breakthrough in providing low-cost day and night visibility. Unfortunately, these reflectorized painted stripes disappear from view when the surface the roadway becomes wet. This loss of visibility occurs when it is most needed — during adverse weather conditions, particularly rainy or foggy nights.

During the past several decades, a significant emphasis has been placed on continuing research to develop a durable marking device that could provide both day and night visibility under adverse conditions. Raised pavement markers (RPM's), reflectorized and non-reflectorized, have emerged from this research as a highly effective alternative. As can be seen in Figure 28, RPM's provide superior night visibility. This chapter addresses the uses, types, characteristics of RPM's in use today and those planned for the future.

USES

Essentially, raised pavement markers can be used in place of, or as a supplement to painted pavement stripes. RPM's are treated in the MUTCD in "Part III Markings" and are defined under marking materials (3A-3) as a suitable variation to paint (Ref. 1). Specifically, the MUTCD states:

> *"Individual unit markers, generally less than 1" height, may be used for pavement marking purposes. They may be placed in continuous contact or separately by spaces, a variation in pattern being used to simulate solid and broken lines, with apparent widths as specified in sections 3A-6 and 3A-8. Raised markers of over 1" in height are sometimes used to form curbs and islands and are discussed in Part V."*

In effect, the same general principles governing the use of painted markings apply to RPM's in terms of color, configuration, and application. The MUTCD does not specifically address location and patterns for application but suggests a 1:3 ratio for broken line spacing. Figures 29, 30, and 31 illustrate the patterns commonly used for center lines, lane lines, and solid lines (edgelines and no passing zones). Applying the 1:3 ratio, these figures assume a 40-foot cycle length with a stripe of 10 feet.

Functional Applications

There are several different types of RPM's. The characteristics of the particular categories of RPM's are directly related to their functional applications. Non-reflectorized markers are used in some installations to completely replace painted longitudinal markings (center lines, lane lines). Reflectorized markers are interspersed to provide night visibility where there is no overhead lighting. The higher initial cost of a complete raised marker system is justified on the basis of the long service life and increased wet weather visibility. More frequently, however, agencies tend to use reflectorized raised markers in conjunction with painted stripes for longitudinal delineation. Because RPM's provide increased visibility at night, especially during rainy conditions, reflectorized RPM's are particularly desirable at high hazard locations such as exit ramps, bridge approaches, lane transitions, horizontal curves, and construction zones.

There are three basic colors of markers in use: white, yellow, and red. The white and yellow markers are used alone or in combination with painted lines to convey the same meanings the lines have. Red reflective markers are used to convey the message "wrong way." Blue markers have been used to denote the location of a nearby fire hydrant.

Considerations for Application

Raised pavement markers have certain advantages over the painted markings:

- Reflectorized RPM's provide increased reflectivity under wet-weather conditions.
- Both reflectorized and non-reflectorized RPM's have durability and life much greater than painted lines; therefore, replacement is much less frequent than for paint lines and hazardous repainting operations under heavy traffic conditions can often be avoided.
- The vehicle vibration and audible tone produced by vehicles crossing the markers creates a secondary warning.
- The capability of providing directional control of reflected color permits their use in conveying a "WRONG-WAY" message.
- Non-reflectorized RPM's can be used as transverse "rumble stripes."

A principle disadvantage is the high initial cost. In order to recover the high initial investment and realize the full benefit of the durable long-life materials in raised markers, their application tends to be limited to important roadways, hazardous locations, and roadways having a surface that will not soon be subject to major repair, replacement, or excavation activity.

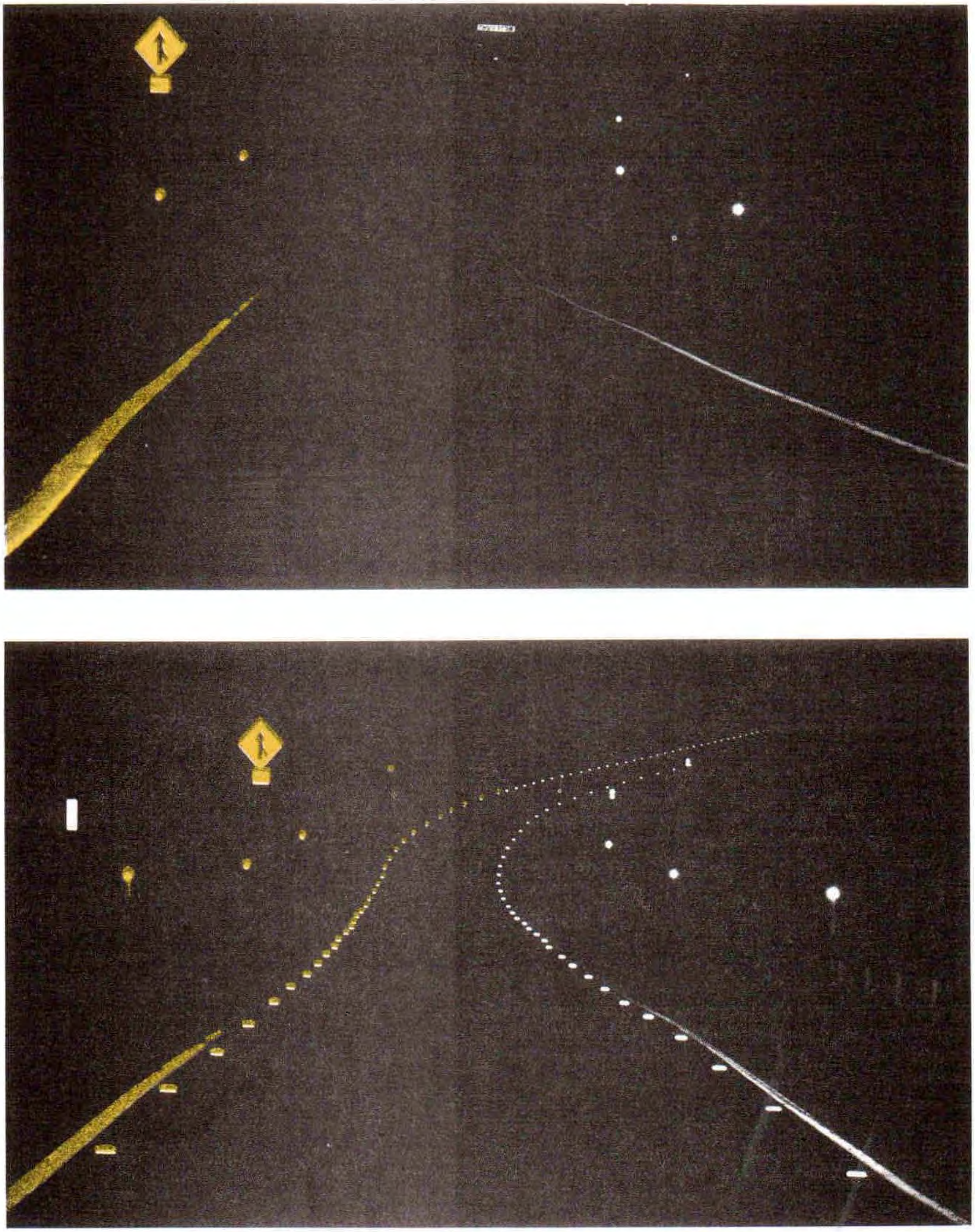
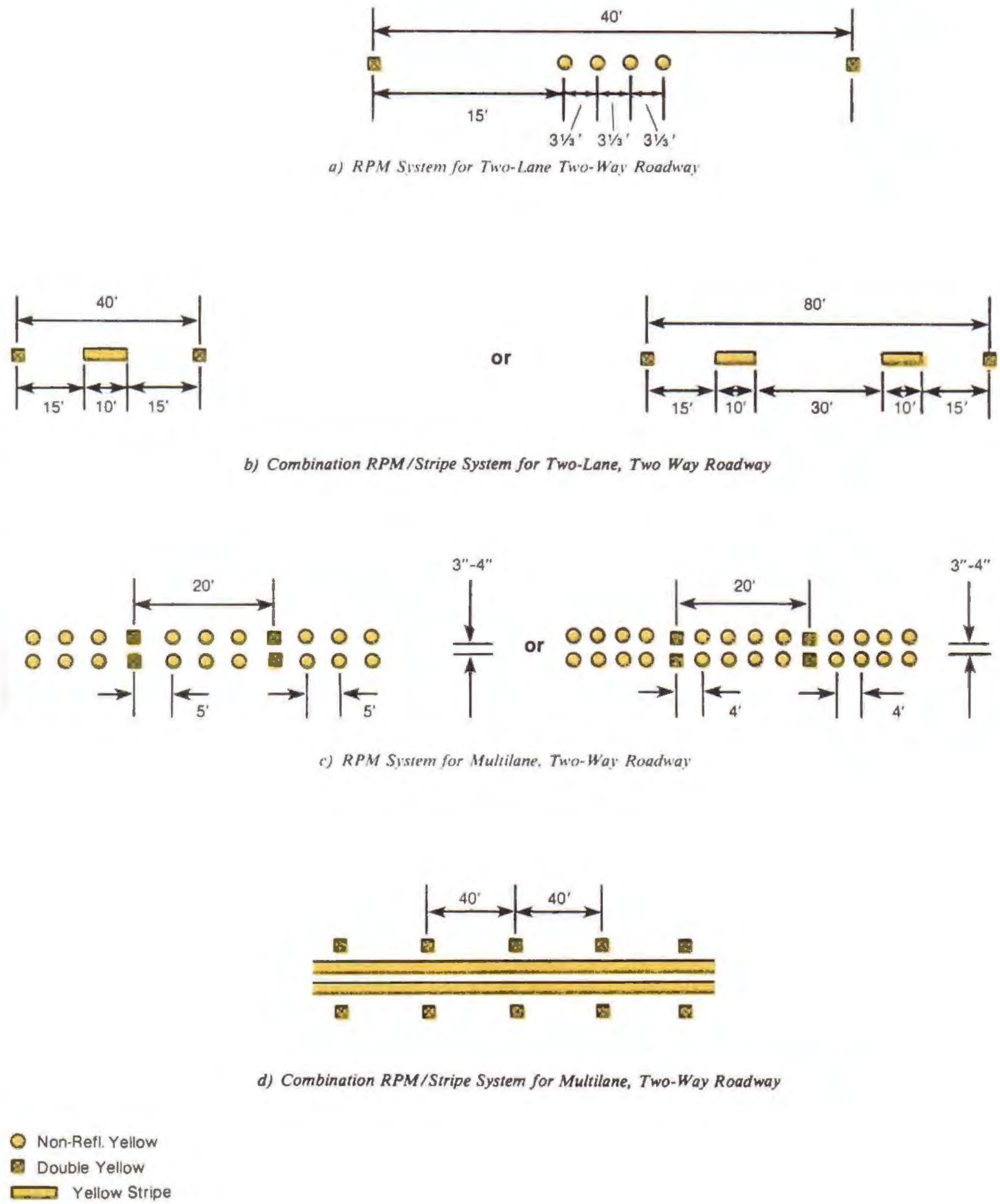


Figure 28. Night View of Roadway Without (Above) and With Reflectorized RPM's (Below)



a) RPM System for Two-Lane Two-Way Roadway

b) Combination RPM/Stripe System for Two-Lane, Two Way Roadway

c) RPM System for Multilane, Two-Way Roadway

d) Combination RPM/Stripe System for Multilane, Two-Way Roadway

Figure 29. Centerline Patterns

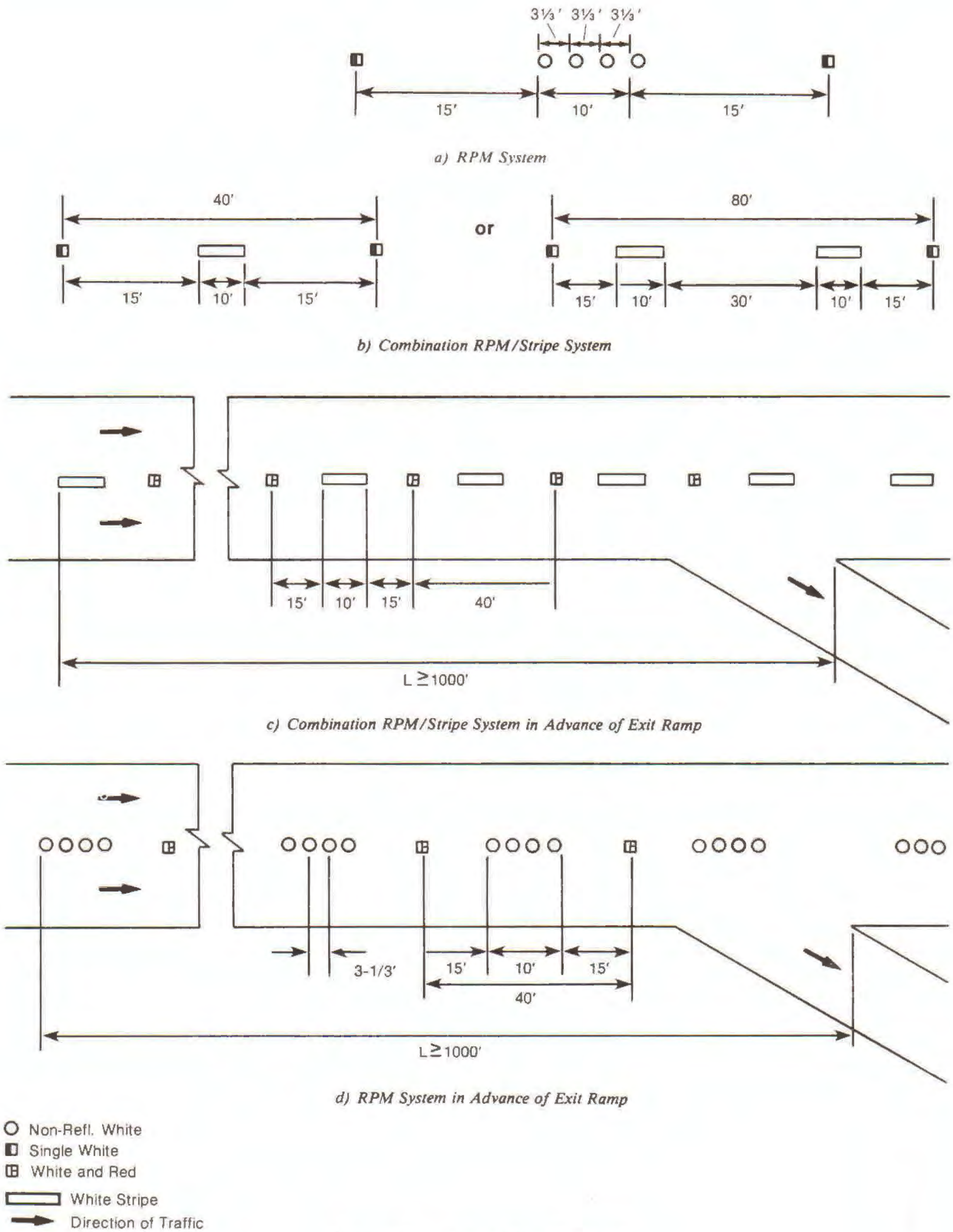
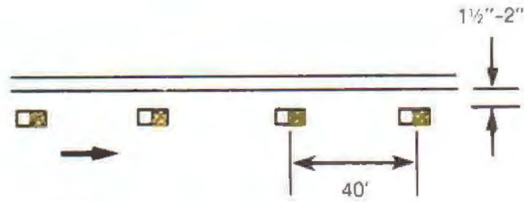
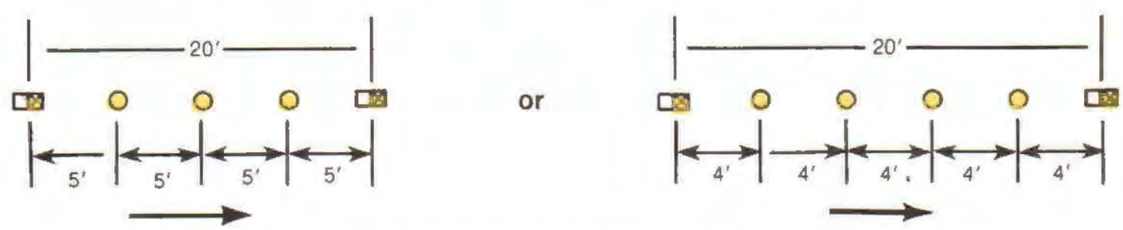


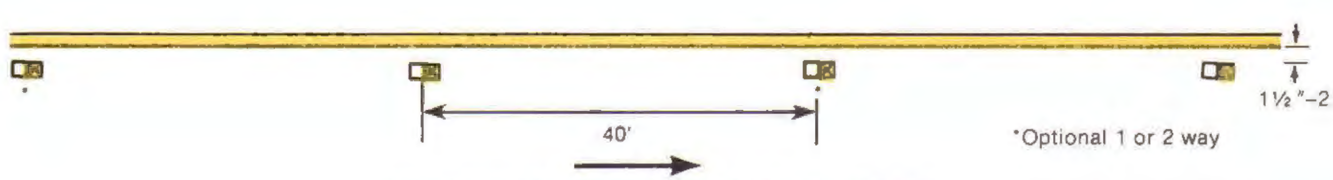
Figure 30. Lane Line Patterns



a) Combination RPM/Stripe for Left Edge Line (RPMs not recommended for right edge line)



b) RPM System for No Passing Barrier



c) Combination RPM/Stripe System for No Passing Barrier

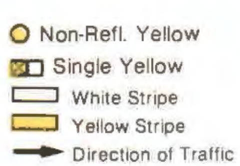


Figure 31. Marking Patterns for Solid Lines

Another area of primary concern is the susceptibility of conventional RPM's to snowplow acitivity. All pavement markings will be obliterated by heavy snowfall. The raised marker has the added disadvantage of being damaged or removed by the snowplow blade. A "snowplowable" marker has been developed that has demonstrated relative effectiveness in resisting snowplow damage. The types, capabilities, and features of RPM's currently in use are described below under "Materials."

MATERIALS

A number of concepts have been applied to developing a low cost, durable pavement marker. A primary goal has been to produce a raised marker that will: 1) provide both day and night visibility at least equal to that of a reflectorized painted stripe, 2) be highly visible under wet night conditions, and 3) not be damaged by snowplow activity or cause damage to the snowplow blade.

Pavement markers commercially available today are quite varied and provide a wide range of capabilities. No one type of marker satisfies all of the capabilities mentioned above. The size, shape, reflective properties, and materials used are selected to fulfill the widest range of delineation requirements at the lowest cost. While there is a tradeoff between high visibility at higher cost and lower visibility at lower cost, this is not a linear relationship and pavement markers should be selected on the basis of site requirements.

In addition to the several types of off-the-shelf markers in general use, there are a number of experimental configurations still in the developmental stages, and some which have been investigated and abandoned. The following discussion highlights the commonly used markers; special-use markers and those in the planning stage are noted for reference purposes.

Physical Characteristics of RPM's

The forerunner of the raised pavement markers was a convex button with glass beads suspended in a flexible polyester resin binder. Referred to as "Botts Dots" after the name of the developer, these markers were introduced in California in 1954 (Ref. 41). These reflectorized markers were cemented to the roadway surface with epoxy adhesive, one each in the center of the 15-foot (4.5 m) gap in the broken painted stripe. In theory, these elevated markers "shed the water" and were not readily submerged. They were used as auxilliary devices to provide delineation during periods of darkness and wet weather. The service life of these markers was estimated to be 20 years on Portland Cement Concrete.

A number of variations to this round-headed button have been developed, but the original convex configuration has been maintained. For example, a non-reflectorized ceramic button is used for day visibility as a low-cost alternative to painted lines. In this case, they should be used in combination with reflective markers to provide both day and night visibility. Another variation of the convex configuration in general use is the ceramic button with a glass or plastic reflective insert utilizing glass beads. Typical examples of these button-type markers are shown in Figure 32.

The rectagular wedge shape marker was developed shortly after the Botts Dots around 1955 to improve durability on asphalt pavement. These early wedges utilized the same concept, that is, polyester resin base with glass beads as the reflective element. The wedge shed water and extended above the water film usually encountered during wet weather. This configuration also allowed one- and two-way delineation.

Subsequent advances in precision molding technology made possible the application of a trihedral angled mirror reflection (corner cube) principle to the wedge-shaped marker. In this system, three mirrored surfaces are arranged at a proper angle to receive the rays of headlights on one of the three mirrors. From there the ray is reflected to a second mirrored surface, then to the third, and finally outward on a line parallel to the entering direction. These tiny tri-mirrored surfaces are arranged as shown in Figure 33 to provide the reflective unit for raised pavement markers. Approximately 360 reflective corner cubes are contained in the face of marker measuring 3⅝ x 1 inch (9.14 x 2.54 cm).

The prismatic, corner cube reflective markers are available in a combination of colors: silver (white), amber (yellow), and red. They come in one-way or two-way configurations combining any of the three standard colors. Generally, these reflective markers consist of an acrylic corner cube reflective unit cased in a plastic shell. In one version, the reflective surface covers the entire slanted face of the wedge. In another version, the face is divided into two reflective surfaces bounded by the base material. Examples of these two configurations are shown in Figure 32.

The basic difference between these two versions involves daytime visibility. The full face reflective element, usually encased in a silver gray housing, produces brilliant delineation on both clear and rainy night conditions, but is almost invisible in daylight. The dual element reflectors cover a smaller area of the face and are encased in white or yellow plastic thereby being somewhat visible in daylight. Specifications for the round and wedge-shaped markers are given in Figure 34.

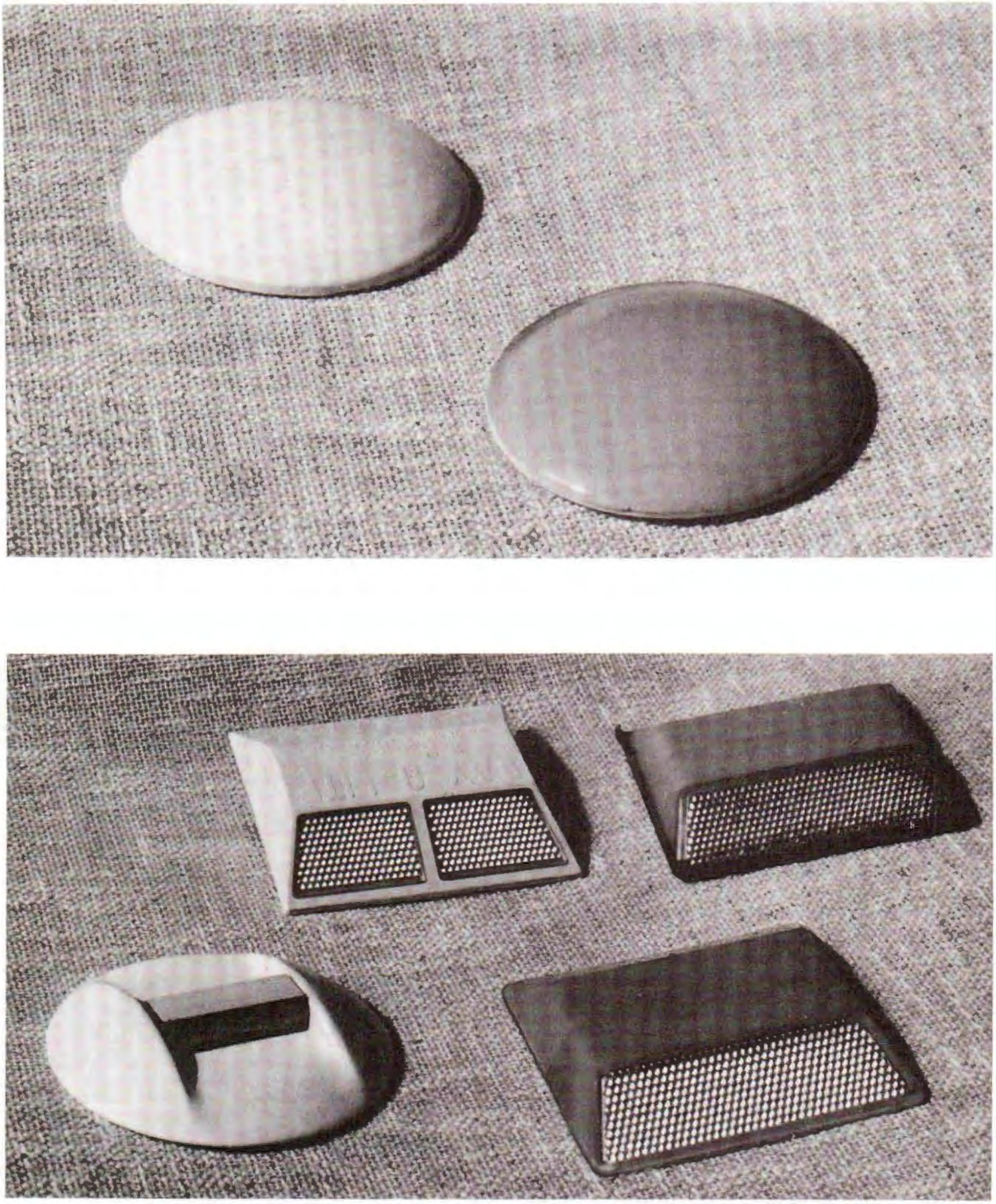


Figure 32. Non-Reflective Ceramic and Reflective Raised Pavement Markers

The use of these conventional RPM's has increased dramatically in areas experiencing minimal snowfall. Damage from snowplow blades has been the major deterrent to their installation in snow areas. The loss and damage factor associated with snowplow activity is prohibitive and has led to the development of a "snowplowable" marker. This marker consists of a two-way replacable reflector assembly protected by a specially hardened metal casting (Figure 35). The casting is firmly anchored by an epoxy adhesive into double grooves cut vertically in the pavement by radial saw blades. Installation details and specifications are given in Figure 36.

The snowplow blade rides up and over the shallow tapered planes usually without damage to the reflector unit, casing, or snowplow blade. Because of the low profile of the casting (6° slope with 7/16 inch (1 cm) maximum height) the rise and fall of plow blade is hardly discernible to the plow operator when the plow is moving slowly. A recent version of one commercial model permits plowing from both directions. This version usually has two reflective faces and are available in the standard colors.

The cast iron housing of the snowplowable marker measures 9¼ x 5⅞ x 1¾ inch (23.5 x 14.9 x 4.4 cm). The maximum projection above the roadway is 7/16 inch (1 cm). The acrylic prismatic reflector element provides 1.62 square inch (10.45 cm^2) of reflective surface for each face.

Adhesion Characteristics

The service life of any roadway delineation materials is a direct function of the bond or adhesion between the delineation materials and the roadway surface. Ideally, the bond strength between the two should be equal to, or greater than, the strength of the pavement itself. The physical strengths of the epoxy resins used today far surpass the physical internal strength of either Portland cement concrete or asphalt pavements. Since road films, laitance in concrete, and other conditions encountered in the field often interfere with the direct access of the epoxy resin bonding material to the main structure of the pavement surface, it is often necessary to undertake some form of surface preparation to achieve a proper bond.

Good adhesion is particularly critical in the use of RPM's as roadway delineation devices. The major factors that impact on good adhesion between the marker and the pavement surface are the properties of the bonding agent, the design of the marker's bonding surface, the type of pavement, temperature, and the care exercised in application.

In general practice, pavement marker epoxy adhesives are proportioned, mixed, and extruded by automatic

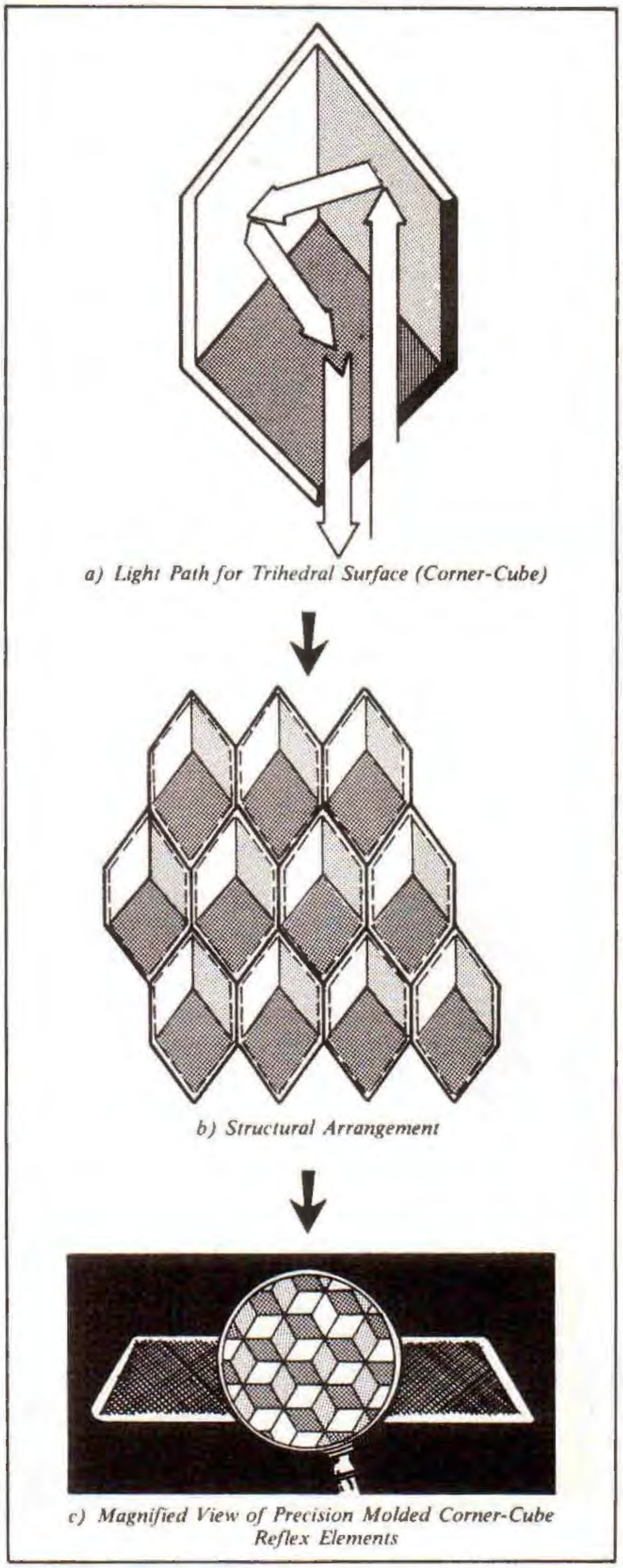


Figure 33. Principle and Structure of Corner-Cube Reflectors

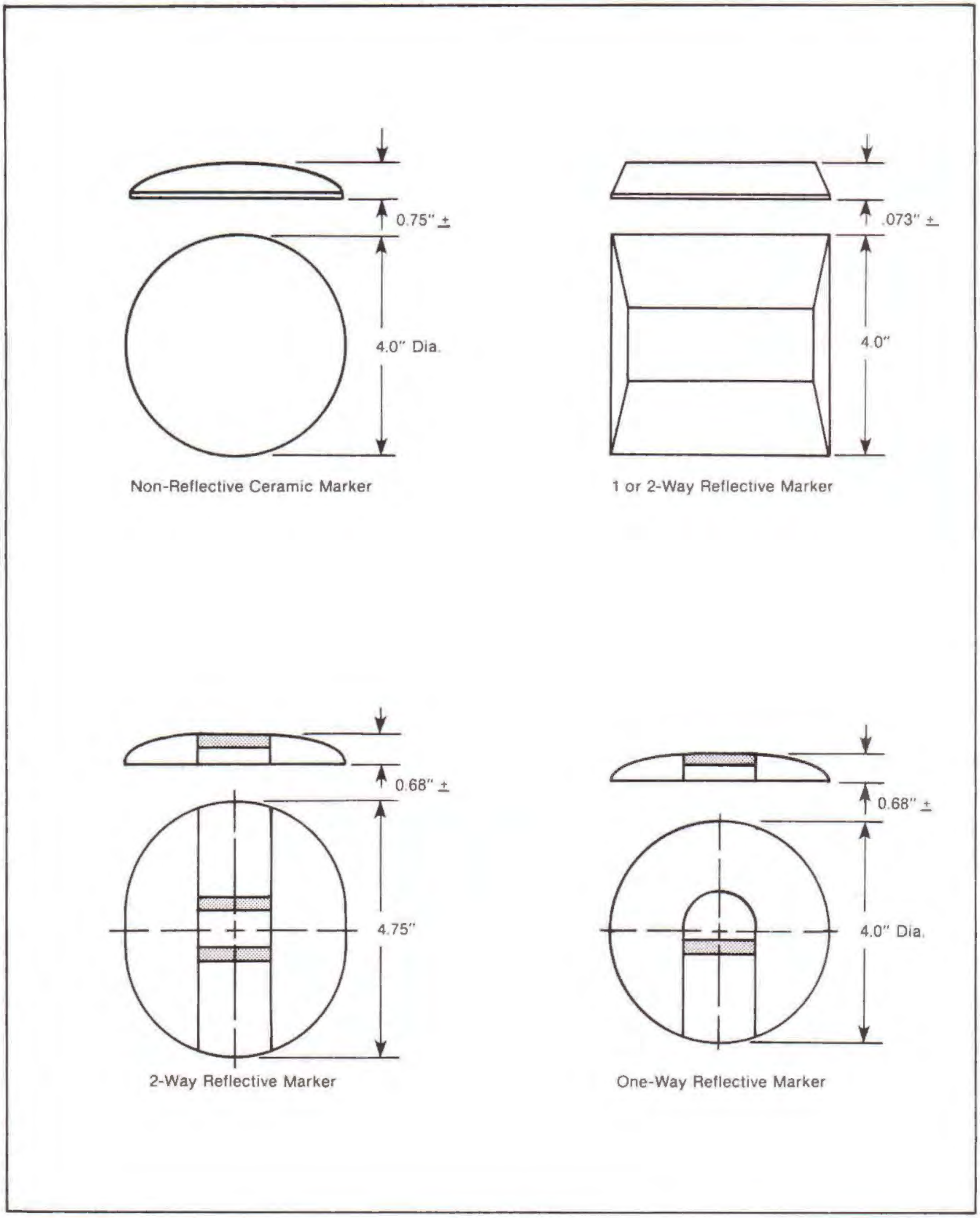


Figure 34. Typical Raised Marker Configurations

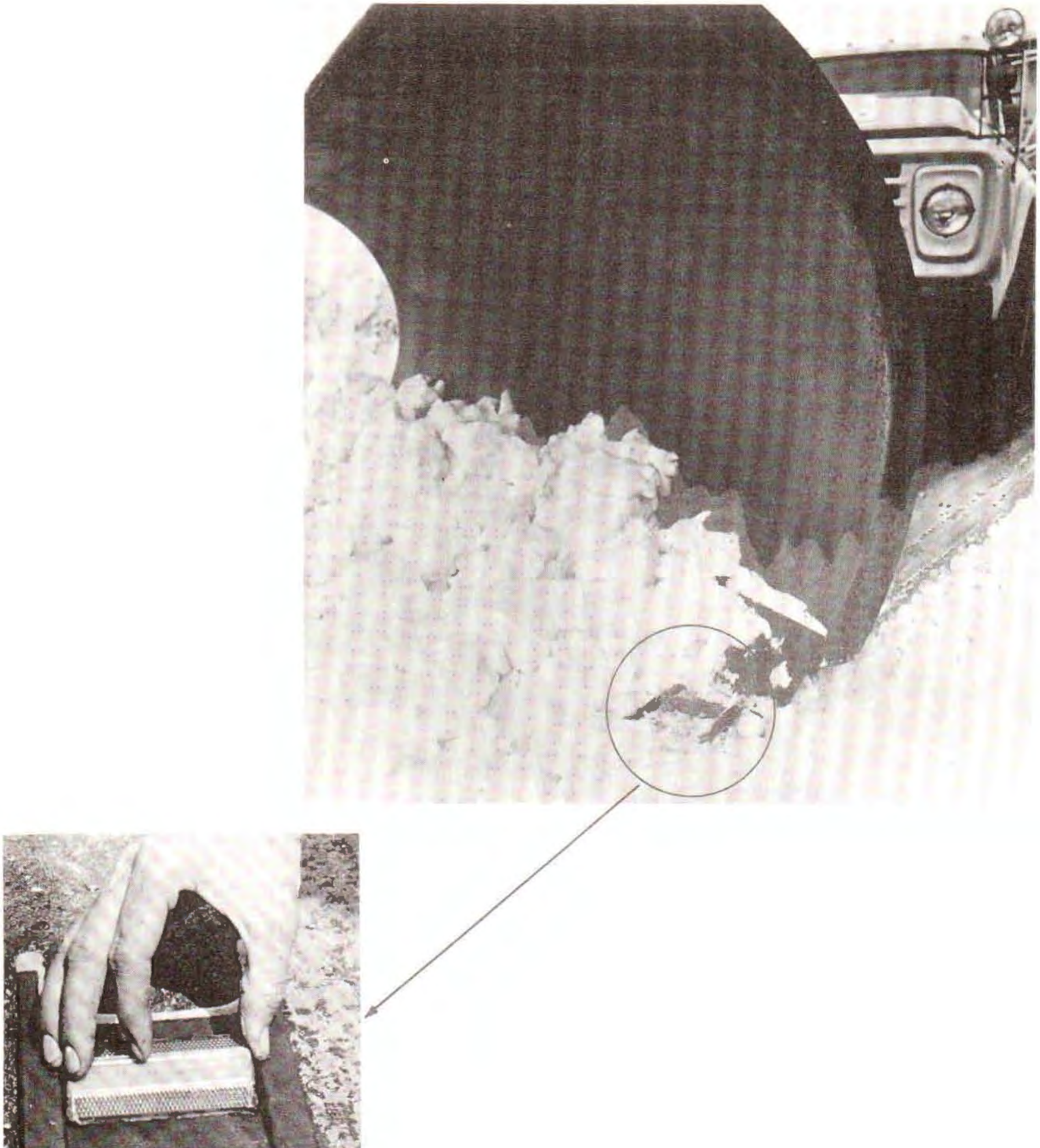
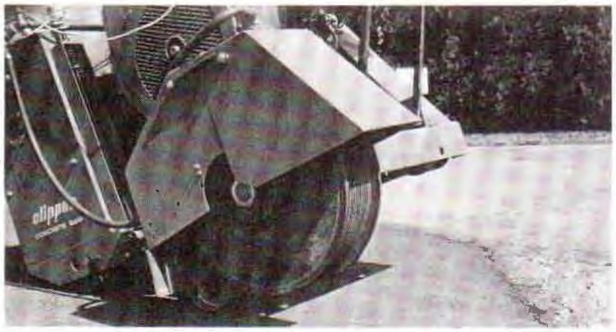
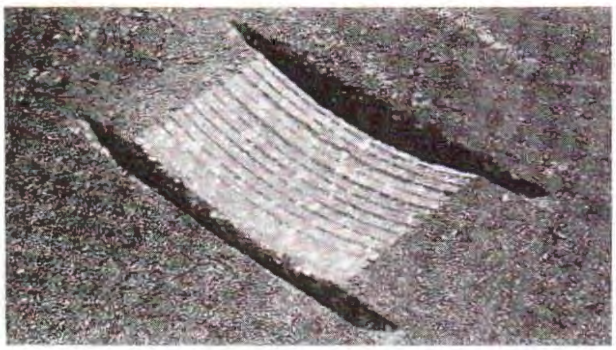


Figure 35. Snowplowable Reflective Marker

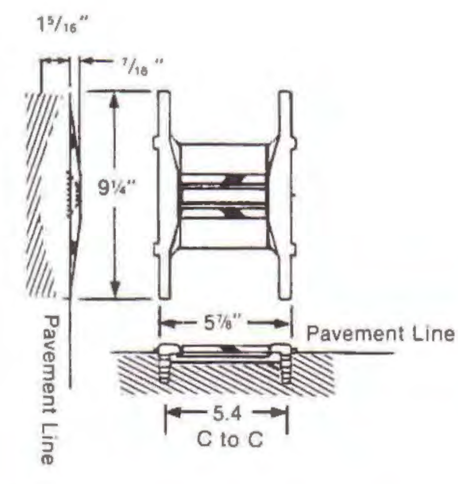




a) The pavement is cut to accept the marker

b) The sawed area is partially filled with an epoxy adhesive

c) The Reflectorized Marker is placed into the pavement



Material	Cast Iron Housing with Acrylic Prismatic
Size	9¼" long, 5⅞" wide, 1¾" high - ⁷⁄₁₆" maximum projection above roadway.
Weight	Approx. 4.8 lbs.
Reflective Area Specific Intensity (@ 1/5° observation angle)	White At 0° Entrance Angle - 3.0 At 20° Entrance Angle - 1.2 Yellow 60% of the value for white Red 25% of the value for white
Colors	White, Yellow, Red

Source: Based on Ref. 20

Figure 36. Application Detail of Snowplowable Reflectorized Marker

mixing equipment. Flow properties of the adhesive (i.e. viscosity) at various temperatures are important not only for proportioning, mixing, and extruding but also to prevent excessive flow of the extruded adhesive from under the marker when placed in position.

