# EVALUATION OF RAISED PAVEMENT MARKERS FOR ROADWAY DELINEATION DURING FOG

by

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(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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# ABSTRACT

Reduced visibility on the highway due to adverse weather conditions results in an inability of motorists to readily observe pavement markings, signs, and vehicles. The condition that presents the most serious restriction is fog, although rainfall during the night frequently creates serious visibility problems. Because of the ability of reflex reflective devices and materials to provide pavement and roadway delineation at relatively low costs, the feasibility of using them for roadway delineation and vehicle guidance during fog was investigated, with emphasis on the nighttime visibility characteristics. Also, consideration was given to various experimental methods of marker placement for roadway delineation and to protecting the markers from snowplow damage.

Two types of corner-cube raised markers were placed along the highway edge line on 20-ft.(6.1 m) centers. In one placement concept, snowplowable and non-snowplowable markers were placed on the pavement surface; in a second concept, the markers were recessed below the pavement surface in grooves. The marking systems were subjectively evaluated by observing the legibility properties during fog and noting the number of markers visible. Based on the observations, the raised pavement markers were thought to provide sufficient nighttime roadway delineation for vehicle guidance during light to medium density fogs. Although data were not available for dense fog, it is felt that adequate delineation would be provided for such fog conditions.

The method of grooving the pavement in the vicinity of the edge line for the purpose of recessing the markers to provide snowplowability was found to be feasible, providing adequate drainage is provided and a groove is placed in front of the marker. The length of the groove depends upon the reflectivity-distance requirements.

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## INTRODUCTION

Reduced visibility on the highway due to adverse weather conditions results in the inability of motorists to readily see pavement markings, signs, and vehicles. The most serious restriction is occasioned by fog, although rainfall during the night frequently creates serious visibility problems.

Roadway delineation systems in the form of painted pavement markings, post delineators, raised pavement markers, pavement inset lights, etc., have been used to assist the motorist during adverse weather conditions by furnishing information for lane control. Much research has been done on roadway delineation systems; however, there is only limited information concerning the effectiveness of the various devices and systems during fog. The pavement inset lighting system recently installed on Afton Mountain in Virginia shows great promise, but its overall effectiveness in terms of its influence on traffic flow, reliability of operation, maintenance problems, etc., is yet to be determined. The inset lights cast light in only one direction (from the light source to the driver) whereas in most other systems, the light travels from the vehicle to the marker and back to the driver, which decreases their efficiency, especially during fog. The primary advantage of the reflected light systems, which are made up of reflex reflective devices and materials, is their low costs.

Because of the ability of reflex reflective devices and materials to provide pavement and roadway delineation at relatively low costs, the feasibility of using such systems for roadway delineation and vehicle guidance during fog was investigated.

# REFLEX REFLECTORS

Reflex reflectors are devices or materials which return a high proportion of incident light in the direction from which it originates over a wide range of angles of incidence, given no conditions that reduce visibility. There are two basic types of reflex reflectors: image forming types, which generally consist of a lens and a reflecting surface, e.g., reflective sheeting and glass beads on paint pavement striping; and corner-cube reflex reflectors, which reflect light off three mutually perpendicular surfaces.[1]

Although both systems are used extensively for delineation, the light reflected by a corner-cube reflector is usually greater than that produced by a beaded reflector, often by a factor of 10 to 100,[2] at least for small angles. Beaded pavement stripes are used primarily because of the ease of continuous application and their low cost. The primary problem associated with pavement striping is the high loss of reflectivity, and therefore visibility, during adverse night weather conditions; namely, rain and fog. Pavement markers utilizing the corner-cube reflex principle are not generally subject to this problem, however, they do present problems when placed on pavements on which snowplows are used. They are available only in single units which have to be placed on the roadway surface or raised, and therefore they project above the surface. Although the raised corner-cube type markers are subject to damage from snowplows, they hold a high potential for providing roadway delineation during fog.

As stated earlier, very little specific information is available on the use of raised pavement markers during fog; however, various studies of roadway delineation systems and visual requirements in night driving have been reported.[2,3] Parts of the reports contain information of interest to persons considering the use of raised markers for improved highway delineation during fog. Taylor and McGhee report that delineation in any reflective system will not usually depend on single units, but rather on patterns of units; and that although it is conceivable for a driver to track individual bright points one at a time in a very dense fog, it is commonly accepted that three units should be visible where delineation is used, regardless of the vertical and horizontal curvature.[2]

Although there is considerable controversy over the maximum distance at which a reflector should be visible,[2] Rockwell has concluded from eye movement studies that driver behavior for nighttime driving does not change when delineation is provided beyond approximately 100 ft.(30.5 m).[3]

Many variables influence the visibility of raised markers. Cook presents a detailed discussion of the most important variables, including reflector size, location, type and condition of the reflector, atmospheric transmissivity, light source, and reflector color.(1)

## PURPOSE

The purpose of this study was to determine the feasibility of using raised pavement markers for roadway delineation and vehicle guidance during fog, with emphasis on the visibility characteristics of the markers. Consideration was given to various experimental methods of marker placement for roadway delineation and to protecting the markers from snowplow damage.

## SCOPE

The research was limited to a study of commercially available standard, corner-cube raised pavement markers. The markers were placed to provide maximum roadway delineation during night fog, with consideration being given to placement along the pavement edge line only.

## PROCEDURES

### Test Site

The area chosen for the evaluation was the top of Afton Mountain, which is traversed by Interstate 64, Route 250, and the Blue Ridge Parkway. Since I-64 already had a lighting system featuring pavement inset lights, Route 250 in the vicinity of the Blue Ridge Parkway was the most desirable location for the marker systems. This 4-lane divided section has a bituminous surface on both the roadway and the shoulder.

Use of the Afton Mountain area allowed the placement of the marker systems in an area subjected to frequent fogs and which is in close proximity to the Research Council.

