RETROREFLECTIVITY: A RECOMMENDED MINIMUM VALUE

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RETROREFLECTIVITY: A RECOMMENDED MINIMUM VALUE

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AN IMPORTANT NOTE FOR THE READER

The research detailed in this report was commissioned by Transit New Zealand when it had responsibility for funding roading in New Zealand. This funding is now the responsibility of Transfund New Zealand.

CONTENTS

EXECUTIVE SUMMARY

1. Introduction

Roadmarkings are provided on roads to give guidance of the route ahead. To be effective, these markings need to be visible enough to give drivers adequate time to respond to changes in the road direction. Reflectorised roadmarkings increase the night-time visibility of the driving route. This reflectorisation is achieved by spreading glass beads onto the wet paint film at the time the paint is applied.

Portable retroreflectometers (e.g. Mirolux 12) have now been developed which can quantitatively measure the amount of retroreflected light from a roadmarking. These retroreflectometers can be used to establish recommended minimum levels of retroreflectivity to ensure that visibility requirements are being met and maintained by roadmarking programmes, for example those employed by road controlling authorities in New Zealand.

2. Objective of Study

The objective was to establish a recommended minimum value of retro-reflectivity of roadmarkings considered appropriate for use in New Zealand where the dominant road surface type is grey-coloured chipseal.

3. Procedure

The general method employed for this study was to both photograph and video-film edgeline roadmarkings at six sites. The sites were selected to cover the range in which the minimum value would lie. Corresponding measurements of retroreflective values were made at these sites with a Mirolux 12 retroreflectometer. These visual records were then evaluated by a Delphi procedure (explained on p.8) to identify the site exhibiting the minimum acceptable value. The measured retroreflective values of this site were then taken as the minimum value of retroreflectivity.

4. Specific Steps

- Six sites, four of grey-coloured chipseal surfaced roadway and two of asphaltic concrete, with markings likely to exhibit a range of overall retroreflectivities, were selected and measured for retroreflectivity (using the Mirolux 12 retroreflectometer). About 100 readings were taken over each of the 300 m-long sites.

- At each selected site, with similar lighting conditions for all sites, the markings were photographed and videoed. The lighting conditions were vehicle headlights, no street lights, dry weather/dark night, and no other vehicles present.

- On two of the road sections, photographs and videos were taken over a range of visibility conditions that included:
  - wet night
  - dark night
  - moonlight
  - dusk
  - oncoming traffic
  - following traffic

  Two visual methods were used to record the "driver's perspective" of the edgeline while driving under night-time conditions: 8 mm video camera, and still photography using both high speed colour and black and white photographs. The video record was taken first from a moving vehicle, and then from a stationary vehicle, in both instances from the front passenger position. The still photographs were taken from just in front of the windscreen of a parked vehicle, also equivalent to a front passenger position. The passenger position had to be used for safety and practical reasons.

- The photographs and videos of the reflective edgelines were evaluated using the Delphi procedure to identify sites with minimum acceptable retroreflectivity values. Cross-reference to the measured values of retroreflectivity for those sites enabled the recommended minimum value to be established.

5. Delphi Procedure

A Delphi procedure is a procedure for structuring a group communication process, so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem. In the context of this study the Delphi procedure involved five professionals, with knowledge in the field of roadmarkings. They evaluated the data (visual records) and came to a consensus view for the minimum acceptable retroreflectivity value.

The panel comprised representatives (one from each organisation) from Ministry of Transport, New Zealand AA Inc., Works Consultancy Services Ltd, Transit New Zealand, and Local Government Association.

6. Evaluation Sequence

Before carrying out the evaluation, members of the panel were given a brief presentation to explain the purpose of the evaluation, background to the photographic and video techniques used, and aspects on the principles and methodology of measuring retroreflectivity with the Mirolux 12 retroreflectometer.

Neutral guidance on techniques of how to view the photographs and video was also given. Participants were asked to assess first the photographs, then the videos, taken at each site.

Each site was to be scored in terms of a four point scale of poor (1), marginal (2), satisfactory (3), and good (4). Individual scores were then averaged to obtain the group score.

This scoring was followed by a general discussion on aspects of visibility, including minimum values used in countries other than New Zealand.

7. Evaluation Results

The evaluations obtained are as follows:

Site	Photograph	Video
1	4.0	4.0
2	3.6	3.8
3	3.4	3.0
4	3.2	2.8
5	2.6	2.0
6	1.6	1.0

Roadmarkings with an average value of 3 or better were considered as acceptable. The roadmarking corresponding to less than this value was found to have a value of retroreflectivity of 90 $mcd.m^{-2}.lux^{-1}$*.

8. Other Recent Studies

Other concurrent studies (Transit New Zealand Research Project PR3-0131**) have shown that the readings obtained from seven Mirolux 12 units, in use in Australia and New Zealand, could vary by as much as ±10% when measuring the same retroreflective roadmarking material. Transit New Zealand Research Project PR3-0123** has shown that the readings from different reflectometer types, even with the same geometry of measurement, may also differ. Mobile retroreflectometers for high speed survey of highway networks that have now become available are also considered in this second concurrent study.

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* mcd = millicandela, unit of luminous intensity
lux = unit of illumination

** TNZ Research Project PR3-0131: Paint film distribution, bead retention and marking effectiveness - stage 1, theoretical aspects.
TNZ Research Project PR3-0123: Road signage and delineation.

Trials of paint materials used for the roadmarking industry in New Zealand indicate that many roadmarkings may fall below the proposed recommended minimum retroreflective value as early as halfway through the annual repaint cycle.

9. Recommendations

The recommended minimum retroreflective value is 90 $mcd.m^{-2}.lux^{-1}$ for road markings on New Zealand chipseal roads.

Adopting and maintaining this recommended value will have cost implications with respect to existing roadmarkings. For example, some roadmarkings could have retroreflectivities that are less than the recommended minimum value for over ½ to ⅔ of their life.

Material specifications will then need to include minimum retroreflective values. Also minimum level requirements may need to be developed for other visual driving aids. Therefore, if this minimum retroreflectivity value is adopted, the following recommendations for further study are made:

- Determine the life of existing roadmarkings on roads with a range of traffic densities, relative to the recommended minimum retroreflective value of 90 $mcd.m^{-2}.lux^{-1}$.

- Develop the method of assessing the retroreflectivities of roadmarkings, from the present pilot stage which is appropriate to smaller scale research use, to a method that is suitable for widespread in-field use.

- Develop appropriate test criteria for minimum retroreflective values that can be included in the specifications used to select paint and thermoplastic materials for roadmarkings.

- Consider the need for minimum retroreflectivity values for other materials used for delineation such as raised pavement markers and edge marker posts, and for materials used for road signs.

ABSTRACT

Roadmarkings are provided on roads to give guidance of the route ahead. To be effective at night-time, roadmarkings need to have adequate retroreflective properties. A recommended minimum value of retroreflectivity was established that is appropriate for roadmarkings used on New Zealand roads. This minimum retroreflective value is 90 $mcd.m^{-2}.lux^{-1}$.

The study method was a panel type, whereby a group of five roading professionals using a Delphi procedure reviewed photographs and video records of six sites, then identified the sites that they judged had roadmarkings of the minimum acceptable level of retroreflectivity. Cross-reference was made to the values of retroreflectivity measured at this site (using a Mirolux 12 retroreflectometer). These measured values were taken as the recommended minimum retroreflectivity value for roadmarkings.

Recommendations were made to determine the performance of existing roadmarkings relative to this minimum value, to develop appropriate test criteria for minimum retroreflectivity values that can be included in roadmarking material specifications, and to extend the principle of a minimum retroreflective value to other materials used for road signs and delineation devices.

1. INTRODUCTION

1.1 Background

Increasing the visibility of the road along the driving route at night, where the lighting condition is supplied only by the vehicle lighting, has been consistently identified as a key factor in improving the safety of night-time driving. Good visibility of the route ahead gives drivers adequate time in which to respond to changes in the road direction. For example, research has shown that, when driving at speeds of 100 km/h, visibility of the route ahead needs to be sufficient to give warning times of 3 to 5 seconds of impending changes.

Reflectorised roadmarkings are one means of increasing the visibility of the driving route in night-time driving conditions. This reflectorisation is achieved by spreading glass beads onto the wet paint film at the time the paint is applied. When properly embedded, these beads can reflect light from the vehicle's headlights back towards the driver, thereby making the marking more visible. This is retroreflectivity.

These beads are progressively removed by wear from car tyres, so that the degree of reflectorisation, and hence distance ahead for which the line is visible, declines. While visibility is a perceived quantity, it is nevertheless directly related to the amount of light being reflected back from the road surface to the driver.