There are numerous formulations for epoxy bonding agents used to affix RPM's to the pavement surface. These formulations generally fall into two classifications: *Standard set* which may take up to several hours to cure and *rapid set* which may be ready to receive traffic in 10 to 15 minutes (Ref. 36). Manufacturers of RPM devices recommend and supply epoxies compatible to their individual product. Some states, however, have formulated and contract manufacture their own epoxy adhesive.

There are some forms of RPM's that are pressure sensitive and do not require a special epoxy adhesive. They do require that a primer be applied to the pavement surface and allowed to dry before placing the marker. The marker is then immediately ready for traffic. This type of RPM is generally used in small municipalities and for work zones and detours and other such applications.

The adhesion characteristics of RPM devices differ as a function of the base material. That is, ceramic materials do not bond as well as the acrylic shell. For this reason, California specifies that their ceramic markers have a textured surface to increase the bond with the pavement. The configuration selected after a comprehensive investigation of alternatives is shown in Figure 37 and described below:

"The bottoms of the ceramic markers shall be free from gloss or glaze and shall have a number of integrally formed protrusions approximately 0.050 inch (1.27 mm) projecting from the surface in a uniform pattern of parallel rows.

Each protrusion shall have a flat surface parallel to the bottom of the marker. The area of each parallel face shall be between 0.101 and 0.065 square inches (65.2 and 41.9 mm²) and the combined areas of these faces shall be between 2.2 and 4 square inches (1419 and 2581 mm²).

The protrusions shall be circular in section.

The number of protrusions should be not less than 50 nor more than 200.

To facilitate forming and mold release, the sides of each protrusion may be tapered. This taper shall not exceed 15 degrees from perpendicular to the marker bottom. Markers manufactured with protrusions whose diameter is less than 0.15 inch (0.38 cm) may have an additional taper not exceeding 30 degrees from perpendicular to the marker bottom and extending no more than one-half the total height of the protrusion.

The overall height of the marker shall be between 0.68 and 0.80 inches (1.72 and 2.03 cm) (Ref. 36).

There is some considerable difference in some physical characteristics of asphalt materials made from various crude stocks which still meet specifications for paving asphalt. Some of these properties can be expected to affect the ability of a fresh asphaltic mix to retain raised markers. Aging seemed to eliminate these differences. Consequently, some agencies adopt a waiting period before placing markers. Similarly, from field reports and discussion with laboratory staffs familiar with the effect of rejuvenating agents, it is clear that such agents soften asphalt so that good marker retention cannot be expected. The softened asphalt will, however, harden again with time. It is, therefore, recommended that no installation of raised pavement markers be made for one year after the application of a rejuvenating agent.

RPM's for Temporary Delineation

The problem of safely carrying traffic through construction and maintenance zones, especially on high-speed, high-volume roadways, requires that the contractor maintain normal traffic flow and provide positive guidance so that potential accident situations are kept to a minimum. To maintain safe traffic flow, the contractor has several alternatives depending on a number of factors such as: normal traffic, peak traffic, percentage of trucks, speed, geometry, seasonality, urgency or reconstruction, etc.

A system of raised markers is one alternative that will provide effective day and night delineation. They are easy to install and remove and, after removal, do not leave a misleading indication to confuse drivers. Despite the apparent safety benefits, the relatively high cost of these devices have retarded their use. Accordingly, FHWA conducted a comprehensive study of the use of these markers for construction zone delineation. Specifically, the objective was to evaluate the costs, spacing, ease of application and removal, and the ability of the markers to guide traffic and produce public acceptance (Ref. 42).

The major findings and recommendations based on the experience of nine states that the markers are effective and provide positive daylight and nighttime guidance through both wet and dry periods. The additional safety, improved operations, reduced vandalism, and unanimous favor of the public, government and construction personnel justify their expanded use. On an economic basis, the cost of markers and paint was equal to or less than the cost of paint striping and removal. Most significantly, the study found that the use of reflective raised pavement markers on construction detours tends to reduce the number of accidents.

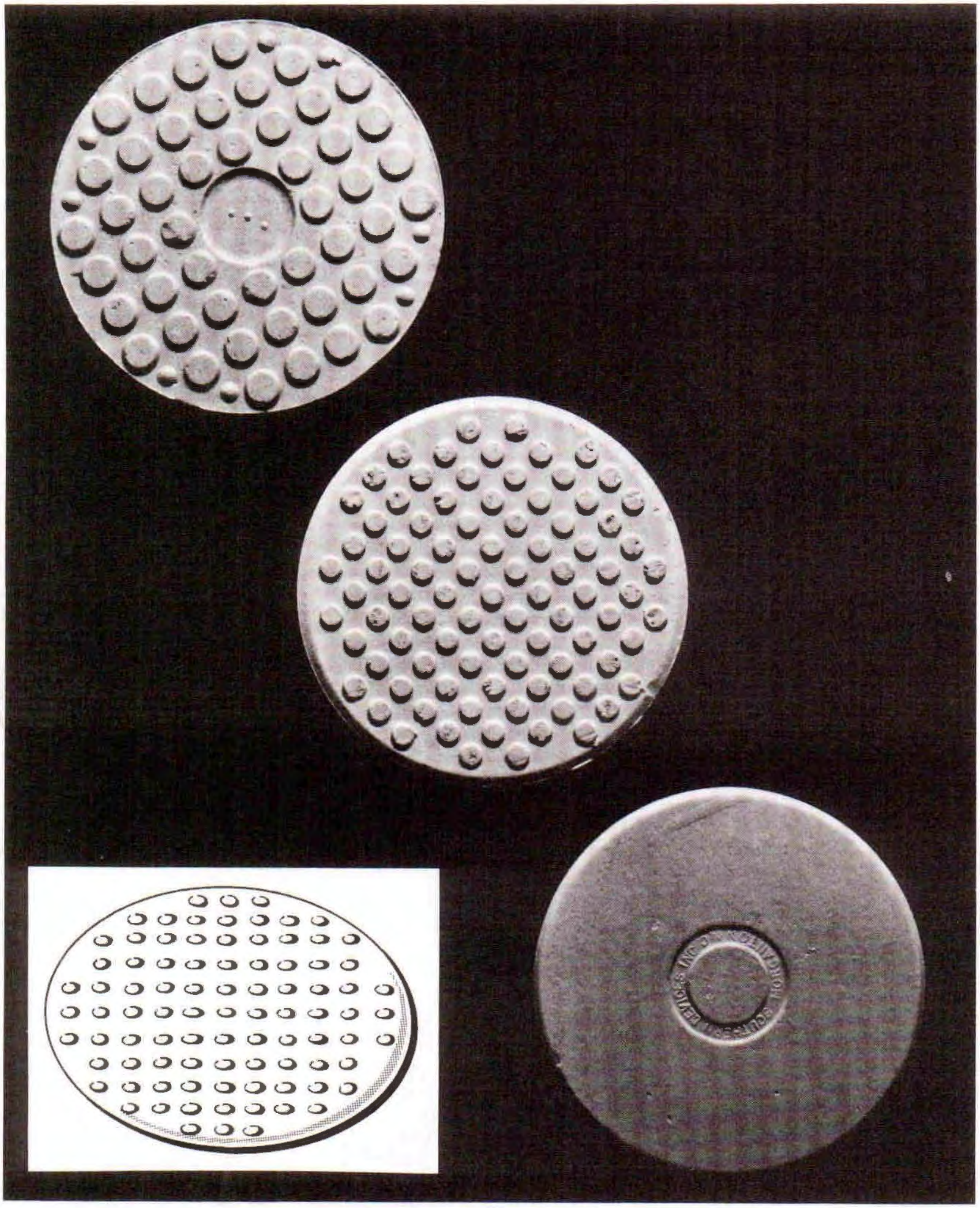


Figure 37. Bonding Surface (Bottom) of Ceramic Marker

Application of Self-Adhesive Markings

The "self-adhesive" marker (Figure 38) with a pressure-sensitive butyl backing provides a satisfactory bond with pavement. These reflective devices are well suited to detour-type applications. They are easy to install and maintain since no epoxy formulation or special application equipment is necessary. These markers are far less labor intensive in terms of actual installation time as well as time required for traffic control since they are virtually ready for traffic as soon as they are installed.

The "self-adhesive" markers proved to be surprisingly durable under normal traffic conditions. There is no significant difference in the loss rate between markers placed with epoxy and those placed with butyl pads in this type of usage. It should be noted, however, that the butyl padded ceramic marker does not perform as well as the acrylic shell marker. It is also noted that lower temperatures (below 50°F (9.4°C)) seem to reduce the bonding capability of the butyl pads. The basic installation procedure is to mark and sweep the location of the marker. Using a marker-size cardboard template, an adhesive primer is applied with a paint brush to each premarked location. The paper backing is removed from the marker and the marker is placed on the cured primer. A following car then sets the marker by slowly driving over it. A force of 1500 lbs. for 6 seconds is required.

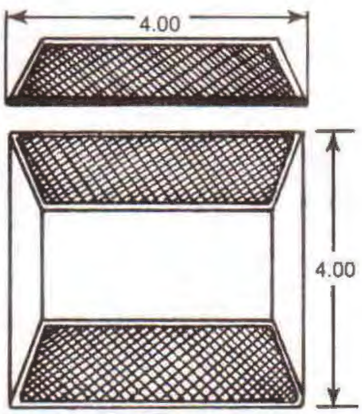
PERFORMANCE

As with other forms of delineation, the performance of raised pavement markers is usually expressed in terms of durability and visibility. The various types of markers provide different forms of visibility. For example, non-reflective ceramic markers are used to provide daytime visibility and to supplement reflective markers in providing nighttime visibility. The corner-cube reflective marker provides excellent night visibility (especially in adverse weather conditions) but is virtually ineffective in daylight. These conventional markers, when combined for day and night visibility, perform exceptionally well in localities which receive little or no snow.

As described earlier, these conventional RPM's are vulnerable to snowplow use. A snowplowable reflective RPM has been developed which consists of a retroreflective unit (replaceable) housed in a steel casting which guides the snowplow blade up and over the plastic reflective unit. Because of the generic and functional differences, performance experience for conventional and snowplowable markers is discussed separately.

Conventional Markers

The experience of using agencies will vary widely depending on the roadway characteristics and



Material	Acrylic plastic reflector filled with a tightly adherent potting compound
Size	4" x 4" x .65"
Weight	
Reflective Area	3.25 sq. in. per reflective face
Specific Intensity (@ 1/5° observation angle)	3.0 at 0° horizontal entrance angle 1.2 at 20° horizontal entrance angle
Colors	Crystal, Yellow, Red

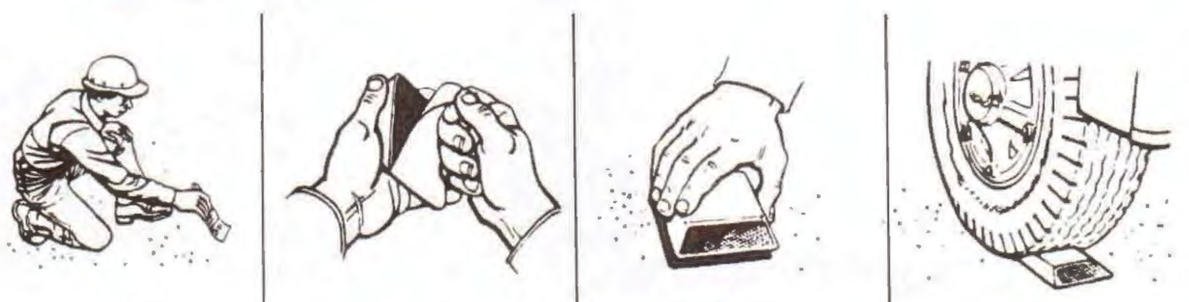


Figure 38. Application of Pressure Sensitive Reflective Raised Marker

conditions. Findings and observations compiled from experience of using agencies are included below for non-reflectorized ceramic markers and conventional reflective raised markers.

Ceramic Markers

- White and yellow ceramic markers may be expected to last in excess of 10 years. Although they may become severely pitted, they will still be visible.
- The ceramic marker system gives good daytime visibility when clean, and when wet it supplements the corner cube reflective marker in producing good nighttime delineation. Alone, the white ceramic marker provides night delineation only in dry weather.
- In hot dry months, considerable road film can accumulate on the ceramic markers and the visual delineation is less than desired in the daytime and almost non-existent at night. This condition is usually reversed after periods of wet weather.
- Poor bonding accounts for most marker losses. The use of a textured bottom creates a better adhesion with the pavement surface.

Reflective Raised Markers

- Within a few months, the reflectance of the corner cube reflective marker is reduced to as much as 1/20 to 1/50 of its original value due to surface abrasion. This reflectance however is adequate and remains relatively constant.
- During dry periods when the reflective lens is covered with tire stain, or when the marker is seriously damaged, reflectance is seriously degraded. During wet weather when the lens is covered with water film, visibility is excellent, often approaching 1/4 to 1/3 the reflective value of the systems when new. Thus, the system is at its best when it is needed most.
- Expected service life for reflective markers varies from 1 1/2 years under severe conditions to up to 8 years on most freeway locations to 10 years on rural low density roads.

The highly reflective (corner cube) lens even when partially obscured or damaged will still provide some level of reflectivity unless the lens face has been completely destroyed such as that shown in Figure 39. The marker depicted in the top photograph (a) although damaged, will still retroreflect light striking the undamaged portion of the lens. The marker shown in the bottom photo is entirely ineffective since very little of the reflective surface remains.

With reference to reflectance, when markers reach a specific intensity of about 0.05, dry night visibility is not as good as a conventional paint stripe. Typical minimum requirements for the traditional colors at incident angles of 0° and 20° are (Ref. 42):

Color	Incident Angle 0°	Incident Angle 20°
Silver-white	2.7	0.9
Amber-yellow	1.8	0.6
Red	0.5	0.22

Results of laboratory test conducted by the State of Kentucky to determine the reflectivity of commercially available markers are given in Table 4.

Snowplowable Markers

A practical, durable RPM compatible with snowplow activity has been under development since 1967. A number of prototype models have been fabricated and tested in the last 10 years. The latest production model can be plowed in either direction and features a replaceable reflective lens (See Figure 35). Extensive testing has been involved in the development process, but performance data from long term, large scale installations is not yet available for the current configuration.

An evaluation study of a previous model was conducted in the State of New Jersey where annual snowfall ranges from 15 to 20 inches (38 to 63 cm). This marker provided excellent wet-night delineation and a good maintenance record when steel plow blades were used. Under severe conditions, particularly where tungsten carbide inserts were used on the plow blades, the results were mixed. Under these conditions, both markers and plow inserts were damaged more often, though it may be questioned whether the plow insert damage actually affects plowing efficiency or is merely cosmetic. In any case, data are still being gathered from installations in high snowfall areas.

The study suggested that the expected life of the steel-hardened casing could be conservatively estimated at 10 years and the life of the replaceable reflective lens insert at 3 to 4 years (Ref. 43).

INSTALLATION PROCEDURES

Although the installation of RPM's is not a difficult procedure requiring neither special complex equipment or specialized staff capability, new installations are commonly part of a construction or improvement contract. Maintenance (replacement), on the other hand, is usually performed by state or local forces.

Typical specifications for contract application of markers are provided in Appendix D.

General practice and individual procedures related to the various types of markers are discussed below.

General Practice

On two-way roads, raised markers should be installed within traffic control conditions like any other operation on the traveled way. Traffic should not be split on both sides of the operation.

Most agencies indicate that the portion of the highway surface to which the marker is to be bonded by adhesive should be free of dirt, curing compound, grease, oil, moisture, loose or unsound layers, paint and any other material which would adversely affect the bond of the adhesive. Cleaning the surface of PCC and old asphalt concrete pavement should be undertaken prior to application of the device. Clean, newly placed asphalt concrete need not be blast cleaned unless the surface contains an abnormal amount of asphalt or the surface is contaminated with dirt, grease, paint, oil, or any other material which would adversely affect the bond of the adhesive.

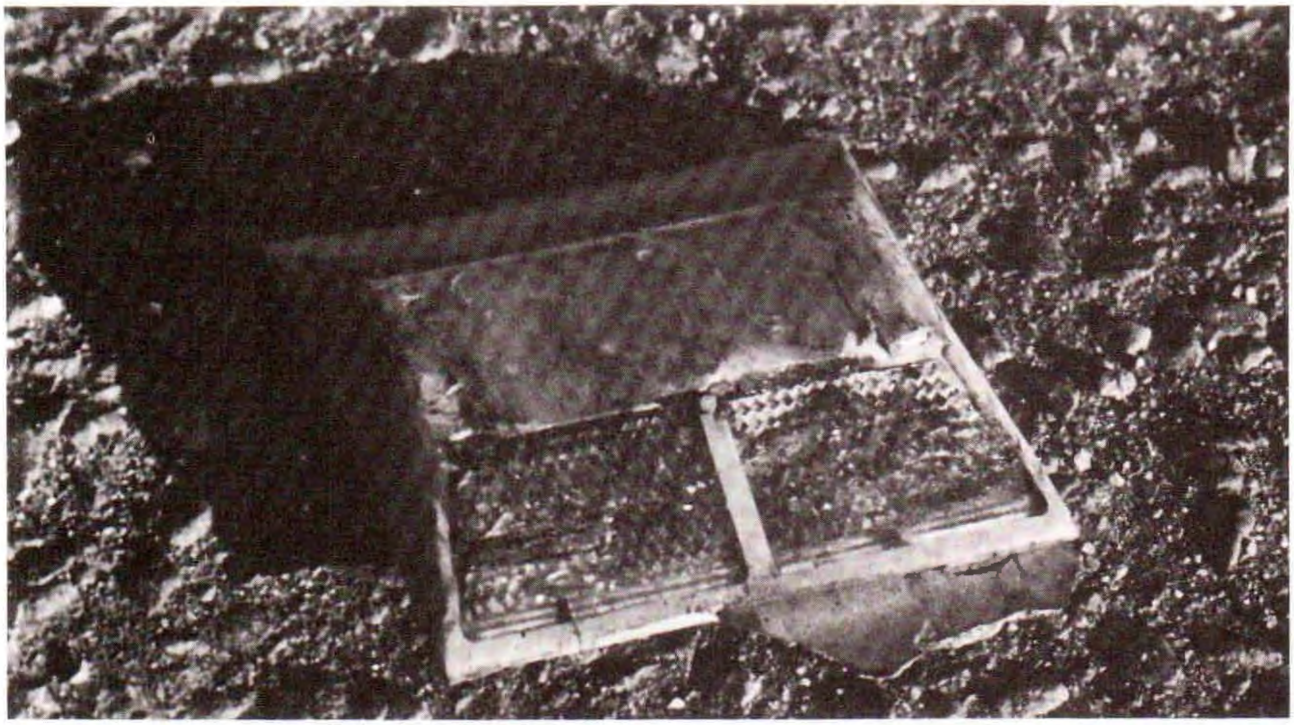
The adhesive should be placed uniformly on the cleaned pavement surface or on the bottom of the marker in a quantity sufficient to result in complete coverage of the area of contact of the marker with no voids present and with a slight excess after the marker has been pressed in place. The marker should be placed in position and pressure applied until firm contact is made with the pavement.

Excess adhesive around the edge of the marker, on the pavement, or on the reflective surfaces of the markers should be removed. A soft rag moistened with mineral spirits conforming to Federal Specifications TT-T-291 or Kerosene can be used, if necessary, to remove any excess adhesive. The marker must be protected against traffic impact until the adhesive has hardened. Traffic control and protection of the markers are similar to striping operations.

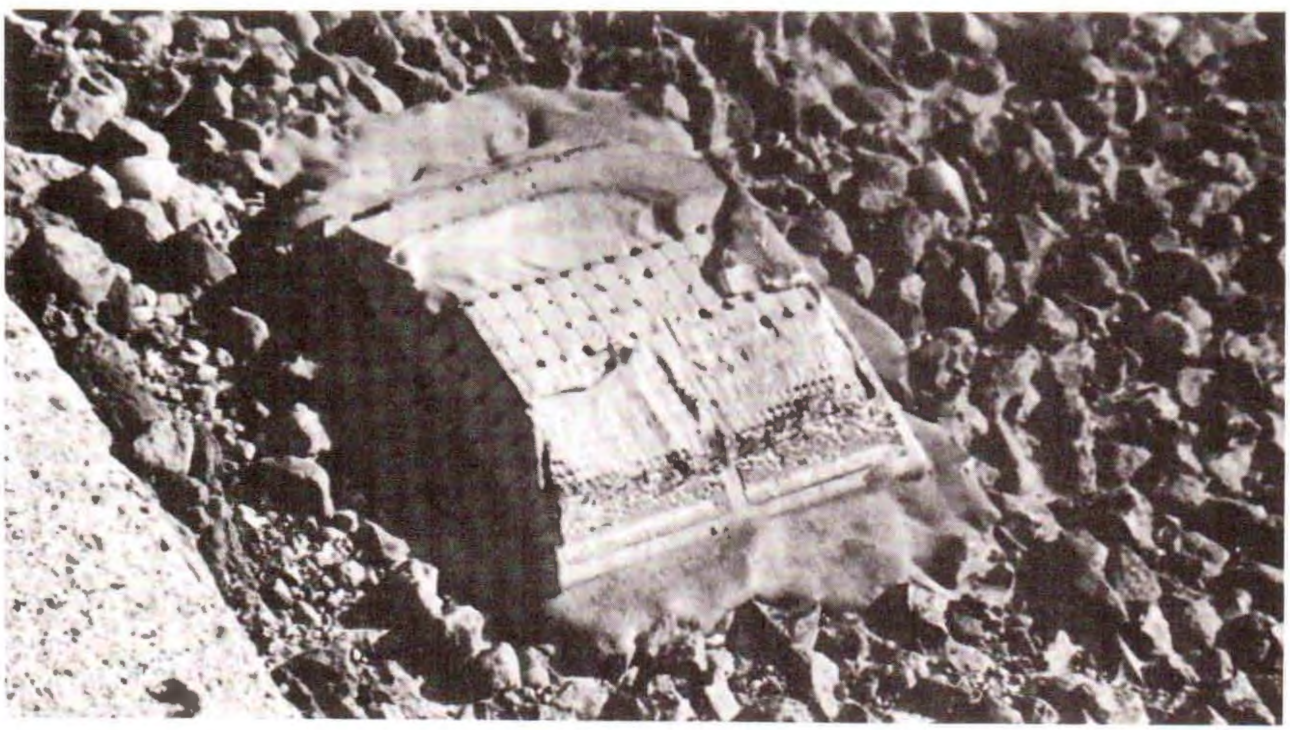
Reflective markers should be placed so that the reflective face of the marker is perpendicular to a line parallel to the roadway centerline. No pavement markers should be placed over longitudinal or transverse joints of the pavement surface.

Table 5. Specific Reflectivity of Selected Raised Pavement Markers

BRAND NAME	COLOR OF REFLECTIVE LENS SYSTEM	SPECIFIC REFLECTIVITY (0.2° DIVERGENCE ANGLE)	
		0° INCIDENCE ANGLE	20° INCIDENCE ANGLE
Stimsonite 88	Silver White	5.5	2.4
	Amber	3.1	1.4
	Red	1.4	0.7
Ray-O-Lite (Regular)	Silver White	3.0	1.6
	Amber	1.3	0.83
	Red	0.64	0.38
Permark P-15	Silver White	1.04	0.82
	Amber	0.60	0.45
	Red	0.17	0.13
Safety Guide	Silver White	0.68	0.40
	Red	0.06	0.02
PD-50 (3M)	Silver White	0.34	0.21
Little Jewel	Silver White	0.15	0.02
	Amber	0.14	0.01
	Red	0.06	0.01



a) Damaged Lens - Still Reflective



b) Completely Destroyed Reflective Lens

Figure 39. Damaged Reflective RPM's

When the raised markers are used to supplement a solid painted or thermoplastic pavement stripe, they are generally offset 2 inches (5 cm) from the edge of the stripe. This permits repainting the stripe without degrading the reflective properties of the markers.

Using Epoxy Adhesives

As described under "Materials" above, there are numerous formulations of epoxy bonding agents. The proper proportioning, mixing, extruding and handling in general are the most critical parts of the application procedure.

Essentially, all two-part epoxies require that the mixing operation and the placement of the marker on the pavement be done quickly. Whether hand mixing or machine mixing is used, most standard types of epoxy require that the marker be coated, aligned, and pressed into place within minutes after mixing is started. Consequently, no more than a quart of adhesive should be hand mixed at one time.

Rapid set adhesive is usually mixed by a two-component automatic mixing and extrusion apparatus such as that shown in Figure 40. For a typical large scale installation, a crew member is positioned on a platform located low on the side of the truck between the two axles. The mixing and extruding apparatus is installed nearby. A predetermined amount of the mixed epoxy is expelled onto the bottom surface of the marker which the operator then positions on the pavement well within the 40 to 60 seconds allowed.

To achieve a proper bond, care should be exercised to assure that the adhesive is used in accordance with manufacturer's instructions. For example, some standard set type adhesives require that the pavement and air temperature be above 50° F (10° C). Rapid set can usually be applied at temperatures as low as 30° F (1° C). Normally, no marker should be set if the relative humidity is over 80% or if the pavement is not surface dry.

One final note: epoxy adhesives can cause severe dermatitis if proper precautions are not followed. Crews should use gloves and protective cream to prevent contact with the adhesive. If contact with the skin occurs, the area of contact should be washed thoroughly with soap and water as soon as possible. Solvents should not be used to remove adhesive from skin. (Toluene or equivalent may be used to clean tools and equipment).

MAINTENANCE

The routine maintenance of raised markers is almost always a function of local or state forces. No complex equipment or special crew capabilities are needed for the replacement of conventional RPM's. The only critical element involves the proportioning and mixing of the two-component epoxy as discussed earlier. Contractors will normally install such markers as part of a resurfacing or other type of construction contract that requires the replacement or new installation of raised markers.

The maintenance of the steel-encased snowplowable marker can be expected to involve the simple replacement of the removable reflective lens, provided that the housing is still in good shape and is properly seated in the pavement. To date, most installations of snowplowable markers have been for field test and demonstration purposes. For this reason, data on routine maintenance procedures is not available.

Observations of maintenance activities and discussions with maintenance crews suggest that procedures have evolved over time that are both efficient and effective for the needs of the agency involved. That is, what works well for one agency or individual crew may not necessarily produce the same results for another under the same set of circumstances. In view of the benefits that accrue from crew experiences and familiarity with equipment and local conditions, most maintenance manuals are relatively general, leaving the step-by-step procedures to the responsible agency within the limitations of established policy and standards.

The following observations address some RPM maintenance practices and developments that have proved effective or show promise for future use.

Routine Maintenance Levels

As in all maintenance functions, there are two basic categories of maintenance: periodic or preventative maintenance (routine), and immediate or emergency repairs (as needed). In the context of delineation, the former is performed to maintain the system at a safe operational level commensurate with established policy or standards. The latter functions usually involve returning a hazardous situation to a safe condition shortly after it occurs and is identified.

The approach to routine maintenance varies among agencies. If expected service life is adopted as the primary determinant for routinely scheduling marker replacement, the history of brand name marker performance and the traffic characteristics of individual roadway sections must be known. For example, if experience or field tests have indicated that a particular type of lane-line marker can be expected to remain effective for 6 years on long sections of high-speed multilane freeways and 3 years in areas of heavy turning movements such as near ramps and

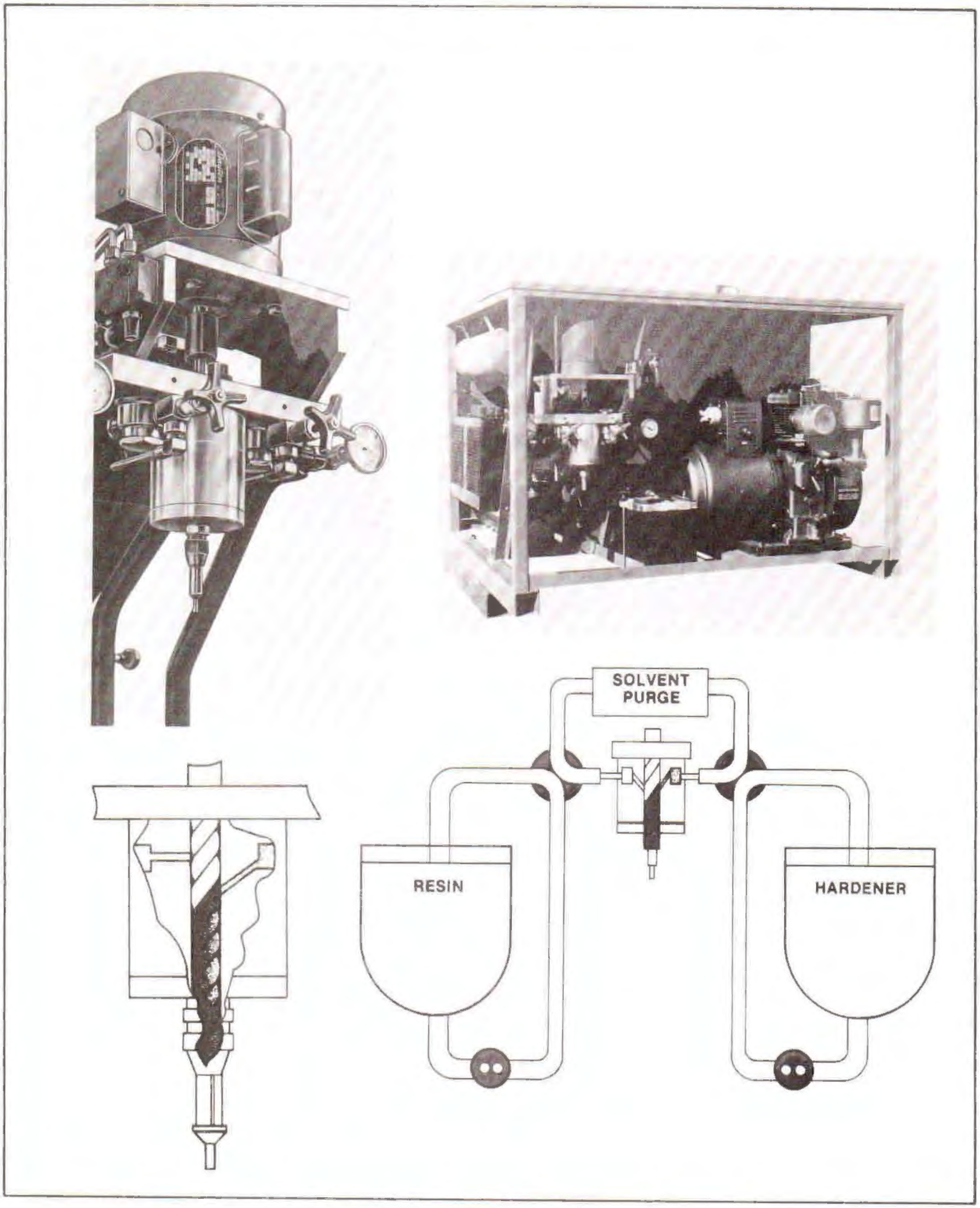


Figure 40. Typical Epoxy Mixing and Dispensing Equipment

merge and diverge areas, then replacement of markers can be scheduled accordingly. This is not always a cost-effective procedure even though this practice does not require night inspection. The number of markers that must be replaced may not warrant the effort, or the marker system may be deteriorated beyond safe levels.

A more commonly used criteria for replacement is based on the number of missing markers that can be tolerated without seriously degrading drivers' visibility, particularly under adverse weather conditions. For example, California specifies that markers should be replaced when 8 or more non-reflective markers are missing in a 100 ft. (30 m) section and when 2 successive reflective markers are missing.

The determination of the acceptable level of missing or damaged markers is based on the spacing, pattern, whether painted markings are present, and the roadway geometry. Once the level is specified, inspections must be conducted, usually at night, to identify areas where missing markers exceed the acceptable level. Such night inspections are usually scheduled near the end of the expected service life. In some cases, spot checks are conducted annually prior to the onset of adverse weather cycles. Inspection of roadway markings may also be included as part of regularly scheduled traffic control device inventories.

As Needed Maintenance

This form of immediate maintenance is important from the standpoint of legal responsibility as discussed in Chapter 8. Although not a frequent occurrence under normal circumstances, care must be exercised to assure that appropriate delineation is not interrupted by major accidents or natural disasters which may have damaged or removed raised markers.

This type of maintenance is most commonly associated with construction work zones and unexpected snow or ice storms. In areas accustomed to seasonal snowfall where RPM's are used, inspection and maintenance of markers after the snowfall season is usually considered routine maintenance.

When self-adhesive markers are used for temporary delineation on roadways through, or adjacent to, construction work zones, inspection and maintenance are critical safety considerations. In particular, areas of heavy truck or construction equipment traffic should be carefully monitored and missing markers replaced to assure that the temporary travelled way is clearly delineated. This is often either a shared responsibility with the contractor, or the sole responsibility of the contractor. The courts, however, have proved somewhat capricious in the adjudication of agency responsibility in accident litigation. The cost expended for monitoring these hazardous locations is miniscule relative to accident judgments.

Marker Replacement Process

California is probably the largest user of RPM's in the United States. With 175,000 miles (283,000 km) of primary and secondary roads and with a state policy that adopted a system of raised markers for all freeways and a majority of secondary roads, where snow is not a problem, California now has in excess of 30 million markers in place and replaces approximately 380,000 a year.

While not applicable to all situations, the various districts have developed several interesting shortcuts in marker replacement. For example, on some freeways where two successive reflective markers are badly damaged another reflective RPM will be placed immediately in front of the defective marker. This can be accomplished very quickly since time is not expended in removing the original marker. It is not unusual to find random groups of two and three damaged reflective markers lined up in place near a new marker.

Replacement on long sections of several freeway miles is often scheduled for early Saturday or Sunday mornings when coning will not be too disruptive to traffic. Whenever possible, other site maintenance is scheduled for the same period to take advantage of lane closure and other protective activities. The simplest form of operation consists of a crew member walking along side the epoxy-dispensing truck and indicating what markers are to be replaced. The "applicator," who is located in the well of the truck, activates the epoxy dispenser which extrudes a measured quantity of the mixed epoxy onto the bottom side of the marker which is then firmly placed next to the damaged marker or near the location of a missing marker. A following crew member removes the old marker by hammer and chisel with one or two taps and disposes of it in a hopper in the back of the truck. Cones and following vehicles are used as needed to protect the crew and the markers from traffic. This operation can move at 1 to 3 miles (2 to 5 km) per hour depending on the number of markers to be removed and replaced.

Semi-annual night inspection of sections containing markers nearing the end of their expected service life are conducted by the maintenance engineer and staff to determine the scheduling priority. This type of replacement operation is normally scheduled when 50 percent or more of the markers are defective or missing. It was also stated that any damaged or missing markers are routinely replaced during other maintenance operations that require coning and/or lane closure.

Development of RPM Skipper Equipment

When raised markers are used to supplement painted markings a problem occurs when the worn painted stripe must be repainted. Whether the RPM is located within the path of the painted stripe or offset to the side, there is a potential for painting over the marker and rendering it ineffective.

Many large scale paint stripers provide an electronic skip line timer device which allows the operator to set a particular pattern for retracing. This is not always effective, in that patterns may change within a section or may not have been followed accurately in the original application. In these cases, the operator must use the off-on toggle switch to activate the spray gun. This slows down the operation considerably and requires such concentration from the operator that multiple operators must be available to alternate after short periods of operation.

In recognition of this problem, FHWA initiated a research project (DOT-FH-11-8250-90) with the State of California to develop an instrument that would detect the presence of a reflective RPM and terminate painting to clear the marker (Ref. 44). An optical Retro-Skip Device was subsequently designed, built, and successfully tested at speeds up to 65 mph (105 km) with approximately 99% accuracy. The only drawback at the higher speeds was that the paint guns could not operate fast enough.

The unit works very well on either asphalt or PCC with new or relatively new reflectors. Reflective markers in poor condition cannot be detected and will be painted. Therefore they can be easily detected and replaced.

The unit is easily installed on any paint striping equipment that has a paint gun control. The detector box is mounted 6 inches (15 cm) above the pavement and was designed to fit typical paint trucks.

The equipment is currently in use in California and shows promise in decreasing the number of markers that are made ineffective by overpainting.

Cleaning Raised Markers

It has been noted that during hot dry periods, road film, oil, grease, and other debris will seriously degrade the reflectance properties of reflective markers. It is also noted that tire marks can stain non-reflectorized ceramic markers to the point that they are no longer visible, day or night. Most of the commonly used markers are self-cleaning to some extent when wet. Loss of delineation from staining is therefore not a critical problem in geographic areas that normally experience summer rains. It can become significant in hot dry areas of the west and southwest.

Because of the long hot dry summers experienced in parts of California, the feasibility of cleaning markers was investigated. It was found that film on markers was not easily soluble in any of the common organic solvents, but was easily removed with a cleanser containing a fine abrasive. This indicated that the film is primarily rubber from tires.

Subsequently, a traffic marker washer unit was developed in the State's Equipment Shop. The unit consists of a brush 14 inches (36 cm) wide and 18 feet (5 m) long with 4 inch (10 cm) nylon bristles impregnated with an abrasive. This unit is mounted to the side of a two-ton truck. A detergent water solution from the truck is supplied to the brush during the cleaning operation. The device folds into three sections for easy transport. This unit was successfully used in five California districts. The State reports that, although effective, the equipment has not been developed beyond the experimental stage.

EXPERIMENTAL DEVELOPMENTS

In areas of little or no snowfall, the use of RPM's for wet night visibility will probably not be seriously challenged in the immediate future. Technical and cost improvements in commercially developed devices may be anticipated in response to the growing market. New development concepts have been pursued and while several show promise, none have progressed to a cost-effective operational status. Most of these are related to techniques potentially compatible with snowplow activities. A summary description of those concepts that appear to warrant further study is included below.