## Type of Raised Marker

Only two types of corner-cube raised pavement markers were considered in the evaluation; namely, the Stimsonite type 88 and type 99 mono-directional white markers. The type 88 marker, shown in Figure 1*, has a 3/4-in.(1.9-cm) profile (reflector area— 3.25 in.$^2$[21.0 cm.$^2$] and has been used primarily on the road surface in areas where snow and plowing is not a problem. The type 99 marker is approximately 7/16 in.(1.1 cm) high (reflector area— 1.7 in.$^2$[11.0 cm.$^2$] and is protected from snowplow damage by placing it in a steel casting attached to the road surface. The type 99 marker with and without the steel casting is shown in Figure 2.

## Marker Placement

Various methods of marker placement were tried with emphasis on protection of the markers from snowplow damage. Four 200-ft.(61.0 m) marking systems were installed with individual markers placed on 20-ft.(6.1 m) centers within each 200-ft.(61.0 m) system. Figure 3 shows the relative position of each system on the roadway. Differences among the four systems were in marker types, location with respect to the edge line, and method of placement. It should be noted that all markers were angled toward the centerline of the highway with the line of sight intersecting the centerline 200 ft. (61.0 m) ahead of the marker. They were angled to give maximum reflectivity during fog.

### Surface Placement

Of the four marking systems installed, two were surface-mounted using standard placement procedures.

System II employs a non-plowable marker (T-88) and was placed primarily as a basis for comparison. It should be noted, however, that this marker type has been placed in areas in Virginia where snowplowing is not a major problem and rubber-tipped snowplow blades are being utilized. Figure 4 shows the marker as it was placed on the right edge line approximately 1 in.(2.5 cm) from the edge of the pavement.

The other surface mounted marker (System III), is a snow-plowable marker (type 99) utilizing a tapered steel casting for protection of the reflecting unit. This type of marker and positioning were included since they are being considered for placement on a future interstate highwav for roadway delineation during adverse weather conditions, especially fog. Figure 5 shows the marker as it appears on the roadway, approximately 1 ft.(.3 m) onto the shoulder to the right of the pavement edge.

*All figures are appended.

### Grooved Mounting

Markers in Systems I and IV were recessed by placing them in grooves with the top of the marker flush with the road surface. The only difference between Systems I and IV is the location of the marker and groove with respect to the pavement edge. Grooves approximately 6 in.(15.2 cm) wide, 2 ft.(.6 m) long, and 3/4 in.(1.9 cm) deep were cut in front of each marker as the motorists views it. This tapered groove, with a top view as shown in Figure 6 (applicable to Systems I and IV), is necessary for proper marker viewing by the motorist. Also a drainage groove approximately 1 in. wide was cut to allow water and debris to be drained away from the groove and marker. Figure 7 shows the type 88 and 99 markers placed along the pavement edge line; Figure 8 shows them placed on the shoulder approximately 1 ft. (.3 m) from the pavement edge. The tapered grooves for the markers were cut with a standard Tennant RS/TLR scraping machine (see Figure 9) equipped with a traffic line removal tool and 3/4-in.(1.9-cm) cutters.

## EVALUATION

The evaluation of each pavement marking system was a subjective one concerned primarily with its visibility characteristics during night fog. Employees of the Research Council observed the legibility properties during fog, noting the number of markers visible. Also, the susceptibility of systems I and IV to snowplow damage and the buildup of debris around the markers were observed.

## RESULTS

Within the time span allowed for data collection, only two fog conditions were encountered from which visibility characteristics could be judged, both being in the medium density range. It was possible, however, to observe the markers under light fog conditions as the medium density was clearing. The fog density was determined by noting the number of shoulder delineators visible during hours of darkness. The observed fog densities were checked against densities as monitored by fog detectors located in close proximity to the test site. Dense fog was considered to be in the 0-100 ft.(0-30.5 m) visibility range, medium in the 100-200 ft.(30.5-61.0 m) range, and light in the 200-400 ft.(61.0-122.0 m) range. It should be noted that the majority of fogs encountered prior to this study had been in the medium density range.

Three engineers from the Research Council evaluated the systems by noting the number of markers visible within each one as viewed from a stationary vehicle with lights on high beam and low beam. Table 1 gives the number of markers visible within each system, the values being obtained by averaging the numbers visible to the three observers. As the table indicates, from 5 to 7 (100 ft.[30.5 m] to 140 ft. [42.7 m]) markers could be seen within each system for medium fog densities and low beam lights. Figure 10 is a photograph of this particular condition within system II. For high beams, 7 to 8 (140 ft. [42.7 m] to 180 ft.[54.9 m]) markers were visible as shown in Figure 11 (medium fog density). For light fog densities and low beams, at least 8 to 10 markers were visible as shown in Figure 12. Figure 13 shows a medium density fog as viewed by the motorist just prior to entering the test site.

Observation of the reflective properties of the type T-88 and type T-99 markers indicated little difference in reflectance; however, it was the consensus of the observers that the type T-88 marker was superior to the type T-99 in reflectivity, especially at close distances.

In recessing the marker below the pavement surface, it is assumed that it will not be damaged by snowplow blades. As shown in Figure 14, the grooves in systems I and IV would allow a blade in contact with the pavement surface to pass over the marker without touching it. System III utilizes a standard snowplowable marker. With the recessed marker being considered snowplowable, the main concern involves water and/or debris buildup in the groove. As there has been no snowfall since the markers were installed, no information on the debris buildup, etc., caused by snowplowing is available; however, after 4 months, during which time there were numerous rains, including storms, no appreciable debris buildup has been noted, except for fine sand accumulating in the vicinity of the marker. This material did not obstruct the reflecting surface and, therefore, caused no problem in reflectivity. Also, it was found that for good drainage of water from the groove and marker, the drainage groove should be at least 1 in.(2.54 cm) wide and the tapered groove in which the marker is placed should be wide enough to allow drainage beside the marker.