Portable retroreflectometers have now been developed which can quantitatively measure the amount of retroreflected light from a roadmarking. They also have the advantage that they can be used in daytime. For these reasons they are being used increasingly in countries other than New Zealand to establish recommended minimum retroreflectivity values. These values can be set to provide quality assurance that visibility requirements are being met and maintained by roadmarking programmes.

The level of retroreflection required in other countries is not consistent (Dravitzki and Munster 1991). A number of factors tend to make each of these levels somewhat unique to each country. For example, countries with light-coloured surface roads, e.g. concrete, would need different retroreflectivity visibility levels to achieve the same level of contrast, and hence marking perception, than would a country with dark-surfaced roads, such as friction course. Conversely, a light surfaced road may make the need for the roadmarkings less.

1.2 Objectives of the Study

The principal objective of this study was to establish a recommended minimum value of measured retroreflection of roadmarkings considered appropriate for use on New Zealand roads which have mainly grey-coloured chipseal surfaces.

The study was carried out in three stages, of which the objectives were to:

1. Obtain photographs and video tapes of roadmarkings viewed at night which convey the true sense of their visibility as perceived by a driver. These photographs and video tapes were to be obtained for a range of roadmarking visibility and lighting conditions.

2. Develop a provisional method of measuring the visibility of a section of roadmarking that is about 200m to 400m long.

3. Using the Delphi procedure[1], select an appropriate level of retroreflection of roadmarkings that can be used as a recommended minimum value.

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[1] Delphi procedure: a procedure for structuring a group communication process that allows a group of individuals to deal, as a whole, with a complex problem.

1.3 Subsequent Research

Although this research for New Zealand roads was initially undertaken in 1992/93, further relevant information which had become available by 1996 is outlined here.

The acceptable minimum retroreflectivity value was determined in the study by means of an expert panel making judgements as to which of a range of specimens was at an acceptable level. Cairney (P.T. Cairney, pers. comm.) has pointed out that such a process tends to bias selection towards the middle of the range of specimens presented, and in this study the value selected was about mid-range.

The consistency of the Mirolux 12 retroreflectometer has also been partly assessed. Over seven Mirolux 12 units held in New Zealand and Australia, when used to measure ideal surfaces of test plates, showed a variation of ±10% between the units. When used to measure a chipseal surface a greater range could be possible.

The study has not taken account of the decline in visual perception with human aging. Because the researchers gathering the field data were in their late 20s and early 30s, and the Delphi panel included some members in their early 40s, the value has been determined by a well-sighted segment of the population.

The nature of the study was one of consciously viewing the edgeline roadmarking and making judgements about its acceptability. The reflectivity of the edgeline was thus deliberately searched for, and its retroreflectivity could have been less than it need be in a more normal driving situation to provide the same level of conspicuity.

Because the researchers were deliberately considering the edgeline, the roadmarking could have been less reflective and still provided an acceptable level of conspicuity than a marking that was being considered in a more normal driving situation.

Taking all these factors into account, the value for minimum retroreflectivity as determined by this study should be seen as a first step which represents a just acceptable minimum retroreflectivity value. This value may need adjustment in the future to incorporate new research findings that accommodate the needs of the older driver.

2. PROCEDURE

2.1 General

The general method employed for this study was to photograph and video record a number of separate roadmarkings, specifically edgelines, believed to cover the range in which the minimum retroreflectivity value would lie, and to measure the corresponding retroreflectivity with a Mirolux 12 retroreflectometer. A Delphi procedure was then used to evaluate these visual records to establish the minimum acceptable values. The minimum retroreflectivity value was obtained from the corresponding Mirolux measurement.

The method chosen was one of two main options for a Delphi procedure. One option would have been to assemble an expert panel and take them to the sites where they could rate each site according to their own perception of its suitability. This method, though considered, was rejected for the following reasons:

- The need to view a number of sites in specific weather conditions meant that it was difficult to assemble a volunteer expert panel from the different agencies at short notice. The weather could be judged as suitable only about 2 hours in advance.
- The comparative nature of the work, i.e. sites were being compared with each other, and the obvious difficulty of panel members to retain a mental picture of the sites already assessed.
- The difficulty of having all the expert panel view the marking from the same relative position in the vehicle.
- The safety of the panel. An inherent danger is the large number of people on foot on the main highway at night, who would be concentrating on technical aspects of roadmarking. Safety lighting to lessen the danger would have interfered with the appraisals being made.

The option chosen had an initial stage to evaluate the extent that photographic and video techniques could record the visual appearance of the site when viewed at night. The Delphi panel then selected an appropriate level of retroreflectivity by viewing these visual records rather than by site visits.

The visual methods used to record the "driver's perspective" of the edgeline while driving under night-time conditions were 8mm video camera and still photography, using both high speed colour and black and white photographic film. Colour slides were also taken at some locations, but these were excluded from the Delphi procedure as the video and still photographs were sufficient. The video used was an 8mm Sanyo CD video camera. For the still photographs, 1600 ASA film (both colour and black and white) was used.

2.2 Outline of Specific Steps

1. Methods of photographing and video recording a roadmarking, which would convey a sufficient sense of its visibility as perceived by a driver at night-time, were evaluated.

2. A provisional technique of measuring the visibility of a section of roadmarking, e.g. 200m to 400m long, was assessed.

3. Sections of road with markings likely to exhibit a range of overall retroreflectivities were selected and measured for retroreflectivity (using the Mirolux 12 retroreflectometer). Before the study began, about six road sections with retroreflectivities within the range 50-150 $mcd.m^{-2}.lux^{-1}$ were required. The average retroreflectivities for each road section were hoped to correspond with an increment of about 25 $mcd.m^{-2}.lux^{-1}$ of this range, i.e. 50-70, 70-90, 90-110, etc.

4. At each selected site the roadmarkings were photographed and videoed, with the lighting condition similar for all sites, i.e. dark night, dry, no traffic.

5. On two of the road sections, photographs and videos were taken over the range of visibility conditions to include:
   - wet night
   - dark night
   - moonlight
   - dusk
   - oncoming traffic
   - following traffic

6. The photographs and videos of the reflective edgelines were prepared for evaluation by the Delphi procedure.

7. The evaluation by the Delphi procedure was undertaken and the findings were reported.

3. STUDY SITES

3.1 Site Selection

For this study the preferred road surface was chipseal, with open highway conditions, i.e. no street lights, intersections, etc. A chipseal surface was required to provide a uniform background for the roadmarking. Both Serres (1983) and Etham and Woltman (1986) have discussed the significance of both the retroreflectivity of the marking and its contrast ratio with the road surface.

Within the Wellington area most chipseals are a uniform greywacke chip, which is a uniformly medium to light grey-coloured aggregate with a retroreflectivity of about 20 $mcd.m^{-2}.lux^{-1}$.

The site requirements were a relatively straight, flat section of road that is 400m to 600m long. For the still photographs a set length of 300m only was required, but for the videos an approach length was also required. However, a combination of many difficulties reduced the number of potential sites to a small number. Some of the difficulties were:

- Using worn markings because the study was of a minimum retroreflectivity value. Worn edgeline markings without joins or patch jobs, so that edgelines had approximately the same reflectivity throughout the testing length, were difficult to find.

- Locating "straight" sections of road without dips or humps that would obscure the edgeline, and from rises or falls that may increase or decrease the visibility distance. Such sites are not common on the undulating topography dominant in the greater Wellington area.

- Locating chipseal areas that were a reasonable travelling distance from the laboratory so that all the sites could be visited within one evening.

- Locating sites that were sufficiently safe for the staff and also for the passing traffic even if they met all the above criteria.

- Selecting enough sites that met the criteria to cover the range of retroreflectivity values outlined in the job brief.

Two of the surfaces were asphaltic concrete. Though originally intended to exclude these surfaces from the study, they had to be included as they were the only suitable sites in the greater Wellington area having retroreflectivity greater than 110 $mcd.m^{-2}.lux.^{-1}$. The retroreflectivity of the unmarked asphaltic concrete is about 10 $mcd.m^{-2}.lux^{-1}$.

3.2 Sites Used

The six sites were:
1. State Highway 1, adjacent Taupo Swamp, Plimmerton (asphaltic concrete surface), after maintenance recoating
2. State Highway 1, as for site 1, worn, before maintenance recoating
3. State Highway 58, near intersection with Moonshine Road
4. State Highway 2, west (Kaitoke) side of Pakuratahi Bridge
5. State Highway 2, east (Rimutaka) side of Pakuratahi Bridge
6. Harcourt Werry Drive, Lower Hutt

4. RETROREFLECTIVITY MEASUREMENTS

The main elements of the technique for assessing retroreflectivity of each site (described in Dravitzki and Munster 1991) had required four locations to be selected at specific intervals of about 50m (Figure 4.1). At each location, four positions each 1m apart were marked out and at each position four readings were made. Criteria of acceptable variation were applied or further readings were taken. At each 1m position the four readings were averaged for a value at that position. Then the values for each of the four 1m positions were averaged to give a value for that location of the roadmarking. Each location value therefore is the average of 16 readings taken about that location.