Grooved Stripes

A study was conducted under contract to the Federal Highway Administration to evaluate grooved paint stripes and a combination of grooved stripes and recessed reflectors as a new approach to a snowplowable wet-night delineation system. Evaluation of 44 combinations of groove geometry and paint treatments indicated that only a recessed reflector system was more visible than conventional beaded paint markings.

Subsequently, a system of recessed markers was field tested in various configurations by the State of New York (Ref. 42, 43) to identify installation problems, the amount of delineation provided, and possible maintenance problems. Essentially, the grooved stripe-recessed reflector system includes a 4 in. (102 mm) wide, 5 ft. (1.5 m) long longitudinal groove pattern as shown in Figure 41 and Figure 42. A recess 2" x 4" x ½"(51 x 102 x 13 mm) is cut at the groove's downstream end, into which a plastic corner cube reflector is mounted with epoxy. The reflectors are produced for use in the Stimsonite Model 99 (Type L2) raised marker and include a metal plate glued to the top to protect against studded-tire wear. Since this system is designed to provide delineation during wet nights, the markers were placed in the skip zones between the conventional beaded white paint stripes used for daytime and dry-night delineation.

To prevent collection of water and debris in the grooves, thereby reducing visibility by blocking a portion of the reflector, transverse drainage grooves ½ x ½ in. (13 x 13 mm) were cut at the low end of each marker. Their length varied with the pavement cross-slope, but extended far enough toward the low side of the pavement to remove water from the grooves.

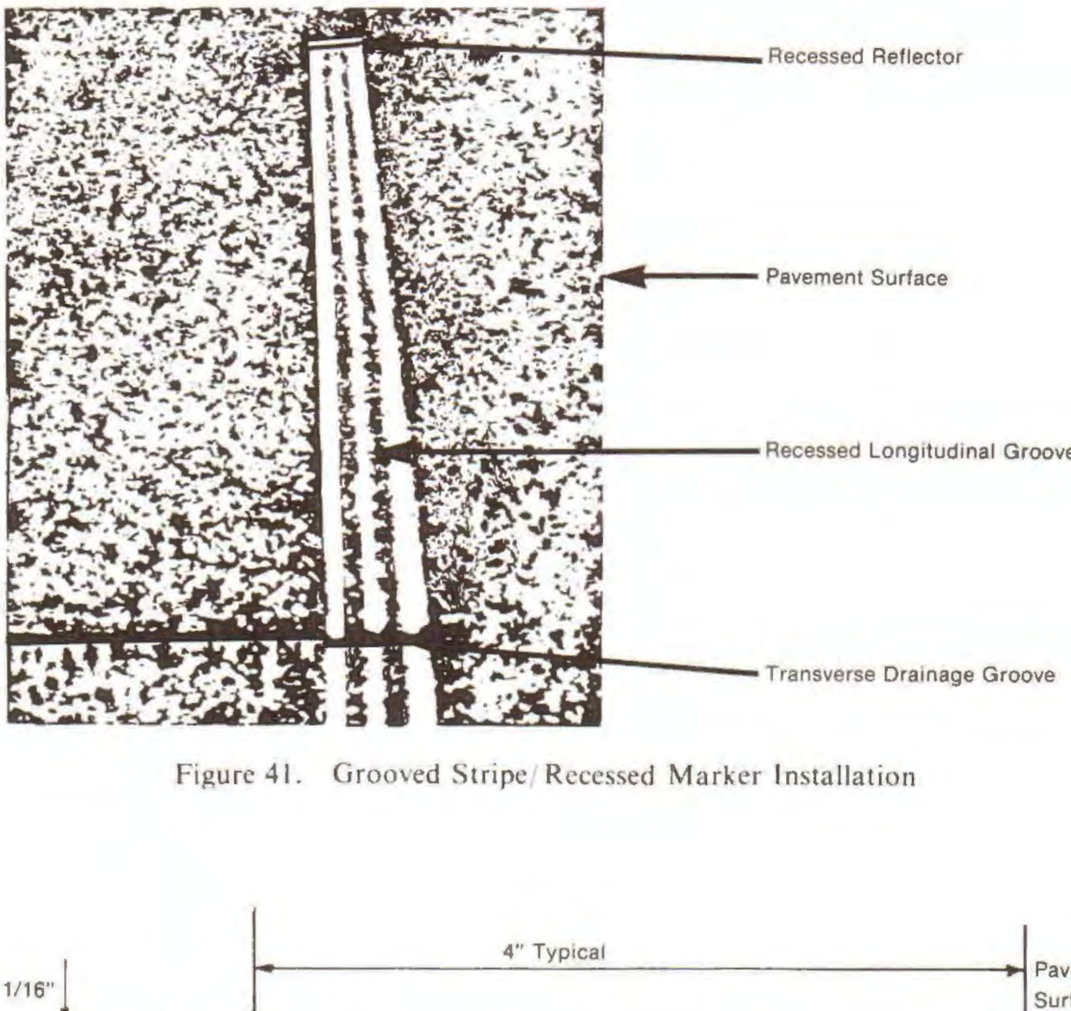


Figure 41. Grooved Stripe/Recessed Marker Installation

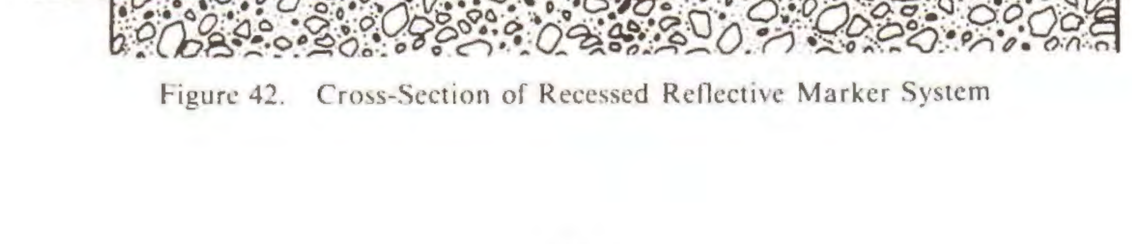


Figure 42. Cross-Section of Recessed Reflective Marker System

Field Test Results

It was apparent from the beginning of the test period that these markers provide poor dry-night visibility. When wet, however, visibility improves dramatically. It appears that the water film masks minor surface imperfections and the wet reflectors remain visible in spite of some surface deterioration. Even when substantial surface area is lost, many of the damaged reflectors are visible for 200 feet or more.

After four years of exposure to traffic and snow-and-ice control operations, most of the reflectors remained in serviceable condition although a third had suffered some degree of chipping and pitting. Only a few were totally destroyed. Averaged sight distance under wet-night conditions for the four year evaluation period is shown in Figure 43. The recessed markers installed in Portland Cement Concrete provided the poorest wet-night visibility probably because of poor drainage on the pavement. Conversely, the installations on asphalt pavements averaged a visibility distance of 215.5 feet (Ref. 43).

Very little deterioration has been experienced in the grooved stripes and drainage slots in asphalt pavements over four years. Those in PCC are unchanged.

Installation Equipment

The practical problem associated with further use of the recessed reflectorized marker system described above concerns the development of a technique and equipment for large scale installation of these devices.

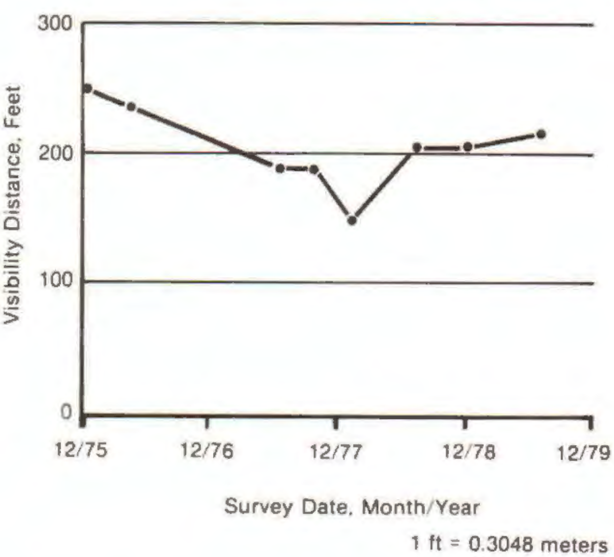


Figure 43. Wet Night Visibility History of Grooved Stripe Reflective Markers

The recessed markers installed for the field test required an inordinate amount of time and effort. Thus, the feasibility of this concept depends on the development of a fast, mechanized procedure that will reduce the per-marker cost to reasonable levels.

A mechanized vehicle to install the RPM delineation system in both Portland cement and bituminous pavements has been designed as shown in Figure 44. The basic equipment requiring a single operator is mounted on the bed of a standard Ford F-700 (or similar) truck. This apparatus automatically cuts the longitudinal main groove and the transverse drainage groove, cuts the reflective marker recess, removes cutting debris from the groove, dispenses the adhesive for securing the reflector base/reflector unit to the pavement, installs the reflective marker, and propels the vehicle between adjacent markers. The development and evaluation of a prototype is underway.

Self-Luminous Markers

A variety of self-luminous markers have been examined since they offer the considerable benefit of not requiring headlight retroreflection to be visible. Thus, they could provide guidance even in situations in which climatic conditions or roadway geometry limit the utility of headlight illumination. Electrically-powered markers employing both incandescent and solid-state lamps have been tested by a number of agencies. These are extremely bright, and under favorable situations or roadway geometry can be visible for up to 2,000 ft (610 m) at night. However, because of their high installation and maintenance costs, use of electrically powered markers in the near future will probably be limited to special hazardous situations. Practically, the markers must be wired into a central power system since available types of batteries have too short a service life for practical use — even if current draw is minimized using solid-state electronic components and lamps.

Radioluminescent and Chemiluminescent Markers

Radioluminescent and chemiluminescent markers have also been investigated (Ref. 45, 46). A radioluminescent marker consisting of a plastic Fresnel surface flush with the pavement surface is coated on the bottom with an inorganic phosphor material. Beneath the lens there is a series of tubes filled with radioactive tritium or krypton gas. Radioactive decay of the gases excites the phosphor material, causing it to luminesce. These markers demonstrated acceptable wet-night delineation capability; but no further work is planned due to the high cost of the gases, their probable limited supply in future years, and potential safety hazards associated with use of the markers in highway operations.

GENERAL GUIDELINES FOR SPECIFIC APPLICATIONS

Part III B of the MUTCD (Ref. 1) provides definitive guidelines for painted markings for a variety of situations. An effort is underway to develop similar national standards for the placement of pavement markers when they are used alone or in combination with painted markings.

The patterns and configurations given in Figures 45 through 51 are intended as general guidelines only and are subject to change when efforts have been completed to adopt national standards. These figures are based upon a report prepared by Amerace Corporation and have been modified by FHWA for use in this Handbook.

Since policy may differ among agencies, the patterns shown are dimensionless. In these figures "Normal Spacing, N" represents the length of the stripe and gap.

The marker pattern for construction zones that appears to provide the driver with the best visual perception on tangent sections when markers are used to supplement painted lines consisted of a spacing of 40 ft. (12 m). That is, a reflective RPM is placed mid-way between each 10 ft. (3 m) paint stripe as shown in Figure 51.

A spacing of 20 ft. (6 m) is recommended for curves since it provides the driver with twice the number of markers as shown in Figure 37b. It also recognizes the premise that the loss rate on curves will be higher, leaving voids in the pattern.

Without painted lines, a 6 to 10 ft. (2 to 3 m) spacing is recommended for solid lines and a cluster of 3 non-reflective markers with a reflective marker every 40 ft. (12 m) for skip lines. The spacing of colored markers 6 to 10 ft. (2 to 3 m) apart is necessary to provide the daytime appearance of a solid line. On critical alignment or abrupt changes in alignment bias, the density of reflective markers should be increased to 6 ft. (2 m) centers.

The color of the markers used (white or yellow) should be the same as that required for painted pavement stripes the markers represent.

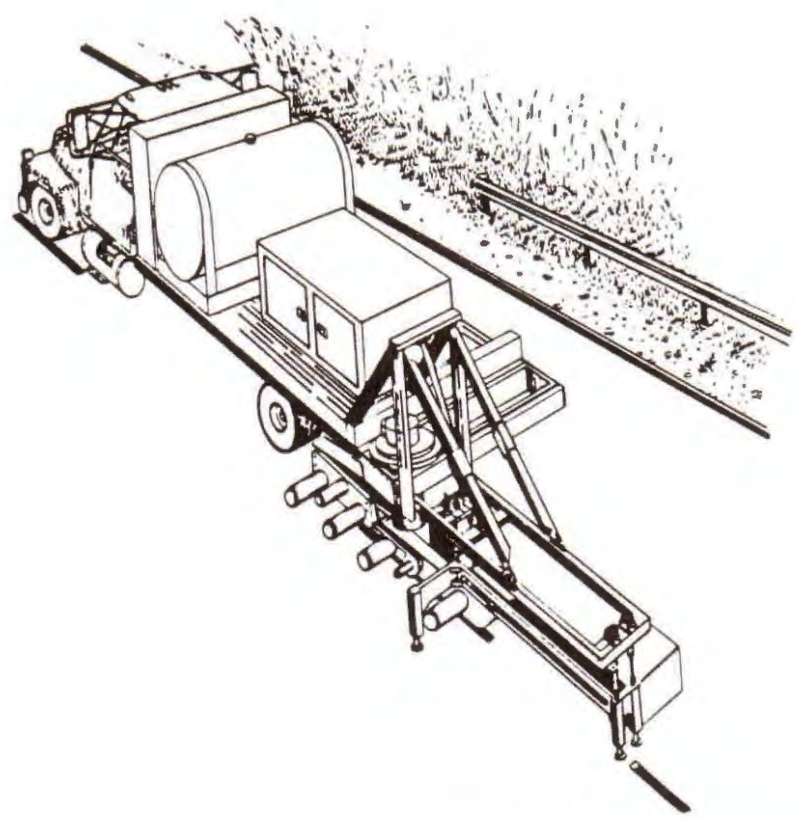
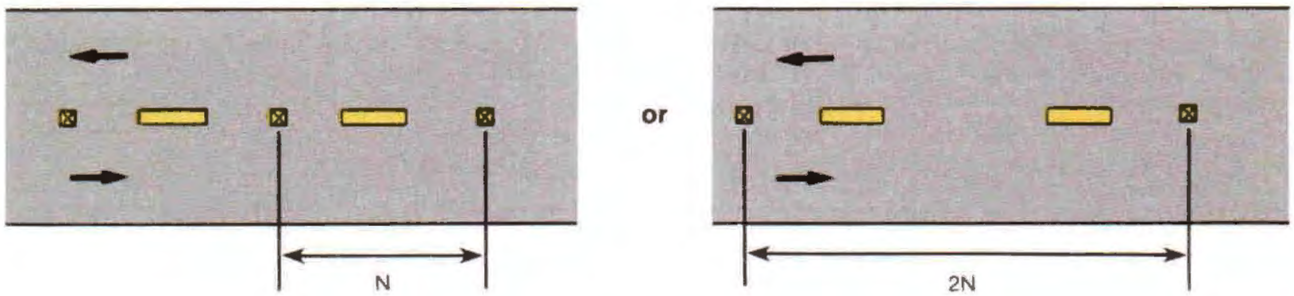
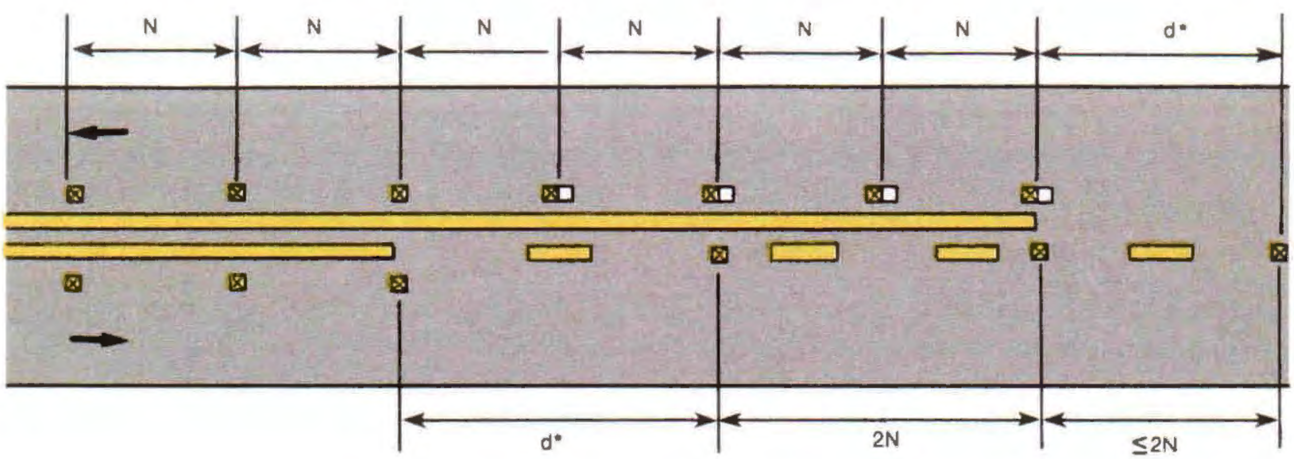


Figure 44. Proposed Groove Stripe Recessed Reflective Marker Equipment



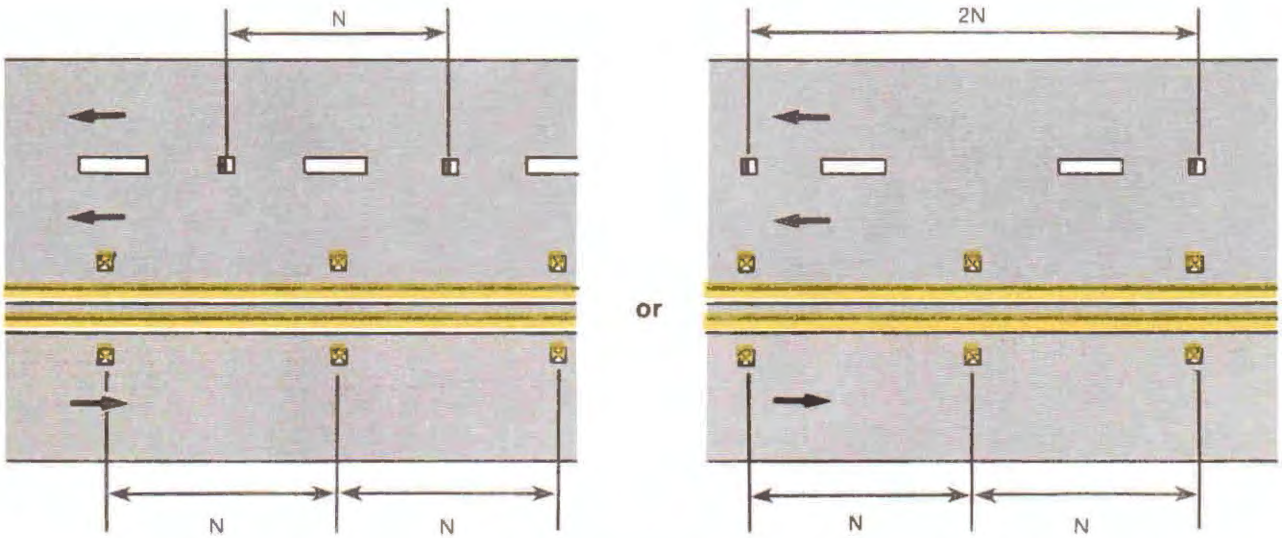
a) Two-Lanes



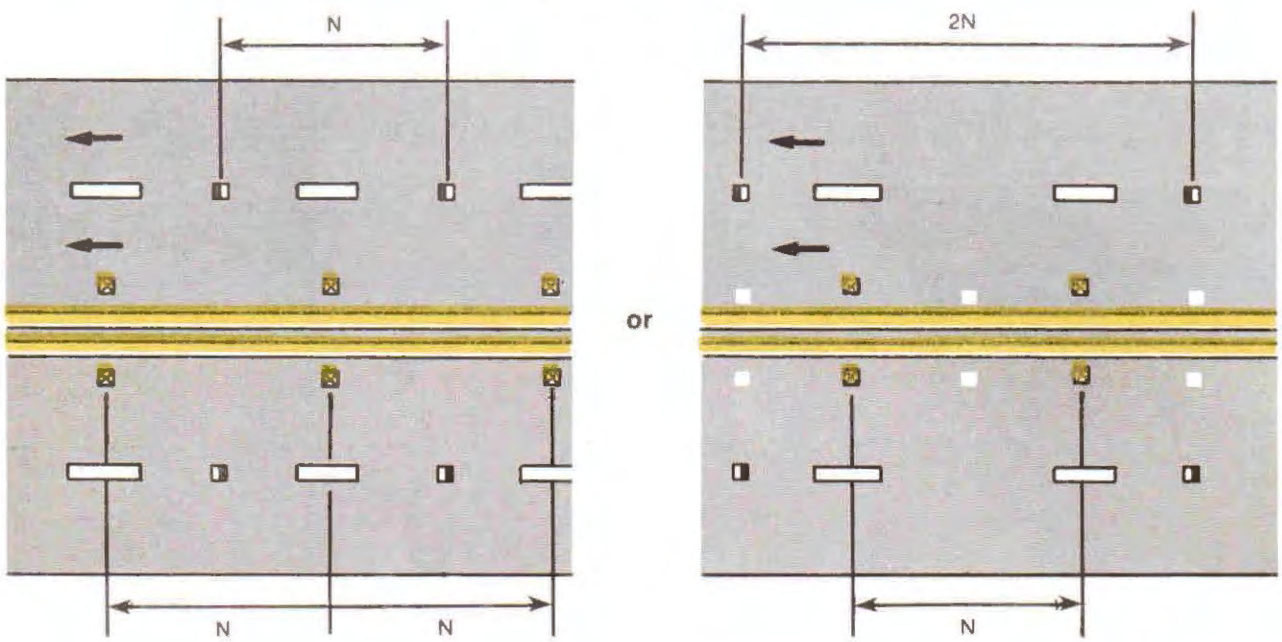
b) No Passing Zone *d ≤2N

N Normal Spacing
Double Yellow
Single Yellow
Yellow Stripe
Direction of Traffic

Figure 45. Marking Patterns for Two-Way Roads



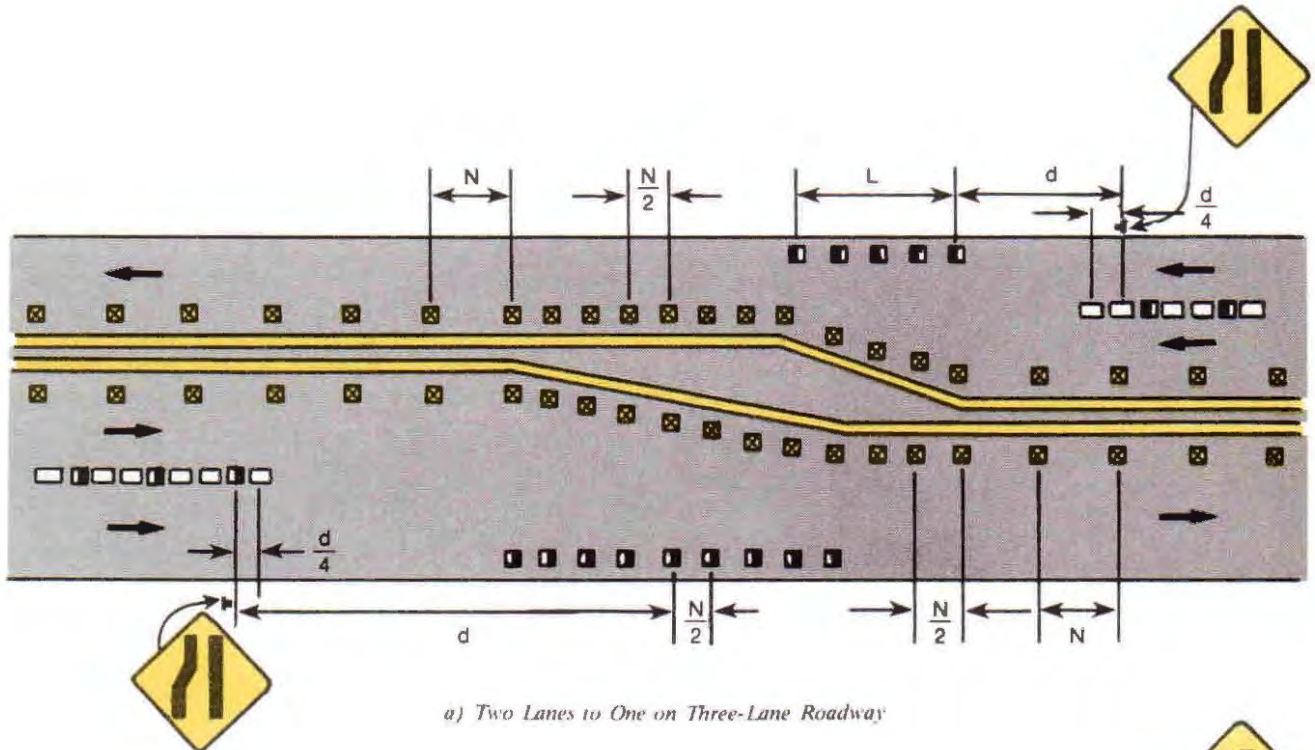
c) Three-Lanes



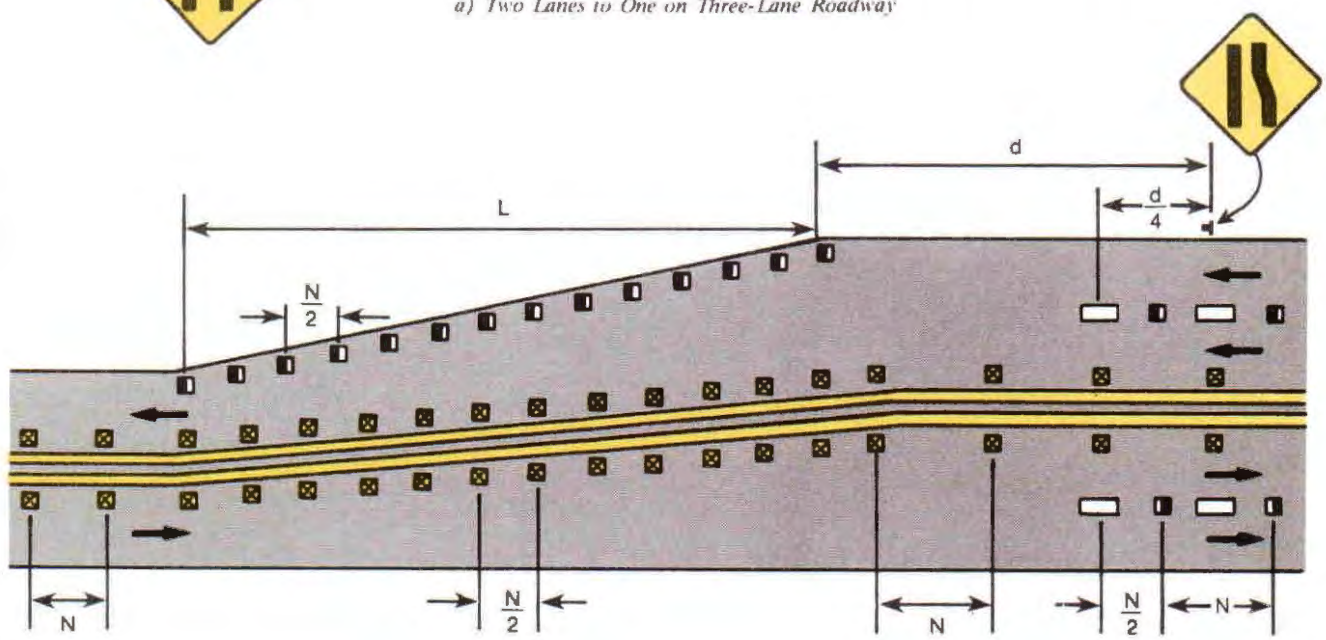
d) Four Lanes

N Normal Spacing
Single White
Double Yellow
White Stripe
Yellow Stripe
Direction of Traffic

Figure 45. Marking Patterns for Two-Way Roads (continued)



a) Two Lanes to One on Three-Lane Roadway



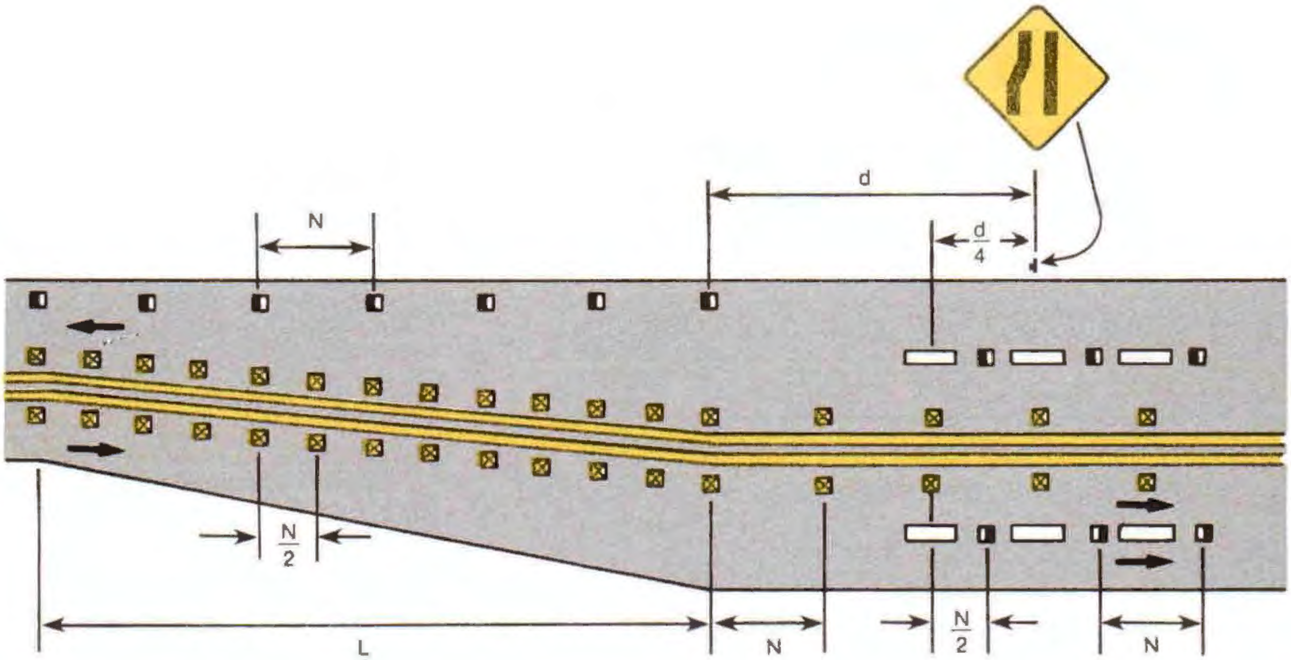
b) Four Lanes to Two-Lane Roadway - Left

- Single White
- Double Yellow
- N Normal Spacing
- White Stripe
- Yellow Stripe
- Direction of Traffic

d = Advance Warning Distance
For S ≥ 45 L = WS
S < 45 L = $WS^2/60$

L = Length of Taper in Feet
S = 85th Percentile Speed
W = Offset in Feet

Figure 46. Marking Patterns for Transition Situations



c) Four Lanes to Two-Lane Roadway - Right

- Single White
- Double Yellow
- N Normal Spacing
- White Stripe
- Yellow Stripe
- Direction of Traffic

d = Advance Warning Distance

For S ≥ 45 L = WS

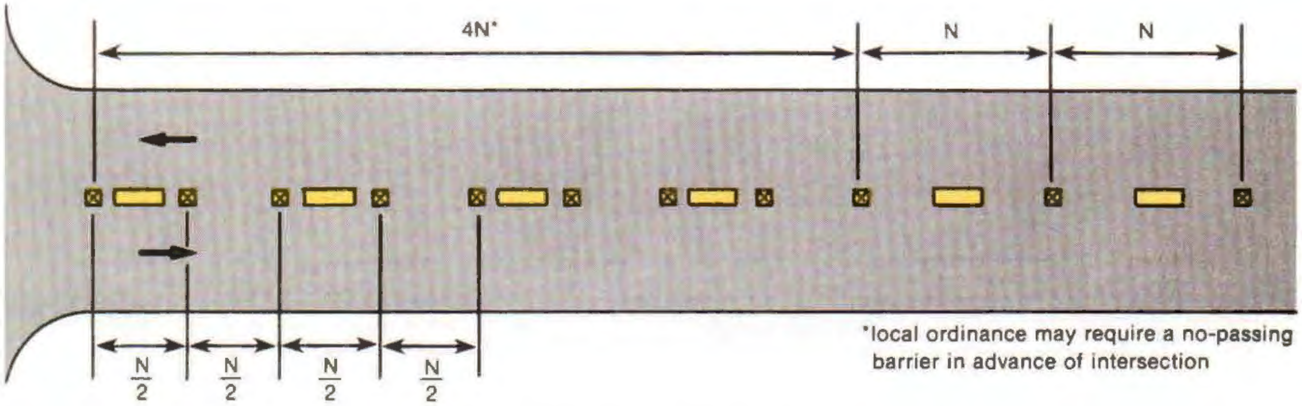
S < 45 L = WS²/60

L = Length of Taper in Feet

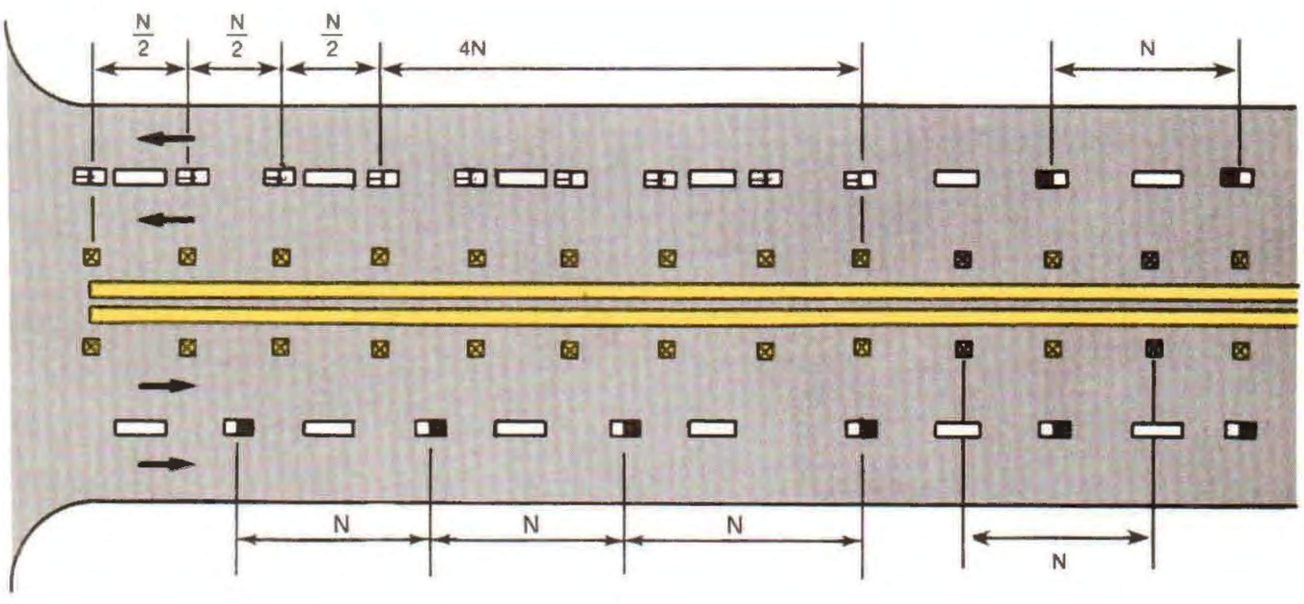
S = 85th Percentile Speed

W = Offset in Feet

Figure 46. Marking Patterns for Transition Situations (continued)



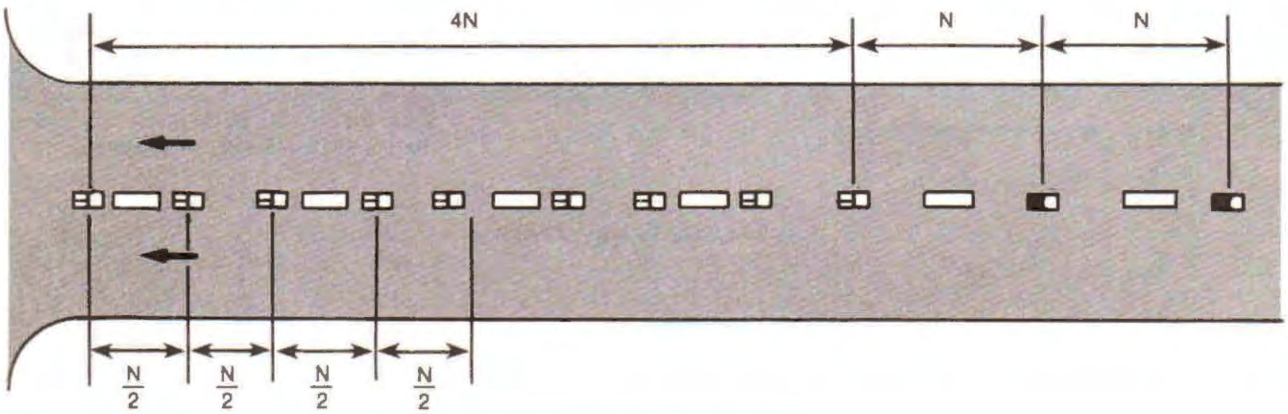
a) Two-Lane, Two-Way Roadway



b) Four Lanes, Two-Way Roadway

- Double Yellow
- Single White
- Red and White
- White Stripe
- Yellow Stripe
- Direction of Traffic

Figure 47. Marking Patterns for Intersection Approaches



c) Two Lane, One-Way Roadway

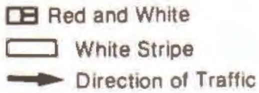
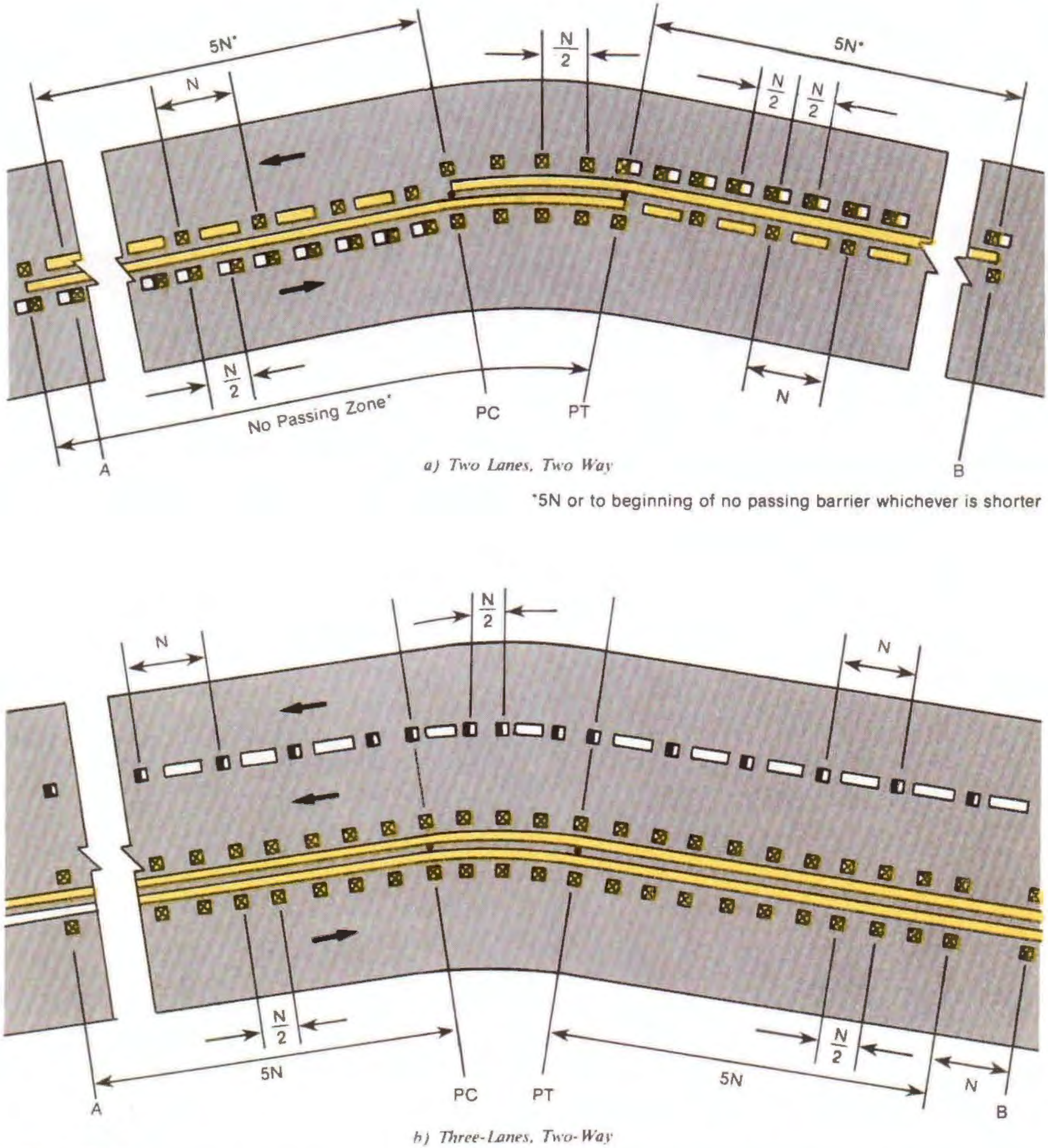


Figure 47. Marking Patterns for Intersection Approaches (continued)

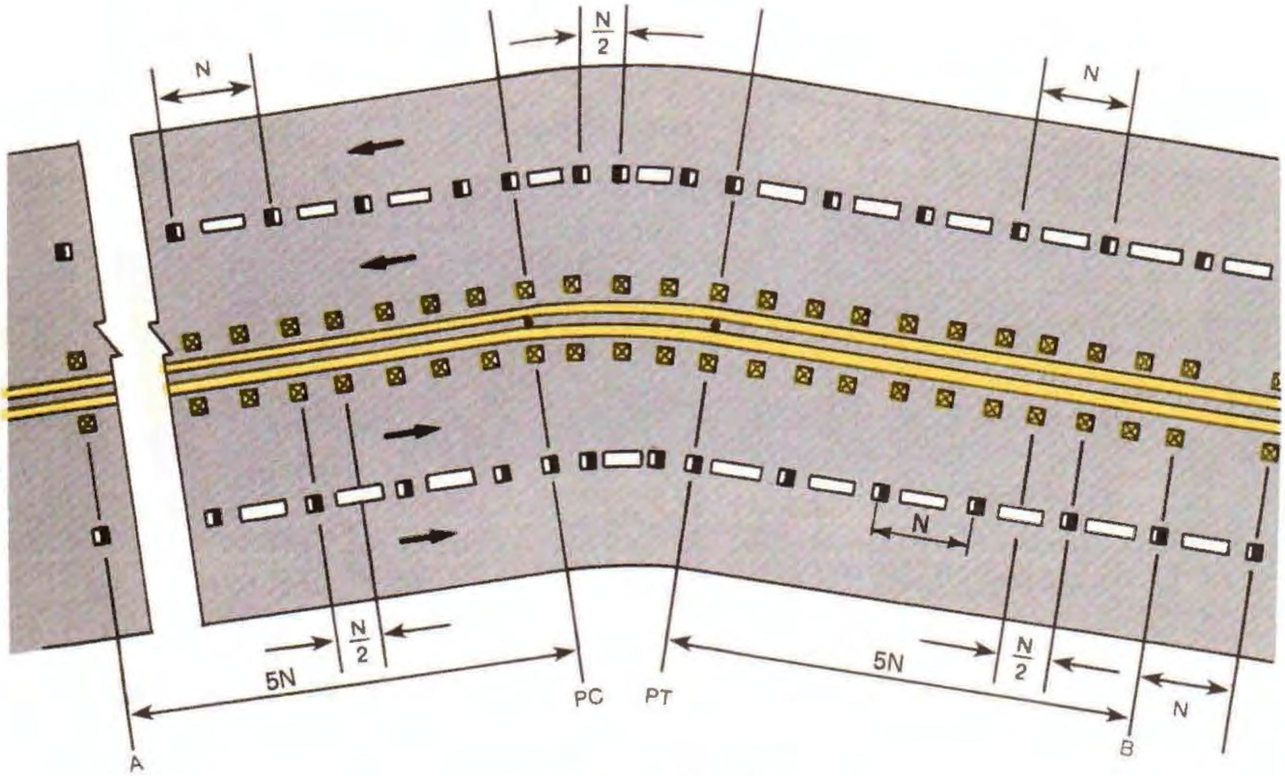


N Normal Spacing
Single White
Double Yellow
Single Yellow

White Stripe
Yellow Stripe
Direction of Traffic

Note: Where D < 6°, N/2 may be increased to N between Points A and B. On vertical curves increase spacing on crests.