Table 1. Number of Markers Visible within Each System.

| SYSTEM | LIGHT BEAM | FOG DENSITY DENSE (0 ft.-100 ft.*) | MEDIUM (100 ft.-200 ft.) | LIGHT (200 ft.-400 ft.) |
|---|---|---|---|---|
| I | High | - | 7 - 8 | 10+ |
| | Low | - | 5 - 7 | 8 - 10 |
| II | High | - | 7 - 8 | 10+ |
| | Low | - | 5 - 7 | 8 - 10 |
| **(L) | High | - | 7 - 8 | 10 |
| (L) | Low | - | 5 - 7 | 8 - 10 |
| III | High | - | 7 - 8 | 10+ |
| | Low | - | 6 - 7 | 8 - 10 |
| IV | High | - | 7 - 8 | 10 |
| | Low | - | 5 - 7 | 8 - 10 |

*1 ft. = 0.3048 m.
**Left edge of pavement. All others along right edge.

## DISCUSSION OF RESULTS

When judging a product or concept, a criterion is needed on which to base the evaluation. For this study, no clear-cut criterion was available because there was, and is, little information concerning the visibility properties of raised pavement markers during various fog densities or motorists' requirements for such delineation in fog. As noted earlier, Taylor and McGhee hold the opinion that delineation in any reflective system will not usually depend on single units, but rather on patterns of units; and that although a driver conceivably could track individual bright points one at a time in a very dense fog, it is commonly accepted that three units should be visible where delineation is used, regardless of the vertical and horizontal curvatures.(2) Also, Rockwell has concluded from eye movement studies that driver behavior in nighttime driving does not change when delineation is provided beyond approximately 100 ft;(3) however, there is considerable controversy over the maximum distance at which a reflector should be visible.

Using the information cited, along with the general feeling of the observers concerning the adequacy of the visible markers in providing sufficient delineation for vehicle guidance during periods of fog, conclusions were drawn as to the effectiveness of the raised markers.

The amount of reflected light from each marker as viewed by the motorist is influenced by a number of factors; namely, the size and efficiency of the reflecting unit, the intensity and height of the light source, the distance between the source and reflector, the density of the intervening atmosphere and, in this particular case, the length and depth of the grooves for the markers. As the marker is placed below the road surface, it is necessary to provide an avenue for the vehicle lights to reach the reflector face, and in this study a tapered groove was placed in front of the marker for this purpose. The length of the groove, the distance between the marker and vehicle, the geometrics of the vehicle lighting system, the driver's line of sight, etc., determine the amount of light reflected for delineation. As this study was primarily concerned with roadway delineation during fog conditions, a 24-in.(61.0-cm) long groove was chosen, because in the critical density range, below 200 ft.(61.0 m) visibility, the majority of the reflecting surface is visible to the motorist. For example, referring to Figure 15, at 150-ft.(46.0-m) visibility, 100% of the type 99 and 80% of the type 88 reflecting surfaces were exposed for reflecting light. If additional retroreflectance is needed for delineation during conditions in addition to fog, namely rain, the length of groove may be extended to give the desired reflectivity.

All markers were angled so that a line of sight perpendicular to the front edge of the reflector would intersect the centerline 200 ft.(61.0 m) ahead. This was done to provide maximum visibility to the motorist during medium to dense fog; however, observation of the markers from the shoulder, which meant the markers were angled away from the motorist, did not cause a noticeable decrease in reflectivity. Therefore, the question of marker positioning for maximum retroreflection would have to be determined through a controlled analysis where retroreflection for small angles, in both vertical and horizontal planes, could be accurately measured.

Close inspection of the reflector face after 3-4 months revealed no breaking or chipping and very little abrasive wear. The life of each marking system is not known; however it should be noted that markers placed in the vicinity of the edge line are not as susceptible to vehicle damage as are those on the centerline and could be expected to last longer. Also, the markers placed close to the pavement edge can be drained easily without long transverse pavement cuts because of the differential in height between the pavement and shoulder for some highways or steep shoulder slopes. These conditions result in shorter distances to obtain a negative slope from the marker for drainage. It is realized that markers placed along the pavement edge are susceptible to being painted; however, it was one of the purposes of this study to investigate the concept of placing markers in the vicinity of the edge lines. For practical purposes, the markers would either be placed inside the edge lines or between the edge line and pavement edge by moving the edge line slightly inward toward the centerline.

Although the marking systems were not observed under dense fog conditions because no such condition occurred during the study, it was felt that at least 3 to 5 markers could be seen in dense fog. This estimate is based on the familiarity of the author with dense fog in the test area. On the basis of this familiarity, comparisons of the relative visibilities of pavement markings, delineators, etc., between the dense and medium fog densities could be interpolated.

## CONCLUSIONS

Based on the observations made of the raised pavement marking systems, the following conclusions are presented.

1. During light to medium density fogs, the four raised pavement marking systems were thought to provide sufficient nighttime roadway delineation for vehicle guidance. Although data were not available for dense fog, it is the general feeling that adequate delineation would be provided for such a condition.

2. The method of pavement grooving in the vicinity of the edge line for the purpose of recessing the markers to provide snowplowability is feasible, if adequate drainage is provided, and a groove is placed in front of the marker. The length of the groove is determined by the reflectivity distance requirements.

3. There were no discernible differences in the visibility characteristics of the four marking systems. Within the fog densities encountered, systems I and IV, utilizing recessed markers, provided delineation comparable to that of systems II and III, which utilized standard marker placement methods. Also, no differences were perceived between the markers recessed on the pavement's edge and those placed 1 ft. off the pavement on the shoulder.

## RECOMMENDATIONS

It is recommended that a system of raised markers recessed below the road surface by pavement grooving be installed at one or two sites which are susceptible to rain, snow, and fog. A study of associated costs and a determination of the service life of the markers should be a part of any further research.

Further consideration of placing markers in grooves along the edge of the pavement should include an investigation of different methods of pavement grooving. For example, grooves possibly could be placed on new pavements by forming the depressions or grooves when the pavement surface is placed and the materials are flexible or workable.

It is anticipated that a delineation system incorporating corner-cube retroreflectors positioned along the pavement edge line will be installed within the next six months for further evaluation.