For this current (1996) study substantially the same method was employed, except that measurement positions were usually spaced at 100m intervals. Where the readings between two positions varied significantly, and where this location was of particular interest, readings at 50m and, on occasions, 25m intervals were also taken.

These measurements have been used to develop a retroreflectivity profile at each of the six sites as shown in Figures 4.2 to 4.7. For reasons which will be discussed in Section 6.3, a profile was considered to be more appropriate than an overall average value for each site.

Figure 4.1 Measurement pattern for assessing the retroreflectivity of a section of edgeline roadmarking.

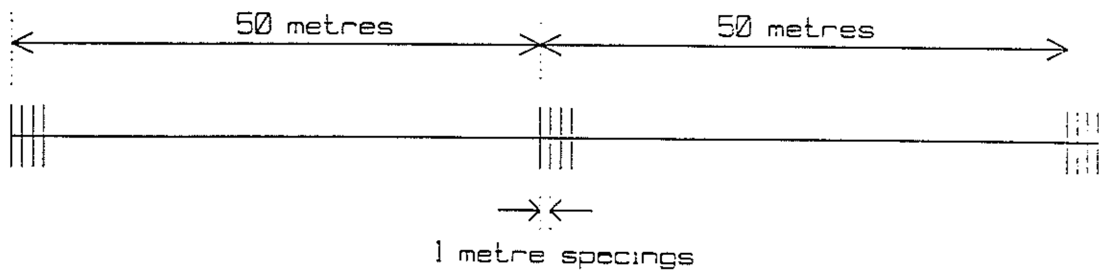


Figure 4.2 Site 1, State Highway 1, recoated.

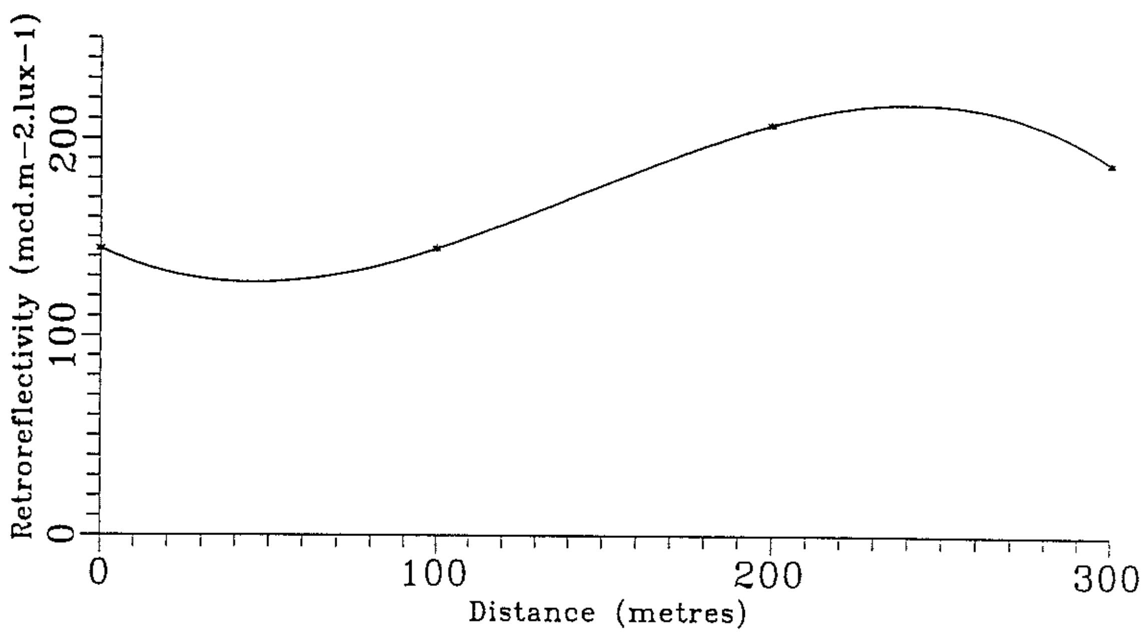


Figure 4.3 Site 2, State Highway 1, worn.

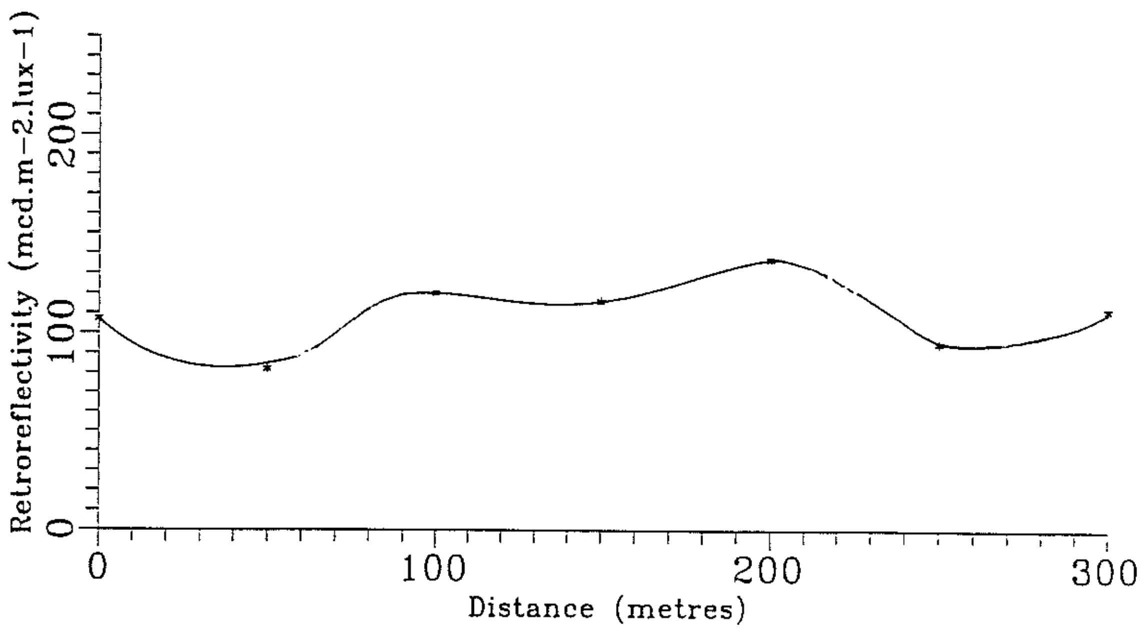


Figure 4.4 Site 3, State Highway 58.

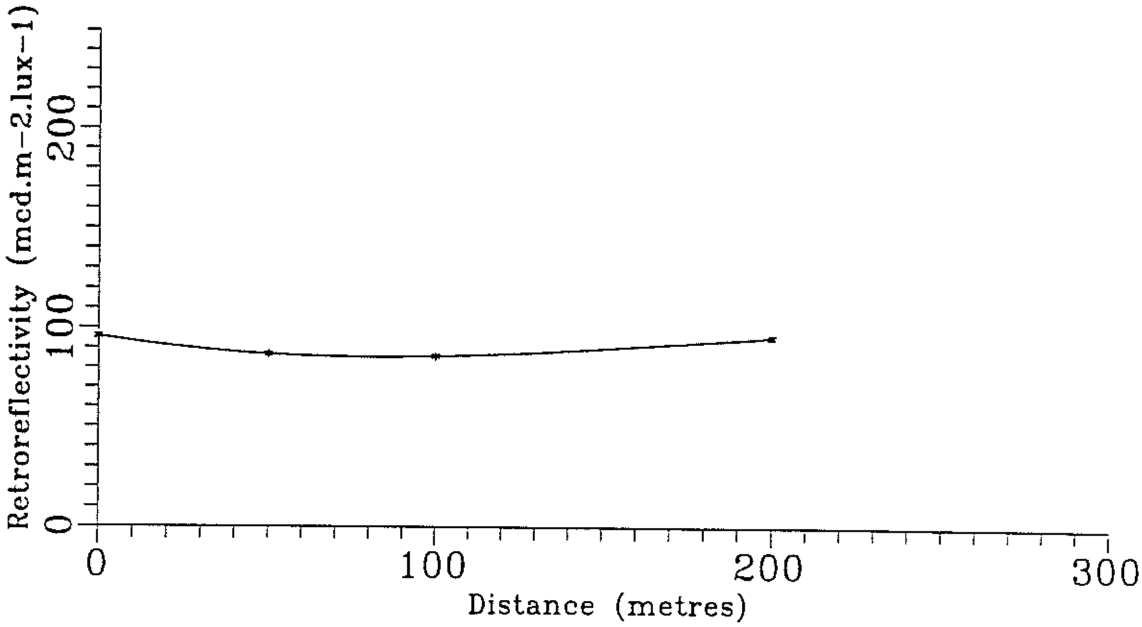


Figure 4.5 Site 4, State Highway 2 (west).