Figure 48. Marking Patterns for Horizontal Curves Having 6° or Greater Curvature

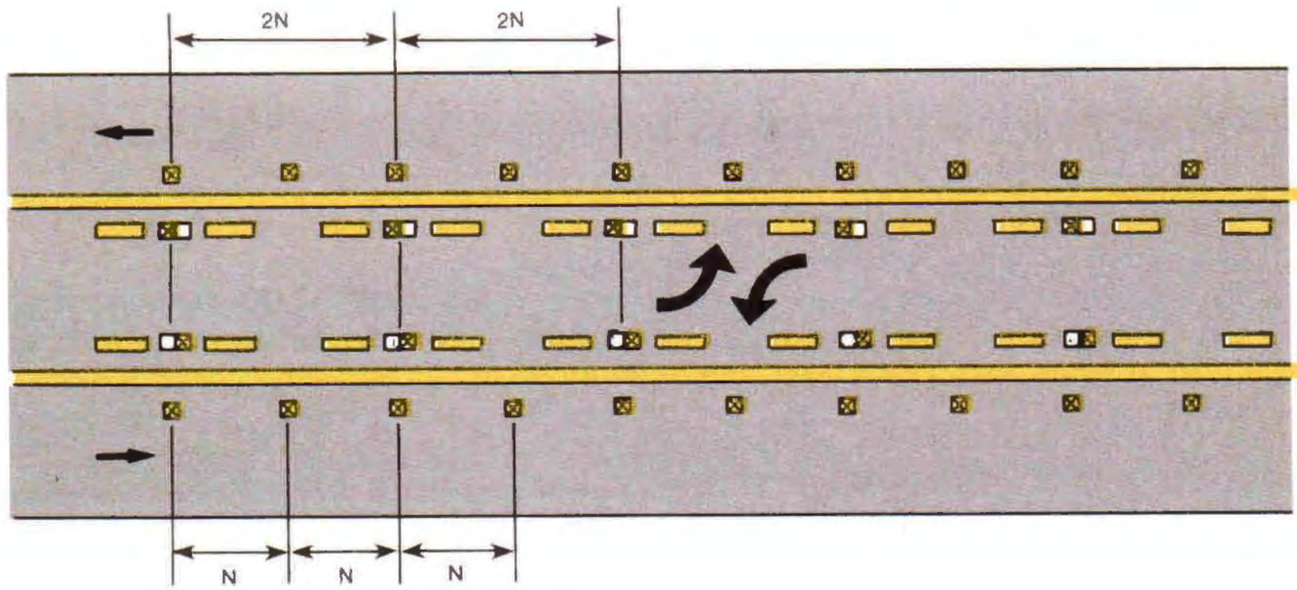


c) Four-Lanes, Two-Way

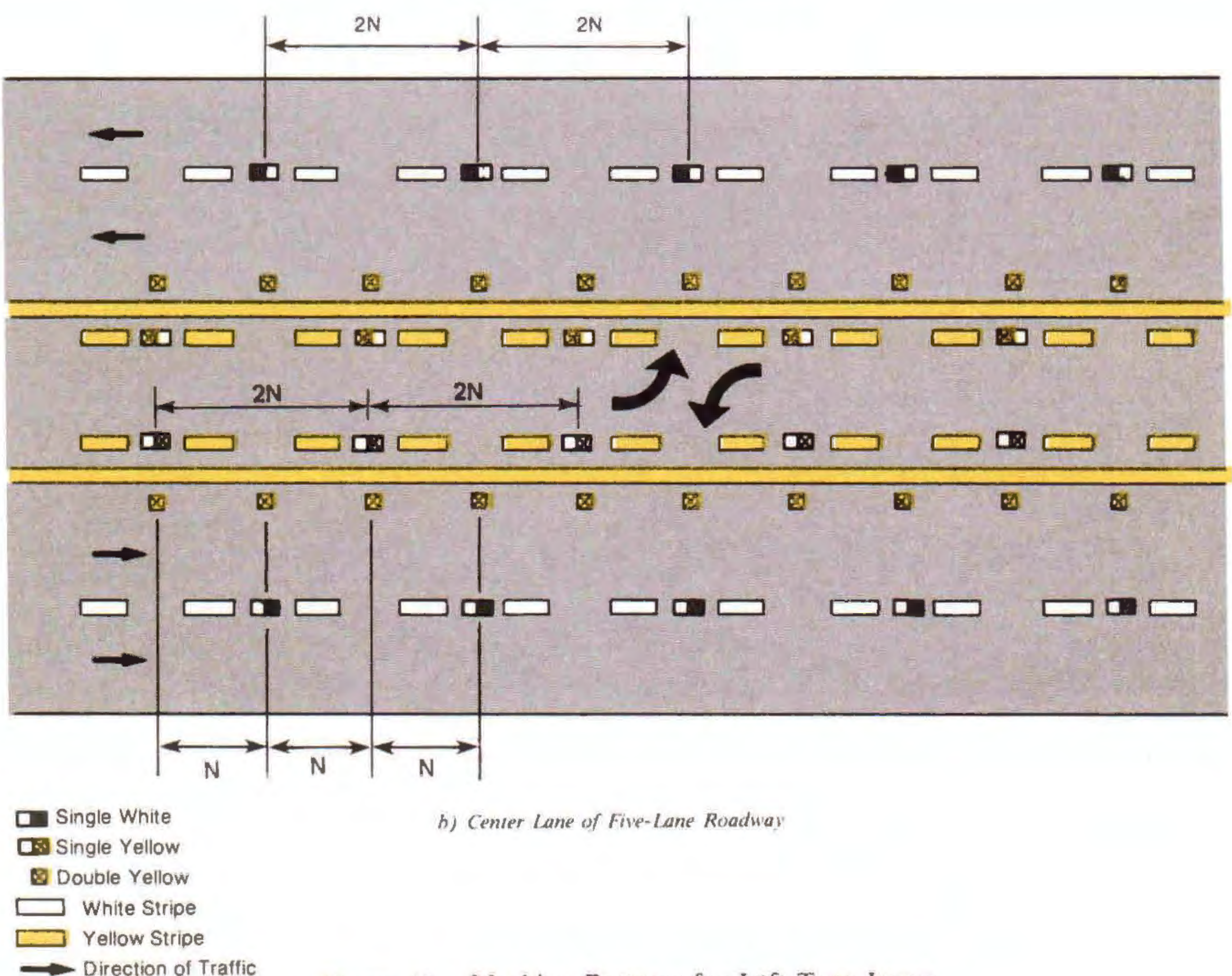
Note: Where D < 6°, N/2 may be increased to N between Points A and B. On vertical curves increase spacing on crests.

N Normal Spacing
Double Yellow
Single White
White Stripe
Yellow Stripe
Direction of Traffic

Figure 48. Marking Patterns for Horizontal Curves Having 6° or Greater Curvature (continued)

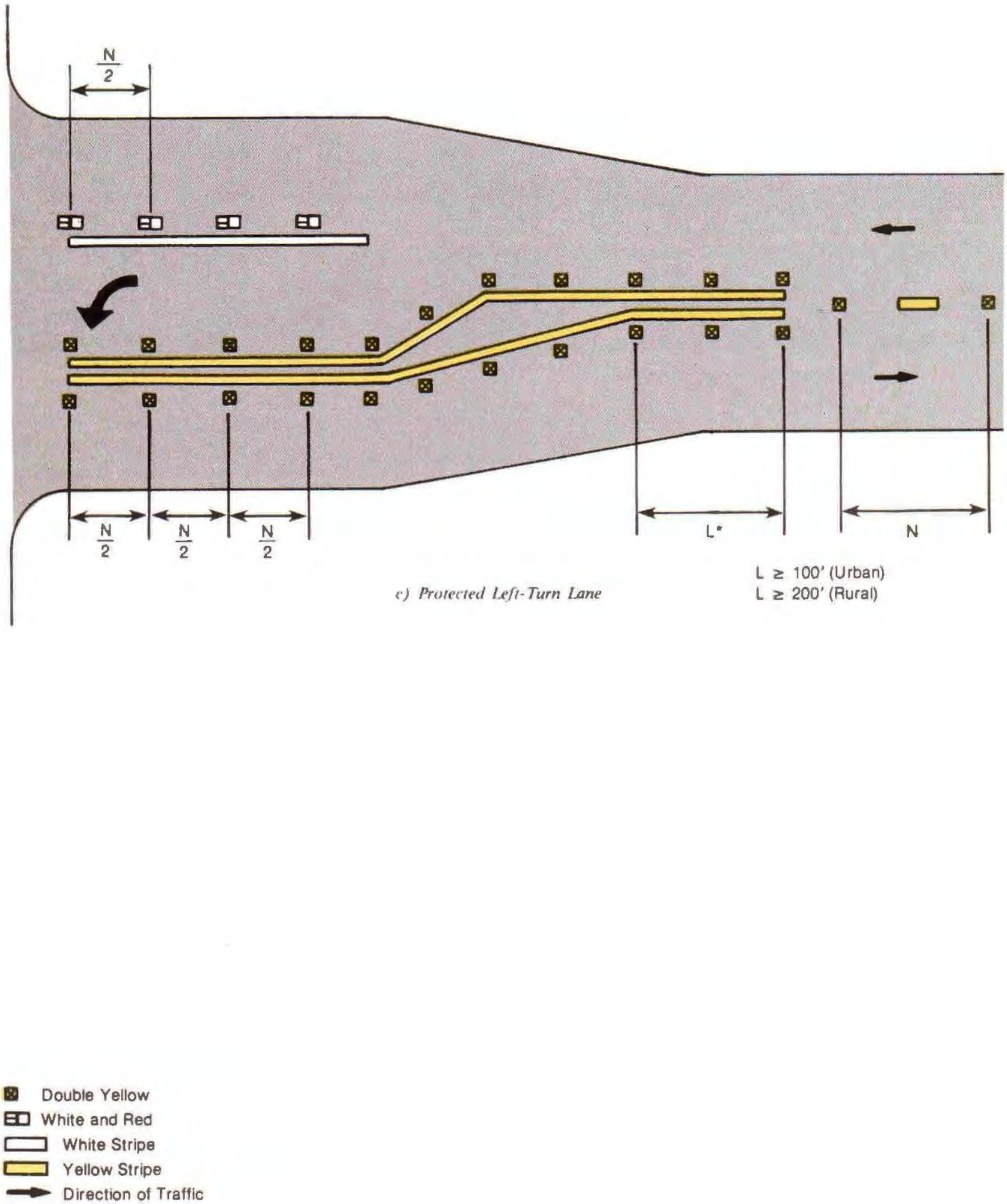


a) Center Lane of Three-Lane Roadway



b) Center Lane of Five-Lane Roadway

Figure 49. Marking Patterns for Left-Turn Lanes



c) Protected Left-Turn Lane

Figure 49. Marking Patterns for Left-Turn Lanes (continued)

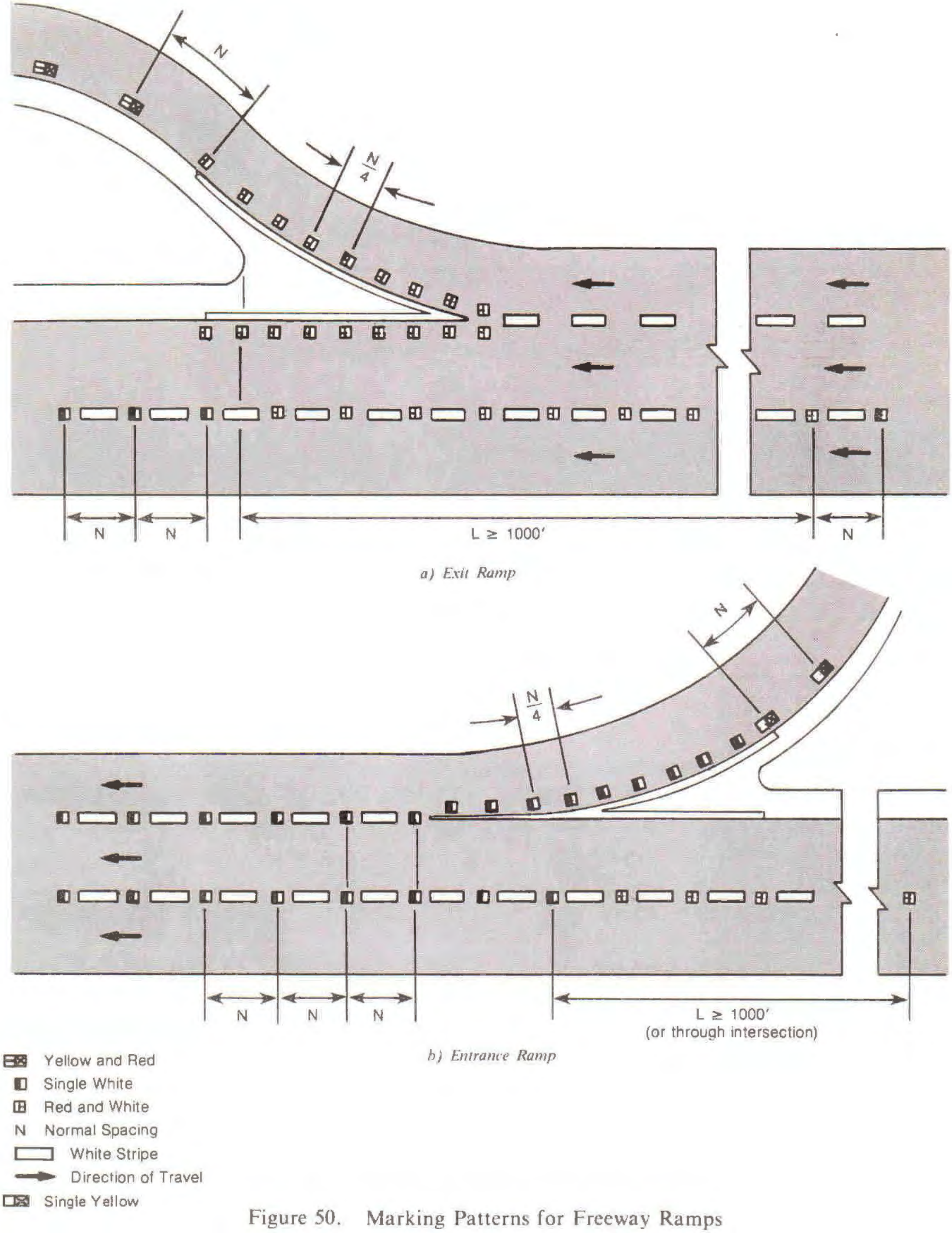
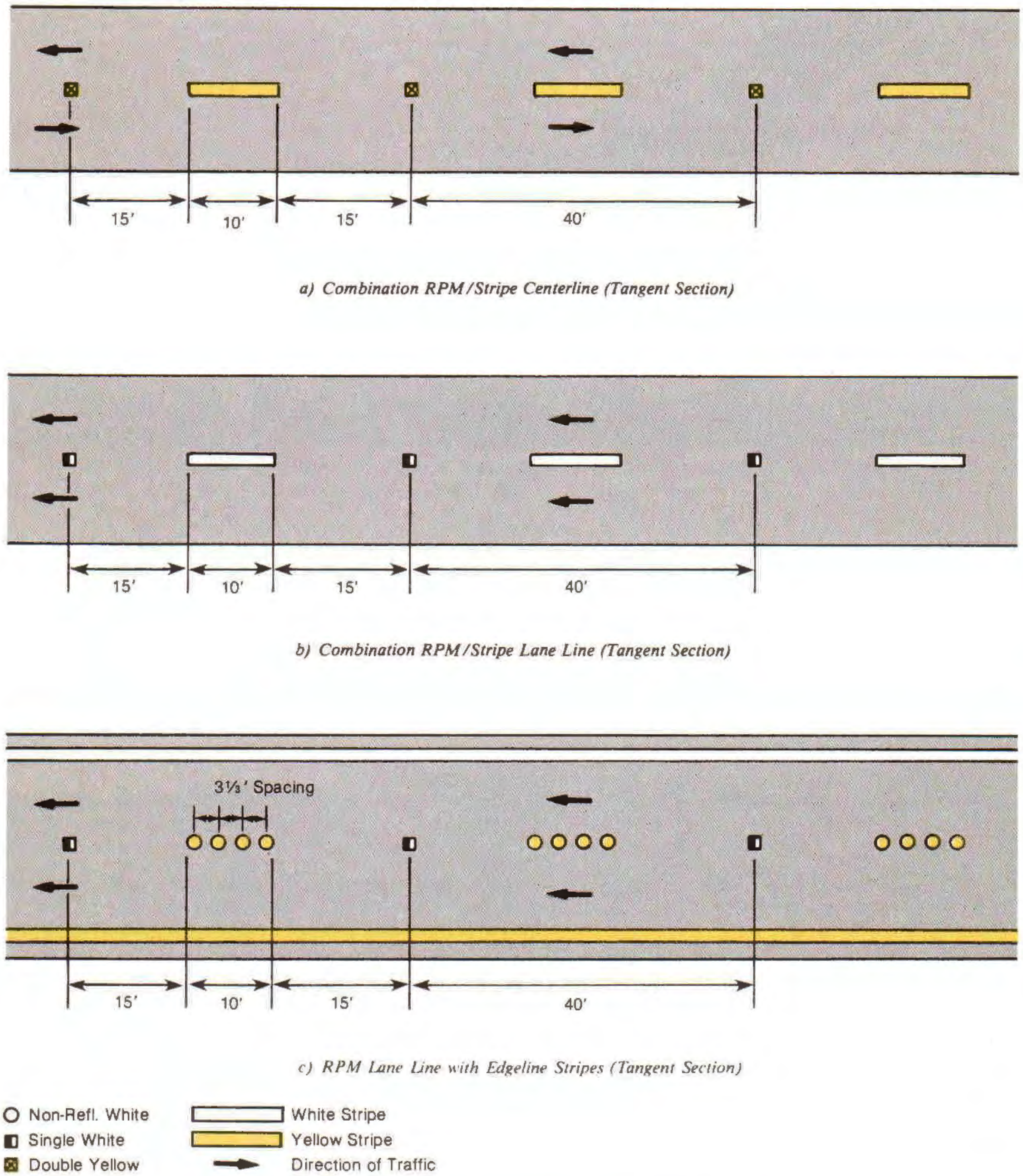


Figure 50. Marking Patterns for Freeway Ramps

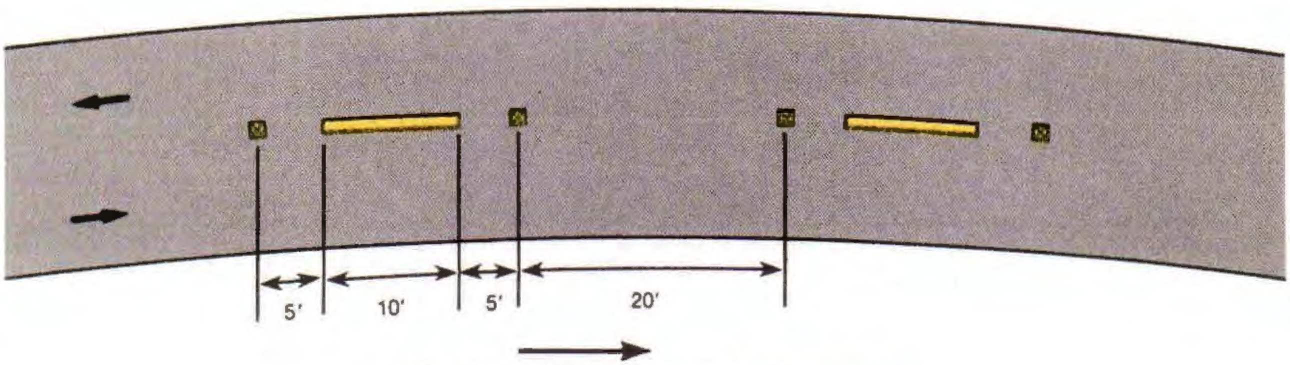


a) Combination RPM/Stripe Centerline (Tangent Section)

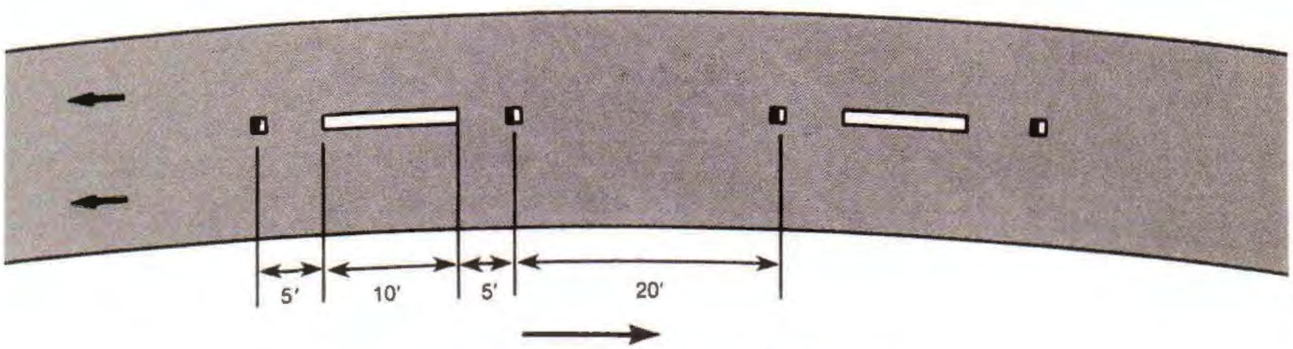
b) Combination RPM/Stripe Lane Line (Tangent Section)

c) RPM Lane Line with Edgeline Stripes (Tangent Section)

Figure 51. Marking Patterns for Construction Zones



d) Combination RPM/Stripe Centerline (Curve Section)
(No passing zones not shown)



e) Combination RPM/Stripe Laneline (Curve Section)

Single White
Double Yellow
White Line
Yellow Line
Direction of Traffic

Figure 51. Marking Patterns for Construction Zones (continued)

Chapter 6. Post Delineators

Daylight delineation of the roadside can generally be accomplished effectively with paint, thermoplastic, or raised pavement markers. Night visibility, however, often requires a different approach to provide "far" delineation of the roadway alignment and to assure adequate visibility during rain or snow which obscure on-the-pavement markings. Post delineators of various forms have gained wide acceptance as a roadside delineation treatment.

This chapter addresses the uses and types of post-mounted retroreflective delineators as defined in the MUTCD (Ref. 1). Object or hazard markings are not included since they are not considered an element of roadway delineation systems.

USES

The overriding purpose of post delineation is to outline the edges of the roadway and to accent critical locations. The uses of these devices have been accepted as an effective delineation and guidance device by the Federal Highway Administration, the Institute of Transportation Engineers, and the American Association of State Highway and Transportation Officials. As a result, roadside delineators are required on the Interstate System.

Specifically, the MUTCD defines these devices as follows:

> *"Road delineators are light-retroreflecting devices mounted at the side of the roadway, in series, to indicate the roadway alignment."*

These delineators are usually post-mounted 4 feet (1.2 m) above the pavement. Under normal atmospheric conditions, they should reflect light from a distance of 1,000 feet (305 m) when illuminated by the high beams of standard automobile headlights. The reflective element should have a minimum dimension of approximately 3 inches (7.6 cm).

The MUTCD further states that *". . . delineators shall be provided on the right side of expressway roadways and on at least one side of interchange ramps."* They are also recommended for use on certain median crossovers, acceleration/deceleration lanes, and transition situations.

On sections of roadways between interchanges where reliable fixed-source lighting is in operation, delineators are optional. Fixed overhead lighting which provides moderate to high ambient light levels tends to wash-out the reflectivity properties of the delineators rendering them ineffective at night.

In tangent sections delineators should be placed 200 to 500 feet (61 - 152 m) apart in a continuous line not less than 2 feet (0.6 m) or more than 6 feet (1.8 m) outside the edge of the usable shoulder. Delineators should also be placed on the outside of curves with a radius of 1,000 feet (305 m) or less including medians in divided highways and freeway ramp curves. The recommended spacing of delineators on curves is given in Table 6. Three delineators should be placed in advance of the curve and three beyond the curve. Curve spacing should be that three markers are always visible to the driver. Spacing between delineators on curves should not exceed 300 feet (91 m) nor be less than 20 feet (6 m). A typical installation is shown in Figure 52.

If there are guardrails at locations where delineators are warranted, the delineators are placed behind the guardrail. In this case, the guardrail reflectors may be eliminated.

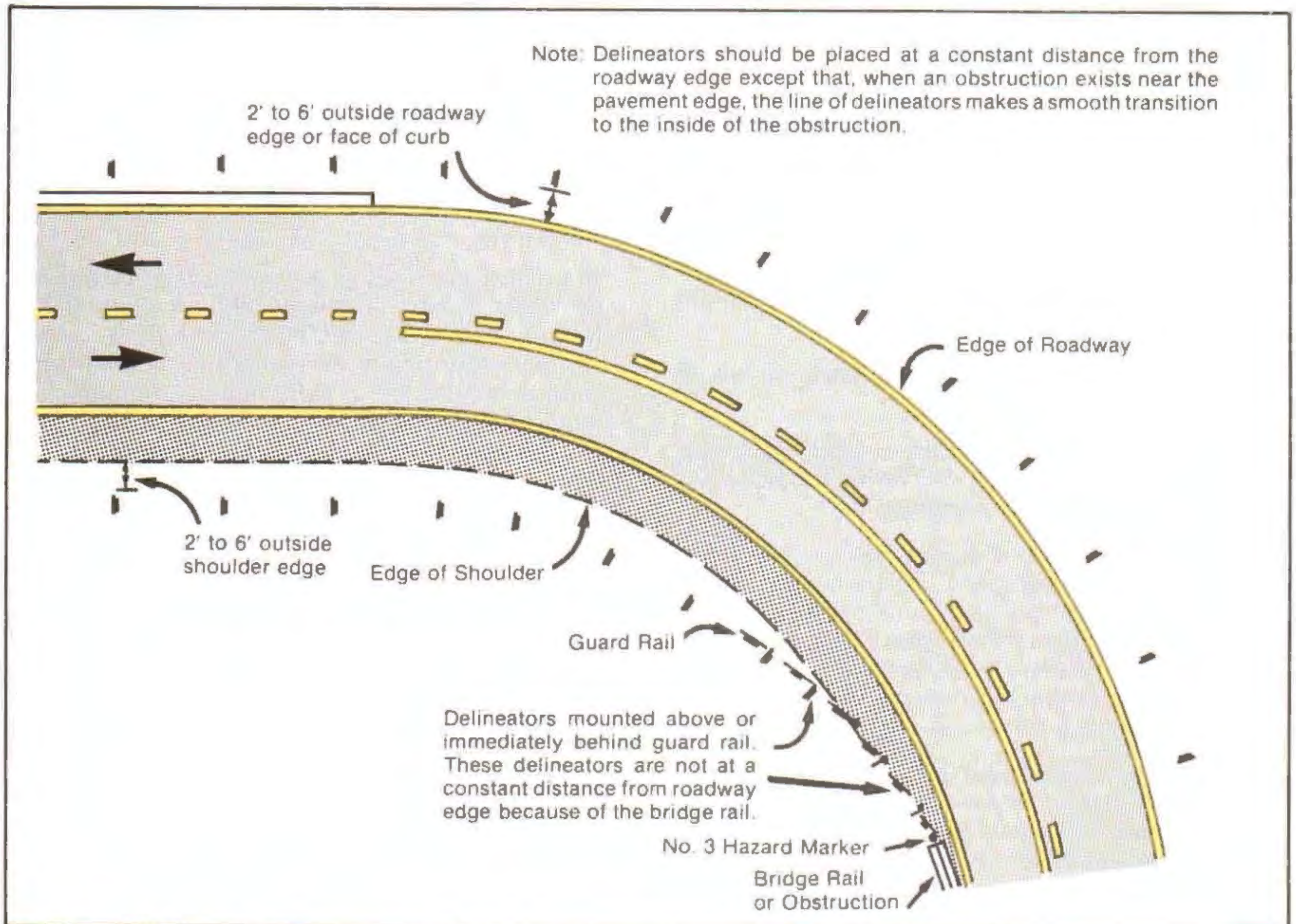
In all cases, the color of delineators must conform to the color of edge lines stipulated in the MUTCD Section 3B-6. The MUTCD standardizes certain characteristics such as mounting height, number and color of reflectors, criteria for reflective elements, and required locations. It does not, however, specifically address physical characteristics and spacing. The types of posts used and other functional considerations are to be determined by the local/state agency. Nonetheless, the MUTCD should be consulted to assure uniformity and consistency in usage.

In actual practice, there appears to be little consistency in the use of post delineators. Such requirements as height of marker and placement in relation to the shoulder are fairly well standardized. Most inconsistencies are likely to be found in the size, shape, and color of the reflective unit, the spacing between delineators, and the warrants for installation. Since the MUTCD is relatively permissive in these areas, the delineator systems not only vary from state to state but may vary between districts and even within districts. Although the safety aspects of roadway delineators have been established, the upgrading or standardizing of delineator usage is often assigned a low priority in this era of tight budgets. Tradeoffs among the various delineation techniques should be carefully evaluated

Table 6. Suggested Spacing for Delineators on Horizontal Curves

Curve Radius, R, feet	Spacing on Curve, S, feet*	Spacing Before and Beyond Curve, feet		
		1st 2S	2nd 3S	3rd 6S
50	20	40	60	120
150	30	60	90	180
200	35	70	105	210
250	40	80	120	240
300	50	100	150	300
400	55	110	165	300
500	65	130	195	300
600	70	140	210	300
700	75	150	225	300
800	80	160	240	300
900	85	170	255	300
1,000	90	180	270	300

$^*S = 3\sqrt{R - 50}$ 1 foot = 0.3048 metre



Source: Ref. 1
Feet = 0.3048 meter

Figure 52. Typical Delineator Installation on Horizontal Curves

to assure that the most "worth" is received for the cost. In this context, the value of "far" delineation and improved night visibility attained with post delineators for relatively low cost over the life of these devices should be recognized.

MATERIALS

A roadside delineator unit consists of a reflective element, the support or mounting post, and possibly a backplate. There is a variety of materials available for each of these components. The basic components and their physical characteristics are discussed below. The fundamental configuration of representative forms of delineators is illustrated in Figures 53 and 54.

Reflective Element

The most common reflective devices utilize either a glass bead impregnated sheeting or corner cube prismatic technique to provide retroreflection. In both cases, the optical elements are enclosed and sealed in a plastic housing or envelope (as shown on Figure 53) to retain the reflective properties when exposed to rain.

The corner-cube delineators are many times brighter than those made from reflective sheeting and white (clear) reflectors of either type are brighter than amber (yellow). Various configurations of the optical elements are used by the different manufacturers to obtain wide angle reflection. Representative patterns of commercially available reflectors are shown in Figure 54.

The reflective sheeting-type reflectors are available in the form of pressure-sensitive disks or mounted within an aluminum case. The version of this type of device shown in Figure 54 is characterized by a honey-comb pattern and provides an air gap between the top surface and the beaded layer.

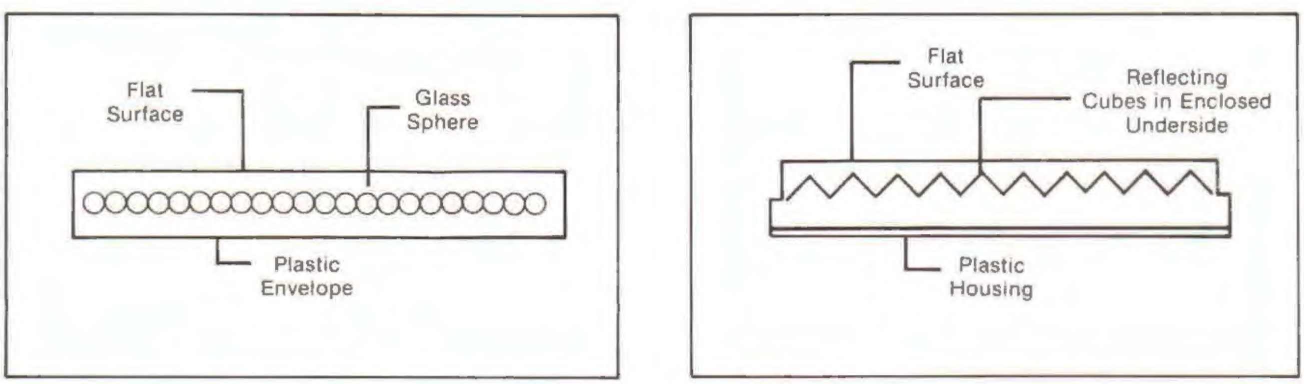
The typical corner-cube reflector consists of a clear and transparent plastic face covering 7 sq. in. (45 cm^2) of reflective area. A plastic coated metallic foil back is fused by heat and pressure to the reflective surface. The entire unit including the 3/16 inch (48 cm) grommet for center mounting is permanently sealed against dust, water, and water vapor.

Mounting Post

The types and materials comprising the support element of post delineators have traditionally been limited to 3-1/2 inch (9 cm) U channel iron post (usually galvanized), 3/4 inch (2 cm) standard black pipe, or 2 x 2 inch (5 x 5 cm) timber post, preferably cedar or redwood. Because of their proximity to the travelled way, post delineators are frequently hit by vehicles. Not only do these knockdowns present a costly time consuming maintenance problem, but they may represent a hazard to the impacting vehicle.

From a maintenance standpoint, the cost of replacement often reaches unacceptable levels. For example, California has approximately 600,000 post delineators in place that require 300,000 repairs annually. Many of these are multiple hits on post delineators that are hit several times a year. In 1978, California budgeted almost $1.6 million for their post delineator system maintenance. Cost of replacement can range from $6 each to as high as $8.00 (Ref. 52).