# REFERENCES


1. Cook, K. G., "Reflector Analysis", Century Research Corporation, USDOT Contract FH-11-6950 (August 1969).

2. Taylor, James I., and Hugh W. McGhee, "Roadway Delineation Systems", NCHRP Report 130, Transportation Research Board, National Academy of Sciences, Washington, D. C. (1972).

3. Rockwell, T. H., R. L. Ernst, and M. J. Rulon, "Visual Requirements in Night Driving", NCHRP Report 99, Transportation Research Board, National Academy of Sciences, Washington, D. C. (1970).


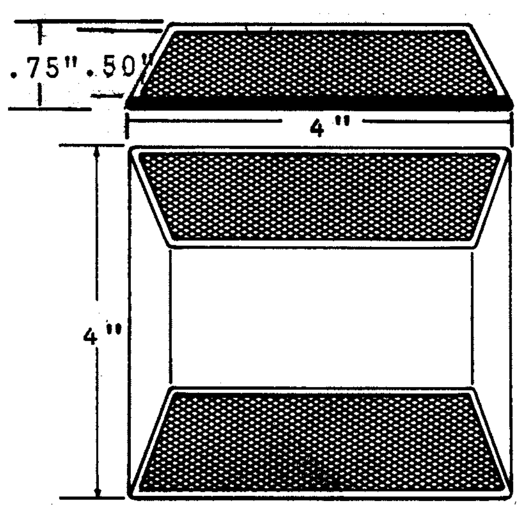


Figure 1. Type 88 mono-directional white (crystal) marker. (1" = 2.54 cm).

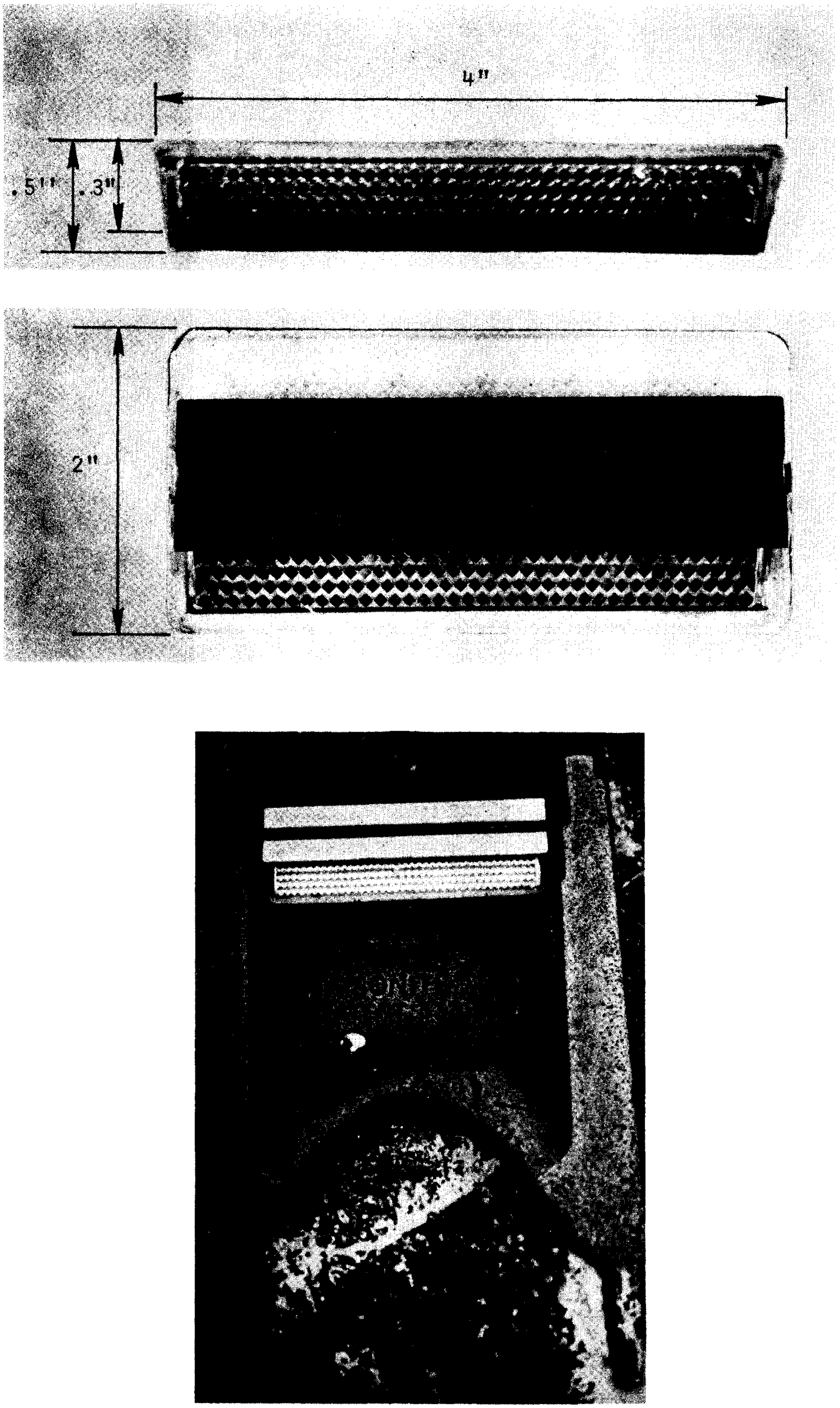


Figure 2. Type 99 marker. (1 in. = 2.54 cm)