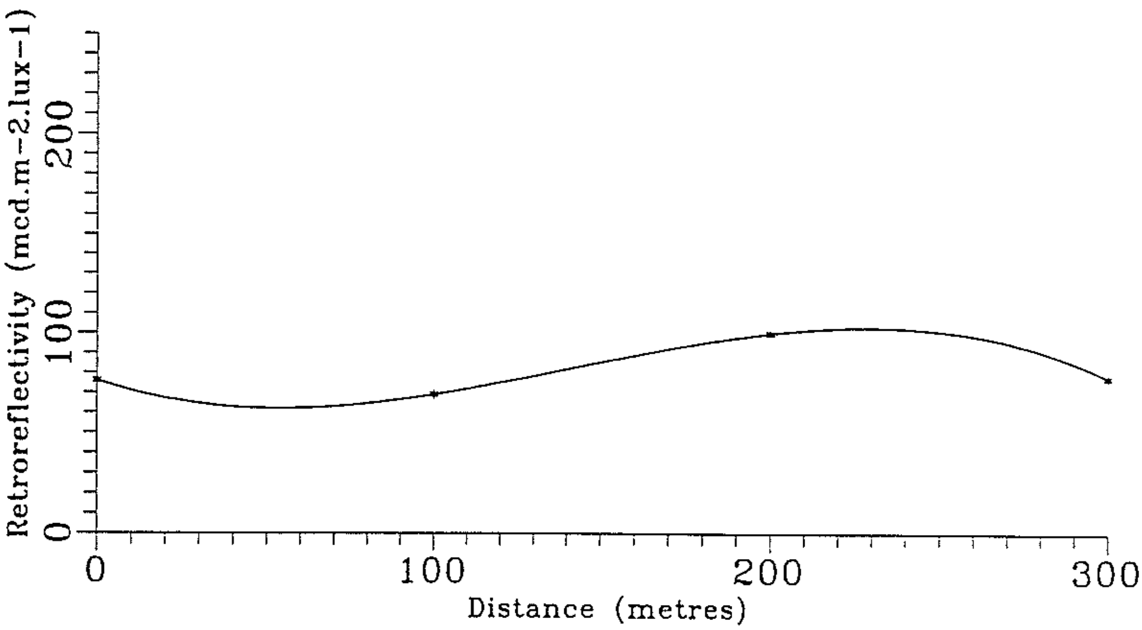


Figure 4.6 Site 5, State Highway 2 (east).

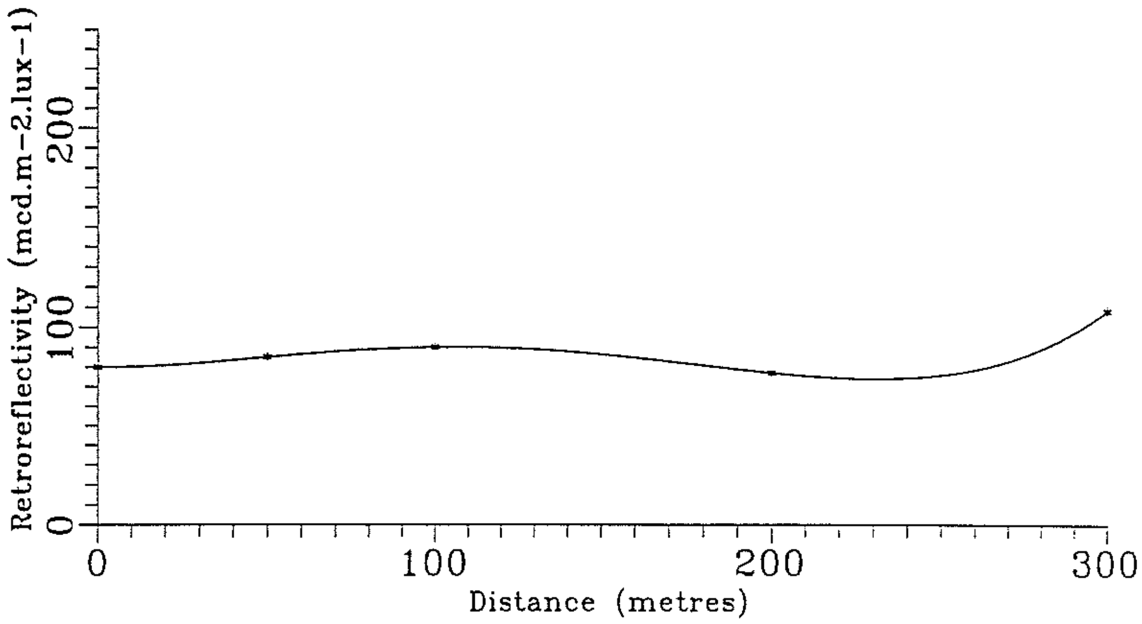
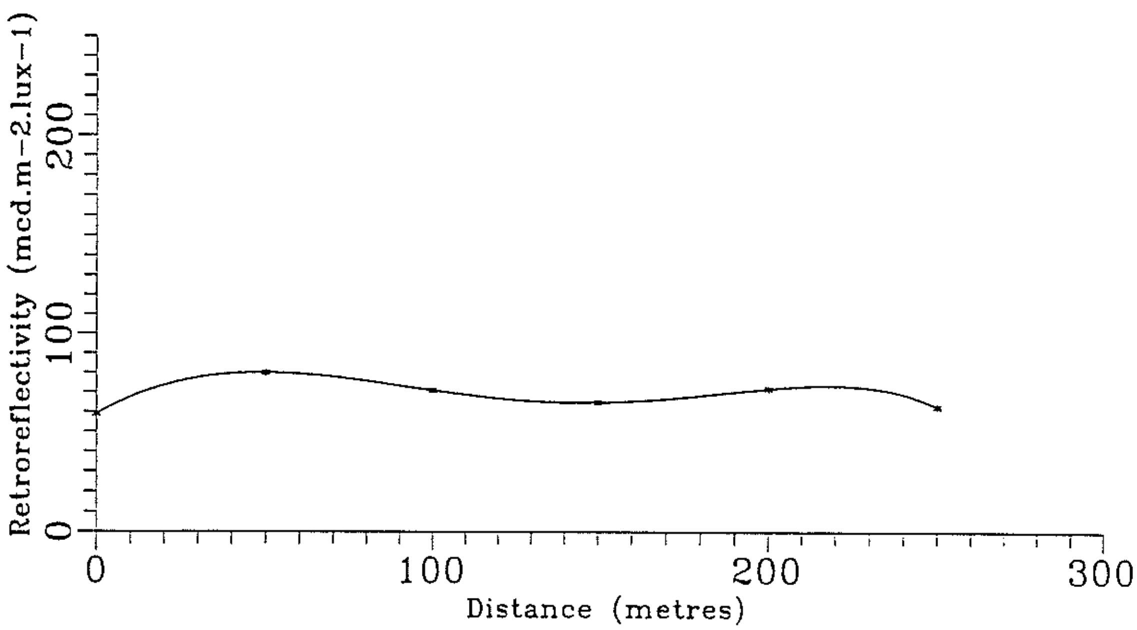


Figure 4.7 Site 6, Harcourt Werry Drive.



5. VISUAL RECORDS

5.1 Video Records

Several video cameras were trialled to take the visual records. A Sony 8mm video was found to give dark, poor quality pictures. A Beta camera, though giving better quality pictures, was very heavy, difficult to handle, and the small gain in quality did not warrant the expense of hire from TVNZ or the additional inconvenience. The camera that was chosen was a Sanyo 8mm CD camera. It was compact, easily operated and, although the visibility distance from the picture is approximately 20% less than the driver's actual perspective, the picture was considered to enable conclusive comparisons to be made between the edgelines.

The initial set of trials established settings and techniques that gave a satisfactory sense of the edgeline's visibility were as follows. The video camera was hand-held in the passenger's seat as close to the windscreen as possible to reduce reflection problems. The speed 50 km/h was used as it was moderately fast but avoided the excessive picture movement which occurred at higher speeds. Filming started about 150m back from the test site and the microphone was left on so that impressions of the visibility of the site could be recorded. The video film highlighted that the practice of "touch ups" on worn sections gave edgelines of variable retroreflectivity and moderately worn segments were interspersed with short bright touched up segments.

The video camera was also used in a stationary mode, filming with the car stationary at the start of the test site. This mode provided information additional to that obtained with the car in motion, as the effects of both dip and high beam headlights, and of cars moving towards and away from the test vehicle, on the roadmarking visibility could be appraised.

Six large reflective roadmarking cones were placed at 50m intervals along the test site to assist in determining how far the edgeline marking was visible. The cones were placed (Figure 5.1) in a narrow taper so they would all be visible in both the still photographic records and in the videos.