In recognition of the safety and cost consequences of these traditional post materials and configuration, new products have been investigated that would reduce the hazard as well as the replacement cost. The most promising approaches have included flexible posts that are relatively impact resistant, a yielding system that will stay down after impact, and the use of colored painted posts to prevent impact.



a) Glass Bead Reflector *b) Corner Cube Reflector*

Figure 53. Post Delineator Retroreflective Techniques

Flexible Delineation Post

The State of California tested a number of commercially developed plastic posts of two basic types: driveable, and non-driveable (Ref. 53). The driveable post can be driven into the ground like a metal post and requires considerably less work and time to install than the non-driveable post. The non-driveable post category of products can be further divided into those requiring and those not requiring backfilling in the interior as well as around the outside of the post. These flexible units are equipped with reflectorized sheeting rather than reflective buttons to prevent damage to the unit on impact.

Each of these posts were subjected to up to ten 55 mph (89 km/hr) vehicular impacts. While some posts reacted better than others, generally, the test program demonstrated conclusively that impact resistant plastic delineation posts are a viable alternative to the rigid steel post. Tests are continuing to evaluate the long time service durability of the materials under various environmental conditions. The design and specifications for these flexible posts are provided in Appendix E.

Caltrans recommended that flexible posts be used in areas where the expected life of a metal post is less than one year and at locations involving short radius curves and high approach speeds.

Yielding Structural Support System

The Wyoming Highway Department in cooperation with the Federal Highway Administration has developed a two-part delineator post that has no recoil and will stay down after impact. The anchor is a triplex socket consisting of a shaft and stabilizer fins to hold it rigid in the ground. The post, which slips into the anchor may be a 1 1/2 inch (4 cm) OD thin walled electrical metal conduit or a 1 1/2 inch (4 cm) ID high density plastic polyethylene tubing fitted over a 24 inch (61 cm) piece of metal conduit.

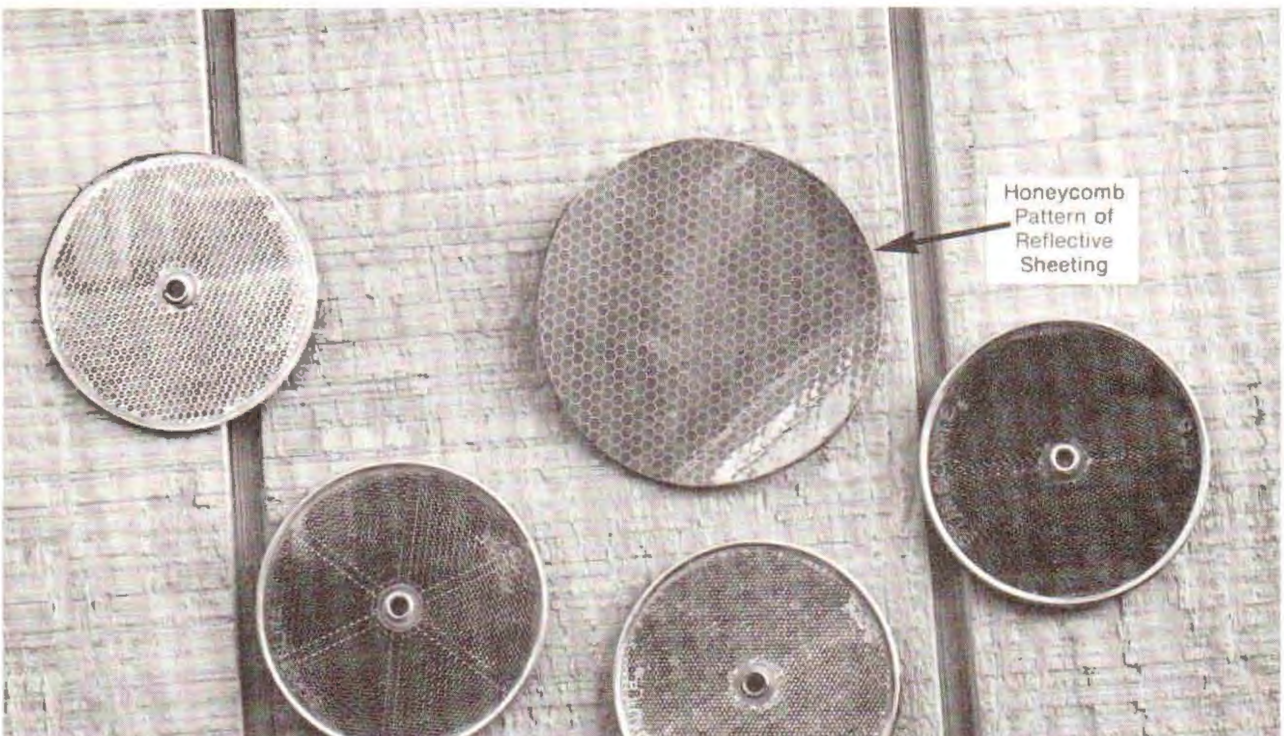


Figure 54. Representative Retroreflective Elements

Three holes are punched in the pipe 4 inches (10 cm) from the bottom to insure it will lie flat when hit. A small portion of the pipe is not broken but only bent. This acts to keep the pieces together and prevent the broken pipe from flying through the air after impact.

The electrical metal conduit may be reused up to 3 times when installed in speed areas of 40 mph (68 km/hr) or less. The broken end is simply cut square, new holes are punched, and the post reinserted in the anchor. The polyethylene assembly may be reused a number of times by replacing the 24-inch (61 cm) metal sleeve.

Wyoming estimates a per unit cost of $3.25 for the metal conduit post and $4.25 for the polyethylene unit. With labor of installation included, the cost should be about $4.50 and $5.75 respectively. The cost of replacement including labor is expected to be less than $2.00 each. The Wyoming Highway Department has recommended that other agencies consider implementation of this system as a safe and cost-effective alternative to the steel post (Ref. 52). The design of this system is included in Appendix E.

PERFORMANCE

In terms of visibility and durability, most forms of post delineators score exceptionally well in both categories. As mentioned earlier, the corner cube type reflector provides more nighttime brightness than reflective sheeting, but both provide adequate far delineation particularly in adverse weather and low visibility conditions. They are not effective in areas with moderate to high ambient light levels; therefore they are not recommended for use with reliable fixed roadway illumination.

It has long been recognized that post delineators have a long life expectancy provided they are kept clean and are not damaged by encroaching vehicles. A field conducted in Australia (Ref. 55) using low-beam headlights showed that dirt accumulation and aging could reduce night visibility from approximately 1,000 feet (3,281 m) to 100 feet (328 m).

There is little question that roadway film and dirt have an important impact on the performance of post delineators. This is not a permanent condition in that the reflectors can be hand or machine washed, and rain will clean them to some extent. Generally, the expected service life of post delineators averages approximately 10 years if knockdowns and vandalism are not considered.

APPLICATION

Conventional roadside post delineators are formed by affixing a 3 inch (1.2 cm) reflector button on the face of a 4 foot (1.2 m) high delineator post. Reflector buttons may also be placed on a 8 x 24 inch (20 x 61 cm) or 3 1/2 x 1/2 inch (9 x 3 cm) metal target plate with one, two, or three holes drilled for fastening the reflector(s) to the plate by means of aluminum rivets.

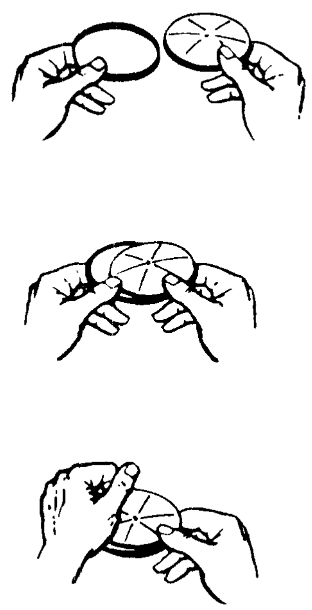
If the center-mount reflective unit is to be enclosed in an aluminum back case, the reflector is slipped into the rim of the case and snapped into place for permanent locking as shown in Figure 55.

The circular, honeycombed plastic enclosed reflective sheeting disk is pressure sensitive and is applied simply by removing the backing and pressing it into place on the target.

Special equipment is available to mechanically drive the steel post into the ground. This relatively expensive equipment is usually used only for large scale installations. Normally, maintenance forces will install the posts with hammer and driving head or with some form of top-weighted driving head with handles on each side to exert the necessary downward force.

These posts are usually driven 2 feet (0.6 m) below the surface with 4 feet (1.2 m) remaining above the pavement. Figure 56 is a cross-section of positioning of a delineator with and without a dike or curb.

The large white-faced target plates are primarily used when daylight route guidance is needed. Where post delineation is required in the vicinity of a guardrail such as on horizontal curves, the pattern should continue uninterrupted through the guardrail section.



1. Hold as shown
2. Slip one edge of reflector firm against inside rim.
3. Force with thumb and with heal of palm along side, snap into place for permanent locking

Figure 55. Encasing Center-Mount Reflector in Aluminum Back Case

MAINTENANCE

Post delineators are highly susceptible to knock-downs, vandalism, and theft. Bent or missing delineators obviously needing attention should be repaired promptly in order to serve their intended purpose. This is particularly urgent where the bent or knocked-down post protrudes in or near the travelled way.

As indicated earlier, "road splash" and dirt can degrade the visibility of the reflective units to an unacceptable level although the reflective properties are still intact when clean. Some agencies have developed methods for washing these reflectors during dry periods. These techniques range from simple watering under pressure to a revolving brush device.

Post delineators are also vulnerable to damage from heavy snowdrifts, snowplows, and other roadside maintenance vehicles. Maintenance crews should be instructed to return to a plumb position posts that have been inadvertently hit by equipment during other maintenance activities.

In high snowfall areas, the condition of post delineators should be routinely observed at the end of the snow season. Replacement and maintenance should be scheduled for those severely damaged by snowplow equipment or bent askew from the weight of the snow pushed onto the shoulder by the plows.

Prior to the beginning of the snowfall season, many agencies install snow poles to extend the delineator above the height of the expected snow drift. It is a relatively simple procedure to attach the snow pole by means of two brackets and associated bolts and washers which fit existing holes. The removal of extended snow poles in the spring can be combined with cleaning, replacement or other delineator-oriented maintenance.

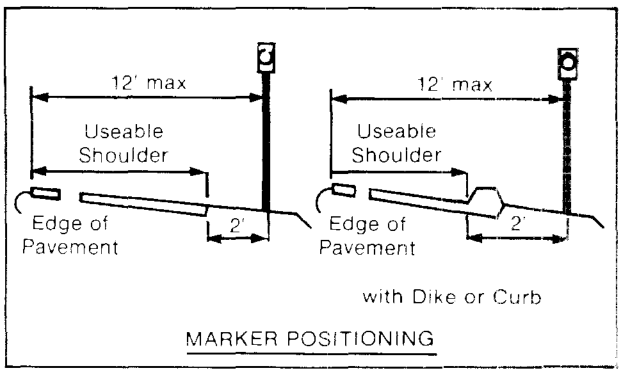


Figure 56. Typical Marker Positioning

Maintenance for post delineators does not ordinarily require a large crew or complex equipment. Because the posts are located slightly off the shoulder, there may be a tendency to forego proper safety precautions while conducting the work. While lane closure or coning may not be required in all cases, protection of the workers by signing or a strategically-placed service vehicle is strongly recommended. Vehicle encroachment onto the shoulder is too common to be ignored.

Lastly, the long life of post delineators may result in a low priority of maintenance for these devices. Lack of prompt attention to the replacement of missing delineators or damaged posts may ultimately prove costly. In extreme weather, post delineators are often the only means of guidance available to the driver. The high priority assigned to the installation of this form of delineation is equally applicable to an effective level of maintenance.

Colored Delineator Posts

Based on the obvious conclusion that the safety hazard and replacement cost of knock-down posts could be eliminated or significantly reduced if the post was not hit in the first place, several agencies have experimentated with using a colored delineator post in place of silver colored galvanized or aluminum posts. Green, orange, white, and yellow-painted posts have been tested. The yellow posts appear to provide better distance visibility when used as both sign supports and delineator posts.

Tests conducted in Houston, Texas (Ref. 54) indicated a 49 percent increase in daytime distance visibility and a 30 percent nighttime increase. During a ten-month before and ten-month after study, the number of knock-downs of sign supports were decreased from 24 to 10. Later studies at different sites within Texas have typically reported a 50 percent reduction in knock-downs.

After a year of testing, yellow sign and delineator posts are considered standard in Texas and have attracted interest nationally.

Chapter 7. Administration and Management Factors

The design, application, and maintenance of an effective roadway delineation system requires a thorough knowledge of drivers' needs in general and as specifically dictated by the geometry and traffic characteristics of the particular roadway. Of equal importance is awareness of the standards, warrants, and legal implications related to the agency's responsibility to ". . . *maintain the highway in a reasonably safe condition.*" Added to this is the multitude of delineation techniques and technologies which can be applied to provide the type and level of delineation that will satisfy drivers' needs in a particular roadway environment.

Under Utopian conditions of unlimited budgets, it would be a relatively simple task to provide and maintain safe and convenient highway facilities. Certainly, technology is responsive to the challenge, traffic departments have the requisite skills, and research is continually furthering the state-of-the-art. Unfortunately, the limited amount of dollars available to satisfy the growing demand for services in all levels of government requires a delicate balance between requirements and the cost benefits of the alternatives for meeting these requirements. Consequently, the role of administration and management becomes more demanding and complex.

This chapter focuses on some of the administrative and management considerations associated with roadway delineation. These include the implication of legal responsibilities, the availability of Federal funding, cost saving procurement practices, the use of agency forces versus contract work, and special treatments associated with the field of delineation.

LEGAL CONSIDERATIONS

Until recently, government entities were generally immune from lawsuits on the theory of "sovereign immunity" derived from English common law. Under the sovereign immunity doctrine, a government entity may only be sued if it consents to the suit in advance. Over the past 25 years this situation has changed dramatically. Sovereign immunity has been eroded through the actions of courts and/or legislatures and now survives in only fifteen states. Consequently, many state highway departments have become vulnerable to lawsuits for damages resulting from highway accidents.

Because of these changes in legal doctrine, traffic and maintenance engineers are increasingly involved in a field of litigation that was recently of concern only to attorneys. Today, it is necessary that state highway department and local transportation agency staffs become aware and keep abreast of highway law in general and the legal elements of functional operational practices in particular. Accordingly, the fundamental legal considerations involved in roadway delineation practices have been included here to provide a basic understanding of the purpose, intent, and direction of current tort liability.

This discussion of legal considerations in the administration and management of roadway delineation systems is a very basic treatment of a very complex subject. It is not meant to interpret the law or establish guidelines. It is intended only to alert transportation agencies of the need to recognize and respond to the possible consequences of failure to maintain and safeguard the highway system.

There are numerous reports and references prepared by legal staffs that can be consulted for more definitive information. The Institute of Transportation Engineers (ITE) has developed a one-day seminar as part of its Continuing Education Program entitled "Traffic Improvements - Legal Aspects and Liability" that is intended to upgrade and expand awareness among operating and maintenance personnel (Ref. 56). In addition, the legal staffs of state agencies can often be called upon to interpret to operating units the statutes applicable to their functions and to suggest ways to avoid tort litigation.

Definition of Tort Liability

Essentially, the legal responsibilities of agencies involved in designing, operating, and maintaining roadways arise from the principles of tort law. Some of these fundamental principles are briefly explained below.

> A *tort* in legal terminology is a ". . . civil wrong, other than breach of contract, for which a court of law will provide a remedy in the form of an action for money damages" (Ref. 57). Torts can be either intentional (e.g., assault and battery, false imprisonment, trespass, and theft) or unintentional (e.g., negligence). The primary grounds for tort liability of concern to highway agencies are allegations of negligence.
>
> *Liability* means the legal obligation of the tortfeasor (the negligent party) to pay money damages to the victim. More than one person or organiza-

tion may be liable for damages arising out of the same event. In the case of negligent conduct by an employee, both the employee and the employer may be held liable for damages, even when the employer is a government.

Negligence can be defined as the omission to do something which a "reasonable person" would ordinarily do, or the doing of something which a reasonably prudent person would not do. Negligent conduct is that conduct which creates an unreasonable risk of harm to others to whom is owed a duty of exercising care.

Contributory negligence is conduct by the plaintiff which falls below the standard of care which persons are legally required to exercise for their own safety and the safety of others, and which is a legally significant contributing cause of the plaintiff's damages. In a jurisdiction which has not adopted the comparative contributory negligence procedure which is described below, a negligent defendant may totally escape liability for the plaintiff's damages if the defendant can establish contributory negligence in the conduct of the plaintiff, which helped cause the damages suffered. This is sometimes known as the all-or-nothing rule.

Comparative negligence is a modern alteration of the strict contributory negligence rule which bars recovery by negligent plaintiffs. Under the comparative contributory negligence system, a negligent defendent becomes liable for plaintiff's damages, but the amount of those damages is reduced by the proportion of "fault" or negligence attributed to the plaintiff in causing the action. Thus, in an accident which is judged to have been the result of 40 percent plaintiff's negligence and 60 percent defendant's negligence, and the plaintiff suffered $10,000 damages, the plaintiff would receive from defendant $10,000 less 40 percent, or $6,000 total. In a jurisdiction which has not adopted the comparative negligence procedure, the plaintiff would not recover at all, since plaintiff's contributory negligence (in any proportion) constitutes an absolute bar to recovery of damages. Of the fifteen western states, only Arizona and New Mexico have failed to adopt the comparative contributory negligence system.

The *reasonable person* (sometimes called the "reasonable man," the "ordinarily prudent person," the "ordinary man," and so on) is a device used to set the standard of care by which conduct is judged negligent. In effect, this device imposes a test of negligence as being the "failure to use ordinary care." This is the test most often used in determining liability. In the context of this handbook, it can be said that an engineer would be found to be negligent if his or her conduct did not measure up to that of a hypothetical reasonable, prudent, and careful engineer under similar circumstances.

Duty in tort law is an obligation requiring persons to conform to a certain standard of conduct, for the protection of others against unreasonable risks. Negligence is a breach of the duty to exercise reasonable care owed to those persons to which the duty applies. In this context, a highway department owes a duty to all travelers on the highway to avoid creating unreasonable risks for those travelers, and to meet the standard of care imposed upon that department.

The *Standard of Care* for any person is set by a multitude of factors. At the bare minimum, all persons are required to avoid the creation of unreasonable risks, where feasible. In addition, statutes and regulations governing conduct are also components of the standard of care by which conduct is judged. For example, failing to observe a STOP sign is not only an infraction, but also a failure to meet the standard of care which sets the boundaries of liability. A violation of a safety statute is considered to be negligence per se (negligence in itself).

Finally, and perhaps most importantly, the accepted standards and practices of a profession, trade, or industry also define the standard of care by which conduct is judged. Included in the definition of "accepted standards and practices" is the *Manual on Uniform Traffic Control Devices* (MUTCD) and other similar national and local standards. In general, "a violation of a uniform law or regulation may be evidence of negligence or may constitute negligence per se" (Ref. 54). In the Highway Safety Act of 1966, the MUTCD was adopted as a national engineering standard. Although technically a federal regulation, not a statute, many states have incorporated the MUTCD standards into their own state laws, with the full force and effect of statutes in that jurisdiction. A failure by government personnel to conform with the requirements of the MUTCD would probably be sufficient to establish negligence (and therefore liability) as a matter of law, should an accident be the result of that failure to conform.

To place the above concepts in perspective, it is necessary to recognize the following characteristics of tort liability:

- The most common tort is negligence.
- Negligence is the failure to use reasonable care in one's actions.
- Court decisions in tort claims are based on the concept of the existence of a "Reasonable Prudent Man" exercising "ordinary care."

- Negligence is the failure to use reasonable care in one's conduct, constituting a breach of legal duty.
- Negligence is established by a failure to meet the standard set by the hypothetical "reasonable person" exercising ordinary prudent care.

In effect, this means that the injured plaintiff bringing suit must prove the following in a negligence case arising from a highway accident:

- The defendant (agency, engineer) had a legal duty to exercise reasonable care towards the plaintiff (victim).
- The defendant was negligent (defendant's conduct failed to meet the standard of reasonable, ordinary care), breaching that duty.
- Plaintiff's damages (injuries, property damage, pain and suffering, loss of income, etc.) were caused by the breach (defendant's negligence), and were the foreseeable result of that breach.
- Finally, the plaintiff must not have been contributorily negligent to recover all of the damages suffered.

Legal Duty and Liability

Government officials and employees concerned with highway construction and maintenance have definite obligations to the public, that is, certain duties imposed specifically or generally by law. Basically, there is a recognized duty to maintain the roadway in a reasonably safe condition. This involves inspection, anticipation of defects, and conformity with generally accepted standards and practices. There is no requirement for *perfect* conditions of repair or for actions "beyond the limits of human ingenuity."

To understand the application of the concepts of legal duty, it is necessary to recognize the distinctions between discretionary acts and non-discretionary (ministerial) acts. Many states which no longer retain the sovereign immunity doctrine described above have enacted Tort Claims Acts which prescribe the conditions under which states, their agencies, and their employees may be held accountable for their torts. These acts typically include a limited exemption from liability for negligence in the performance of (or the failure to perform) so-called *discretionary* activities.

The term "discretionary" refers to the power and duty to make an informed choice among competing valid alternatives; it requires the exercise of due consideration and independent expert judgment in choosing a course of action or arriving at a decision. On the other hand, "ministerial" duties generally involve clearly defined mandatory tasks performed with a minimal amount of personal judgment or evaluation of alternatives. In modern law, the distinctions between discretionary and ministerial functions are of great importance in adjudicating tort claims against government entities. In general, a public organization or its employees are not liable for negligence in the performance of discretionary activities. However, the courts are involved in a constant revision of the law in these areas, and the classification of a particular governmental activity as either discretionary or ministerial is constantly subject to shifting legal interpretations.

It must also be strongly emphasized that the limited exemptions from liability which have been afforded to discretionary activities in no way provide absolute protection from legal liability. If discretion is abused or exercised recklessly or unjustly, courts may move in and substitute their own discretion for that of the agency, in order to reach a particular result in a particular case.

However, the cases are fairly uniform in holding that the design of highways is a discretionary government function, because it involves high-level planning activity and evaluation of policies, competing alternatives, and other factors. This conclusion is supported by decisions which hold that design functions are quasi-legislative in character and must be protected from the "second guessing" of inexpert courts. Absent an abuse of discretion sufficient to justify a court in resorting to "second guessing," most roadway design issues remain within the primary control of engineers. In a further effort to immunize state agencies and employees from tort liability, some legislatures have passed specific design immunity statutes which further isolate from legal activity designs which are properly approved.

Notice of Defect

The duty of the agency to correct a dangerous condition arises when it has actual or constructive notice of the hazard. Most courts hold that the state must have had notice of the defect or hazard for a sufficient or reasonable time "to afford them a reasonable opportunity to repair the condition or take precautions against the danger". When the dangerous condition is the result of the state's own negligence, the notice requirement does not apply. It is not necessary for the state to have notice of faulty construction, maintenance, or repair of its highways, because the state is deemed to know of its own actions. However, if the danger did not occur as a consequence of the active negligence of the public entity, it has the duty to repair once it has actual or constructive notice of the defect.

Statutes may require that states have notice of the condition for a specified period of time. If, for example, the notice period is five days, and an accident was caused by a defect that originated early in the day of the accident, the statutory notice period would not be satisfied and the agency would not have had a reasonable opportunity to effect repairs. The notice must be of the particular defect which caused the accident, not merely of conditions that may produce and subsequently do produce the highway defect. In this example, the statutory period may be considered satisfied if the state had actual knowledge of the unsafe condition.

Finally, the notice may exist where the condition has existed for such a time and is of such a nature that the state should have discovered the condition by reasonable diligence. In that instance, the notice is said to be constructive, and the state's knowledge of the condition is said to be implied. The courts may consider, in deciding whether the state had notice, whether the defect was latent and difficult to discover. That is, the court will consider the nature of the defect, its location and duration, the extent and use of the highway, and whether the defect could be readily and instantly perceived.

Maintenance of Delineation Systems

The legal implications of delineation system maintenance are suggested by the wording of the MUTCD. Only in the case of the Interstate system is the installation of delineation markings mandated (by use of the word "shall"). In most cases, the MUTCD does not specifically state that markings are required. It appears to leave the decision of installing markings to the discretion of the states or cognizant agencies.

The duty of governmental agencies to install and maintain highway pavement markings is summarized as follows:

- "In the absence of a statute, it has been held that there is no general duty of a state or other governmental unit to install or provide highway signs, lights, or markings. . . ."
- "However, the duty to provide warnings, lights, or markings may arise where the particular highway presents an unusual, dangerous condition. . . ."
- "Although there may be no duty to install warnings, signals, or markings in the first instance, once installed, there is a duty to maintain them in good serviceable condition" (Ref. 59).

Implications for State and Local Agencies

The incidence of civil litigation, primarily in the area of tort law, has increased by many orders of magnitude in the last decade. This strong tendency toward legal action is closely associated with a trend towards large awards to litigants. For example, the June 6, 1977 issue of BUSINESS WEEK noted that Federal Court civil cases have increased by 84 percent in the last ten years. A February 20, 1978 article in TIME is quoted as saying that the first million dollar tort judgment was awarded in 1962, with 59 more from 1962 to 1972. Another 145 such judgments were recorded in the five year period from 1972 to 1977.

The increasing trend to litigation and large awards coupled with the erosion of sovereign immunity for governmental agencies poses critical problems for highway departments. A good example of these impacts is the experience of California.

The State of California lost its sovereign immunity by a 1961 ruling of the state Supreme Court. At that time, there was one full-time attorney assigned to handle damage claims for the Department of Transportation (Caltrans). In that year of 1960-1961, there were 193 claims totaling $10 million. Following the passage of the California Tort Claims Act in 1963, Caltrans began to experience a rapid increase in tort claims. By 1976, the Department had 40 full-time attorneys and 18 full-time investigators. In early 1978, Caltrans had 65 attorneys assigned to handle the Department's tort claims. There were 1,048 lawsuits pending, claiming a total of $981 million in damages. An AASHTO survey in 1978 reported over 8,000 tort claims against all state transportation agencies totaling $2.414 billion (Ref. 60).

The increase in claims and awards has also resulted in an increase in the cost of liability insurance, where it was not cancelled outright. Deductibles have been raised to multimillion dollar levels in some cases, and some states have had to self-insure.

It should be self-evident that it is more desirable to expend limited public funds in sound management and proper maintenance of the roadway system rather than in payment of adverse judgments. Consequently, it would seem appropriate to review maintenance activities and reporting procedures to limit exposure to tort liability. It would also be helpful to assure that all agency employees involved in such activities are well informed of the legal implications of their functions.

FUNDING AVAILABILITY

One of the major concerns facing transportation agencies is obtaining the adequate funding for their various programs. While the courts are quick to point out inefficiencies in the form of negligence decisions, these inefficiencies most often stem from lack of adequate budget or funds rather than inattention to standard engineering practices. In many cases, there is simply not enough money available to support all of the desired programs.

In recognition of this nationwide problem, Federal funds have been made available to assist states under various programs. These funds are in addition to the Federal effort in research and development of new technology. A significant Federal program which provides funding for delineation-related activities is the Highway Safety Act of 1973 (as amended) as codified in 23 USC 151. This Act emphasizes improving safety on rural roads where about two-thirds of all traffic deaths and severe injury occur.

Pavement Marking Demonstration Program (23 U.S.C. 151)

Under the Section 205 Pavement Marking Demonstration Program (PMD), 100 percent Federal funds are available for activities such as painting centerlines and edgelines on roads, off and on the Federal-Aid System (except Interstate). Any hard surface road may be marked.

The PMD program is intended to give impetus through Federal aid to wider use of pavement markings since the installation of such roadway markings have effectively reduced fatalities and injury accidents. During the past two fiscal years, over 218,000 miles (339,319 km) have been marked under this program with approximately 155,061 miles (249,540 km) remaining to be marked (Table 7).

In addition to painted centerlines and edgelines, other forms and types of pavement markings were eligible under this program including thermoplastic markings and raised pavement markers; markers in advance of rail-highway grade crossings; roadside delineators; and school zone, pedestrian crossing, and stop bar markings. According to the Secretary of Transportation's 1979 Annual Report on Highway Safety Improvement Programs (Ref. 61). Approximately 25 percent of Pavement Marking Demonstration funds were used for these eligible items.

As an example of the extremes, in FY 1977 Massachusetts used Pavement Marking Demonstration funds, only for painting edgelines and centerlines, while Louisiana used all its funds to supplement existing painted centerlines with raised pavement markings.

From data reported by 49 States, approximately 60 percent of the 111,000 miles marked in FY 1979 were on the Federal-aid system. Slightly less than half of the 155,000 miles remaining to be marked are on the Federal-aid system. This indicates that, of the total mileage to be marked, the roads on the Federal-aid system are being marked more expeditiously than the mileage off the Federal-aid system. This could be expected since the roadways off the Federal Aid System would likely have lower ADTs and, therefore, lower priorities. Almost half of the miles marked in FY 1978 were marked for the first time.

Table 7. Miles of Markings by Demonstration Program Pavement Marking Highway System

HIGHWAY SYSTEM	MILES MARKED				MILES TO BE MARKED *	(%)
	FY 1977*	(%)	FY 1978**	(%)		
Federal-aid Primary	17,145	16.0	23,193	20.9	16,195	10.4
Federal-aid Secondary	54,056	50.5	42,389	38.3	51,066	33.0
Federal-aid Urban	675	0.6	2,518	2.3	6,332	4.1
Total Federal-aid	71,876	67.2	68,100	61.5	73,593	47.5
Off Federal-aid State	4,966	4.6	1,172	1.1	6,099	3.9
Off Federal-aid Local	30,000	28.0	41,468	37.4	74,887	48.3
Total Off Federal-aid	34,966	32.7	42,640	38.5	80,986	52.2
TOTAL	106,980 +	100.0 +	110,740	100.0	155,061 +	100.0 +

* 43 States Reported
** 49 States Reported
+ Columns do not add to totals due to some States not reporting mileage by system.

From a funding standpoint, since the beginning of the program only 18 percent of the funds have been earmarked for Federal Aid Primary or Urban systems in accordance with the legislative intent to upgrade rural roadways. The allocations are also about equally divided between state and local roads.

Section 402, Title 23 USC, Highway Safety Programs

Provisions in the 1973 Highway Act extend the on-going safety program begun as a result of the 1966 Highway Safety Act for certain support activities. Under Section 402, up to 100 percent funding in the form of State and Community Grants may be available for the use of cities and states in pavement marking activities.

The Governor's Highway Safety Representative in each state is directly responsible for all 402 projects — this includes project review, priority assignment and inclusion in the state's annual work plan which is submitted to the Federal Highway Administration for final funding approval. The Governor's Highway Safety Representative will furnish information regarding Federal and State criteria for participation in the Program, and procedures for preparation of a project proposal known as a "sub-element plan".

As criteria and procedures may vary from state to state, time and money will be saved by careful attention to given instructions. It is important to note that Federal Highway Administration sources state that small, neighboring communities can substantially increase chances for funding approval if their project is a group venture. If communities group together, greater utilization of the equipment is likely, thereby maximizing the cost effectiveness of the investment.

Applying for Section 402 Funding

The sub-element plan is a formal presentation which describes the potential project in detail. The following information should be included:

1. Project Description - A brief statement which describes the proposed project and the benefits expected from it.
2. Effectiveness Statement - Project goals should be stated in relation to highway safety. Effectiveness is of particular significance when applying for funding under Section 402, and should be documented, if possible, with accurate statistical data. The report Tests of Striping Effectiveness, testimony before the Transportation Subcommittees of both the House of Representatives and the Senate, and the report of the Committee on Public Works which accompanied the Highway Safety Act to the floor of the House can provide background data (Ref. 57).
3. Project Operation Responsibility - An assignment of responsibility to an agency within the jurisdiction (or group of jurisdictions), to oversee project implementation.
4. Cost Estimates Per Quarter - All costs involved must be itemized by quarters. Included is rental or purchase of equipment, initial training and salaries of the operating crew, purchase of supplies and other related expenditures. Expenses incurred as a result of the project, other than rental or purchase of equipment and the initial training of the operating crew, must be assumed by the participating state or community. The ability to meet such obligations should be documented. The 205 Program funds may be used for this purpose.

Since the number of proposed projects generally exceeds the limited 402 funds available, a project's chances for funding approval will be substantially increased by comprehensive and accurate preparation. Many potentially worthwhile projects have been denied funding approval due to inaccurate and incomplete planning. Of primary importance is the coordination with the Governor's Highway Safety Representative during the development of the project statement.

Authorities should keep in mind that priority assignments are generally given to projects where favorable cost/benefit ratios are shown. Final funding approval may depend upon accurate and comprehensive statistical documentation. Every effort should be made to compile the following data for the jurisdiction or group of jurisdictions requesting the Federal aid:

- *Miles of Paved Roadway* - Total mileage of all paved roads, on or off the Federal-Aid System, having a surface width of 16 feet or more, and an average daily traffic volume of at least 250 vehicles. If the project emphasizes marking two-lane rural roads, it will likely receive higher priority. The Interstate System must be excluded.
- *Miles of Marked Paved Roadway* - Total mileage of paved roads with pavement markings conforming to the Manual on Uniform Traffic Control Devices.
- *Miles of Unmarked Paved Roadway* - Total mileage of unpaved roads without pavement markings, or with pavement markings which do not conform to the Manual on Uniform Traffic Control Devices.
- *Traffic Volume* - Day and night count should be made, if possible.

- *Traffic Accidents* - Pavement markings specifically mitigate against head-on collisions, running off-the-road accidents and sideswiping. Data on the occurence and severity of such accidents is important.

- *High Accident Locations* - Accidents frequently occur at hazardous locations which lack adequate pavement markings.

Information regarding methods of statistical compilation and available data sources can usually be obtained from the State Highway Engineer.

PROCUREMENT PRACTICES

Standard purchasing procedures used by individual agencies have evolved over the years often without periodic review to ascertain whether all possible economies have been realized. In addition, procurement policies have not been updated to reflect changing conditions. This section discusses some of the considerations and tradeoffs involved in the purchase of materials and equipment and the best use of contractor forces.

Quantity Purchase of Materials

In purchasing materials such as paint, thermoplastics, markers or delineators, quantity discounts are generally available from suppliers. For example, a one-way reflective raised marker may cost $1.75 each when purchased in quantities of 1 to 99. When purchasing lots of 5,000 markers, the unit price is reduced to about $1.25. This would result in a savings of $2,500 when purchased in lots of 5,000. Extremely large scale purchases would reduce the unit cost even more.

Many states establish an arrangement with the supplier whereby materials will be furnished to local agencies by the supplier at the quantity prices quoted the state. This "buying off the state contract" requires an estimate of quantity that may be needed and acceptance of the materials as specified by the State.

Interagency purchases is another method used by state and local agencies to obtain lower unit prices. In this case, the state will prepare the specifications, test the materials, select the contractor. Local agencies are then allowed to buy material directly from the state. There is frequently a small surcharge to cover the state's administrative expenses in handling the paper work. For instance, Wisconsin allows city and county units to purchase materials which are distributed from state warehouses for state cost plus a 5 percent surcharge. New York, on the other hand, allows local agencies to order through the state, without surcharge.

Where the state makes no provision for bulk purchasing to accommodate local agencies, local/regional agencies can band together in a cooperative purchase effort. Even if agencies are purchasing direct from the supplier, it is generally cost effective to purchase those materials with a long shelf life in sufficient quantity to obtain the unit discount. This may mean space problems in storing, however. In case of paint, small agencies can purchase one or more years supply of paint (depending on shelf life) to be delivered at specified times throughout the period. Because material may be damaged or may deteriorate in storage, the savings in unit cost must be balanced against the potential waste.

Another consideration that will effect the cost of materials is the size and type of packaging. Small sacks, pails, or cartons may prove to be easier to handle and store, but may cost too much more than larger containers to justify their use. (See the discussion on Storing and Warehousing, Page 28).

Inventory and Recordkeeping

Good business practice dictates the maintaining of an adequate and well-documented inventory of supplies and materials. This, of course, requires proper planning and scheduling. Shortages can foul up scheduled maintenance activities and/or require emergency purchases at inflated prices.

In general practice, the anticipated volume of materials is established in budget preparation activities. Frequently, however, the budgeted item is based on some traditional "rule of thumb" such as last year's usage plus a percent increase. Where good historical records are available as a basis, this practice may suffice.

It is more likely that the budget cuts being experienced in today's environment are such that project and activity priorities become more important. In addition, it is becoming increasingly difficult to estimate with reasonable accuracy future cost on the basis of last year's costs. The economic advantages that can be realized by careful planning, scheduling, and balancing the inventory of needed materials will normally offset the effort involved.

Use of Model Specifications

A great deal of time and effort has been expended by ITE, ASTM, and individual agencies in developing specifications for the purchase of various categories of materials and equipment. Model specifications are available for most commonly used delineation devices or components. These models reflect extensive research and field experience and can be easily adapted for local use. (Examples of some model specifications are provided in Technical Appendices B through E.)

State transportation departments are generally cooperative in furnishing copies of their standard specifications to local agencies. This will save staff time and most probably will produce a comprehensive and complete specification in accordance with standard practice and regional characteristics.

The most critical issue in the preparation of specification is the choice between issuing a composition (formulation) specification or a functional (performance) specification. This issue is discussed in Chapter 3 under Purchase of Materials, Page 19.

Use of Contractors

The use of private contractors to install or maintain delineation markings rather than the use of agency forces is another significant consideration in the procurement process. Contractors are typically used in the following circumstances:

- Roadway delineation installation is part of a larger improvement project under contract and it is more economic and efficient for the contractor to be responsible for the total job.
- The installation requires special equipment and staff capability not available within the agency.
- The magnitude and immediacy of the work is beyond the resources of the agency.

Cost of services are, of course, the primary factor in determining the best course of action. It should be stressed, however, that other factors may play an important role in the decision. For example, some delineation techniques require very sophisticated installation processes in order to perform as expected. Under contract, performance warranties will protect the agency against early failures and can be more economical in the long run. Moreover, manufacturers who provide contract installation are likely to be more familiar and better trained in the application of their own product.

On the other hand, there is little doubt that state or local forces can perform the work at "least cost" provided that the proper equipment is available. They would be more familiar with the condition and characteristics of the roadways to be marked and, in actual practice, often adapt application procedures to the specific need of a specific section. It is not unusual, for example, for a maintenance crew to adjust the amount of glass beads applied to provide more reflectivity in a troublesome area. This intimate knowledge based on past experience of the field crew is often overlooked at administrative levels; yet it is a valuable resource that cannot be purchased under contract.

At a higher planning level, the cost of equipping and staffing up to provide all the necessary installation and maintenance services must be balanced against the possible additional cost of using contractor services and equipment. The miles of roadway, the seasonal time available for marking activities, other maintenance activities that must be accomplished, and the existing staff and equipment must all be considered in the decision process.

COORDINATION OF ACTIVITIES

The functions, plans, and activities of other agencies and of other departments within the same agency require close coordination to avoid conflicts, duplications, and inefficiencies in the delineation process. For example, where maintenance is scheduled on a regular basis, e.g. repainting, it is possible to restripe a section just prior to other scheduled roadwork that may destroy the markings.