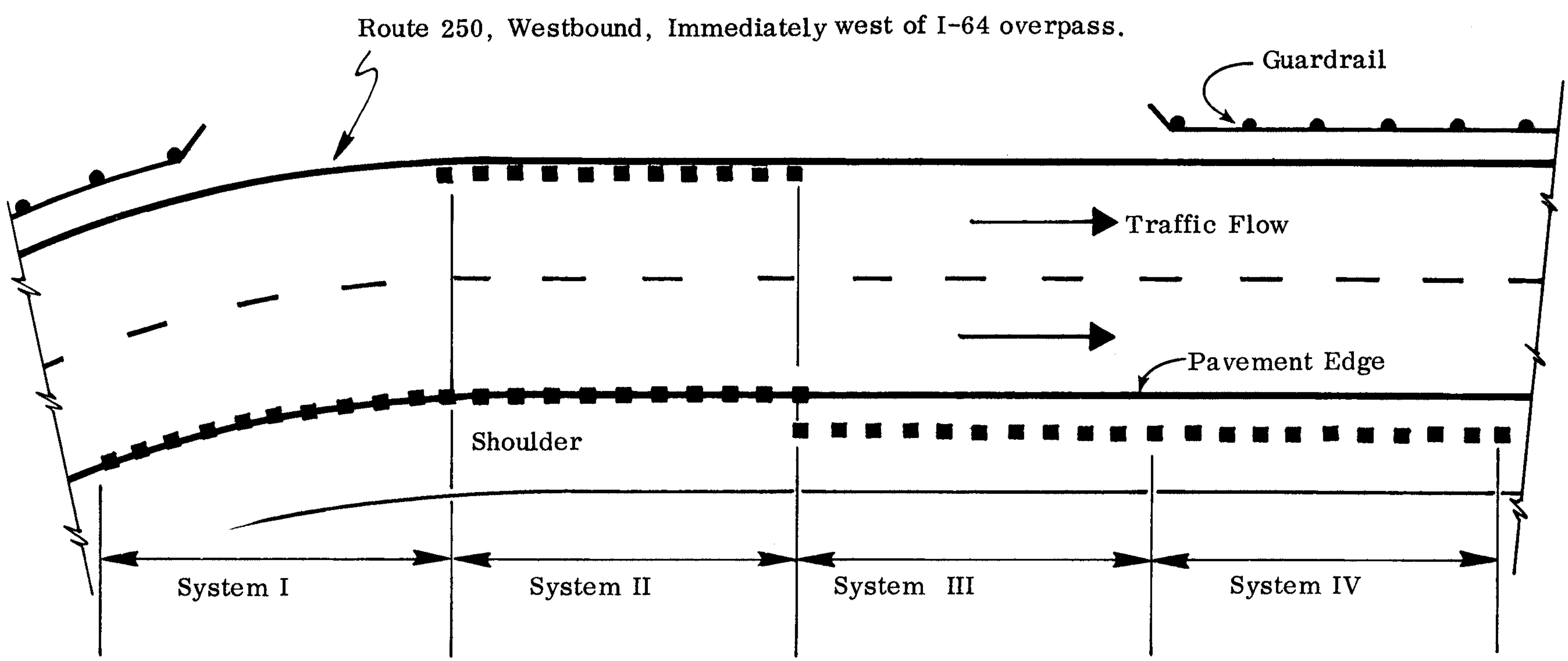


Figure 3. Relative positions of marking systems.

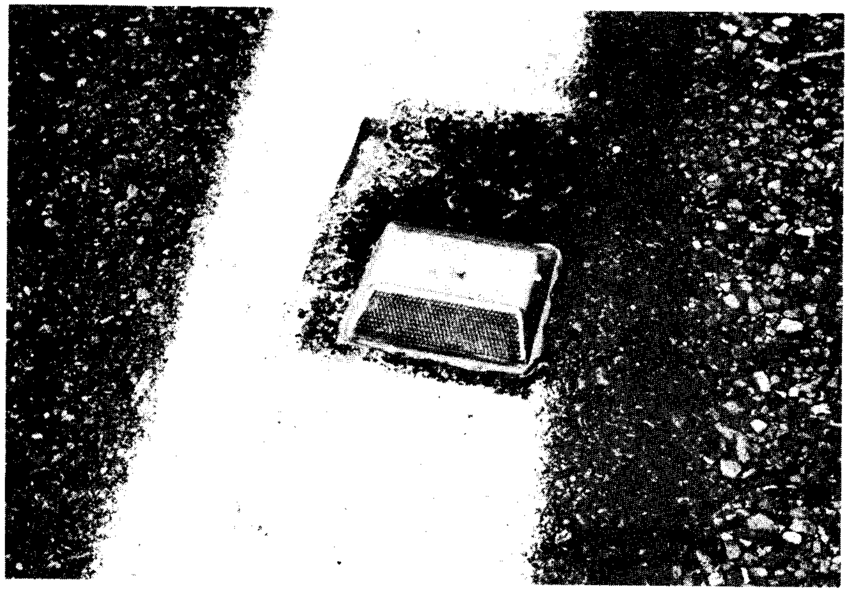

Figure 4. T-88 marker placed on pavement surface along edge line (system II).

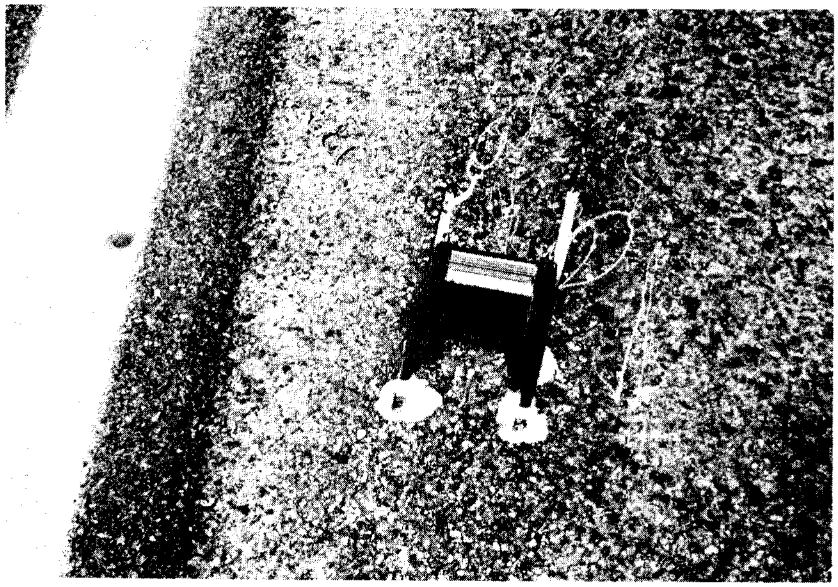

Figure 5. T-99 marker placed on shoulder (system III).