5.2 Still Photography Records

The initial trials established a technique for taking still photographs that conveyed the visibility of the site.

A tripod-mounted camera was placed on the vehicle bonnet in the driver's line of view. Different film speeds and types were trialled, with 1600 ASA for both colour or black and white being preferred. Colour prints, black and white prints, and colour slides were all evaluated. The black and white prints probably gave the closest portrayal of the actual visibility distance, but the absence of colour detracted from conveying the overall sense of visibility of the sites.

Colour slides also demonstrated a good sense of the visibility of the site, but the difficulty of viewing a number of slides at once meant that the colour prints, which still gave a good sense of site visibility but showed a shorter visibility distance, were used in preference.

For the still photographs, the vehicle was positioned so that the edgeline was in a direct line with the driver's vision, i.e. almost directly under the driver. (The position was adopted for safety reasons so that the photographing could be carried out without presenting a hazard to normal traffic.)

Figure 5.2 is one set of photographs of a typical site in both colour and black and white. The figure demonstrates one of the less favourable aspects of the photographs in considering visibility distances. The foreground, which is quite a short distance, occupies a large proportion of the photograph, and the perspective of the photograph reduces the distance aspects of the line to only a small area of the photo. The final 50m of the line still visible occupies only a very small portion of the photo. Therefore care and some skill is needed to assess adequate levels of visibility from the photographs.

Figure 5.1 The typical marking out of a site.

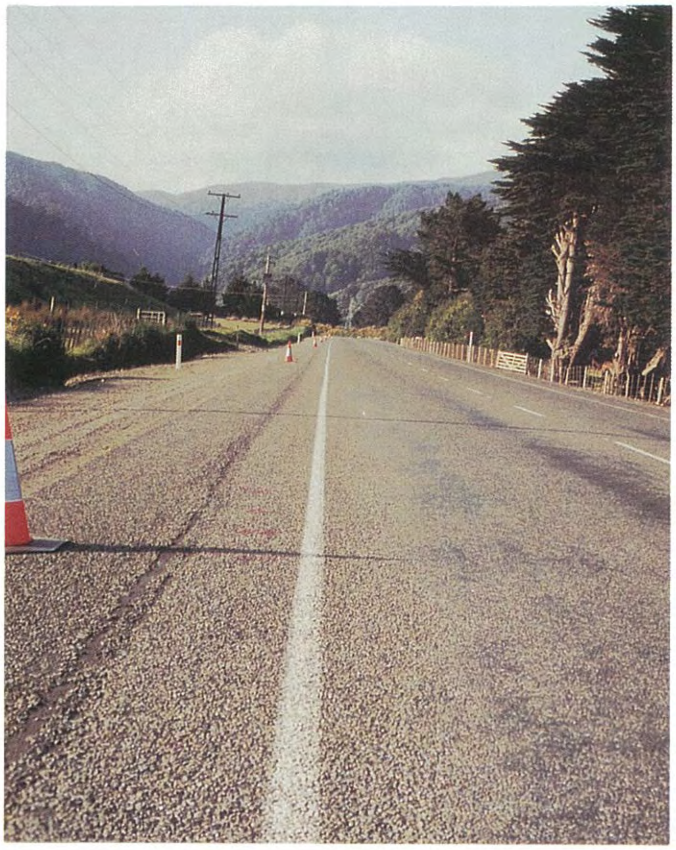
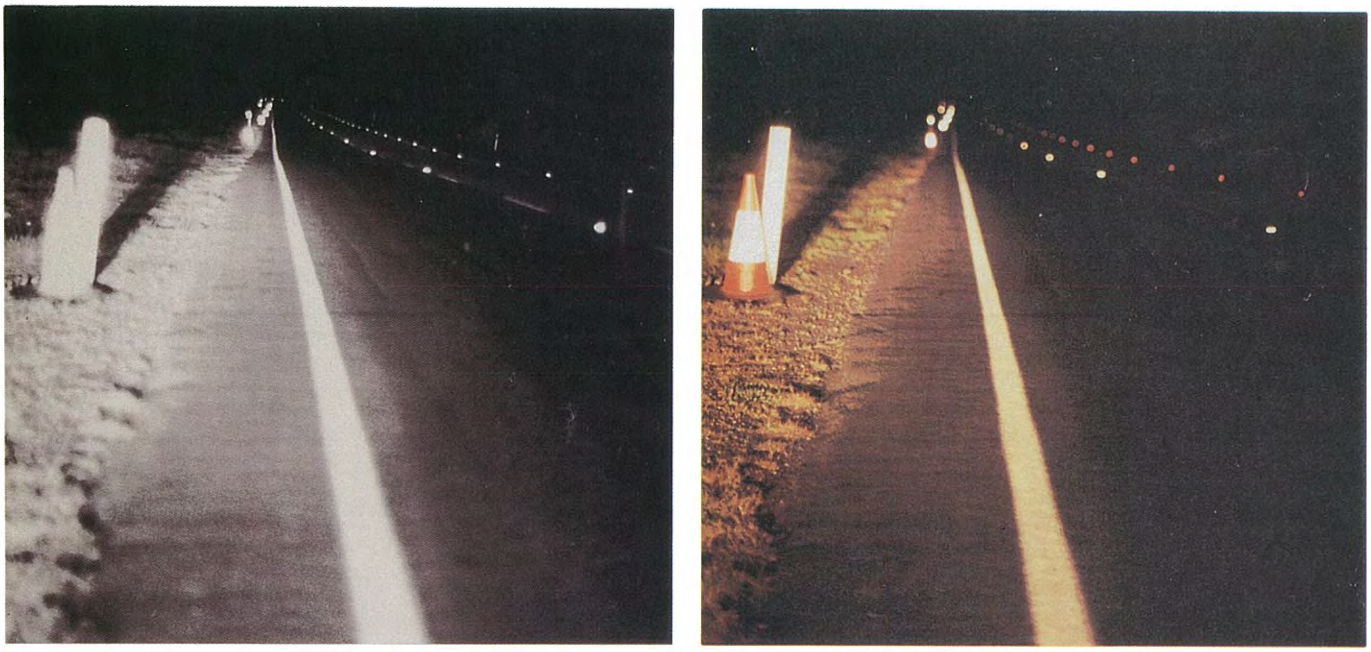


Figure 5.2 Set of photographs of the same site (left: black and white print; right: colour print) of a typical site, showing effect of large foreground.



6. VIEWING DISTANCES

6.1 Estimating the Distance

An additional assessment of site visibility was made and supplied to the Delphi panel (see Section 7 of this report).

While the vehicle was positioned for still photographs, an estimate was made of the distance viewed by the two researchers. If the estimates differed, an average of the two estimates was taken. These "driver" estimates (DE) were made for both high and low beam situations. A comparable estimate of the distance viewed in the photograph (PE) was also made. Table 6.1 gives details of these pairs of assessed viewing distances. (The estimates were also documented on the photographic displays used for the panel in the Delphi procedure.)

Table 6.1 Estimates of viewing distances for each location, made by driver on site (DE) and from the photograph (PE).

Conditions	Location											
	Site 1 SH1 recoated		Site 2 SH1 worn		Site 3 SH58		Site 4 SH2(west)		Site 5 SH2(east)		Site 6 Harcourt Werry Dr.	
	DE	PE	DE	PE	DE	PE	DE	PE	DE	PE	DE	PE
Dark, high beam			210	170	170	120	170	140	100	90	70	60
Dark, low beam			70	50	70	50	70	50	70	60	60	50
Wet, high beam			170	110	130	110					70	70
Wet, low beam			70	60	70	60						
Full moon, high beam	280	170					230	120	120	100		
Full moon, low beam	200	70					90	50	90	70		
Dusk, wet, high beam											230	130
Dusk, wet, low beam											170	120
Dusk, high beam							200	100				
Dusk, low beam							180	50				

Note: All photograph estimates are taken from the colour photographs.

6.2 Effect of Alternative Lighting Conditions on Viewing Distances

In all cases the viewing distance was decreased by the lights from oncoming vehicles. For a car travelling in front of the video camera car, viewing distance was increased as the lead car provided assistance in illuminating the line past the normal viewing length. The car lights of the lead car also provide a guide independent from the road edgelines. Other factors influencing the viewing distance were:

- Full moon. The visibility increased by about 20m on high beam. On low beam there was little apparent change.
- Wet road. The visibility on high beam decreased, but on low beam it remained almost unchanged.

On low beam, the driver's estimate and photograph estimate are generally very close but, more importantly, the viewing distance is 50-90m regardless of the retroreflectivity of the edgeline. The viewing distance appears to be almost solely determined by the angle of the car's headlights, with the condition of the line having only a minor effect for the range of retroreflectivities examined.