The installation of costly, long term delineation techniques such as reflectorized markers or thermoplastic striping is justifiable only on the basis of durability, safety, and service life. These benefits are negated if these markings are placed on roads scheduled for resurfacing or widening, etc. This happens much more often than realized simply because of lack of departmental communications. This also occurs when planned roadway activities of utility companies are not known by the maintenance forces.

There is an obvious advantage in scheduling delineation maintenance or installation at the same time as other roadwork that requires crew protection such as coning or lane closure. This requires coordination among activities if the other roadway work is the responsibility of another section or department.

In addition to the economic considerations, the installation of roadway markings such as turn arrows or "STOP" legends must be coordinated with the installation of signs and signals to prevent the type of conflict apparent in Figure 57. The situation illustrated could result in driver confusion at a minimum; more importantly, it could result in a serious accident and potential law suit. In this case, the agency could be cited for negligence in not providing ordinary care in maintaining a safe roadway as discussed earlier. To correct the situation will require sandblasting, grinding, or chipping away of the left turn arrow—an unnecessary expense that could have been avoided by proper coordination between the signing function and the marking function.

COST CONSIDERATIONS

Administrators and managers responsible for delineation systems are vitally concerned with the increasing costs of labor, materials, and equipment, as

Source: San Francisco Chronicle
Nov. 7, 1978, pg. 4

Figure 57. Conflicting Sign and Markings

well as with the diminishing budgets. As other programs and functions compete for available funds, it becomes highly necessary to justify expenditures in terms of cost-effectiveness and cost benefits of planned activities.

Several recent studies have been undertaken to determine the cost-effectiveness of various delineation techniques (Ref. 4, 5). Other studies have attempted to quantify the cost-savings (benefits) accruing from the reduction of accidents attributable to roadway delineation (Ref. 62). Still other studies have examined ways in which costs may be reduced in the application of commonly used materials, equipment, or procedures (e.g. Ref. 36).

It has proved extremely difficult to keep abreast of rapidly changing costs associated with the application of roadway markings. Costs experienced by one agency are seldom comparable with costs for similar applications employed by another. Not only do costs of materials and labor vary in different sections of the country, but accounting procedures and policies differ.

To be realistic, cost should not be based on initial expenditure, but on total cost amortized over the life of the marking. However, because of the numerous site-dependent variables, there is little agreement on the service life of a particular delineation material or device.

Another point of concern is trying to quantify benefits. Benefits are usually expressed as a dollar value associated with accident reduction. Accident reporting systems are constantly being upgraded to provide the necessary information for such studies, but, so far, accident data remains sketchy, incomplete, and incapable of precisely identifying delineation-associated improvements. At best, these figures are only approximations.

Hopefully, the results of the Pavement Marking Demonstration program which encompasses some 950 Federally-funded projects will provide additional information of value in determining cost-benefits of delineation systems. When all the projects within this Program are fully documented, more definitive evaluations will be possible. In the interim, there are statistical analysis techniques available for use in estimating the accident reductions associated with various delineation treatments. There are also economic analysis models developed to evaluate the cost-benefit and cost-effectiveness of the individual delineation treatments. These models are reproduced in summary form in Appendix F.

The series of research studies initiated in 1975 provides some insight into the effect of various types and patterns of delineation on accident experience and traffic behavior (Ref. 2,4,5,14, and 62). The major findings are summarized below.

Striping

The most common type of delineation is the paint stripe. One of the first issues addressed in the research program was the need for striping. Although the need for pavement marking, especially for a centerline, is rarely questioned, there are many miles of low-volume, two-lane roadways without any marking.

Striping reduced accidents approximately 30 percent; the data were significant at the 0.05 level. If this finding is extrapolated to traffic volumes lower than those observed in the study, centerlines can be cost beneficial at ADT volumes as low as 50 vehicles.

Driver behavior studies have shown that adding a centerline to a previously unmarked roadway reduced the road's predicted hazard level by almost 50 percent. Therefore, there is strong evidence that the centerline should be used whenever a roadway has a paved surface that will retain a paint marking and is wide enough to carry two-way traffic.

Edgeline striping is a generally accepted practice on major roadways, although its effectiveness has been questioned. Results of accident analyses showed that edgelines improved safety somewhat; however, this improvement was greater on straight roads than on widening roads. This is contrary to what might be expected. This may illustrate the role of stress on driver attentiveness; that is, a driver is less attentive on straight roads and appears to rely on edgelines if it is necessary to respond to a particular driving situation. On winding roads where a driver is under stress and therefore already attentive to the driving task, edgelines do not appear to be as vital for guidance.

It can be concluded that edgelines are important in a roadway delineation system and should be used on major roads wider than 20 ft. (6m). If traffic safety is the only consideration, an ADT volume of 1,000 vehicles is necessary to make edgelines cost beneficial. If other factors are considered, such as reduced costs for shoulder maintenance, edgelines may be justified on roads having ADT volumes lower than 1,000 vehicles.

The MUTCD requires a stripe-to-gap ratio of 1:3 for both centerlines and lanelines. Although the 1:3 stripe-to-gap ratio is adequate for most roadways, it may need to be supplemented in situations where forward visibility may be restricted. In mountainous terrain or where climatic conditions commonly cause limited visibility, the 1:3 ratio should be supplemented by raised markers.

Raised Pavement Markers

Raised pavement markers have widely replaced painted centerlines, especially in the sunbelt States. Typically, four nonreflective raised markers are used in place of the stripe, and a retroreflective marker is placed at the center of every other gap. This type of marking reduces the amount of lane changing and discourages encroachments onto opposing lanes, possibly because of the rumble effect produced when running over the markers. Research has shown that RPM's reduce a vehicle's lateral placement variance and driver stress at night in wet weather.

Accident analysis studies showed that when painted centerlines were replaced with raised pavement markers, there was reduction of approximately 0.50 accidents per million vehicle-miles (0.31 per million veh-km). In areas with no snow and where markers have a service life of 5 years and cost less than $4,000 per mile ($2,500 per km) to install, raised pavement markers are cost beneficial at an ADT volume of 3,000 vehicles.

Because of the high initial cost of raised pavement markers, especially the snowplowable types, many highway agencies have supplemented standard painted centerlines with retroreflective raised pavement markers every 80 feet (24.4m) to develop an all-weather delineation system at minimum cost. The cost of such a supplemental system, $1,000 to $1,500 per lane mile, ($620 to $930 per lane km) is considerably lower than the cost of complete replacement. In the human factors and traffic performance studies, hazards were reduced 30 to 40 percent with this type of treatment.

Traffic performance studies indicated that RPM's are more effective than postmounted delineators on isolated horizontal curves. Raised pavement markers provide steering guidance in the area near the driver where actual steering decisions are made and provide far-distance information needed by drivers to anticipate road alignment changes. Raised markers also provide for a more accurate perception of the driving situation than do most other forms of supplemental delineation. Research suggests that one-way raised pavement markers along the outside of each driving path are more effective than two-way curved roadway. The cost effectiveness of such an installation depends on the particular site.

Post Delineators

Post delineators of various shapes, colors, and reflective characteristics are used widely throughout the United States. These markings have proven especially effective at night and in adverse weather when standard paint markings are covered by snow or water. They provide the driver with a preview of roadway direction, but they are not very useful for near-roadway steering information because of their offset location.

Accident rates are significantly lower where post delineators are used; a reduction of approximately 1 accident per million vehicle-miles (0.6 accidents per million veh-km) has been demonstrated. The post delineator, therefore, can be very cost effective as an edge marking. If safety is the only benefit considered such treatment is cost beneficial at all reasonable values of installation cost and service life for ADT volumes exceeding 1,000 vehicles. In many cases, depending on local services and cost specifics, such treatments can be justified for the ADT volumes as low as 500 vehicles.

As with raised pavement markers, the selective use of post delineators as a supplement to standard pavement striping appears to be cost effective for all weather conditions. Performance improves significantly with the use of post delineators on horizontal curves. Accident analyses demonstrate a lower accident rate at isolated horizontal curves where post delineators supplemented the standard paint markings. However, the sample size was too small to make a definite conclusion.

Conclusions

Based on the findings of this research program, it was concluded that centerline delineation is highly cost beneficial and should be used on any paved roadway that carries two or more lanes of through traffic. If a low-volume roadway warrants the expenditure for paving and maintaining that surface, it certainly warrants the additional annual expenditure of $50 a mile ($30 a km) to maintain a centerline and reduce accidents 30 percent. Delineation of the outside edge of the travel lane is also highly desirable, especially for roads wider than 20 ft (6 m). Post delineators are somewhat more effective for this application than edgelines, but both treatments are especially useful for roadways with high ADT volumes.

There is substantial evidence that delineation provides important guidance information to motorists, especially when visibility decreases due to adverse weather or nighttime conditions, and there is little difference in effectiveness between various delineation materials and treatments as long as there is adequate contrast and enough continuity to the delineation to inform the driver of roadway direction. For this reason, least life-cost systems are usually preferred for most roadway situations.

The above conclusions do not rule out the need for delineation in excess of minimum standards at certain locations. For example, standard delineation systems supplemented by other delineation treatments to improve traffic flow for nonstandard, high-hazard situations are generally very effective and result in great safety benefits. Among the critical locations that should be considered for such supplemental treatments are isolated horizontal curves, areas where driver expectation is different from what is actually encountered, and areas frequently subject to reduced visibility from dense fog, blowing snow, or heavy rain.

The state of the art is well enough established to provide minimum standard delineation treatments for general situations in terms of color, configuration, and contrast. General guidance is available to determine when these standard treatments should be supplemented. Better definition and solutions for determining where, when, and how much delineation should be provided are still needed. However, much of the remaining effort depends on local problem solving for unique applications. This research program has developed the tools needed to evaluate alternative solutions.

In general, it can be concluded that wider application of conventional delineation treatments is desirable and will significantly reduce accidents.

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Appendix A
Definition of Terms

Abrasion: A condition manifested in traffic markings by more or less gradual surface erosion, thinning, and disappearance of the film, due to wind, water, sand, and vehicle tire wear.

Acrylic: Any of a class of transparent, thermosetting plastics or resins made from acrylic acid.

Air Atomizing Spray: Spray atomization of the liquid compound accomplished through supplied air pressure only.

Airless Spray: Spray atomization of the liquid compound accomplished through hydraulic fluid pressure only. No atomizing air is used.

Aliphatic Solvent: Solvents such as mineral spirits and heptane used in thinning paints.

Alkyd: Synthetic resin used as a bonding agent in paints and lacquers.

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

Applied Line: Marking material in place on the substrate.

Aromatic Solvents: Solvents such as Xylol and Toluene used in thinning traffic paints.

Beads: Spheres used in conjunction with binder to produce retro-reflectivity:

(a) Conventional - Glass composition with approximate refractive index of 1.52 with no surface treatment.

(b) Low refractive index - Spheres with refractive index between 1.50 and 1.64.

(c) Medium refractive index - Spheres with refractive index between 1.65 and 1.89.

(d) High refractive index - Spheres with refractive index greater than 1.89

(e) Plastic - Spheres manufactured from organic materials.

(f) Glass - Spheres manufactured from a material that is essentially fused silica.

(g) Premix - Spheres dispersed in the binder prior to application.

(h) Drop-on - Spheres applied to the stripe after the stripe has been applied to the pavement.

(i) Moisture resistant (proof) - Spheres treated to reduce conglomeration when spheres are exposed to moisture.

(j) Floating - Spheres treated to control depth to which they will sink into the binder.

(k) Static charge - Force tending to cause erratic flow of beads caused by attraction between unlike-charged beads and repulsion between like-charged beads.

(l) Retro-directive reflectivity - Return of light by a reflector along a path parallel to the entrance path.

(m) Divergence angle - Angle formed by a line extending from the light source to a point on the reflector and a line extending from the eye to the same point on the reflector (light-sign-eye angle). Brightness is maximum when divergence angle is zero.

(n) Entrance angle - Angle formed by a line extending from the light source to a point on the reflector and a line forming a 90° angle with the reflector at the same point.

Bisymmetric: Having double symmetry - i.e., in floating bead context, it means that the bead surface embedded in the paint is symmetrical with the exposed surface.

Bleeding: Conditions in which an asphalt substrate is softened, due to heat or solvents, causing the oils to rise to the surface producing multiple black spots on the paint surface.

Bond: Adhesive quality of a coating to a substrate.

Center Line: A line indicating the division of the roadway between traffic traveling in opposite directions.

Ceramic: Baked clay.

Chipping: The breaking away of small fragments of the painted line from the substrate.

Chlorinated Rubber: Hard resin which speeds up drying of varnish or alkyd paints; dries by solvent evaporation only.

Curing: Commonly identified as the hydraulic hardening of portland cement. It also refers to the crosslinking of hardening of paint.

Curing Compound: A coating applied to freshly placed portland cement concrete to retain moisture in the concrete.

Divergence Angle: (Or Angle of Deviation) The angle at the reflector position between the observer's eye and the light source.

Dry Film Thickness: Thickness of line when dry (less than the wet film thickness due to evaporation of solvents in paints).

Durability: A measure of traffic line's resistance to the wear and deterioration associated with abrasion and chipping. For standard methods of evaluation of durability, refer to the American Society for Testing and Materials (ASTM) Bulletins D913 for Chipping and D821 for Abrasion (erosion).

Edge Line: A line that indicates the edge of the roadway.

Entrance Angle: (Or Incidence Angle) The angle between the light source and a line normal to the reflector surface.

Epoxy: Bonding of different atoms to form durable epoxy resins used in adhesives and varnishes.

Film Integrity: The properties of a film that result in the film's ability to resist scuffing, marring, etc.; cohesive strength.

Gradation: The sizing of glass beads; there are two main variables - the size range and uniformity in each size.

Heat Exchanger: A device used to transfer heat from the hot heat transfer fluid to the cold product prior to spraying. It generally consists of multiple lines passing product through the heat transfer fluid-filled line.

Heat Transfer Fluid: Fluid capable of reaching high temperature and transferring much of its heat by means of conduction to the cold product.

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

Liquid Heater: A device used to heat transfer fluid to its required temperature before it enters the heat exchangers.

Longitudinal: Running lengthwise; placed lengthwise; opposed to transverse.

Mil: Unit of measure equivalent to 0.001 inch.

Negative Delineation: Provides information to vehicle driver on where not to go.

Orbitrol Control: A brand name device, located at the base of the platform operator's steering columns and powered by a hydraulic mechanism, which acts as a power steering unit for control of the outriggers.

Orientation Angle: (Rotation Angle) This is related to rotation of the reflecting unit in its own plane or the plane normal to the line of observation.

Outrigger: A mechanism, powered by hydraulic action, that extends and supports the outrigger carriages, which, in turn, support the spray guns.

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

Paints: Classified by drying time:

(a) Instant dry - less than 30 sec.

(b) Quick dry - 30 to 120 sec.

(c) Fast dry - 2 to 7 min.

(d) Conventional - over 7 min.

Phenolics: (Resins) A large class of synthetic plastics made from aldehydrephenol base.

Plastic: Anything moldable; any material, natural or synthetic which may be fabricated into a variety of shapes by application of heat or pressure.

Polyester: (Polyethylene) Tough, flexible thermoplastic resin made by polymerization of ethylene and used in making moisture-proof plastics.

Premix: a paint that contains reflective glass spheres held in suspension throughout the paint.

Positive Delineation: Provides information to vehicle driver in terms of where to go.

Refractive Index: Describes the "light bending" property of a glass as the light wave passes from the air to glass or vice versa. It is a constant value for the ratio of the refraction of one given medium to another. It is a measure of the brilliance of retro-reflectivity for glass spheres.

Reflective: Bending or turning light.

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

Retro-reflective: Capable of returning light to its source.

Sieve Size: The sieve size refers to the sizing or mesh of a sieve or screen used to determine size of glass beads. The larger the U.S. Mesh number is numerically, the more threads there are and the smaller the openings are.

Silica: Silicondioxide is one of the major oxide constituents of glass used for manufacturing reflective spheres.

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

Solvent: Usually a liquid that, when added to paint, will reduce the viscosity of that paint and may also dissolve the resin (binder).

Spraying: A procedure of applying paint to a surface:

(a) Air atomizing spray - Spraying atomization of the liquid paint through air pressure only.

(b) Airless spray - Spraying atomization of the liquid paint is accomplished through hydraulic fluid pressure only. No atomization air is used.

Striper: A self-contained paint spray system mounted on a truck chassis and used for over-the-road striping.

Striping Cycle: The ratio of the length of painted line to the length of line left unpainted, with constant repetition of this cycle giving a "skip" effect.

Substrate: The surface to which the paint is applied.

Through Set: Property of the paint to be uniformly dry or set through its entire thickness from the line surface to the substrate surface (as opposed to skinning).

Timer: A semi-automatic device that controls the "skip" to paint ratio. It consists of a surface-running timing wheel connected by drive mechanisms to a control box (on the platform), which is then connected to the paint spray controls.

Tip Life: The length of time that a spray gun tip will continue to function properly. The tip is no longer useful when the orifice elongates and the applied line deviates from its desired appearance.

Trace Free: The applied line will not be picked up by vehicle tires and transferred to the adjacent pavement.

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.

Wet Film Thickness: Thickness of line at time of application.

Wetting: A prime requisite for good adhesion, it is the flow of liquid product over the surface of the substrate to yield complete coverage. Wetting, and hence adhesion, is poor over dirty or oily surfaces.

Appendix B. Technical Specifications Related to Painted Markings

Tentative Revised ITE Standard

A Model Performance Specification for the Purchase of Pavement Marking Paints

Foreword

This report was approved as a Tentative Revised Standard of the Institute of Traffic Engineers by the ITE Board of Direction on January 20, pursuant to a recommendation of the Institute's Technical Council. Following a period of time sufficient for the submittal of comments on its provisions, the report will be reconsidered by the Council and Board for final action.

The Tentative Revised Standard was developed by Project Committee 7M in Department 4 of the ITE Technical Council. Members of the committee were: William G. Galloway (Chairman); D. R. Adams; Morris Alexander; Frank DeRose, Jr.,; Charles E. Dernbach; James H. Havens; John C. Henberger; L. E. Laviolette; D. A. Reese, Jr.; C. E. Searight; Robert E. Titus; Earl C. Williams; and William L. Williams.

Certain modifications in the report were made as a result of recommendations made by a special Technical Council review committee consisting of: C. Dwight Hixon (Chairman); Charles E. Besanceney; John F. Exnicios; John S. Humphries; and Charles H. McLean.

The Institute of Traffic Engineers welcomes comments on this Tentative Revised Standard. Please direct such correspondence to: Secretary, Technical Council, Institute of Traffic Engineers, 2029 K Street, N. W., Washington, D. C. 20006.

CONTENTS

Chapter I—General

1. INTENT OF SPECIFICATION. It is the intent of this specification to describe the general and specific requirements for reflective pavement marking paints to be used by the (*city or state*) * in its pavement marking program as well as to provide for the submission of samples and to describe the laboratory and service test procedure which will be used to rate the materials submitted for test. It is intended that samples will be received under this specification from any individual, company, or corporation desirous of furnishing traffic marking paints to the (*city or state*), that such samples will be subjected to appropriate laboratory and field service tests, and that the (*city or state*) will request competitive bids for the (*city's or state's*) requirements on such materials as prove satisfactory. Depending upon the materials tested, it is expected that the field service test will require from six months to three years for completion.

Note: This model specification is a *performance* specification. It should be recognized that pavement marking paints can also be purchased on the basis of *chemical* or *composition* specifications.

2. TYPES OF PAINTS. This specification covers those reflective pavement marking paints whose description and physical properties are given in Chapter II of this specification. The procedures given in Chapter III of this specification may be used to test any pavement marking paint against other similar paints and to test any type of paint against a completely different type.

3. METHODS OF TESTING. The methods of sampling and testings all paints covered by this specification shall be in accordance with

* The name of the state or city, or the name of the commission, department, or other purchasing authority should be inserted at all points shown as (*city or state*). Elsewhere throughout this model specification values in parentheses and italicized, as *(40)*, are suggested values, and other values appropriate to the specific needs or requirements of the particular purchasing authority may be substituted.

the latest standards of the American Society for Testing Materials, the American Association of State Highway Officials, the Federal Government, or of other recognized standardizing agencies as indicated for each paint.

Chapter II— Properties, Application, and Packaging of Paints

1. PAINTS

A. Type of Paint

This section covers ready mixed paint products of spraying consistency suitable for use as reflecting pavement markings on portland cement concrete or bituminous pavement. The paint may be of any of the following types:

1. T type in which the glass spheres are mixed in the paint during the process of manufacture (hereinafter designated as the premix type) so that upon drying (and subsequent to exposure of the spheres due to wear of the paint film) the paint line is capable of retro-direction of the headlight beams from the vehicles, or

2. A type in which glass spheres are dropped by suitable means into the wet paint as it is applied to the pavement (hereinafter designated as the drop-on type), or

3. A type which combines the characteristics of premix and drop-in paints, i.e., having beads mixed in the paint and also requring some beads to be dropped on the paint at the time of application (hereinafter designated as the combination type).

B. General Properties

1. Condition and Stability. The paint shall be homogeneous, shall be well ground to a uniform and smooth consistency, and shall not skin nor settle badly, nor cake, liver, thicken, curdle, or gel in the container. The paint shall be capable of being broken up and mixed without difficulty by use of a paddle and shall show the desired characteristics at any time within a period of six months from the date of delivery. The paint shall be tested in accordance with ASTM designation D-869 and D-1309 and a paint rated below *(6)* shall be considered unsatisfactory.

2. Foreign Matter. The paint shall be free from skins, dirt, and other foreign matter and shall not contain more than 1 percent water. The paint shall be tested in accordance with methods 4081, 4091, and 4092 of Federal Test Method No. 141.

3. Suitability to Application. The paint shall be suited to application by means of spray-type pavement marking equipment used by the *(city or state)* and when used with such equipment shall be capable of producing a solid, full-width line of the required thickness.

4. Drying Time. The paint, when applied with its complement of glass spheres to a concrete or bituminous pavement surface under normal field conditions at the required rate and at air temperatures between *(60° and 80°)* Fahrenheit and relative humidities less than 60 percent, shall dry sufficiently hard within *(45)* minutes after application so that there will be no pick-up, displacement, or discoloration under traffic. The paint may also be tested in accordance with ASTM designation D-711 and when so tested, it shall dry to no pick-up in not more than *(30)* minutes.

Note: The above requirements are intended to apply to regular traffic paints having a drying time range of twenty-five to sixty minutes. Special quick-dry traffic paints having a maximum drying time of three minutes may be purchased. If these are desired, the drying time values recommended above should be altered as appropriate.

5. Viscosity. The paint, as received, shall have a consistency as determined on the Stormer Viscosimeter and expressed as Kreks units at 77°F. of *(70-90)* for any type of paint (ASTM designation D-562). The paint will be applied without thinning with the temperature of the paint above *(65°)* F. Any paint which changes consistency within six months after receipt so that the consistency falls outside the viscosity limits stated above, shall be considered to have failed this requirement.

Note: A Viscosity range of 65 to 80 Krebs units at 77° F. is recommended for drop-in type paint and a range of 70 to 90 Krebs units at 77° F. is recommended for premix or combination types of paint.

6. Color. The paint shall conform to U.S. Bureau of Public Roads standard yellow (red to green tolerance), or standard white, as required by the order. The color determination shall be made after the paint has dried for twenty-four hours on premix as received and on combination and drop-on types after the beads have been dropped in. The paint shall not contain any organic coloring matter and shall not discolor in sunlight.

Note: If a light yellow shade of yellow is desired a green tolerance should be shown. If an orange-yellow shade is desired, a standard to red tolerance should be shown.

7. Bleeding. When tested and evaluated on both tar and asphalt substrates in accordance with the Method of Laboratory Test for Degree of Resistance of Traffic Paint to Bleeding, ASTM designation D-969, and The Method of Evaluating Degree of Resistance of Traffic Paint to Bleeding, ASTM designation D-868, the numerical rating of degree of bleeding for both white and yellow paints shall not be less than *(6)*. Paints will be tested for bleeding with the prescribed quantity of glass spheres in or on the paint.

8. **Wet Hiding Power.** The pigmented binder, when tested in accordance with Method 4121 of Federal Test Method 141, "Dry Opacity" and when applied at the rate of 10 mils wet film thickness over a Morest Black and White Hiding Power Chart, Form 03-B, shall show complete hiding or give a contrast ratio of not less than 0.98 between the reflectance of the black and of the white chart surfaces as determined by a Hunter Multi-Purpose Reflectometer.

C. Application

In road service tests and in routine use, the paint shall be applied at the rate recommended by the manufacturer within + or — 10 percent as determined by quantitative measurements made of the area of line applied per unit volume of material. If no rate is specified by the manufacturer, the paint will be applied at the rate of 16.5 gallons per mile of 4-inch continuous stripe (wet film thickness of 15 mils), and glass spheres shall be applied at the rate of six pounds per gallon of paint of the drop-on type and three pounds of glass spheres per gallon of paint of the combination type.

D. Packaging

The packaging of paint for road service test samples and for laboratory tests is described in Chapter III of this specification. Unless otherwise specified, paint purchased under this specification for regular use by the (*city or state*) shall be shipped in celan, open-headed steel drums of .... gallons capacity, sealed, vapor proof, and meeting current Interstate Commerce Commission requirements. Each container shall be plainly marked, both on the head and side, with a durable, weather-resistant ink or paint, showing the name and address of the manufacturer or vendor, description of material, purchase order number, batch number, and volume and weight of contents.

Note: The capacity of paint containers desired by the city or state should be inserted in the blank space left. Pails or drums with a capacity of 5, 30, or 55 gallons are commonly used.

2. PROPERTIES OF GLASS SPHERES FOR REFLECTORIZATION

A. General Requirements

1. **Crushing Resistance.** The crushing resistance of glass spheres may be determined in accordance with ASTM designation D-1213. A forty-pound dead weight for twenty to thirty mesh spheres should be the average resistance of the spheres tested.

2. **Roundness.** The roundness of glass spheres may be determined by ASTM designation D-1155. A typical requirement is that 70 to 80 percent of the spheres of each sieve size be free from imperfections of all types including film, scratches, pits, clusters, opaqueness and non-spherical shape.

3. **Index of Refraction.** The liquid immersion method at 25 percent C. may be used to determine the refractive index of glass spheres. A refractive index of 1.50 to 1.60 is usually required for glass spheres used with traffic marking materials.

4. **Gradation.** A sieve analysis of glass spheres should be made in accordance with ASTM designation D-1214. *Typical* gradations required for various types of pavement marking materials are as follows:

(1) For pre-mix and combination type paints—
- 100 percent passing the no. 70 sieve
- 15 to 55 percent passing the no. 140 sieve
- 0 to 10 percent passing the no. 230 sieve

(2) For drop-on type paints—
- 97 to 100 percent passing the no. 20 sieve
- 80 to 95 percent passing the no. 30 sieve
- 15 to 35 percent passing the no. 50 sieve
- 0 to 10 percent passing the no. 100 sieve
- 0 to 2 percent passing the no. 200 sieve

5. **Chemical Resistance.** The glass spheres shall withstand immersion in water and acids without undergoing noticeable corrosion or etching and shall not be darkened or otherwise noticeably decomposed by sulfides. The tests for chemical resistance shall consist of one hour immersion in water and in solutions of corrosive agents followed by microscopic inspection. A 3 to 5 gram portion of the sample shall be placed in each of three pyrex-glass breakers or porcelain dishes; one sample shall be covered with distilled water, one with a 3N solution of sulfuric acid and the other with a 50 percent solution of sodium sulfide. After one hour of immersion, the glass spheres of each sample shall be examined microscopically for evidence of darkening and frosting.

Note: The tests described in United States Military Specifications TT-P-85b, items 4.4:13, 4.4:14, 4.4:15, and 4.4:16 may be substituted for the test described above.

6. **Flow Properties.** The glass spheres shall flow freely through the dispensing equipment in any weather suitable for striping.

Note: For areas experiencing relatively high humidity during the striping season, the use of additives or special treatments in the production ot the spheres may be required to insure adequate moisture-proof qualities. If such additives or silicone treatments are required, either of the following tests or others may be used to insure that the spheres will flow freely, even in periods of high humidity.

(1) Desiccator Test—100 grams of spheres shall be spread evenly in a flat dish over sulphuric acid (density 1.10) in a desiccator. The desiccator shall remain closed 4 hours at 20°C. The spheres shall then be poured immediately through a dry funnel (4-inch stem with 1/4-inch arifice). The entire sample shall flow freely. If the spheres clog the funnel when first introduced, it is permissible to tap the funnel lightly to start the flow of spheres.

(2) Bag Test—A 2-pound sample of spheres is placed in a cotton bag and immersed in a container of water for 30 seconds or until water completely covers the spheres, whichever is longer. The bag shall then be removed and excess water forced from the sample by squeezing the bag. The bag shall then be suspended and allowed to drain for 2 hours at 70°-72° F. after which the sample shall be thoroughly mixed by vigorously shaking the bag. The entire sample shall then be slowly transferred to a clean, dry, glass funnel having a stem 4 inches in length, a 3/8-inch inside diameter stem opening, and an exit opening of 1/4-inch. The entire sample shall flow freely through the funnel without stoppage. If the spheres clog the funnel when first introduced, it is permissible to lightly tap the funnel to start the flow of spheres.

B. Packaging

Packaging requirements for glass spheres used for road service tests of laboratory tests may vary depending upon the quantities required for the various materials listed in Chapter IV of this specification. Glass spheres for routine applications in conjunction with drop-on or combination paints shall be shipped in bags or drums that are strong enough to permit normal handling during shipment and transportation on the job without loss of spheres and shall be sufficiently water resistant so that the spheres will not become wet or caked in transit.

Note: Multi-ply paper bags or burlap bags with a polyetheyene liner having a capacity of fifty pounds of spheres are normally used.

Chapter III—
Road Service Tests

1. INTENT OF SPECIFICATION. It is the intent of this portion of the specification to describe a procedure to be followed by manufacturers and others in submitting samples for this test, and the procedure which will be followed by the (*city or state*) in testing the pavement marking paints submitted to determine the most economical paint for the (*city or state*) to purchase. Only paints submitted for performance tests under the specification and thereby found to be acceptable will be considered when bids are taken. It is therefore the responsibility of the manufacturer to submit for tests samples of all types and colors of paints on which he later may wish to submit bids.

2. SAMPLES REQUIRED

A. An invitation to submit samples may be issued several months or, for relatively long-life paints, two or three years in advance of the invitation to submit bids in order to permit evaluation of the service test results. All samples shall be properly identified with the manufacturer's code number, which shall be different for each type and color submitted. The manufacturer's name, address, type of paint, and code number for each sample shall be submitted separately.

B. Each sample shall consist of the following amounts of each material which the manufacturer proposes to furnish:

(1) For premix type paints:
- a. Two (2) one-gallon cans of the finished product.
- b. Three (3) one-quart cans of the finished product.
- c. Two (2) one-quart cans of the paint without beads.
- d. Ten (10) pounds of beads.

Note: One five-gallon can of the finished product may be substituted for the above items.

(2) For drop-on type paints:
- a. Two (2) one-gallon cans of the finished product.
- b. Three (3) one-quart cans of the finished product.
- c. Twenty-five (25) pounds of beads.

Note: One five-gallon can of the finished product and thirty pounds of beads may be substituted for the above items.

(3) For combination type paints:
- a. Two (2) one-gallon cans of the finished product.
- b. Three (3) one-quart cans of the finished product.
- c. Two (2) one-quart cans of the paint without beads.
- d. Ten (10) pounds of premix type beads.
- e. Twenty-five (25) pounds of drop-on beads.

Note: One (1) five-gallon can of the finished product and sufficient drop on beads may be substituted for the above items.

The one-gallon paint samples are for the road service test; the one-quart samples are for the laboratory tests, including can stability; the five-gallon samples are for the *(city's or state's)* use to determine if the paints will perform satisfactorily in its regular marking equipment and they will therefore be applied under normal operating conditions and at prescribed application rates.

The number of samples of each type of paint that will be accepted from each manufacturer can be reduced if the city or state does not desire to accept the number of samples permitted in the model specification.

C. On each invitation to submit samples, each manufacturer may submit not more than (3) samples of each color paint. The *(city or state)* reserves the right to request from manufacturers the submission of only those types and colors of paints in which purchases are contemplated.

3. CERTIFICATIONS REQUIRED

A. Certificate of Compliance

The manufacturer shall submit for each sample a Certificate of Compliance on the form provided certifying that the sample meets all of the requirements in this specification.

B. Statement of Characteristics

The manufacturer shall submit with each sample a Statement of Characteristics on the form provided giving all of the information requested. This statement shall be for the confidential use of the *(city or state)*, and the information therein will not be revealed by the *(city or state)*, but will serve and assist in identifying and testing paints furnished.

C. Submission of Samples and Certifications

Samples, certificates of compliance and statements of characteristics shall be sent prepaid to the *(city or state)*. Unless the samples and corresponding certificates and statement of characteristics are received by the hour and date fixed in the inquiry for the receiving of such samples, the *(city or state)* shall not be obligated to include the samples in the test or to consider them for purchase.

Note: Due to the time required for the preparation of samples by manufacturers, the inquiry shall allow forty-five to sixty days for the submission of samples.

4. SERVICE TESTS

A. Application

The test stripes shall be 4 inches in width and applied transversely across the lanes of the road. The application will be made by selected personnel under the supervision of the *(city or state)* using a special pavement marking machine with a spray nozzle similar to the spray nozzle used on the regular pavement marking equipment. The selection of test sites and all aspects of the test line applications shall be in accordance with ASTM designation D713-66T. The material shall be applied to four sections of highway, two of which have a concrete surface and the other two a bituminous surface. The section selected shall be areas where traffic is heavy and where it is uniform with full exposure to sun throughout the daylight hours. The test area shall be laid out where traffic is free rolling, and with no grades, curves, intersections, or access points near enough to cause excessive braking or turning movements.

At least three lines of each sample shall be applied in order that differences due to position and time of day when placed will be compensated for, insofar as it is practical to do so. The material shall be applied at the rate recommended by the manufacturer within plus or minus 10 percent as determined by quantitative measurements made of the area of line applied per unit of volume of material. If no rate is specified by the manufacturer of paint samples, the samples will be applied at the rate of 16.5 gallons per mile of 4-inch continuous stripe (wet film thickness of 15 mils) and glass spheres at the rate of 6 pounds per gallon of paint on drop-on types and 3 pounds per gallon on combination types.

Note: The number of test lines can be reduced if the city or state does not intend to apply the paint to both Portland cement concrete pavements and bituminous pavement. Test lines are needed only on the type of pavement that is to be marked.

All samples received for test lines are needed only on the type of pavement that is to be marked.

All samples received for tests will immediately be given a code identification number which shall be recorded and filed with the manufacturer's code number and certifications. All identification other than the said code identification number shall be removed from the sample containers and the code number shall be used for identification of the material for all succeeding operations of testing, application, and field rating of the material.

B. Evaluation

The uniformity of application, covering properties, and drying time will be determined at the time paints are applied on the road and the comparative results obtained on these properties of the various paints will be taken into consideration in the final evaluation.

Periodic inspections will be made of the test sections in accordance with ASTM designations D-713, D-821, D-913, and D-1011. Records will be made at each inspection of general daytime appearance (including color), film condition and reflectivity. It is desirable to carry on the inspections for a period of one year or more, depending upon the types of paints under test, or until all of the transverse test lines are more than fifty percent worn off in the wheel tracks.

Representatives on the inspection team may be varied as desired; however, it is suggested that the Traffic, Materials, and Purchasing Bureaus or Departments be represented on the inspection team.

Evaluation of service will be based on appearance, durability, and night visibility as defined below. The test lines will be rated numerically from very poor to perfect, using numbers of 0 to 10, with number 10 indicating a perfect condition and 0 complete failure.

C. Definitions

The following definitions shall be applied in evaluating the test lines and in computing the economic aspects of the various lines and materials.

1. **Appearance** This is the complete impression conveyed when the marking is viewed at a distance of at least 10′ before any detailed inspection has been made, and is estimated purely in terms of satisfactory or unsatisfactory appeal to the observer. It also includes a comparison of color of the paint under consideration with the original color, taking into account changes due to yellowing, darkening, fading, dirt collection, mold growth, etc. The determination is to be made with preliminary washing or other modification of the surface of the test lines.

2. **Durability.** The factor used in rating film failure is equal to 1/10 of the percentage of paint remaining on the pavement when examined closely by the unaided eye, this determination to be made in each wheel track in an area extending 9 inches each side of the point of greatest wear. Percentage of paint remaining on the pavement will be considered as the percentage of the prescribed area of test stripe in which the substrate is not exposed.

3. **Night Visibility.** Night visibility designates the apparent brightness when examined at night under Tungsten illumination from the side of the road, with eye and light source separated by distance which corresponds to a divergence or viewing angle of approximately 1/3°. Photometric readings, made in accordance with ASTM designation D-1011, may be substituted for the visual comparison at the option of the *(city or state)*, the reading being based on a factor of 10 for the highest reading and 0 for complete failure. Night visibility determinations will be made on the same areas as those used for rating durability.

4. **Service Factor (R).** In evaluating each sample at the end of the test (or at any time prior thereto) a service factor (R) will be determined for each quality (R_a for appearance, R_d for durability, and R_n for night visibility) on the basis of the following formula (in which each value of r is the average of the ratings for the specific quality by all *(three)* observers for all four test sections) at the time (t) in days between successive evaluations. The time t_x at which the rating of a paint goes below *(four)* which is r_x at the time of any inspection will be determined by interpolation.

$$R = \frac{r_1t_1 + r_2t_2 + r_3t_3 \ldots r_xt_x}{t_1 + t_2 + t_3 \ldots\ldots t_x}$$

Note: When it is desired to determine the service factor, etc., separately for concrete and bituminous surfaces, a separate set of calculations will have to be made for the ratings of the materials on the two pavement surfaces.

5. **Weighted Rating (W).** The three qualities of appearance, durability and night visibility are not considered of equal importance in rating a pavement marking paint and will be weighed as follows: Appearance—30 percent, durability—30 percent, night visibility—40 percent.

The weighted rating (W) of a paint will, therefore, be determined by the formula $W = .30R_a + .30R_d + .40R_n$ in which R_a, R_d, and R_n are the service factors for appearance, durability and night visibility.

Note: The weighted ratings indicated above are suggestive only. The purchaser may add additional qualities or assign other values to increase or decrease the importance of each quality as he may desire. As an example, if the pavement marking is to be applied to a well illuminated city street, the weight for night visibility could be reduced and the weight of either appearance or durability increased. The three rates must, however, total 100 percent.

D. Final Evaluation

After the test lines have been in service for one year or whenever all paints are rated below *(4)* in one or more of the service factors, a final evaluation will be made and the weighted rating for each paint will be determined. The average of the figures of performance for all four test sections arrived at by all *(three)* observers of the committee will be used to determine the final figure of each performance or weighted rating for each paint sample.

Note: The one year shown can be decreased if results must be obtained at an earlier date, but it is desirable to subject the test lines to both summer and winter wear and deterioration.

E. Length of Useful Life (L)

The length of useful life of each sample is the product of the length of the test period and the comparable rating of the line with a perfect line and with one that has reached the end of its useful life *(a rating of 4)*. The length of useful life is determined by the formula:

$$L = D \times \frac{(10 - E)}{(10 - W)}$$

Where D = days of the period of test,

E = Weighted rating of a line at the end of its useful life (*4*), and

W = Weighted rating at the end of the test period.