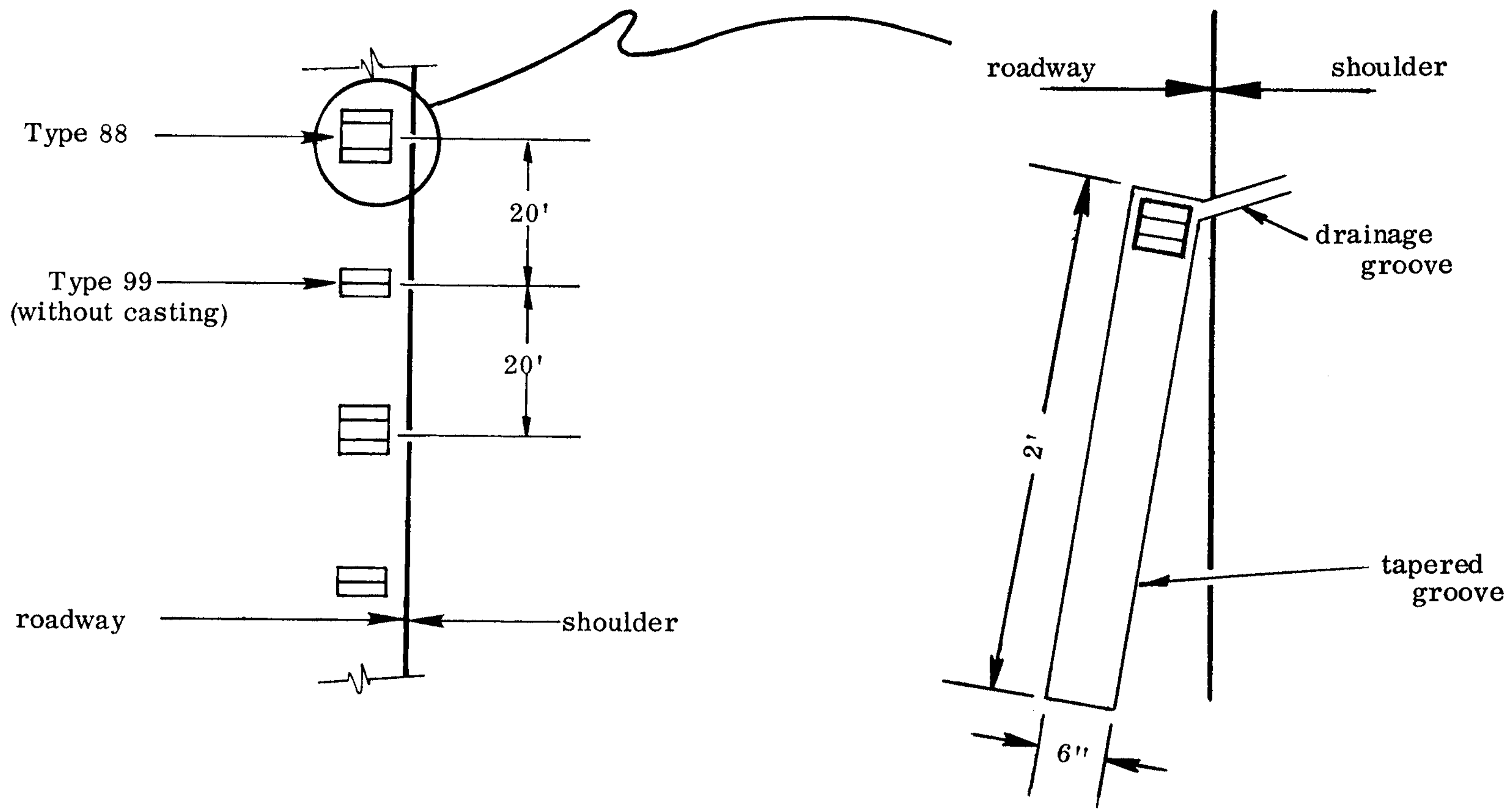


Figure 6. Type 88 and type 99 marker placed in grooves along pavement edge.

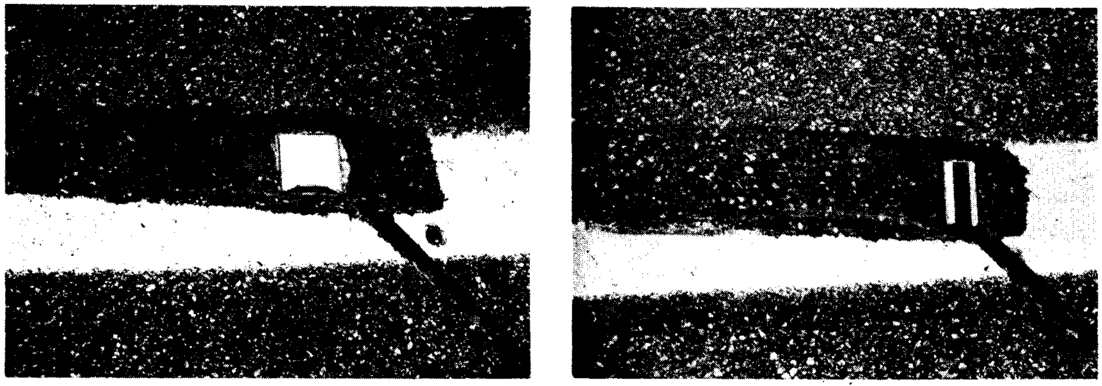

Figure 7. T-88 and T-99 (reflecting unit only) markers placed in grooves along pavement edge.