6.3 Relationship of Edgeline Retroreflectivity to Assessed Viewing Distances

The profiles of the retroreflectivity versus distance were developed (Section 4 of this report) for each of the study sites (Figures 4.2 to 4.7), and are not uniform. In assigning a retroreflectivity value to each site, a choice had to be made how to select the retroreflectivity value for that site.

Selection could have been a simple averaging of the values along the site. However, a second technique is based on the logical assumption that, for an illuminated line of variable retroreflectivity, the viewing distance will be primarily a function of the retroreflectivity at the last section of the edgeline still just visible. The retroreflection of the section line before and after this last section will only partly enter into the consideration. The retroreflection was taken as the retroreflection of a 50m section of the line about the nominated visibility distance.

Using site 2, on State Highway 1, adjacent to the Taupo Swamp (worn condition) as an example, the dark night high beam viewing distance is 210m (Table 6.1). The retroreflectivity profile in Figure 4.3 shows that at around 210m the retroreflectivity is 130 $mcd.m^{-2}.lux^{-1}$.

In a similar manner, retroreflectivity values for each site were determined, and these are shown in Table 6.2.

Table 6.2 Retroreflectivity values at each site compared to estimated viewing distance (high beam).

Site	Driver		Photograph	
	Estimated viewing distance (m)	Retroreflectivity ($mcd.m^{-2}.lux^{-1}$)	Estimated distance (m)	Retroreflectivity ($mcd.m^{-2}.lux^{-1}$)
1. SH1, recoated	280	200	170	185
2. SH1, worn	210	130	170	120
3. SH58	170	90	120	85
4. SH2, west	170	90	140	80
5. SH2, east	100	85	90	85
6. Harcourt Werry Dr.	70	75	60	75

7. DELPHI PROCEDURE

This procedure was used to chose minimum retroreflectivity values. By definition, *"Delphi may be characterised as a procedure for structuring a group communication process, so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem"* (from Linstone and Turoff 1972). For this study, the Delphi procedure involved five professionals with knowledge in the field of roadmarkings, who evaluated the data (visual records), and came to a consensus view of the minimum acceptable retroreflectivity value.

7.1 The Delphi Panel

The panel comprised representatives (one from each organisation) from Ministry of Transport, New Zealand AA Inc., Works Consultancy Services Ltd, Transit New Zealand, and the Local Government Association.

7.2 Prepared Visual Information

For the Delphi panel, a photo board for each site was prepared. These boards consisted of colour photographs of the site as viewed at night. For all sites, the board contained the following photographs, viewed as on a "dark night", i.e. little moonlight, or with cloud cover. For three sites, photographs taken in other lighting conditions were provided as well.

Table 7.1 Lighting and traffic conditions portrayed in photographs for Delphi panel.

Sites	Viewing Situation	High Beam	Low Beam
All sites 1-6	Site with no other traffic	✓	✓
	Site with oncoming traffic	✓	✓
	Site with traffic ahead, same direction	✓	✓
Sites 2, 3, 6	Wet night, no other traffic	✓	✓
	Wet night, oncoming traffic	✓	✓
	Moonlit night, no other traffic	✓	✓
	Moonlit night, oncoming traffic	✓	✓

Each photograph was marked with an estimate of both the driver's viewing distance and the viewing distance as assessed from the photograph by the research team. Several black and white photographs were included to demonstrate this viewing distance.

A video of each site was also prepared. For each site, about 3 to 5 minutes of video was shown, each segment consisting of at least one drive-over the site, followed by stationary viewing from the site "start" position. High and low beam views were included, as were following and oncoming traffic headlight effects. Extra footage of the three sites filmed in wet and moonlight conditions was also included.

7.3 Evaluation Procedure

Members of the panel were given a brief presentation of background information. This information included: explanation of the purpose of the project; commentary on the photographic and video techniques used; comments on the principles and methodology of measuring retroreflectivity with the Mirolux 12 retroreflectometer; and suggestions (while avoiding bias) on techniques for viewing the photographs and video.

Participants were then asked to assess the photographs taken at each site, with their decision to be based primarily on the "dark night, high beam photograph", but tempered with the evidence presented in the ancillary photographs of the edgelines as viewed under the other less favourable viewing conditions.

Each site was to be scored in terms of a four point scale of: poor (1), marginal (2), satisfactory (3), and good (4). Individual scores were then averaged to obtain the group score.

Next the video segments were viewed with scoring to the same scale as above being made at the completion of viewing each site.

7.4 Evaluation Results

The evaluations obtained are shown in Table 7.2.

Table 7.2 Average score for the sites by the Delphi panel.

Site	Photograph	Video
1. SH1, recoated	4.0	4.0
2. SH1, worn	3.6	3.8
3. SH58	3.4	3.0
4. SH2, west	3.2	2.8
5. SH2, east	2.6	2.0
6. Harcourt Werry Drive	1.6	1.0

7.5 General Discussion by Panel

The panel discussed the evaluations obtained and, where applicable, offered reasons for a score that departed widely from the panel's mean. Discussion also included some general aspects of the importance of painted edgeline markings. Some of the salient points were:

- Because the foreground dominated the photograph, these could have been cropped from the photograph.

- Some panellists commented they were strongly influenced by the driver's commentary on the video of the estimates of viewing distance.

- Most panellists considered the video very helpful as it gave a much more "live" presentation of the site.

- The importance of the edgeline, particularly in conditions of oncoming traffic, as the principle means of guidance was emphasised.

- Continuous edgeline marking had a valuable role for providing direction on sections where the road geometry caused the guidance given by point markers, such as raised pavement markers, to be overlooked or confused.

- The consensus was that the relative scores for each site represented adequately the relative view of the sites, i.e. Sites 1 and 2 were clearly the best, and Site 6 was the worst. Views were mixed as to the relative order of the other three sites.

7.6 Retroreflectivity Values Used in Other Countries

Table 7.3 was presented to the panel to indicate some of the minimum retroreflectivity values used in countries other than New Zealand. The panel was also advised that measured retroreflectivity depends on the measurement methodology used, but that the methodology underlying each of these overseas values was not known.

Table 7.3 Recommended minimum retroreflectivity values used in countries other than New Zealand.

Country	Coefficient of Reflectivity ($mcd.m^{-2}.lux^{-1}$)		
	Roadmarking status		Geometry of measurement (°)
	New	Used	
Austria	70	70	3.5°/1.5°
Belgium	70		
England	150	100	(provisional)
France	150	150	3.5°/1.0°
The Netherlands	80	80	3.5°/1.5°
Singapore (hot melt only)	300	150	3.5°/1.5°
Sweden (hot melt only)	100	100	
United States (recommendation by FHWA)	150		
West Germany	150	70/100	3.5°/1.5°
West Germany (CIE)		150 (dry) 60 (wet with 30 mm/h rain)	

(°) Angle of the incident beam and reflected beam relative to the surface being measured.

FHWA = Federal Highway Administration, US Department of Transport, Washington DC
CIE = Commission Internationale d'Eclairage

Source: Potter Industries, Australia (pers.comm.).

7.7 Selection of Minimum Retroreflectivity Value

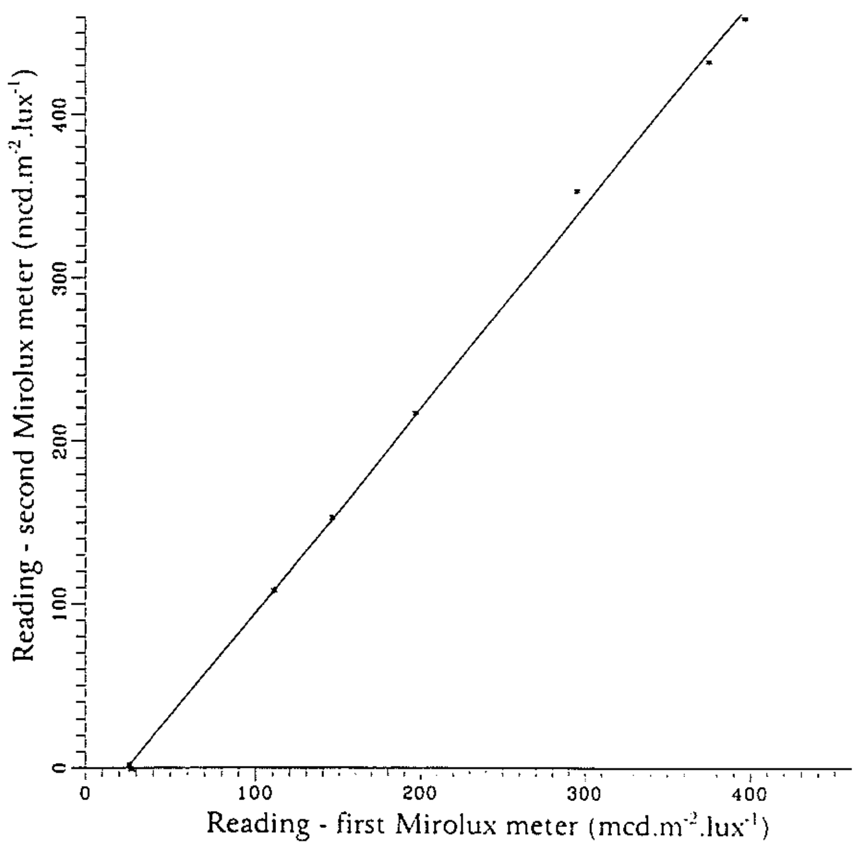
Table 6.2 (Section 6.3 of this report), showing the retroreflectivity values for each of the sites, was presented to the panel who were then asked, on the basis of the scores of Table 7.2 in Section 7.4 and the other information presented, to select a minimum value of retroreflectivity. The consensus value was 90 $mcd.m^{-2}.lux^{-1}$.