5. BIDS. All vendors whose samples receive a satisfactory rating will be given an invitation to bid. Each bidder will be required to file an affidavit that the paint which he proposes to furnish will be identical with that of the sample submitted for performance tests or within the tolerances allowed. Paints will be evaluated by ranking them in ascending order on the basis of (C), the cost (in dollars) per foot per day of useful life, determined by (M), the cost in dollars per foot of paints installed and (L), the length of useful life of the paint. The formula for this purpose is as follows:

$$C = \frac{M}{L}$$

Note No. 1: The cost of paints installed (M) is determined by the formula:

$$M = \frac{c_p + c_b + c_a}{F}$$

Where c_p = The cost of paint per gallon, including any premixed beads,

c_b = Cost of drop-on beads per gallon of paint.

c_a = Cost of application of paint per gallon including all labor, administrative, equipment, traffic control costs, etc.

F = Rate of application in feet of 4-inch line per gallon of paint.

Note No. 2: For drop-on paints, with bead application rates of six pounds per gallon, (F) should be 1.2 times the actual binder application rate. For combination types in which three pounds of beads are dropped on each gallon of paint, (F) should be 1.1 times the actual binder application rate. These adjustments are necessary to insure equal application rates when using the formula to compare premix type paints with combination and drop-on type paints.

When comparing paints with thermoplastics in the same test, the paint line should be repainted each time their rating (W) reaches 0.4. The formula for paint samples thus repainted should be modified as follows:

$$C = \frac{M \times A}{L_t}$$

Where (M) = the average cost for each application, computed as shown above for each application,

(A) = The number of applications, and

(L_t) = The total length of useful life of the several applications.

6. SAMPLING AND TESTING

A. Paints purchased under this specification will be sampled and tested by the *(city or state)* using the indicated standards and methods to determine conformance with specification requirements and to establish identity with the sample originally submitted for performance tests. A sample of paint shall consist of three pints taken from each production batch of *(500)* gallons or more. When sampled at the plant from vats, one-third of the paint shall represent the paint coming from the vat at the beginning of the pour, one-third shall represent the paint coming from the vat at the middle of the pour, one-third shall represent the paint coming from the vat at the end of the pour. If the paint is in containers, a three-pint sample shall be taken at random from a single container in each batch.

Note: If it is considered desirable to specify the minimum size of the production batch, this amount should be shown. Where large quantities of paint are being purchased, a 500 gallon minimum size batch should not be considered unreasonable.

B. The *(city or state)* reserves the right to inspect and accept the paint either at the destination or at the point of manufacture. In either case, the manufacturer shall furnish whatever samples and formulas are required to ascertain that the finished paint complies with specifications. If factory inspection is required, the inspector shall be afforded all necessary facilities to make the inspection, including one quart containers for shipment of samples to the *(city or state)*. At the time when contracts are awarded, it will be decided, unless otherwise indicated when invitations to bid are extended, whether the paint is to be inspected at the factory or at the destination. Any paint not meeting the specifications shall be replaced with satisfactory paint, and all handling and transportation charges for such replacement shall be paid by the vendor.

7. ACCEPTANCE AND REJECTION. Paints furnished under the contract shall be identical with the sample submitted for performance tests or within the tolerances allowed and shall comply with the requirements herein set forth. In the event that the paint does not comply with this specification or is not identical with the sample submitted or within the tolerances allowed, the vendor will be required to replace all such paint at his own expense, including all handling and transportation charges, with paints that do so comply.

Tolerances permitted between the paint delivered and the original sample submitted for service tests are as follows:

GLASS SPHERES

1. Refractive index ____________________
2. Crushing resistance ____________________
3. Imperfections ____________________
4. Gradation

Pre-mix		Drop-in	
US Standard Sieve	% Passing	US Standard Sieve	% Passing
________	________	________	________
________	________	________	________
________	________	________	________
________	________	________	________
________	________	________	________

____
(Signature and Title)

____
(Company)

Mail to Mr. ____________________
____
____

A. Paints

1. Weight per gallon. Weight per gallon of all paint purchased on the basis of a service test for regular use by the *(city or state)* shall be within plus or minus *(0.25)* pounds of that of the original test sample.

2. Viscosity. While the viscosity of the original test sample of paint may be anywhere within the range stipulated in this specification, the viscosity of all paint purchased on the basis of the performance test for regular use by the *(city or state)* shall be within plus or minus *(5)* Krebs Units of that of the original test sample throughout the production of the entire order, with the further requirement that such range in viscosity be entirely within the limits specified in Chapter II.

3. Color. Slight differences in color between the paint delivered and the original sample will be permitted provided that the change does not detract from the appearance of the paint.

4. Vehicle. The percent of non-volatile paint in the vehicle of the paint delivered shall not vary more than *(2)* percent from percent of non-volatile paint in the original sample submitted.

5. The weight of the pigment in the paint delivered shall not vary more than *(2)* percent from the weight of the pigment in the original sample.

6. Drying Time. The drying time of the paint delivered shall not be less than the limits specified in Chapter II.

B. Glass Spheres

1. The amount of spheres per gallon of premix or combination types of paint shall not vary by more than plus or minus *(10)* percent from the amount contained in the service test sample.

2. The crushing resistance of the glass spheres shall not vary by more than plus or minus *(10)* percent from the crushing resistance of the service test samples.

3. Roundness and Imperfections. The roundness and imperfections of the glass spheres shall not vary by more than minus *(10)* percent from the values obtained for the service test samples.

4. Index of Refraction. The index of refraction of the glass spheres shall not vary by more than plus or minus *(10)* percent from the index of refraction of the service test samples.

5. Gradation. The gradation of the spheres of any sieve size shall not vary by more than plus or minus *(10)* percent from the gradation of the service test sample.

Regardless of these tolerances, all aspects of all materials delivered shall fall within the ranges specified in Chapter II.

Appendix C. Technical Specifications Related to Thermoplastic Markings

A Model Performance Specification for the Purchase of Thermoplastic and Preformed Plastic Pavement Marking Materials

CHAPTER 1—GENERAL

A. Intent of Specification. It is the intent of this specification to describe the general and specific requirements for reflective pavement marking thermoplastics (hot spray, hot extruded and cold preformed) to be used by the (city or state)* in its pavement marking program as well as to provide for the submission of samples and to describe the laboratory and service test procedure which will be used to rate the materials submitted for test. It is intended that samples will be received under this specification from any individual, company or corporation desirous of furnishing traffic marking materials to the (city or state), that such samples will be subjected to appropriate laboratory and field service tests, and that the (city or state) will request competitive bids for the (city's or state's) requirements on such materials as prove satisfactory. Depending upon the materials tested, it is expected that the field service test will require from six months to three years for completion.

Note: This model specification is a performance specification. It should be recognized that pavement marking materials can also be purchased on the basis of general specifications.

B. Types of Materials. This specification covers those reflective pavement marking materials whose description and physical properties are given in Chapter II of this specification. The procedures given in Chapter III of this specification may be used to test any pavement marking material against other similar materials and to test any type of material against a completely different type.

C. Methods of Testing. The methods of sampling and testing all materials and products covered by this specification shall be in accordance with the latest standards of the American Society for Testing Materials, the American Association of State Highway and Transportation Officials, the federal government or of other recognized standardizing agencies as indicated for each material.

CHAPTER II—PROPERTIES, APPLICATION AND PACKAGING OF MATERIALS

A. Hot Extruded Thermoplastics.

1. Type of Material. This section covers thermoplastic materials suitable for use as reflecting pavement markings on Portland cement concrete or bituminous pavement. The materials shall be so manufactured to be applied by extrusion onto the pavement in molten form with glass spheres mixed in and also dropped into the material immediately after it is applied.

2. General Characteristics. The compound shall not deteriorate by contact with sodium chloride, calcium chloride or other chemicals used against formation of ice on roadways or streets, or because of the oil content of pavement materials or from oil droppings from traffic. In the plastic state, materials shall not give off fumes which are toxic or otherwise injurious to persons or property. The material shall not break down or deteriorate if held at the plastic temperature for a period of four hours, or by reason of four reheatings to the plastic temperature. The temperature versus viscosity characteristics of the plastic material shall remain constant through up to four reheatings, and shall be the same from batch to batch. There shall be no obvious change in color of the material as the result of up to four reheatings, or from batch to batch. To insure the best possible adhesion, the compound, as specified, shall be installed in a melted state at a minimum temperature of 375° F., and the material shall not scorch or discolor if kept at this temperature for up to four hours.

a. Foreign Matter. The binder shall consist of a mixture of synthetic resins, at least one of which is solid at room temperature. The total binder content of the thermoplastic compound shall be not less than 15 percent nor more than 35 percent by weight. The pigmented binder shall be well dispersed and free from all skins, dirt, foreign objects or such ingredients as will cause bleeding, staining or discoloration. The filler shall be a white calcium carbonate silica or an equivalent filler with a compression strength of 5,000 pounds per square inch.

b. Suitability for Application. The thermoplastic material shall be a product especially compounded for traffic markings. The markings shall not smear or spread under normal traffic conditions at temperatures below 120° F. The markings shall have a uniform cross-section. Pigment shall be evenly dispersed throughout the material. The density and character of the material shall be uniform throughout its thickness. The stripe shall maintain its original dimensions and placement. The exposed surface shall be free from tack and shall not be slippery when wet. The material shall not lift from the pavement in freezing weather. Cold ductility of the material shall be such as to permit normal movement with the road surface without chipping or cracking.

c. Drying Time. The drying time shall not exceed a characteristic straight line function, the lower limits of which are 2 minutes at 50° F., the upper limits of which are 15 minutes at 90° F., both temperatures measure at a maximum relative humidity of 70 percent. After application and proper drying time, the material shall show no appreciable deformation or discoloration under local traffic conditions or in air and or road temperatures ranging from (0 to 120° F.).

d. Color. White thermoplastic material shall have a pigment containing from 8 to 10 percent titanium dioxide and, after setting, shall be pure white and free from dirt or tint. Yellow reflectorized thermoplastic material shall be "federal yellow" in color (Federal Test Method Standard 141 Method 4252). The material shall not change its color and brightness characteristics after prolonged exposure to sunlight.

e. Reflectorization. During manufacture, reflectorizing glass spheres shall be mixed into the material to the extent of not less than 20 percent nor more than 50 percent by weight of the material. Glass spheres shall also be automatically applied to the surface of the material at a uniform rate of approximately 6 pounds of glass spheres of every 100 square feet of line. These glass spheres shall be dropped onto the thermoplastic material while it is in a molten state immediately after it has been extruded onto the pavement. Required properties of glass spheres used in hot thermoplastic installations are described in Chapters II and III of this specification.

3. Physical Requirements.

a. Color.

White: Initially white; as demonstrated by a standard color difference meter such as the Gardner Color Difference Meter, the material shall show deviations from a magnesium oxide standard not greater than the following:

Reflectance (Rd) 100 70 minimum.
Redness-greenness (a)0+or-5 percent
Yellowness-blueness (b)0+or-10 percent.

Yellow: Initially yellow; equal to standard color ships using Federal Test Method Standard 141 Method 4252.

b. Water Absorption. Materials shall have no more than 0.5 percent by weight of retained water when tested by ASTM designation D-570. "Water-Absorption of Plastics," procedure (A).

c. Softening Point Materials shall have a softening point of not less than 190° F., as determined by ASTM designation E-28, "Method of Test for Softening Point by Ring and Ball Apparatus."

d. Specific Gravity. Specific gravity of the thermoplastic compound, at 77° F. shall be from 1.6 to 2.3.

e. Impact Resistance. Impact resistance shall not be less than 10 inch-pounds at 77° F. after the material has been heated for four hours at 400° F. and cast into bars of 1-inch cross-sectional area, 3 inches long and placed with 1 inch extending above the vise in a cantilever beam (Izod type) tester using the 25 inch-pound scale. This instrument is described in ASTM designation D-256.

f. Abrasion Resistance. The material shall show a maximum loss of 0.5 grams when subjected to 200 revolutions on a Taber Abraider at 77° F. using H-22 calibrade wheels weighted to 500 grams. The panel for this test shall be prepared by forming a representative lot of material at a thickness of 125 mils on a 4-inch square monel panel 0.050 inch thick, on which a suitable primer has been applied. The wearing surface shall be kept wet with distilled water during the test.

4. *Application.* The material shall be applied to the pavement by extrusion method wherein one side of the shaping die is the pavement and the other three sides are contained by, or a part of, suitable equipment for heating and controlling the flow of material.

The material, when formed into traffic stripes, must be readily renewable by placing a thin overlay of new material directly over an old line of compatible material. Such new material shall bond itself to the old line in such a manner that no splitting or separation takes place.

5. *Packaging.*

a. The material shall be delivered in cardboard containers or heavy duty bags of sufficient strength to permit normal handling during shipment and transportation on the job without loss of material. Each container when filled shall weigh no less than (21) nor more than (52) pounds.

b. Each unit container shall be clearly and adequately marked to indicate the color of the material, the process batch number or other similar manufacturer's identification, the manufacturer's name, address of the plant and the date of manufacture.

6. *Contract Application.*

a. Equipment. The equipment used to install hot thermoplastic materials by contract under this specification shall be constructed to provide continuous mixing and agitation of the material. Conveying parts of the equipment between the main material reservoir and the shaping die shall be so constructed as to prevent accumulation and clogging. All parts of the equipment which come in contact with the material shall be so constructed as to be easily accessible and exposable for cleaning and maintenance. The equipment shall be constructed so that all mixing and conveying parts, up to and including the shaping die, maintain the material at the plastic temperature.

The equipment shall be so constructed as to insure continuous uniformity in the dimensions of the stripe. The thickness of the material on the pavement shall be no less than 90 mils and no more than 125 mils measured as an average in any 3-foot length. The applicator shall provide a means for cleanly cutting off square stripe ends and shall provide a method of applying "skip" lines. The use of pans, aprons or similar appliances which the die overruns will not be permitted under this specification. The equipment shall be so constructed as to provide for varying die widths and to produce varying widths of traffic marking.

Glass spheres applied to the surface of the completed stripe shall be applied by an automatic bead dispenser attached to the striping machine in such a manner that the beads are dispensed almost instantaneously upon the installed line. The glass sphere dispenser shall be equipped with an automatic cut-off control synchronized with the cut-off of the thermoplastic material.

A special kettle shall be provided for melting and heating the thermoplastic material. The kettle must be equipped with an automatic thermostatic control device so as to provide positive temperature control and prevent overheating of the material. The heating kettle and applicator shall be so equipped and arranged as to meet the requirements of the National Board of Fire Underwriters, of the National Fire Protection Association of the state and of the local authorities.

The equipment shall be so arranged as to permit preheating of the pavement immediately prior to application of the thermoplastic material if preheating is recommended by the thermoplastic manufacturer. The applicator shall be mobile and maneuverable to the extent that straight lines can be followed and normal curves can be made in a true arc. The applicator shall be capable of containing a minimum of 125 pounds of molten material.

b. Installation Techniques. The finished lines shall have well-defined edges and be free of waviness.

The contractor (if installation is made by contract) shall clean off dirt and grease where necessary by sandblasting or other approved methods. On pavements containing (less than 8 percent) bituminous asphalt and on all Portland cement concrete pavements, to insure optimum adhesion the contractor (if installations are made by contract) shall apply a binder-sealer material over the application prior to the actual thermoplastic installation. The binder-sealer material will form, when sprayed, a film over the pavement surface which shall dry rapidly and mechanically adhere to the pavement surface. The binder-sealer used shall be as recommended by the manufacturer of the thermoplastic compound.

To insure optimum adhesion, the thermoplastic material shall be installed in a melted state at a temperature of 375° F. to 475° F.

The minimum thickness of thermoplastic lines, as viewed from a lateral cross-section, shall be not less than 90 mils at the edges, nor less than 125 mils at the center. Measurements shall be taken as an average throughout any 36-inch section of the line.

The material, when formed into traffic stripes, must be readily renewable by placing a thin overlay of new material directly over an old line of compatible material. Such a new material shall bond itself to the old line in such a manner that no splitting or separation takes place.

Note: Care must be taken to insure that an adequate bond exists between the old line and the pavement before renewing the line by the overlay method.

Longitudinal lines shall be offset at least (2) inches from construction joints of Portland cement concrete pavements.

Note: It is suggested that openings of (6)-inch lengths be provided at (20)-foot intervals in edgelines placed on the inside of superrelevated curves to prevent the ponding of water on the pavement surface.

7. Warranty (Contract Applications Only). The thermoplastic pavement marking material furnished and installed by contract under this specification shall be guaranteed by the contractor against failure due to poor adhesion resulting from defective materials or methods of application.

For nondefective pavement surfaces carrying low volumes (50,000 vehicles per day or less), the contractor shall guarantee to replace or renew without cost to the (city or state) that part of the pavement markings installed which have not remained to perform useful service as follows:

a. Crosswalks and Stop Lines. Ninety percent of the total of any one intersection for one year, and 75 percent of the total of any one intersection for two years, and 50 percent of the total of any one intersection for three years.

b. Lane Lines, Edge Lines and Center Lines. Ninety percent of a unit for one year, and 80 percent of a unit for two years and 60 percent of a unit for three years (A "unit" is defined as any length of highway having installed thereon 2,000 lineal feet of line of specified width in any combination or pattern.)

The replacement material installed under this guarantee shall be guaranteed the same as the original material, from the date of the original installation.

Note Number 1: The intent is not to extend the original warranty period.

Note Number 2: The warranty does not cover those markings that have been removed by such devices as snow plows, chains or studded tires.

B. Hot Spray Thermoplastic.

1. Type of Material. This section covers thermoplastic materials suitable for use as reflecting pavement markings on Portland cement concrete or bituminous pavement. The materials shall be so manufactured to be applied by spraying onto the pavement in molten form with glass spheres applied during the spraying process.

2. General Characteristics. The compound shall not deteriorate by contact with sodium chloride, calcium chloride or other chemicals used against formation of ice on roadways or streets, or because of the oil content of pavement materials or from oil droppings from traffic. In the plastic state, materials shall not give off fumes which are toxic or otherwise injurious to persons or property. The material shall not break down or deteriorate if held at the plastic temperature for a period of four hours, or by reason of four reheatings to the plastic temperature. The temperature versus viscosity characteristics of the plastic material shall remain constant through up to four reheatings, and shall be the same from batch to batch. There shall be no obvious change in color of the material as the result of up to four reheatings, or from batch to batch. To insure the best possible adhesion, the compound as specified shall be installed in a melted state at a minimum termperature of 375° F., and the material shall not scorch or discolor if kept at this temperature for up to four hours.

a. Foreign Matter. The binder shall consist of a mixture of synthetic resins at least one of which is solid at room temperature. The total binder content of the thermoplastic compound shall be not less than 15 percent nor more than 35 percent by weight. The pigmented binder shall be well dispersed and free from all skins, dirt, foreign objects or such ingredients as will cause bleeding, staining or discoloration. The filler to be incorporated with the resins as binder shall be a white calcium carbonate, silica or an approved substitute with a compression strength of 5,000 pounds per square inch.

b. Suitability for Application. The thermoplastic material shall be a product especially compounded for traffic markings. The markings shall not smear or spread under normal traffic conditions at road temperatures below 150° F. The markings shall have a uniform cross-section. Pigment shall be evenly dispersed throughout the material. The density and character of the material shall be uniform throughout the thickness. The stripe shall maintain its original dimensions and placement. The exposed surface shall be free from tack and shall not be slippery when wet. The material shall not lift from the pavement in freezing weather. Cold ductility of the material shall be such as to permit normal movement with the road surface without chipping or cracking.

c. Drying Time. The maximum elapsed time after application when normal traffic shall leave no impression or imprint on the new line will vary, depending upon thickness of the applied line. It should, however, be no more than 10 minutes at road temperature of 90° F. and below.

d. Color. White thermoplastic materials shall have a pigment containing from 8 to 10 percent titanium dioxide and, after setting, shall be pure white and free from dirt. Yellow reflectorized thermoplastic material shall be "federal yellow" in color (Federal Test Method Standard 141 Method 4252). The material shall not change its color and brightness characteristics after prolonged exposure to sunlight.

c. Reflectorization. During manufacture, reflectorizing glass spheres shall be mixed into the material to the extent of not less than 20 percent nor more than 30 percent by weight of the material. Glass spheres shall also be automatically applied to the surface of the material at a uniform rate of approximately 6 pounds of glass spheres to every 100 square feet of line. These glass spheres shall be dropped or sprayed into the thermoplastic material while it is in a molten state immediately after it has been applied to the pavement. Required properties of glass spheres used in hot thermoplastic installations are described in Chapter II, Section D of this specification.

3. Physical Requirements.

a. Color.

White: Initially white; as demonstrated by a standard color difference meter such as the Gardner Color Difference Meter, the material shall show deviations from a magnesium oxide standard not greater than the following:

Reflectance (Rd) 100 70 minimum.

Redness-greenness (a) 0 # or - 5 percent

Yellowness-blueness (b) 0 # or -10 percent.

Yellow: Initially yellow; equal to standard color chips using Federal Test Method Standard 141 Method 4252.

b. Water Absorption. Materials shall have no more than 0.5 percent by weight of retained water when tested by ASTM designation D-570, "Water Absorption of Plastics," procedure (A).

c. Softening Point. Materials shall have a softening point of not less than 190° F., as determined as ASTM designation E-28, "Method of Test for Softening Point by Ring and Ball Apparatus."

d. Specific Gravity. Specific gravity of the thermoplastic compound at 77° F. shall be from 1.6 to 2.3.

e. Impact Resistance. Impact resistance shall not be less than 10 inch-pounds at 77° F. after the material has been heated for four hours at 400° F. and cast into bars of 1-inch cross-sectional area, 3 inches long and placed with 1 inch extending above the vise in a cantilever beam (Izod type) tester using the 25 inch-pound scale. This instrument is described in ASTM designation D-256.

f. Abrasion Resistance. The material shall show a maximum loss of 0.5 grams when subjected to 200 revolutions on Taber Abraider at 77° F. using H-22 calibrade wheels weighted to 500 grams. The panel for this test shall be prepared by forming a representative lot of material at a thickness of 125 mils on a 4-inch square monel panel 0.050 inch thick, on which a suitable primer has been applied. The wearing surface shall be kept wet with distilled water during the test.

4. Application. The material shall be applied to the pavement by the spray method. The material, when formed into traffic stripes, must be readily renewable by placing a thin overlay of new material directly over an old line of compatible material. Such new material shall bond itself to the old line in such a manner that no splitting or separation takes place.

5. Packaging. The material shall be delivered in cardboard containers or heavy duty paper bags of sufficient strength to permit normal handling during shipment and transportation on the job without loss of material. Each container when filled shall weigh no less than (24) or more than (52) pounds.

6. Contract Application.

a. Equipment. The equipment used to install hot thermoplastic materials by contract under this specification shall be constructed so as to insure continuous uniformity in the dimensions of the stripe. The thickness of the material on the pavement shall be as specified on the plans. The applicator shall provide a means for clearly cutting off square stripe ends and shall provide a means for applying "skip" lines. The lines shall be applied with no splatter or overspray.

The equipment shall be so constructed as to provide for varying widths of traffic markings.

Glass spheres applied to the surface of the completed stripe shall be applied by an automatic bead dispenser attached to the striping machine in such a manner that the beads are dispensed almost instantaneously upon the installed line. The glass sphere dispenser shall be equipped with an automatic cut-off control synchronized with the cut-off of the thermoplastic material.

A special kettle shall be provided for melting and heating the thermoplastic material. The kettle must be equipped with an automatic thermostatic control device. The applicator shall be mobile and maneuverable to the extent that straight lines can be followed and normal curves can be made in a true arc.

b. Installation Techniques. The finished lines shall have well-defined edges. The contractor (if installation is made by contract) shall clean off dirt and grease where necessary by sandblasting or other approved methods.

A primer sealer of a type and if recommended by the manufacturer of the thermoplastic material shall be applied to the pavement surface prior to the installation of the thermoplastic material.

To insure optimum adhesion, the thermoplastic material shall be installed in a melted state at a temperature of 375° to 475° F.

Longitudinal lines shall be offset at least (2) inches from construction joints of Portland cement concrete pavements.

Note: It is suggested that openings of (6)-inch lengths be provided at (20)-foot intervals in edge-lines placed on the inside of superelevated curves to prevent the ponding of drainage on the pavement surface.

7. Warranty (Contract Applications Only). The thermoplastic pavement marking material furnished and installed by contract under this specification shall be guaranteed by the contractor against failure due to poor adhesion resulting from defective materials or methods of application.

Warranties may vary depending upon the applied line thickness, the positioning of the line, the traffic density, the use of studded snow tires and the frequency of snow plow operations.

The following warranties are typical for application thicknesses of 125 mils for crosswalks and stop lines and 90 mils for lane lines, center lines and edge lines. Warranties for thinner lines in these applications or for higher traffic volumes may be reduced commensurately.

For nondefective pavement surfaces carrying low volumes (50,000 vehicles per day or less), the contractor shall guarantee to replace or renew without cost to the (city or state) that part of the pavement markings installed which have not remained to perform useful service as follows:

a. Crosswalks and Stop Lines. Seventy-five percent of the total of any one intersection for one year.

b. Lane Lines, Edge Lines and Center Lines. Eighty percent of a unit for one year, and 60 percent of a unit for two years. (A "unit" is defined as any length of highway having installed thereon 2,000 lineal feet of line of specified width in any combination or pattern.)

The replacement material installed under this guarantee shall be guaranteed the same as the original material, from the date of the original installation.

Note Number 1: The intent is not to extend the original warranty period.

Note Number 2: The warranty does not cover those markings that have been removed by such devices as snow plows, chains or studded tires.

C. Preformed Plastics.

1. Type of Material. This section covers reflectorized plastic materials preformed into rolls or ribbons of various lengths, pliability, and widths suitable for use as reflecting pavement markings on Portland cement concrete or bituminous pavement.

2. General Characteristics. Reflectorized preformed plastic pavement marking material shall consist of uniform consistency, width, and shape of either white or yellow color with reflective glass spheres uniformly distributed throughout the base film and shall be capable of being affixed to non-bleeding bituminous or Portland cement concrete pavements. The reflectorized material shall be of the plastic, cold flow type.

There are two types of reflectorized preformed plastic marking materials. These materials shall consist of the following components with minimum composition by weight as shown:

	Type I	*Type II*
Resins & Conditioners	40%	20%
Pigments & Fillers	38%	30%
Glass Spheres	14%	33%

Pigments shall include titanium dioxide conforming to the requirements of ASTM D-476 for white plastic material and CP medium chrome yellow conforming to the requirements of ASTM D-211 for yellow materials. Reflective glass spheres shall contain the physical properties described in this specification.

The edges shall be clean cut and true. The preformed plastic material may be supplied complete with a precoated, factory applied adhesive so as to make possible immediate pavement application without the use of heat, solvent, or other types of adhesive operations or it may be furnished with separate adhesives as recommended by the manufacturer. Whether the adhesive is precoated or supplied separately, the adhesive shall be such as to allow the preformed plastic material to be repositioned on the pavement surface to which it is applied before permanently fixing it in its final position with a downward pressure. The material shall be capable of conforming to the pavement contours and irregularities through the action of traffic at normal pavement temperatures.

3. Physical Requirements.

a. Type I Preformed Plastic.

(1) Bend Test No. 1 (with precoated adhesive). The plastic shall be of such a structure that at a temperature of 80° F., a piece of 3-inch x 6-inch material (with paper backing) placed upon a 1-inch diameter mandrel may be bent over the mandrel until the end faces are parallel and 1 inch apart. By visual inspection, there shall be no fracture lines apparent in the uppermost surface.

(2) Bend Test No. 2 (without paper backing). A piece of plastic 6-inch x 12-inch in size (paper backing removed) when balanced upon a supported ½-inch diameter mandrel, reflective side up, and left in this position at a temperature of 80° F. shall have flexed out of its own weight at the end of eight hours into an inverted "V" position with the free ends at an angle of not more than 30° from the vertical. The uppermost surface of the plastic shall show no fracture or breaks. Upon removing the plastic from the mandrel, the material should be firmly but not abruptly returned to a semi-flat position with the reflective side down. The plastic, at a temperature of 80° F. on a smooth, flat, glass surface, shall have

returned to its original flat condition in not more than eight hours.

(3) Tensile Strength and Elongation. Employing ASTM designation D-638, the plastic shall have a tensile strength of 300 psi plus or minus 100 psi. The tensile strength calculations should be based on the minimum measured thickness of the test specimen. The rate of pull on the test shall be 0.25 inch per minute. The test shall be conducted at a temperature of 70° to 80° F., using a strip of material 6 inches long and 1 inch wide. The elongation shall be no greater than 50 percent at break.

(4) Plastic Pull Test. A 6-inch long by 1-inch wide section of the thermoplastic material shall support a dead load weight of 6 pounds for not less than 30 minutes. This test shall be conducted at a temperature of 70° to 80° F.

(5) Glass Sphere Retention. A 2-inch specimen of thermoplastic material shall be cut at right angles to the long edge and bent parallel to the long edge on a ½-inch diameter mandrel. While the specimen is bent, a strip of ½-inch wide masking tape shall be applied firmly along the length of the area of maximum bend and then removed. Retention of a number of glass spheres on the masking tape when the tape is removed shall be cause for rejection of the material.

(6) Gloss. The plastic material shall have a maximum 60° gloss of 10 units as measure in accordance with ASTM designation D-523.

(7) Abrasion Resistance. The plastic material shall have a minimum loss in weight of 0.25 grams in 500 revolutions when abraded according to Federal Test Method Standard No 141 Method 5192, using H-18 calibrade wheels with 1,000 gram load on each wheel.

(8) Thickness. The extruded cold plastic, without adhesive, shall be supplied in a nominal thickness of 90 mils unless otherwise specified.

b. Type II Preformed Plastic.

(1) Tensile Strength and Elongation. The film shall have a minimum tensile strength of 40 pounds per square inch of cross-section when tested according to ASTM D-638. A sample 6-inch long and 1-inch wide shall be tested at a temperature between 70° and 80° F. using a jaw speed of 0.25 inch per minute. The film shall have a minimum elongation of 15% at break.

(2) Patchability. The material shall be capable of fusing into worn areas of previously applied material of the same type and composition of film following manufacturer's recommended patching procedures.

(3) Glass Sphere Retention. When tested with a 2-inch by 6-inch sample bent over a ½-inch diameter mandrel with the 2-inch dimension perpendicular to the mandrel axis, microscopic examination of the area on the mandrel shall show no more than 10 percent of the beads with entrapment by the binder of less than 40 percent.

(4) Plastic Pull Test. A 6-inch long by 1-inch wide section of the thermoplastic material shall support a dead load weight of 4 pounds for not less than 5 minutes. This test shall be conducted at a temperature of 70° to 80° F.

(5) Thickness. The material, without adhesive, shall be supplied in nominal thickness of 60 mils unless otherwise specified.

4. Application. The preformed plastic material shall be capable of application to nondefective pavement surfaces that are dry and free from dirt or other foreign matter. For normal application, the pavement temperature should be at least 65° F. and rising.

Special instructions should be supplied by the vendor for application to be made at pavement temperatures below 60° F. Application shall be according to manufacturer's recommended procedures. Plastic pavement marking materials shall only be applied to surfaces with temperatures within the range specified by the manufacturer for optimum adhesion.

Adhesive, activators or special coatings for various types of pavement surfaces shall be provided with the thermoplastic material. Detailed information must be supplied with the thermoplastic material outlining required application procedures for such adhesives, activators or special coatings.

Preformed plastics shall be capable of being applied to new asphaltic pavement immediately prior to the final rolling of the new surface and of being rolled into place with conventional pavement and highway rollers. The plastic material and adhesives used in such applications shall be of the type that water used on the roller to prevent asphalt pickup shall not be harmful to the successful application of the plastic.

Special equipment necessary for the successful installation of any preformed plastic material shall be available from the manufacturer of the plastic material on a lease, loan or purchase basis.

Longitudinal lines shall be offset at least 2 inches from construction joints of Portland cement concrete pavements. When directed by the engineer, openings of 6-inch lengths shall be left at 20-foot intervals in edge lines not inlayed into the pavement surface that are placed on the inside of superelevated curves so as to prevent the ponding of drainage on the pavement surface.

5. Packaging. The preformed plastic material shall be supplied in rolls or strips of specified lengths and widths. Material for symbols and work messages may be precut to other widths and lengths for convenience of application. Packaging of the materials shall be in accord with commercially acceptable standards.

CHAPTER III—PROPERTIES OF GLASS SPHERES FOR REFLECTORIZATION

A. General Requirements.

1. Crushing Resistance. The crushing resistance of glass spheres may be determined in accordance with ASTM designation D-1213. A 40-pound dead weight for 20 to 30 mesh spheres should be the average resistance of the spheres tested.

2. Roundness. The roundness of glass spheres may be determined by ASTM designation D-1155. A typical requirement is that 70 to 80 percent of the spheres of each sieve size be free from inperfections of all types including film, scratches, pits, dusters, opaqueness and nonspherical shape.

3. Index of Refraction. The liquid immersion method at 77° F. may be used to determine the refractive index of glass spheres used with traffic marking materials.

4. Gradation. A sieve analysis of glass spheres should be made in accordance with ASTM designation D-1214. Typical gradations required for various types of pavement marking materials are as follows:

a. For hot thermoplastics to be included in the manufacture of the thermoplastic material: 80 to 100 percent passing no. 60 sieve; 0 to 100 percent passing no. 140 sieve. For application on molten thermoplastic material: 90 to 100 percent passing no. 20 sieve; 20 - 50 percent passing the No. 50 sieve; 0 - 10 percent passing the No. 80 sieve.

b. For cold thermoplastics: 100 percent passing the No. 60 sieve; 0 to 15 percent passing the No. 140 sieve.

Note: The gradation of glass spheres used in various hot and cold thermoplastics may vary greatly from the typical ranges shown above. Current gradation ranges should be obtained from manufacturers before developing specifications.

5. Chemical Resistance. The glass spheres shall withstand immersion in water and acids without undergoing noticeable corrosion or etching and shall not be darkened or otherwise noticeably decomposed by sulfides. The tests for chemical resistance shall consist of one hour immersion in water and in solutions of corrosive agents followed by microscopic inspection. A 3 to 5 gram portion of the sample shall be covered with distilled water, one with a 3N solution of sulfuric acid and the other with a 50 percent solution of sodium sulfide. After one hour of immersion, the glass spheres of each sample shall be examined microscopically for evidence of darkening and frosting.

Note: The tests described in United States Military Specification TT-P-85b.

items 4.4:13, 4.4:14, 4.4:15 and 4.4:16 may be substituted for the test described above.

6. Flow Properties. The glass spheres shall flow freely through the dispensing equipment in any weather suitable for striping.

Note: For areas experiencing relatively high humidity during the striping season, the use of additives or special treatments in the production of the spheres may be required to insure adequate moisture proof qualities. If such additives are required, either of the following tests or other may be used to insure that the spheres will flow freely, even in periods of high humidity.

(1) Desiccator Test. One hundred grams of spheres shall be spread evenly in a flat dish over sulfuric acid (density 1.10) in a desiccator. The desiccator shall remain closed four hours at 68° F. The spheres shall then be poured immediately through a dry funnel (4-inch stem with ¼-inch orifice). The entire sample shall flow freely. If the spheres clog the funnel when first introduced, it is permissible to tap the funnel lightly to start the flow of spheres.

(2) Bag Test. A 2-pound sample of spheres is placed in a cotton bag and immersed in a container of water for 30 seconds or until water completely covers the spheres, whichever is longer. The bag shall then be removed and excess water forced from the sample by squeezing the bag. The bag shall then be suspended and allowed to drain for two hours at 70° to 72° F., after which the sample shall be thoroughly mixed by vigorously shaking the bag. The entire sample shall then be slowly transferred to a clean, dry glass funnel having a stem 4-inches in length, a ⅜-inch inside diameter stem opening and an exit opening of ¼-inch. The entire sample shall flow freely through the funnel without stoppage. If the spheres clog the funnel when first introdced, it is permissible to tap the funnel lightly to start the flow of spheres.

B. Packaging. Packaging requirements for glass spheres used for road service tests or laboratory tests may vary depending upon the quantities required for the various materials listed in Chapter IV of this specification. Glass spheres for routine applications in conjunction with drop-on or combination paints and for application on hot thermoplastic lines in the molten state shall be shipped in bags or drums that are strong enough to permit normal handling during shipment and transportation on the job without loss of spheres and shall be sufficiently water resistant so that the spheres will not become wet or caked in transit.

Note: Multiple paper bags or burlap bags with a polyethylene liner having a capacity of 50 pounds of spheres are normally used.

CHAPTER IV—ROAD SERVICE TESTS

A. Intent of Specification. It is the intent of this portion of the specification to describe a procedure to be followed by manufacturers and others in submitting samples for this test, and the procedure which will be followed by the (city or state) in testing the pavement marking materials submitted to determine the most economical material for the (city or state) to purchase. Only materials submitted for performance tests under the specification and thereby found to be acceptable will be considered when bids are taken. It is therefore the responsibility of the manufacturer to submit for test samples of all types and colors of materials on which he later may wish to submit bids.

B. Samples Required.

1. An invitation to submit samples may be issued several months or, for relatively long-life materials, two or three years in advance of the invitation to submit bids in order to permit evaluation of the service test results. All samples ples shall be properly identified with the manufacturer's code number, which shall be different for each type and color submitted. The manufacturer's name, address, type of material and code number for each sample shall be submitted separately.

2. Each sample shall consist of the following amounts of each material which the manufacturer proposes to furnish:

a. For hot extruded thermoplastics:

(1) Ten (10) pounds of beads.

(2) Five (5) pounds of unmelted thermoplastic material.

(3) One (1) quart can of primer.

Note: The above samples are for laboratory testing and do not include quantities for road service tests since service test lines will normally be placed by installation contractors.

b. For cold (preformed) thermoplastics:

(1) Three (3) 1-foot x 4-inch sections of each color (for laboratory tests).

(2) One (1) 1-quart can of primer or adhesive if the use of such surface preparation material is recommended by the manufacturer.

(3) Ample quantities of 4-inch wide materials (and primer or adhesive material, if required) for road service test applications.

The number of samples of each type of material that will be accepted from each manufacturer can be reduced if the city or state does not desire to accept the number of samples permitted in the model specification.

3. On each invitation to submit samples, each manufacturer may submit not more than (3) samples of each color material. The (city or state) reserves the right to request from manufacturers the submission of only those types and colors of materials in which purchases are contemplated.

C. Certifications Required.

1. Certificate of Compliance. The manufacturer shall submit for each sample a Certificate of Compliance on the form provided certifying that the sample meets all of the requirements in this specification.

2. Statement of Characteristics. The manufacturer shall submit with each sample a Statement of Characteristics on the form provided giving all of the information requested. This statement shall be for the confidential use of the (city or state), and the information therein will not be revealed by the (city or state), but will serve and assist in identifying and testing materials furnished.

3. Submission of Samples and Certification. Samples, certificates of compliance and statements of characteristics shall be sent prepaid to the (city or state). Unless the samples and corresponding certificates and statement of characteristics are received by the hour and date fixed in the inquiry for the receiving of such samples, the (city or state) shall not be obligated to include the samples in the test nor to consider them for purchase

Note: Due to the time required for the preparation of samples by manufacturers, the inquiry shall allow 45 to 60 days for the submission of samples.