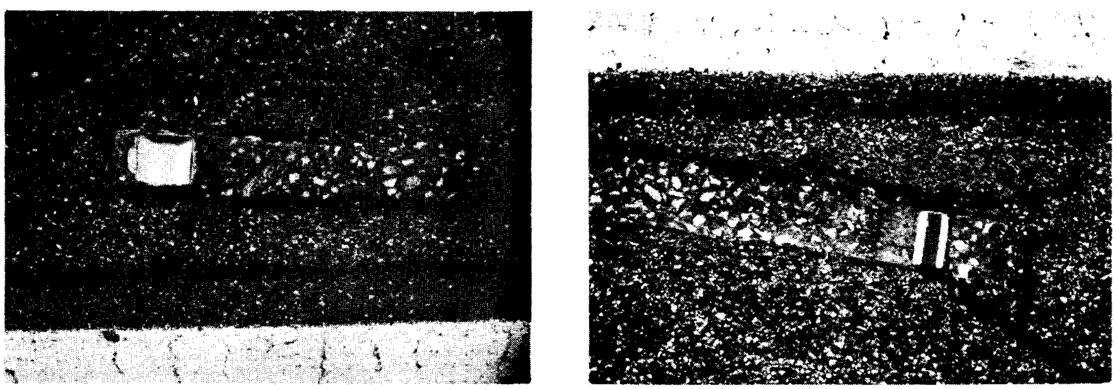

Figure 8. T-88 and T-99 (reflecting unit only) markers placed in grooves on shoulder.

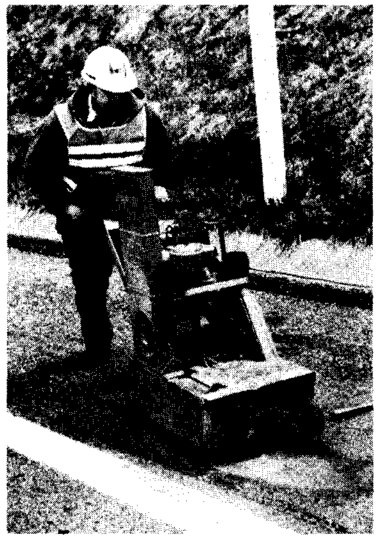

Figure 9. Cutting groove with scraping machine.

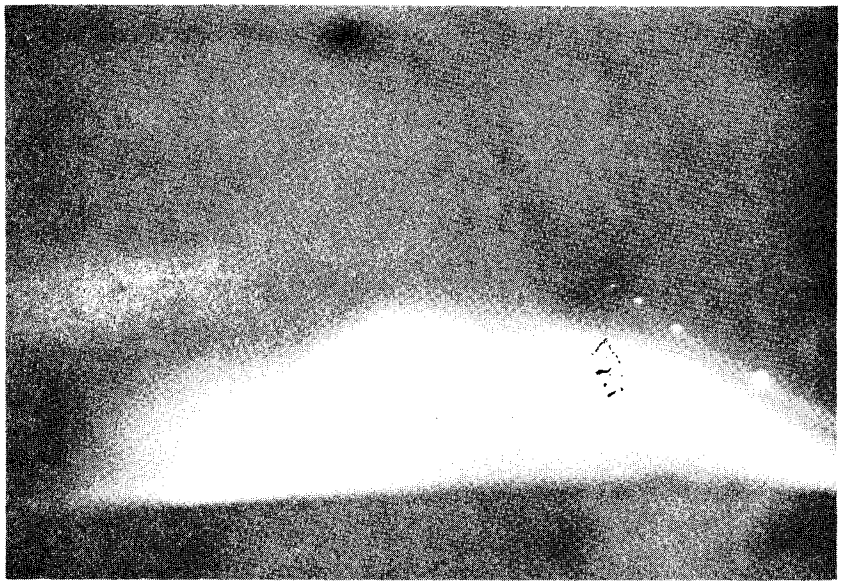

Figure 10. Marker visibility under low beam lights in medium density fog (system II).

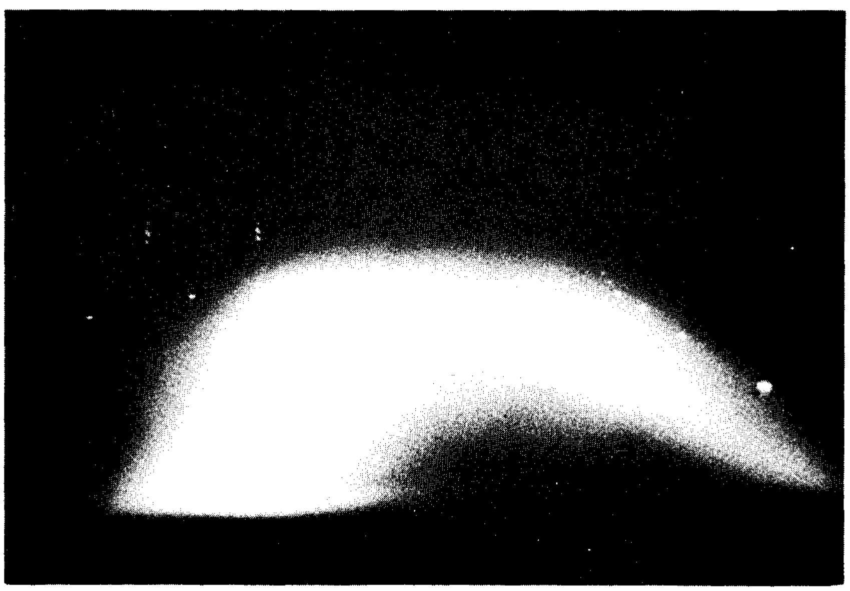

Figure 11. Marker visibility under high beam lights in medium density fog (system II).

Figure 12. Marker visibility from shoulder in low beam lights in light density fog (system I).