8. ADJUSTMENT OF RETROREFLECTIVITY VALUE

In carrying out the site measurements, a fault was detected with the Mirolux 12 unit as its zero reading was offset by about 20 $mcd.m^{-2}.lux^{-1}$. However, eight reference surfaces were available. A cross-check of the instrument was carried out against a second retroreflectometer which was verified as reading through zero. The respective readings on the calibration surfaces were plotted against each other (Figure 8.1).

Using the graph of Figure 8.1, the measured value for the minimum retroreflectivity of 95 $mcd.m^{-2}.lux^{-1}$ was adjusted to the reported 90 $mcd.m^{-2}.lux^{-1}$.

Figure 8.1 Comparison of readings on eight reference surfaces obtained from two Mirolux 12 retroreflectometers.



9. IMPLICATIONS OF MINIMUM RETROREFLECTIVITY VALUE

While the implications of this minimum retroreflectivity value on current roadmarking practice is a subject worthy of a wider study, some indication can be obtained from the earlier field trial using the Mirolux retroreflectometer and described in Dravitzki and Munster (1991), and the thermoplastic field trial (Dravitzki et al. 1991).

Figures 9.1 and 9.2 are based on data extracted from Central Laboratories Report 91-27329 (Dravitzki and Munster 1991). Each figure shows the retroreflectivity values of four edgeline segments on State Highway 2, Kaitoke. Each segment is approximately 50m long and is part of an edgeline adjacent to an internal corner. Traffic movements tend to be across the edgeline for the last two segments 3 and 4. Segments 1 and 2 are therefore only lightly trafficked, segment 3 moderately trafficked, and segment 4 heavily trafficked.

For each segment, mean retroreflectivity values were measured on five occasions. These were:

- 24 hours after line application
- 3 days after line application
- 30 days after line application
- 90 days after line application
- 180 days after line application

Figure 9.1 shows four segments of a beaded paint edgeline. The lightly worn road (segments 1 and 2) exceeds the minimum retroreflectivity of 90 $mcd.m^{-2}.lux^{-1}$ for the entire period, while the moderately worn portion (segment 3) just exceeds the value after 180 days. The more heavily worn portion (segment 4) drops below the minimum value after about 90 days.

Figure 9.2 shows three segments of an unbeaded paint line where moderately worn segments drop below the minimum value at about 140-160 days.

As recoating is on a 12 monthly cycle (360 days) for most edgelines, it is possible that markings are below required values for more than 50% of the period. Figures 9.1 and 9.2 also show that unbeaded lines on chipseal can exceed the minimum value for a significant time period, although their initial reflectivity is less.

Figure 9.3 is based on data from a trial on a section of SH1 near Paremata, Wellington area, recorded in Dravitzki et al. (1991). It shows that, even with very high wear, the retroreflectivity of thermoplastic is maintained for a much longer period (c. 600 days). However, it also demonstrates the need to choose appropriate formulations and application thicknesses as two of the formulations trialled (e.g. 2 and 3) spent much of their life at retroreflectivities less than this minimum value.

If markings are to serve their purpose of route guidance, they must provide a level of reflected light which enables them to be readily visible. This underlies the concept of a recommended minimum retroreflectivity value for markings.

Figure 9.1 Retroreflectivity readings on 100 mm beaded edgelines, on chipseal surface, location on SH2, Kaitoke (from Dravitzki and Munster 1991).

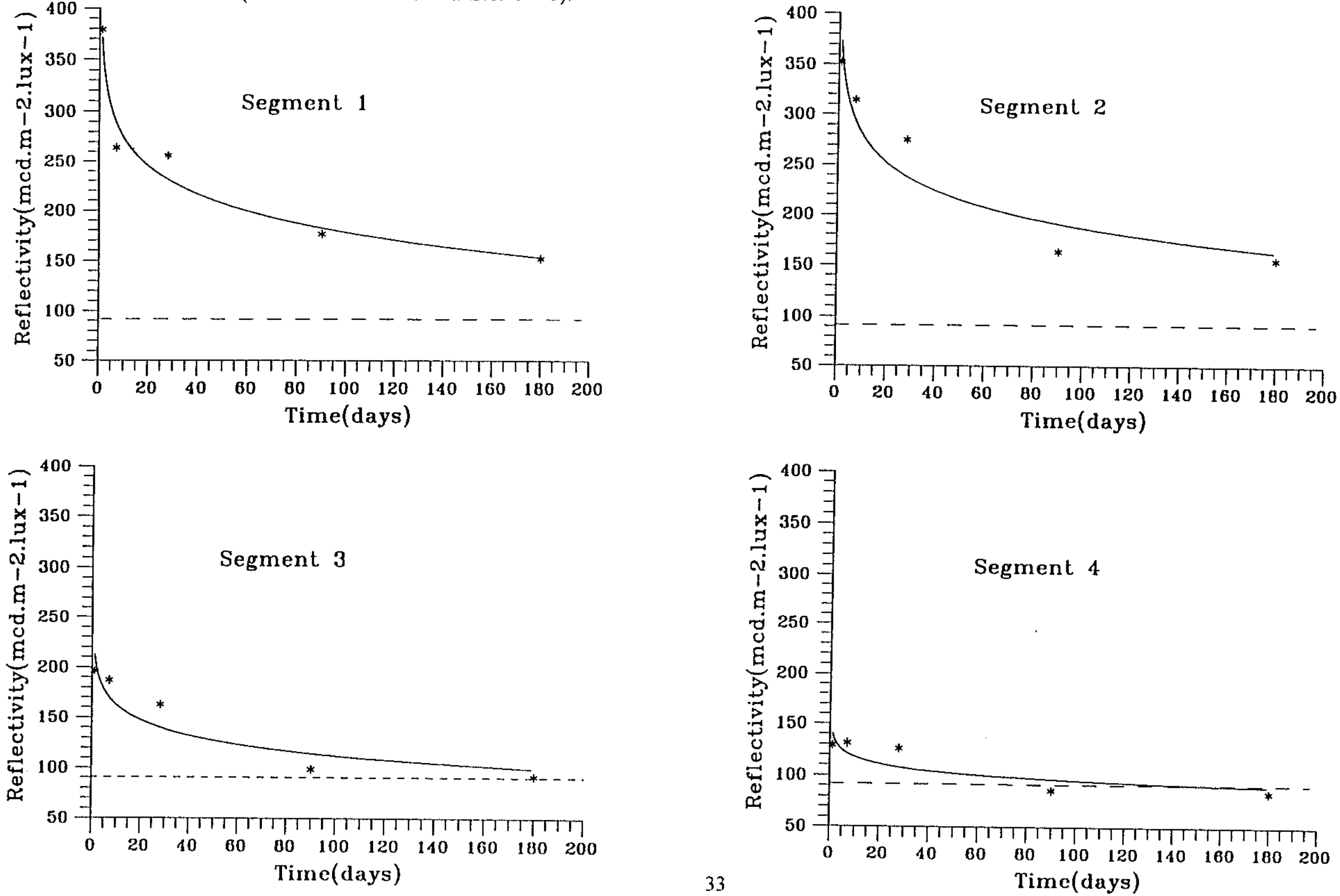
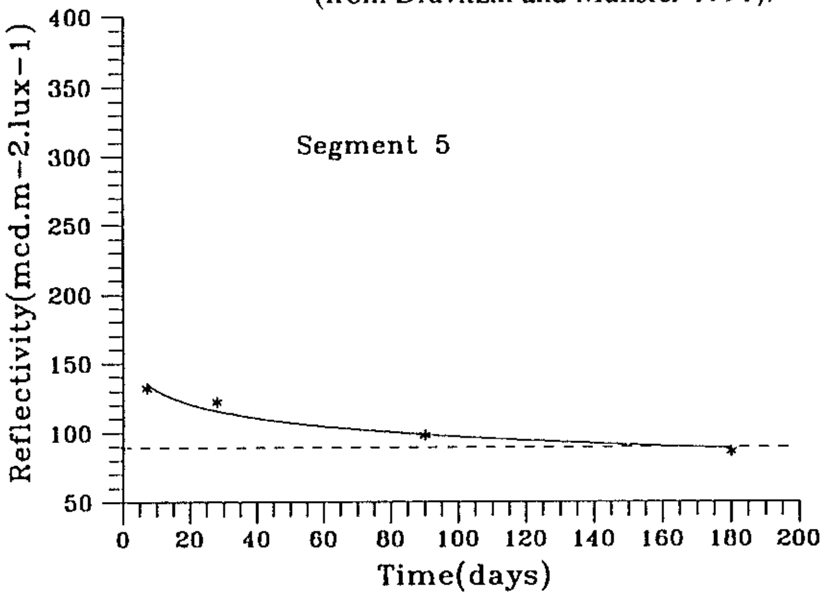
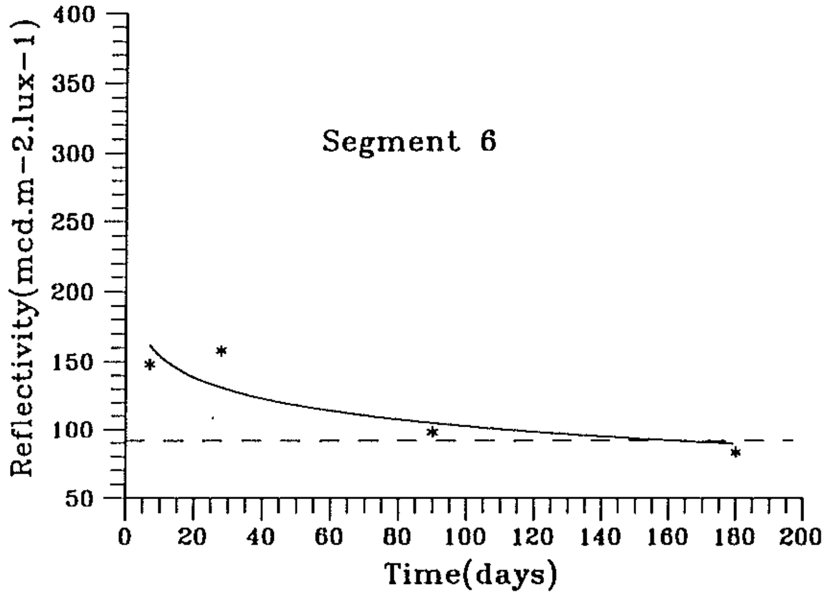
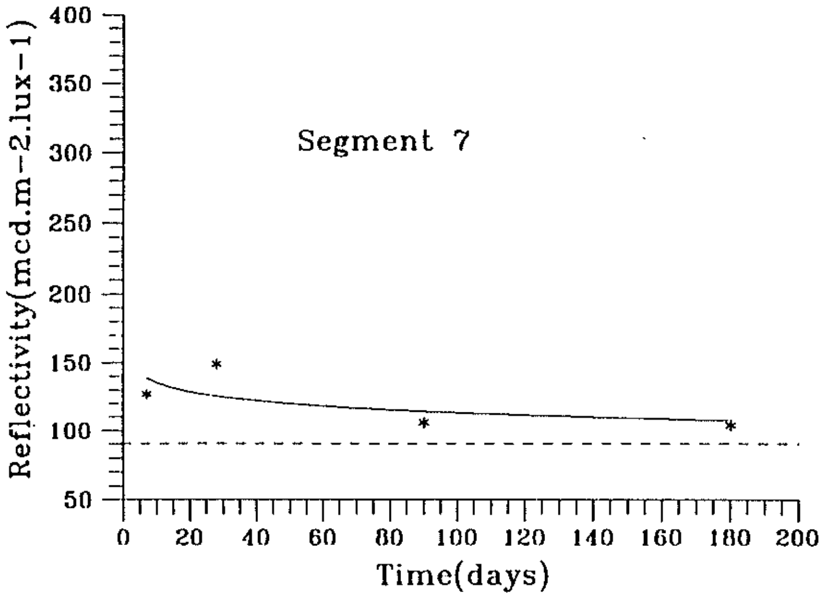