D. Service Tests.

1. Application. The test strips shall be 4 inches in width and applied transversely across the lanes of the road. The application will be made by selected personnel under the supervision of the (city or state). The selection of test sites and all aspects of the test line applications shall be in accordance with ASTM designation D-713. The material shall be applied to four sections of highway, two of which have a concrete surface and the other two a bituminous surface. The section selected shall be areas where traffic is heavy and where it is uniform with full exposure to sun throughout the daylight hours. The test area shall be laid out where traffic is free rolling, and no grades, curves, intersections or access points near enough to cause excessive braking or turning movements.

At least three lines of each sample shall be applied in order that differences due to position and time of day when placed will be compensated for, insofar as it is practical to do so. The material shall be applied at the rate recommended by the manufacturers within plus or minus 10 percent as determined by quantitative measurements made of the area of line applied per unit of volume of material.

Note: The number of test lines can be reduced if the (city or state) does not intend to apply the material to both Portland cement concrete pavements and bituminous pavement. Test lines are needed only on the type of pavement that is to be marked.

All samples received for test lines are needed only on the type of pavement that is to be marked.

All samples received for tests will immediately be given a code identification number which shall be recorded and filed with the manufacturer's code number and certifications. All identification other than the said code identification number shall be moved from the sample containers and the code number shall be used for identification of the material for all succeeding operations of testing, application and field rating of the material.

2. Evaluation. The uniformity of application, covering properties and drying time will be determined at the time materials are applied on the road, and the comparative results obtained on these properties of the various materials will be taken into consideration in the final evaluation.

Periodic inspections will be made of the test sections in accordance with ASTM designations D-713, D-821, D-913 and D-1011. Records will be made at each inspection of general daytime appearance (including color), film condition and reflectivity. It is desirable to carry on the inspections for a period of one year or more depending on the types of materials under test, or until all of the transverse test lines are more than 50 percent worn off in the wheel tracks.

Representatives on the inspection team may be varied as desired; however, it is suggested that the traffic, materials and purchasing bureaus or departments be represented on the inspection team.

Evaluation of service will be based on appearance, durability and night visibility as defined below. The test lines will be rated numerically from very poor to perfect, using numbers of 0 to 10, with number 10 indicating a perfect condition and 0 complete failure.

3. Definitions. The following definitions shall be applied in evaluating the test lines and in computing the economic aspects of the various lines and materials.

a. Appearance. This is the complete impression conveyed when the marking is viewed at a distance of at least 10 feet before any detailed inspection has been made, and is estimated purely in terms of satisfactory or unsatisfactory appeal to the observer. It also includes a comparison of color of the material under consideration with the original color, taking into account changes due to yellowing, darkening, fading, dirt collection, mold growth, etc. The determination is to be made without preliminary washing or other modification of the surface of the test line.

b. Durability. The factor used in rating film failure is equal to 1/10 of the percentage of material remaining on the pavement when examined closely by the unaided eye, this determination to be made in each wheel track in an area extending 9-inches each side of the point of greatest wear. Percentage of material remaining on the pavement will be considered as the percentage of the prescribed area of test stripe in which the substrate is not exposed.

c. Night Visibility. Night visibility designates the apparent brightness when examined at night under tungsten illumination from the side of the road, with eye and light source separated by distance which corresponds to a divergence or viewing angle of approximately 1/3° (one-third degree). The rating is based on a factor of 10 for the highest reading and 0 for complete failure. Night visibility determinations will be made on the same areas as those used for rating durability.

d. Service Factor (R). In evaluating each sample at the end of the test (or at any time prior thereto), a service factor (R) will be determined for each quality (R_a for appearance, R_d for durability, and R_n for night visibility) on the basis of the following formula (in which each value of r is the average of the ratings for the specific quality by all [three] observers for all four test sections) at the time (t) in days between successive evaluations. The time t_x at which the rating of a paint goes below (four), which is r_x at the time of any inspection, will be determined by interpolation.

$$R = \frac{r_1t_1 + r_2t_2 + r_3t_3 \cdot \cdot \cdot r_xt_x}{t_1 + t_2 + t_3 \cdot \cdot \cdot t_x}$$

Note: when it is desired to determine the service factor, etc. separately for concrete and bituminous surfaces, a separate set of calculations will have to be made for the ratings of the materials on the two pavement surfaces.

e. Weighted Rating (W). The three qualities of appearance, durability and night visibility are not considered of equal importance in rating a pavement marking material and will be weighted as follows: Appearance—30 percent; durability—30 percent; night visibility—40 percent.

The weighted rating (W) of a material will, therefore, be determined by the formula $W = .30R_a + .30R_d + .40R_n$, in which R_a, R_d and R_n are the service factors for appearance, durability and night visibility.

Note: The weighted ratings indicated above are suggestive only. The purchaser may add additional qualities or assign other values to increase or decrease the importance of each quality as he may desire. As an example, if the pavement marking is to be applied to a well illuminated city street, the weight for night visibility could be reduced and the weight of either appearance or durability increased. The three rates must, however, total 100 percent.

4. Final Evaluation. After the test lines have been in service for (2) years, or whenever all materials are rated below (4) in one or more of the service factors, a final evaluation will be made and the weighted rating for each material will be determined. The average of the figures of performance for all four test sections arrived at by all three observers of the committee will be used to determine the final figure of each performance or weighted rating for each material sample.

Note: The one year shown can be decreased if results must be obtained at an earlier date, but it is desirable to subject the test lines to both summer and winter wear and deterioration.

5. Length of Useful Life (L). The length of useful life of each sample is the product of the length of the test period and the comparable rating of the line with a perfect line and with one that has reached the end of its useful life (rating of 4). The length of useful life is determined by the formula:

$$L = D \times \frac{(10 - E)}{(10 - W)}$$

Where D = days of the period of test.
E = weighted rating of a line at the end of its useful life (4), and
W = weighted rating at the end of the test period.

E. Bids. All vendors whose samples receive a satisfactory rating will be given an invitation to bid. Each bidder will be required to file an affidavit that the material which he proposes to furnish will be identical with that of the sample submitted for performance tests or within the tolerances allowed. Materials will be evaluated by ranking them in ascending order on the basis of C, the cost (in dollars) per foot per day of useful life, determined by M, the cost in dollars per foot of materials installed and L, the length of useful life of the material. The formula for this purpose is as follows:

$$C = \frac{M}{L}$$

Note Number 1: The cost of materials installed (M) is determined by the formula:

$$M = \frac{C_p + C_b + C_a}{F}$$

Where C_p = the cost of the thermoplastic per pound, including any premixed beads.

C_b = the cost of drop-on beads per gallon of paint or

C_a = the cost of application of paint per gallon or thermoplastic per pound including all labor, administrative, equipment, traffic control costs, etc.

F = the rate of application in feet of 4-inch line per gallon of paint or pound of thermoplastic.

The procedure outlined above can be used with the following modifications for the comparative testing of various thermoplastic pavement marking materials.

1. Tests involving thermoplastics should be confined to roads having ADT's of 25,000 or more, and test area pavement should be stable and require no surface treatment for at least three years. These restrictions are necessary because thermoplastic materials are comparatively long life materials and may require a testing period as long as two to three years, depending upon the traffic volumes involved.

2. When thermoplastic lines are to be installed by contract, M in the above formula should reflect the cost of material installed in dollars per foot of 4-inch wide line.

3. When comparing paints with thermoplastics in the same test, the paint line should be repainted each time their rating (W) reaches 0.4. The formula for paint samples thus repainted should be modified as follows:

$$C = \frac{M \times A}{L_1}$$

Where M = the average cost for each application, computed as shown above for each application

A = the number of applications

L_1 = the total length of useful life of the several applications.

F. Sampling and Testing.

1. Materials purchased under this specification will be sampled and tested by the (city or state) using the indicated standards and methods to determine conformance with specification requirements and to establish identity with the sample originally submitted for performance tests. An adequate size sample of thermoplastic material shall be extracted at random from each production batch.

Note: If it is considered desirable to specify the minimum size of the production batch, this amount should be shown.

2. The (city or state) reserves the right to inspect and accept the material either at the destination or at the point of manufacture. In either case, the manufacturer shall furnish whatever samples and formulas required to ascertain that the finished material complies with specifications. If factory inspection is required, the inspector shall be afforded all necessary facilities to make the inspection, including one quart containers for shipment of samples, to the (city or state). At the time when contracts are awarded, it will be decided, unless otherwise indicated when invitations to bid are extended, whether the material is to be inspected at the factory or at the destination. Any material not meeting the specifications shall be replaced with satisfactory material, and all handling and transportation charges for such replacement shall be paid by the vendor.

G. Acceptance and Rejection. Materials furnished under the contract shall be identical with the sample submitted for performance tests or within the tolerances allowed and shall comply with the requirements herein set forth. In the event that the material does not comply with this specification or is not identical with the sample submitted or within the tolerances allowed, the vendor will be required to replace all such material at his own expense, including all handling and transportation charges, with materials that do so comply.

Tolerances permitted between the material delivered and the original sample submitted for service tests are as follows:

1. Thermoplastics.

a. Weight per cubic foot of all plastic purchased on the basis of a service test for regular use by the (city or state) shall be within plus or minus (0.25) pounds of that of the original test sample.

b. Slight differences in color between the plastic delivered and the original sample will be permitted provided that the change does not detract from the appearance of the thermoplastic.

c. The weight of the pigment in the plastic delivered shall not vary more than (2) percent from the weight of the pigment in the original sample.

2. Glass Spheres.

a. The amount of spheres per gallon of premix or combination types of paint shall not vary by more than plus or minus (10) percent from the amount contained in the service test sample.

b. The crushing resistance of the glass spheres shall not vary by more than plus or minus (10) percent from the crushing resistance of the service test samples.

c. The roundness and imperfections of the glass spheres shall not vary by more than minus (10) percent from the values obtained for the service test samples.

d. The index of refraction of the glass spheres shall not vary by more than plus or minus (10) percent from the index of refraction of the service test samples.

e. The gradation of the spheres of any sieve size shall not vary by more than plus or minus (10) percent from the gradation of the service test sample.

Regardless of these tolerances, all aspects of all materials delivered shall fall within the ranges specified in Chapter II.

ADDENDUM

(This Addendum does not constitute a part of the specification.) The following general conclusions can be drawn:

1. Thermoplastics, both hot and cold, have been widely used in most regions of the United States and Canada in practically all pavement marking applications.

2. Although thermoplastics are more durable than traffic paints, their initial cost is greater than that of paints.

3. The most economical applications of thermoplastics are those which are applied on high-volume roads with stable pavement surfaces (Portland cement concrete or asphaltic concrete).

4. Better adhesion of thermoplastic materials to the pavement surface can be achieved on asphaltic concrete than on Portland cement concrete.

5. High quality workmanship in installing both hot and cold thermoplastics is necessary to achieve long product life.

6. Due to their greater thickness than conventional traffic paints, both hot and cold thermoplastic pavement markings may be damaged or removed by snow plows unless special precautions are taken; however, the greater thickness does produce better reflectivity than paint when the pavement is wet.

7. Material warranties are usually available on hot thermoplastics installed by contract to protect the buyer against excessive material failures.

8. Due to the frequent improvements that are made in thermoplastic materials (especially in the hot type), bonding agents and installation techniques, any exhaustive chemical or composition specification would soon become obsolete. However, minimum specifications on general and physical properties and installation procedures are desirable to protect the buyer.

9. Insufficient formal research has been undertaken and completed to allow firm conclusions to be reached regarding economic and durability comparisons between different thermoplastic materials or between thermoplastic materials and paint in all regions and in all types of applications. It is felt, however, that any agency could make such comparative tests by employing the techniques suggested in the body of this report.

Appendix D. Technical Specifications Related to Raised Pavement Markers

SPECIFICATIONS FOR PRISMATIC REFLECTOR TYPE PAVEMENT MARKER

GENERAL DESCRIPTION

Markers shall consist of an acrylic plastic shell filled with a tightly adherent potting compound. The shell shall contain one or two prismatic reflective faces as required to reflect incident light from a single or opposite directions. The markers shall be in the shape of a shallow frustum of a pyramid.

DETAILED SPECIFICATIONS

1. Design and Fabrication

A. *Plastic Shells*

Dimensions	4" x 4" x .65"
Slope of Reflecting Face	30°
Area of Each Reflecting Surface	3.25 sq. in.

B. *Surface*

The outer surface of the shell shall be smooth except for purposes of identification.

The base of the marker shall be substantially free from gloss or substances that may reduce its bond to adhesive. This shall be done by embedding sand or inert granules on the surface of the potting compound prior to its curing. The overall height of the marker after the addition of this material shall not exceed 0.75 inches.

C. *Material*

Shell shall be molded of methyl methacrylate conforming to Federal Specification L-P-380a, Type I, Class 3.

Filler shall be a potting compound selected for strength, resilience, and adhesion adequate to pass physical requirements as outlined below.

OPTICAL REQUIREMENTS

1. Definitions

Horizontal entrance angle shall mean the angle in the horizontal plane between the direction of incident light and the normal to the leading edge of the marker.

Observation angle shall mean the angle at the reflector between observer's line of sight and the direction of the light incident on the reflector.

Specific intensity (S.I.) shall mean candlepower of the returned light at the chosen observation and entrance angles for each foot candle of illumination at the reflector on a plane perpendicular to the incident light.

2. Optical Performance

The specific intensity of each crystal reflecting surface at 0.2° observation angle shall be not less than the following when the incident light is parallel to the base of the marker.

HOR. ENT. ANGLE	S. I.
0°	3.0
20°	1.2

For yellow relectors the specific intensity shall be 60% of the value for crystal. For red reflectors the specific intensity shall be 25% of the value for crystal.

3. Optical Testing Procedure

A random lot of markers will be tested. The markers to be tested shall be located with the center of the reflecting face at a distance of 5 feet from a uniformly bright light source having an effective diameter of 0.2 inches.

The photocell width shall be 0.05 inch. It shall be shielded to eliminate stray light. The distance from light source center to the photocell center shall be 0.21 inches. If a test distance of other than 5 feet is used, the source and receiver dimensions and the distance between source and receiver shall be modified in the same proportion as the test distance.

Failure of more than 4% of the reflecting faces shall be cause for rejection of the lot.

PHYSICAL PROPERTIES

1. Strength Requirements

Markers shall support a load of 2000 pounds as applied in the following manner:

A. Strength Testing Procedure

A random sample of three markers shall be selected for test purposes.

A marker shall be centered over the open end of a vertically positioned hollow metal cylinder. Cylinder shall be 1" high, with an internal diameter of 3" and wall thickness of 1/4". Load shall be slowly applied to the top of the marker through a 1" diameter by 1" high metal plug centered on the top of the marker.

Failure shall constitute either breakage or significant deformation of the marker at any load of less than 2000 pounds.

SPECIFICATIONS FOR PRESSURE SENSITIVE PRISMATIC REFLECTOR TYPE PAVEMENT MARKER

GENERAL DESCRIPTION

Markers shall consist of an acrylic plastic shell filled with tightly adherent potting compound to which is permanently adhered a pressure-sensitive adhesive. The shell shall contain one or two prismatic reflective faces as required to reflect incident light from a single or opposite directions. The markers shall be in the shape of a shallow frustum of a pyramid. Marker is intended for application to a primed surface.

DETAILED SPECIFICATIONS

1. Design and Fabrication

A. Construction Details

Overall Dimensions	4" x 4" x .79"
Slope of Reflecting Face	30^0
Area of Each Reflecting Surface	3.25 sq.in.
Thickness of Adhesive Layer	.120" (included in .79" overall height)

B. Surface

The outer surface of the shell shall be smooth except for purposes of identification.

C. Material

Shell shall be molded of methyl methacrylate conforming to Federal Specification L-P-380a, Type I, Class 3.

Filler shall be a potting compound selected for strength, resilience, and adhesion adequate to pass physical requirements as outlined below.

The adhesive shall be pressure sensitive 100% solids .120" thick. Minimum application pressure shall be 60 p.s.i. Minimum shear stress shall exceed 10 p.s.i. at 70°F.

OPTICAL REQUIREMENTS

1. Definitions

Horizontal entrance angle shall mean the angle in the horizontal plane between the direction of incident light and the normal to the leading edge of the marker.

Observation angle shall mean the angle at the reflector between observer's line of sight and the direction of the light incident on the reflector.

Specific intensity (S.I.) shall mean candlepower of the returned light at the chosen observation and entrance angles for each foot candle of illumination at the reflector on a plane perpedicular to the incident light.

2. Optical Performance

The specific intensity of each crystal reflecting surface at 0.2° observation angle shall be not less than the following when the incident light is parallel to the base of the marker.

HOR. ENT. ANGLE	S. I.
0°	3.0
20°	1.2

For yellow reflectors the specific intensity shall be 60% of the value for crystal. For red reflectors the specific intensity shall be 25% of the value for crystal.

3. Optical Testing Procedure

A random lot of markers will be tested. The markers to be tested shall be located with the center of the reflecting face at a distance of 5 feet from a uniformly bright light source having an effective diameter of 0.2 inches.

The photocell width shall be 0.05 inch. It shall be shielded to eliminate stray light. The distance from light source center to the photocell center shall be 0.21 inches. If a test distance of other than 5 feet is used, the source and receiver dimensions and the distance between source and receiver shall be modified in the same proportion as the test distance.

Failure of more than 4% of the reflecting faces shall be cause for rejection of the lot.

PHYSICAL PROPERTIES

1. Strength Requirements -- Marker

Markers shall support a load of 2000 pounds as applied in the following manner:

A. Strength Testing Procedure

A random sample of three markers shall be selected for test purposes.

A marker shall be centered over the open end of a vertically positioned hollow metal cylinder. Cylinder shall be 1" high, with an internal diameter of 3" and wall thickness of 1/4". Load shall be slowly applied to the top of the marker through a 1" diameter by 1" high metal plug centered on the top of the marker.

Failure shall constitute either breakage or significant deformation of the marker at any load of less than 2000 pounds.

2. Strength Requirements - Pressure Sensitive Adhesive

Pressure-sensitive adhesive, when applied with minimum application pressure of 60 PSI, must possess a minimum tensile or shear strength of 15 PSI at 70°F ambient.

A. Strength Testing Procedure

"A standard 4" X 4" X .79" marker with pressure-sensitive adhesive on the bottom, shall be adhered to appropriate flat (1/8" thick) carbon steel test plate, properly primed, with 60 PSI (1000 pounds) minimum application pressure. Both top of the marker and bottom of the flat plate shall have fastened to it an appropriate coupling device to insure compatibility with the tensile testing device. The test sample shall then be tested in the tensile mode at 2"/min. pull rate. Minimum load to produce failure shall be 250 pounds at 70°F. Any figure below 250 pounds consistitutes a system failure.

3. Primer -- Strength Requirements

The primer will provide for the proper surface condition to promote optimum adhesion between the substrate and pressure-sensitive adhesive.

A. Strength Testing Procedure

Prime test plates with primer and allow to dry. Apply pressure-sensitive adhesive between primed test plates with 60 PSI application force.

The primer shall be judged as acceptable if after subjecting specimen to tensile loading at 70° ambient the failure is cohesive.

Appendix E. Technical Specifications Related to Post Delineators

SPECIFICATION FOR 3-1/4" DIA. CENTER MOUNT REFLECTOR

GENERAL DESCRIPTION

The reflector shall consist of a hermetically sealed acrylic plastic prismatic reflex reflector housed in embossed aluminum and provided with a single grommetted mounting hole.

DETAILED SPECIFICATIONS

Design and Fabrication of Metal Parts:

Housing shall be .020" 5052-0 aluminum formed to approximately 3.25" in diameter and .235" in depth to retain the acrylic reflector. Housing shall be provided with four embossed circular reinforcement ribs and marked with name and part number of manufacturer.

An aluminum grommet with a 3/16" inside diameter shall be expanded within the reflector mounting hole.

Acrylic Plastic Reflector

The reflector shall be acrylic plastic and the bidder will specify the manufacturer of the raw material and the identification number of the particular molding compound to be furnished. Acceptable formulations are:

MANUFACTURER	TRADE NAME	TYPE OF MOLDING COMPOUND
E. I. du Pont de Nemours & Co., Inc.	Lucite	HM-140
Rohm and Haas Company	Plexiglas	V

The reflector shall consist of a clear and transparent plastic face, with 7 sq. inches of reflective area, herein referred to as the lens with a heat sealable plastic coated metallic foil back fused to the lens under heat and pressure around the entire perimeters of the lens and the central mounting hole to form a unit permanently sealed against dust, water and water vapor. The reflector shall be colorless, yellow, or red.

The lens shall consist of a smooth front surface free from projection or indentations other than a central mounting hole and identification with a rear surface bearing a prismatic configuration such that it will effect total internal reflection of light. The manufacturer's trade mark shall be molded legibly into the face of the lens.

OPTICAL REQUIREMENTS

1. **Definitions:**

Entrance Angle shall mean the angle at reflector between direction of light incident on it and direction of reflector axis.

Observation Angle shall mean the angle at reflector between observer's line of sight and direction of light incident on reflector.

Specific Intensity shall mean candlepower returned at the chosen observation angle by a reflector for each foot-candle of illumination at the reflector.

2. **Specific Intensity:**

The specific intensity of each reflex reflector intended for use in delineators or markers shall be equal to or exceed the following minimum values with measurements made with reflectors spinning. Failure to meet the specific intensity minimum shall constitute failure of the reflector being tested; failure of more than 2 reflectors out of 50 subjected to test shall constitute failure of the lot.

OBSERVATION ANGLE DEGREES	ENTRANCE ANGLE DEGREES	SPECIFIC INTENSITY ANDLEPOWER PER FOOT-CANDLE CRYSTAL	YELLOW	RED
0.1°	0°	119	71	29
0.1°	20°	47	28	11

3. **Optical Testing Procedure:**

The reflex reflector to be tested shall be located at a distance of 100 feet from a single light source having an effective diameter of 2 inches; the light source shall be operated at approximately normal efficiency. The return light from the reflector shall be measured by means of a photoelectric photometer having a minimum sensitivity of 1×10^{-7} foot-candles per mm scale division. The photometer shall have a receiver aperture 0.5" diameter, shielded to eliminate stray light. The distance from light source center to aperture center shall be 2.1" for 0.1° observation angle. During testing the reflectors shall be spun so as to average the orientation effect.

If a test distance other than 100 feet is used, the source and aperture dimensions and the distance between source and aperture shall be modified in the same proportion as the test distance.

DURABILITY

1. **Seal Test:**

The following test shall be used to determine if a reflector is adequately sealed against dust and water.

Submerge 50 samples in water bath at room temperature. Subject the submerged samples to a vacuum of five inches gage for five minutes. Restore atmospheric pressure and leave samples submerged for five minutes, then examine the samples for water intake. Failure of more than 2% of the number tested shall be cause for rejection.

2. **Heat Resistance Test:**

Three reflectors shall be tested for four hours in a circulating air oven at 175° plus or minus 5° F. The test specimens shall be placed in a horizontal position on a grid or perforated shelf permitting free air circulation. At the conclusion of the test the samples shall be removed from the oven and permitted to cool in air to room temperature.

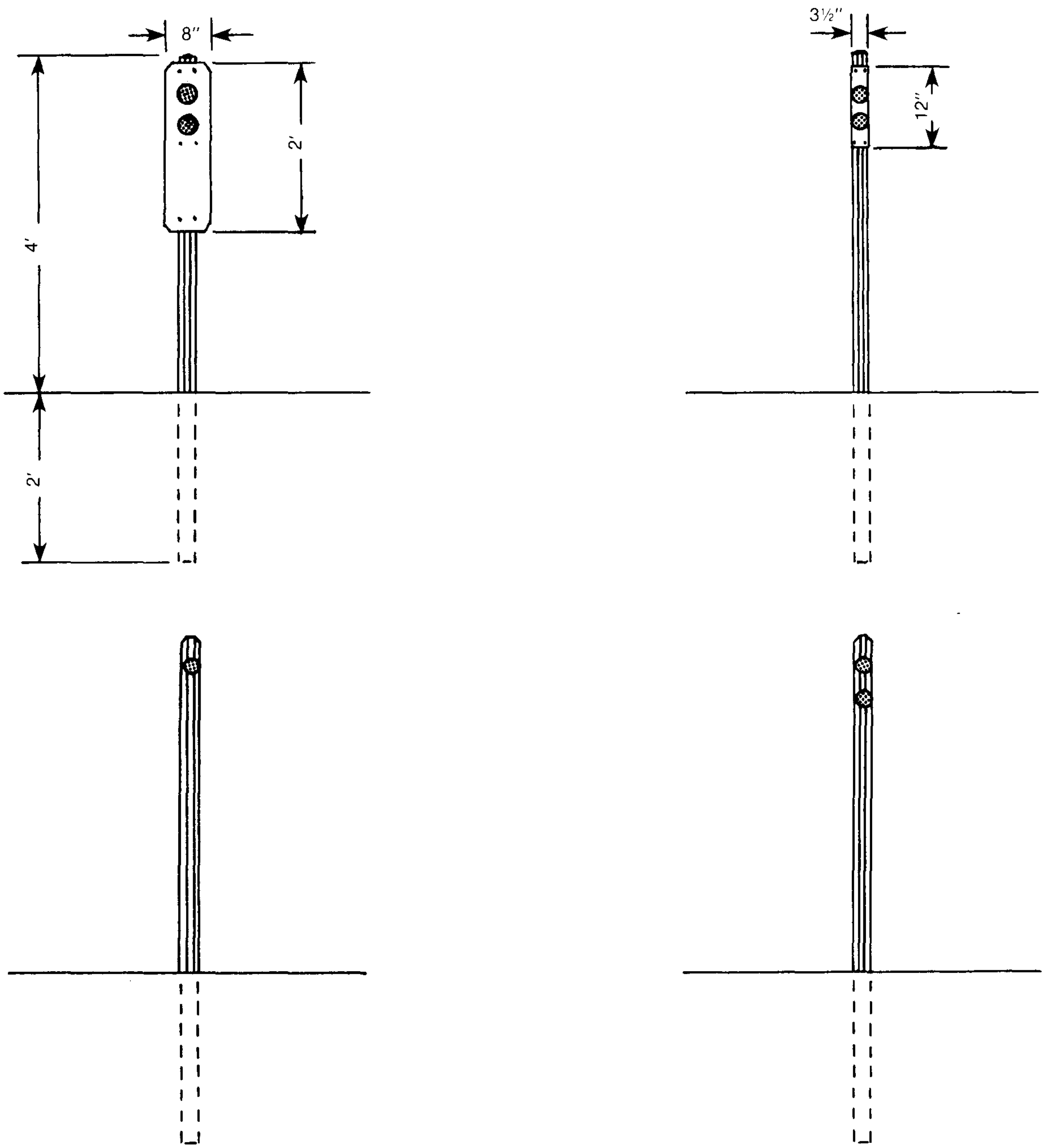
The samples after exposure to heat shall show no significant change in shape and general appearance when compared with unexposed control standards. No failures will be permitted.

SAMPLING PROCEDURE

For qualification purposes only, 50 samples required for all of the tests set forth in this specification may be submitted by the manufacturer. For acceptance purposes, the 50 samples will be selected at random by the purchaser from each shipment. Sample lot and acceptance practice will be the same regardless of the size of the shipment unless specified otherwise in the bid request.

PACKAGING

Fifty reflectors shall be supplied in an individual cardboard tube container with contents marked thereon.



Appendix F. Cost Analysis Techniques

This appendix provides a short review of the statistical analysis and economic models developed in a major FHWA research effort entitled "Cost Effectiveness and Safety of Alternative Roadway Delineation Treatments" (Ref. 58). The complete documentation of this research is available through the National Information Service, Springfield, VA 22161.

The summary included here was adapted from "An Overview of Roadway Delineation Research" (Ref. 60).

STATISTICAL ANALYSIS

This element of the research was designed to evaluate the effect of alternative delineation treatments on accident experience in various highway situations and under varying environmental conditions. To meet this objective, over 500 test sites were selected in ten states, and accident, geometric, traffic and environmental data for these sites were collected. These data were then statistically analyzed to identify important parameters which alter the effects of delineation on accident occurrence and to assess the reduction in accidents associated with various treatments.

In carrying out this analysis, both hypothesis testing and estimation procedures were used. Hypothesis testing procedures were used to assess whether the changes in accident rate resulting from changes in site delineation treatment were statistically significant. These procedures used the t-test, one-way analysis of variance, two-way and higher-order analysis of variance, and covariance analysis. The t-test and one-way analysis of variance provided a means to test for statistical differences in mean accident rate under different treatment categories. Two-way and higher-order analysis of variance and covariance analysis provided a means for studying how these differences were affected by other variables such as roadway geometrics, traffic operations, and climatic parameters. The estimation procedures included the t-test and regression analysis and were used to quantify the changes in the accident rate resulting from different delineation treatments, changes in geometrics, and traffic operational conditions.

Within this study, two types of highway sites were used. The first, termed "matching-control" sites, were those for which the delineation treatment remained unaltered over the analysis period. The second, termed "before-and-after," were those sites for which accident data were available for both before and after the installation of a test delineation treatment.

The general findings resulting from the statistical testing using matching-control sites and using accident rate as a dependent variable were as follows:

For Tangent and/or Winding Sites

- Highways with centerlines have lower accident rates than those with no treatment at all.
- Highways with raised pavement marker centerlines have lower accident rates than those with painted centerlines.
- Edgelines seem to have insignificant effect on traffic accidents.
- Highways with post delineators have lower accident rates than those without post delineators.

For Isolated Horizontal Curves

- There is a slight indication that sites with post delineators have lower accident rates than sites without post delineators.
- Accident rates appeared to be somewhat lower at horizontal curve sites with centerlines than at horizontal curve sites with no delineation treatment.

The analysis of the "before-after" sites yielded insignificant results for all the tests and therefore could not be accepted with any degree of confidence. It was felt that the small sample (31 pairings) was a major contributing factor to the lack of positive results.

Economic Analysis Models

This element of the research involved the development of two economic models that could be used to evaluate roadway delineation treatments. The first, a cost-benefit model, was designed to compare major delineation treatment applications. The second, a cost-analysis model, was designed to evaluate treatments for which the benefits are assumed constant and independent of minor treatment variations; i.e., paint versus thermoplastic.

The geometric, traffic, and climatic parameters are not entered directly into either of the models, but these variables do enter through their effect on traffic accidents and the cost and service life of candidate treatments. The two models are also supplemented by installation-costing procedures designed to provide a uniform basis for computing treatment installation costs.

The mathematical expressions for the two models are:

- Cost-Benefit Model

  Net Present Worth (NPW) = New Present Worth of Benefit (PWB) - Present Worth of Cost (PWC)

$$PWB = \frac{AADT(365)}{10^6} \sum_{n=0}^{N} \left[RAR \times CA \times \frac{1 + v^n}{1 + i} \right]$$

$$PWC = \sum_{n=0}^{N} \left[\frac{(TIC)_n}{(1 + i)^n} + \frac{(MC)_n}{(1 + i)^n} \right] + \frac{TC}{(1 + i)^N}$$

- Cost-Analysis Model

  Present Worth of Cost = PWC

$$PWC = \sum_{n=0}^{N} \left[\frac{(TIC)_n}{(1 + i)^n} + \frac{(MC)_n}{(1 + i)^n} \right] + \frac{TC}{(1 + i)^N}$$

where:

AADT = annual average daily traffic in year zero

RAR = estimated reduction in accident rate in year zero

CA = cost of accident

v = annual percent increase in traffic volume

i = discount rate

N = analysis period

$(TIC)_n$ = total installed cost in year n

TC = terminal cost at the end of analysis period

$(MC)_n$ = maintenance cost in year n

The block flow diagram shown in Figure F-1 indicates the procedure for executing the models. First, the highway situation and the candidate treatments are identified. Next, appropriate data are compiled for each candidate treatment. Either the cost-benefit or the cost-analysis model is then utilized to compute NPW or PWC (as appropriate). NPW and PWC are indices of economic desirability and are interpreted as follows:

- Treatments with NPW ≥ 0 are all economically desirable; the economic desirability increases with an increasing value of NPW.
- The treatment with the least PWC value is most economical.

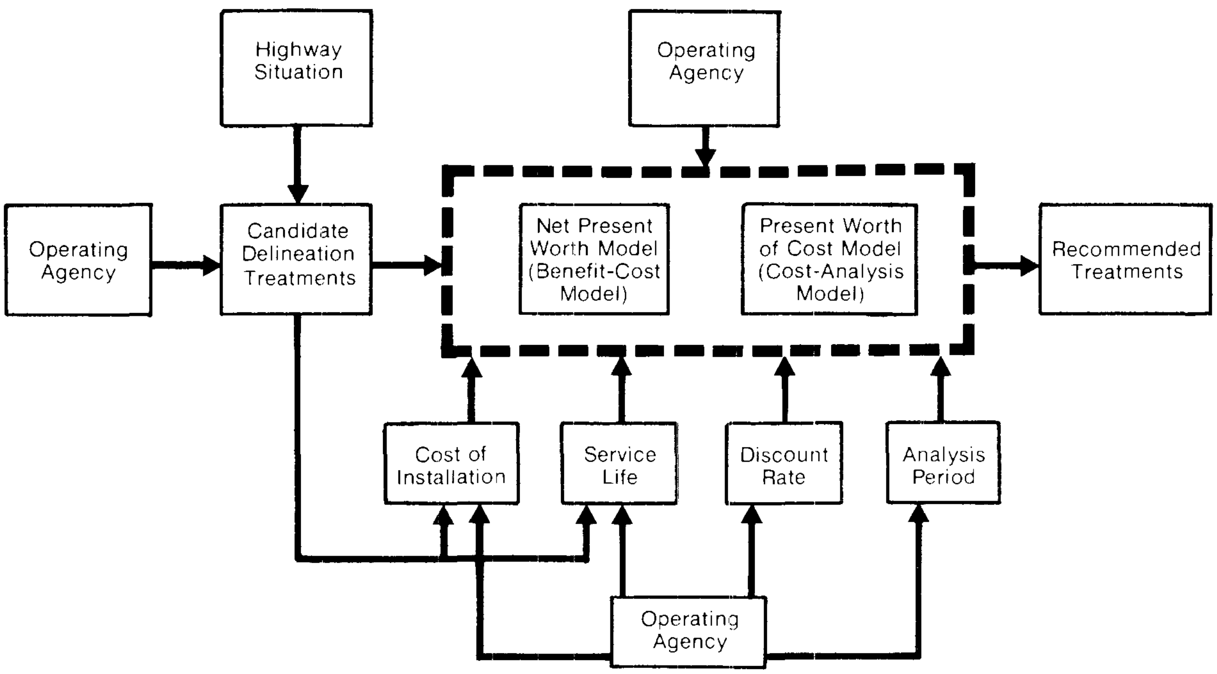


Figure F-1. Schematic Representation of "Benefit-Cost" and "Cost Analysis" Model

Delineation Guidelines

This element of the research involved the application of the cost-benefit model to a set of specific delineation situations to determine the desirability of specific treatments applied under specific roadway and traffic conditions. The scope of the cost-benefit calculations included continuous delineation applications along both tangent and winding sections, as well as spot improvements at 2 horizontal curve sites. The types of treatment applications considered are shown in Table F-1.

The cost-benefit calculations were carried out parametrically where ranges of values for all costs, service lives, etc., were chosen for each selected treatment application. Economics was the sole basis for the evaluation of the various treatments with reduction in traffic accidents as the sole measure of benefits to be derived from the delineation systems. One fallacy in this procedure is the uncertainty associated with the selected accident model. If the accident model is questionable, then the cost-benefit is likely to produce questionable results.

Table F-1. Treatment Applications Used in Cost-Benefit Calculations

Type of Site	Description of Treatment
Tangent Sections	Painted Centerline Added to No Treatment
	Raised Pavement Markers Added to Painted Centerline
	Post Delineators Added to Painted or RPM Centerline
	Edgeline Added to Centerline with Post Delineators
	RPM Centerline Added to Painted Centerline
	Edgeline Added to Centerline (Post Delineators Optional)
Winding Sections	Post Delineators Added to Centerline with Edgeline
	Painted Centerline Added to No Treatment
	RPM Centerline Added to No Treatment
	Centerline Added to No Treatment (Mountainous)
	Centerline Added to No Treatment (Level)
Horizontal Curves	Post Delineators Added to Centerline at Sites in Georgia and Louisiana

Utilizing the cost-benefit model, a series of calculations were performed to develop the benefits and costs for each combination of parameters for each treatment type. Some general conclusions based on the calculations are:

- A painted centerline added to tangent and winding sections with no previous treatment was cost-beneficial for all values of cost, service life and AADT considered.
- RPM centerlines were more cost-effective than painted centerlines where a service life of five years or more is expected from the RPM's and the AADT exceeds 3,000 vehicles per day.
- Post delineators were cost-justified at all AADT's above 1,000 vehicles per day and under most combinations of installation costs and service lives for AADT's as low as 500 vehicles per day.
- Edgelines with service lives of five years or more were cost-effective for most highways with an AADT of 500 vehicles or more per day. If this installation cost is less than $165 per mile, they are cost-effective with service lives of two years. If the AADT exceeds 1,000 vehicles per day, they are almost always cost-effective with a one-year service life.

COMMENTS ON THE RESEARCH

Although this was a very extensive and comprehensive analysis of the cost-effectiveness of various delineation treatments, it is important to recognize that the results of this research were obtained through the statistical analysis of accident data and therefore are subject to all the strengths and drawbacks which a statistical analysis entails. Of particular concern are the shortcomings of statistical analysis related to the accident data base. Accident data take a long time to accumulate. Over this period, the roadway environment can change, driving population may alter, and traffic regulations can be modified. In addition to such changes over time, no two roadway sites are exactly alike, causing a variation in data from site to site. These variations make it extremely difficult to conduct a controlled study, a prerequisite for good statistical results. Other problems encountered in statistical analysis of accident data relate to the variation in accident reporting procedures from state to state and county to county, discrepancies and abnormalities in the data base, and the time and cost involved in selecting highway sites with specified characteristics.

It is therefore important that the use of the statistical results be used with some care. The t-test results estimate the mean reduction in accidents for a particular delineation treatment but these results do not take into account roadway geometrics, operational conditions and climatic conditions.

Regression models, like the t-test results, also estimate accident reduction associated with various delineation treatments, but unlike the t-test, they provide a measure of its dependence on other roadway characteristics and climatic parameters. It is important to remember, however, that although the regression models provide estimates of the average accident rate on a particular section of highway, the application of these models to an individual highway section can be subject to rather large variations and should be used only as a general guide.

General recommendations on the use of the results of this accident modeling research are:

- If the intended objective is to assess the overall reduction in accidents from the installation of a particular delineation treatment without regard to consideration of roadway features, then the t-test results should be applicable.
- If the effect of delineation treatment is to be assessed for a given highway and geometric and operational characteristics are of concern, then the regression models should be considered.
- Among the regression models available, preference should be given to the one which best reflects the highway environment. For example, if the objective is to assess the effect of delineation on California roads, the models developed for the Western states are more appropriate.

The economic models developed to evaluate various roadway delineation treatments include all the important variables that need to be considered and seem to provide a good basis for computing the costs and benefits of different systems. As better accident models are developed, the economic models can become better planning and research tools for evaluating different forms of delineation treatments.

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