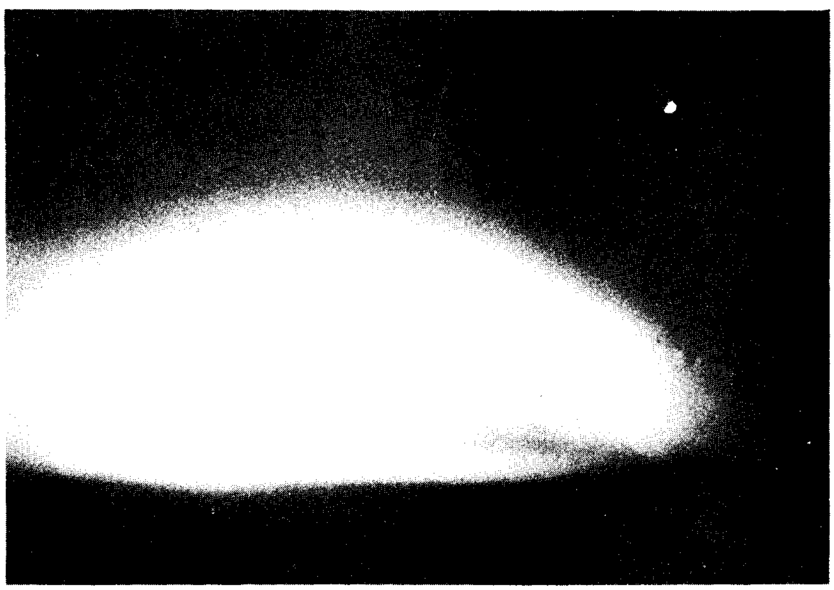

Figure 13. Medium fog conditions ahead of test site (low beams).

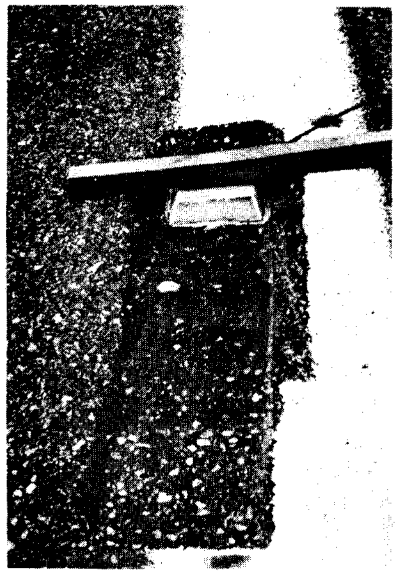

Figure 14. Snowplow blade in relation to recess in a groove.

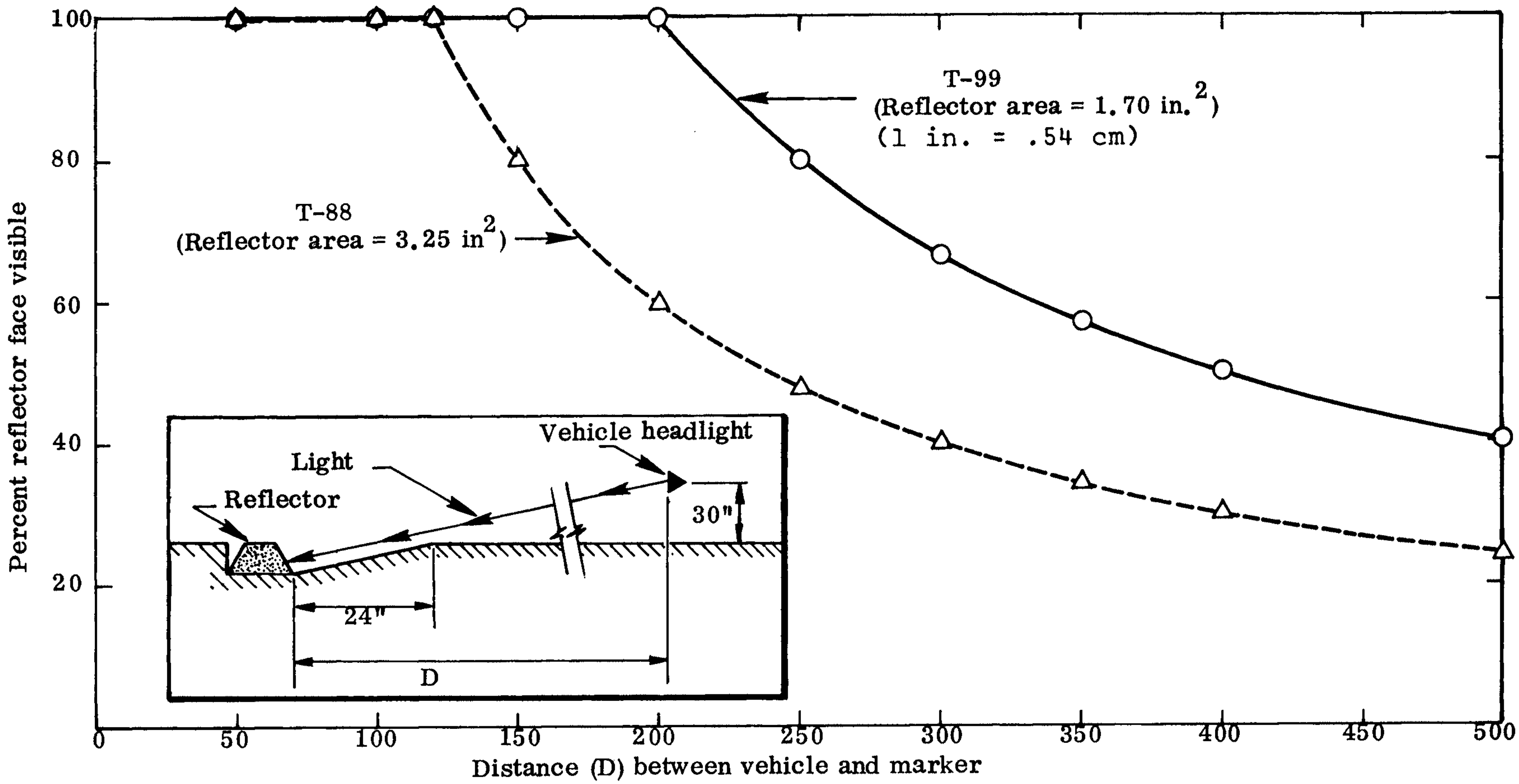


Figure 15. Percent of reflector face visible at various sight distances for 2 ft. groove.