Figure 9.2 Retroreflectivity readings on 100 mm unbeaded edgelines, on chipseal surface, location on SH2, Kaitoke (from Dravitzki and Munster 1991).







However, painted markings are only one of several aids provided for route guidance. Other aids are retroreflective raised pavement markers, retroreflective edge markers and signs. The materials used in these aids are required to meet material specifications. Although these specifications prescribe initial levels of retroreflectivity and, while sometimes including accelerated aging criteria, they do not specify a minimum level required in service. Therefore a further implication of this minimum retroreflectivity value for marking is that it should form part of a series of criteria applicable to other visibility aids.

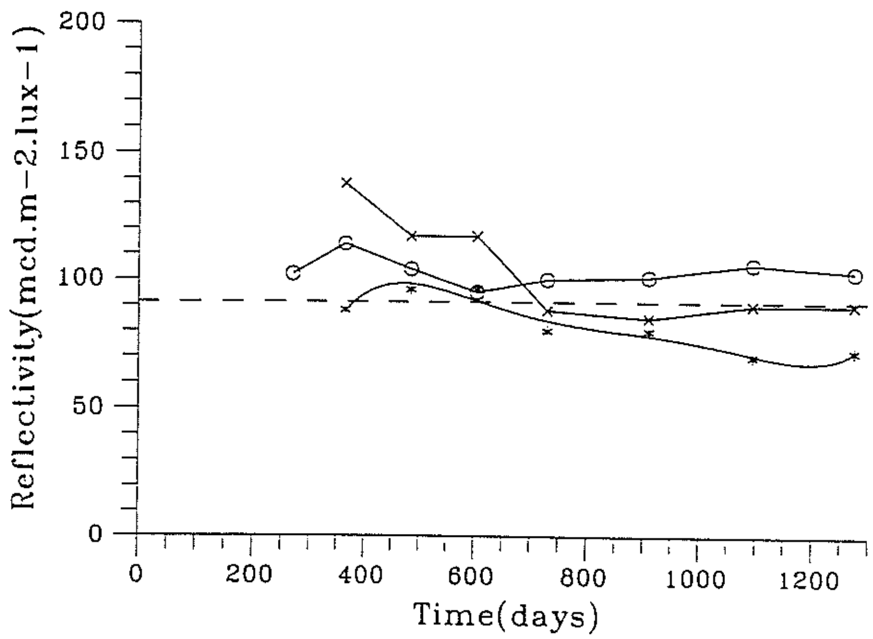
Other concurrent studies (Dravitzki et al. in progress 1996) have shown that the readings from seven Mirolux 12 units in use in Australia and New Zealand could vary as much as ±10% when measuring the same material.

Another study by Dravitzki (in prep. 1994) has shown that the readings from different retroreflectometer types, even those with the same geometry of measurement, may also differ. The study also considers the mobile retroreflectometers for high speed survey of highway networks that are now available. Some versions of these mobile retroreflectometers, e.g. Ecodyn from the Laboratoire des Ponts et des Chaussées (LCPC), are able to simultaneously measure daytime and night-time retroreflective values of the roadmarking and the road, and calculate the contrast values along the route.

Trials of paint materials for the roadmarking industry indicate that many roadmarkings may fall below the proposed recommended minimum retroreflectivity value by as early as halfway through the annual repaint cycle.

Figure 9.3 Retroreflectivity of thermoplastic markings: results of field trial on SH1 near Paremata, Wellington area, from Dravitzki et al. (1991).

Key: Thermoplastic Formulations 1 o ; 2 * ; 3 x



10. RECOMMENDATIONS

The recommended minimum retroreflective value is 90 $mcd.m^{-2}.lux^{-1}$ for road markings on New Zealand chipseal roads.

Adopting and maintaining this recommended value will have cost implications with respect to existing roadmarkings. For example, some roadmarkings could have retroreflectivities that are less than the recommended minimum value for over ½ to ⅔ of their life.

Material specifications will then need to include minimum retroreflective values. Also minimum level requirements may need to be developed for other visual driving aids. Therefore, if this minimum retroreflectivity value is adopted, the following recommendations for further study are made:

- Determine the life of existing roadmarkings on roads with a range of traffic densities, relative to the recommended minimum retroreflective value of 90 $mcd.m^{-2}.lux^{-1}$.

- Develop the method of assessing the retroreflectivities of roadmarkings, from the present pilot stage which is appropriate to smaller scale research use, to a method that is suitable for widespread in-field use.

- Develop appropriate test criteria for minimum retroreflective values that can be included in the specifications used to select paint and thermoplastic materials for roadmarkings.

- Consider the need for minimum retroreflectivity values for other materials used for delineation such as raised pavement markers and edge marker posts, and for materials used for road signs.

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